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Feasibility Study of Developing Wind Power Projects in Iceland: An Economic Analysis

Thesis for the Master of Science Degree (MSc)

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Abstract

Wind power development world-wide has been fast in past decades and the need for renewable energy sources continues to increase. The wind turbine technologies have proven established and are more inexpensive than they were ten years ago. However, not a single wind turbine has been installed and connected to the Icelandic power system. This study thus aims at evaluating the feasibility of harnessing wind power in Iceland from a wide range of perspectives with focus on economic analysis. It could serve as a preliminary guide for those interested in developing such a project.

First of all, meteorological and geographical data collection and analysis is required. The Icelandic wind atlas contained the information on the wind availability is used to identify three best locations of a small wind farm to be studied further. Wind data is used to approximate the annual energy production for a hypothetical wind farm of 10 wind turbines, 2 MW each. The expected annual energy production is highest at Rauðinúpur with 8000 MWh and a capacity factor of 46% which is exceptionally high for an on-shore wind farm. The thesis also reviews laws and regulations with regard to wind power development such as environment and taxes since they have strong influence on the feasibility of the project. The review shows that there are lacks of wind power specific legislations and public policy to encourage wind power. This would likely cause the delay and add cost to such a project. Technical issues such as wind technology and wind-grid integration issues with regards to the impacts of wind power on power system operation and power quality are discussed.

Finally, the indispensable economic evaluation of the wind power project is performed using simple work sheet models. The key project evaluation methods used for the chosen locations of the wind farm include internal rate of return (IRR), present value (PV), benefit-to-cost (B/C) ratio, and payback time methods. Risk management related to such a project is also discussed. An important part of the economic evaluation is the sensitivity analysis of the economic results performed by varying different key techno-economic inputs of the projects, such as the investment cost, electricity price, interest rate, size of the wind farm, and so on. The sensitivity analysis shows that with large investment costs, presumably financed by loans, the effect of discount rate and electrical price are the principal factors that determine the feasibility of the project. It could be concluded that the feasibility of raising a wind farm in Iceland is rather low at the moment, although it is clear that possible changes in the electricity markets such as the introduction of a green certificate system or rising energy prices could make the investment in wind power more economically attractive. It should also be noted that to promote wind power in Iceland, pilot wind turbines could be constructed to stimulate research in the area and increase knowledge and experience in the field of wind power.

Keywords: wind power, feasibility study, economic analysis, IRR, PV, B/C, payback period

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Smári Jónasson
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Terms and Abbreviations

Abbrev.	**Long**
HV	High Voltage
MV	Medium Voltage
P_{el}	Electrical Power [W/year]
ρ	Air density [kg/m^3]
C_P	Power Coefficient
A_r	Rotor Swept Area (πr^2 [m^2])
V	Wind Speed [m/s]
η	Efficiency
H_Y	Hours/year
IRR	Internal rate of return
B/C ratio	Benefit to cost ratio
PV	Present Value
A	Equal Annual Payment
r	Discount Rate
N	Economic Life of Project (years)
MWh	Megawatt hour
kWh	Kilowatt hour
rpm	Revolutions per minute
$P_{turbine}$	The maximal energy extraction capacity of the wind turbine [W]
P_{wind}	The total power in the wind [W]
DFIG	Doubly-fed Induction Generator
E_{kin}	Kinetic energy (J)
m	Mass (kg)
v	Velocity (m/s)
ρ	Air Density (kg/m^3)

Chapter 1: Introduction

This chapter begins with a brief summary of wind power development in general and then describes the actual power supply situation in Iceland. The purpose of the project is then defined and a problem analysis presented identifying key factors needing evaluation in the thesis. The scope of the work including its limitations is finally discussed, ending with a disposition of the thesis's layout.

1.1 Wind Power Development World-wide

Wind power is a renewable environmentally friendly source of energy and its exploitation has been growing fast since the 1970´s world wide but to this date no wind farms have been built in Iceland. The reason for this is probably the land's richness in other natural energy sources that have been more efficient and economical to harness, such as hydropower and geothermal power. Nevertheless, an exploitation of wind power with its many positive aspects should be considered as a future energy source in Iceland as well as in other countries.

The utilization of wind energy is no new concept in the world, it lies so far back in the past that we do not know when it begun. The first wind-mill documented dates from the year 947, approximately 80 years after Iceland was found, and it was located near today's Afghanistan. The well known European wind-mills were developed in the beginning of the 13th century and forward, they reached a maximum in number in the middle of the 19th century where after they were replaced by new technology. Using the wind to produce electricity began early in the 20th century with a development of a so-called wind charger used mainly in isolated areas to charge batteries. As the transmission system advanced improving the delivery of electricity from other sources, even to remote areas, the wind chargers decreased in number. The development of wind turbines continued and the first wind turbine to connect to a transmission grid was built in Denmark and started operating in 1957. Though, it wasn't until after 1970, a period of oil crisis, that attention was drawn towards alternative sources of energy, that the development of wind turbines gained speed [1], [2].

Wind industry is now one of the fastest growing industries in the world at a rate of almost 30% annually, in the year 2005 employing around 70,000 people, with around 55,000 wind turbines installed, since then it has continued to grow at a similar rate. The total generating capacity has now increased beyond 90 GW as shown in Figure 1 below [3], [4].

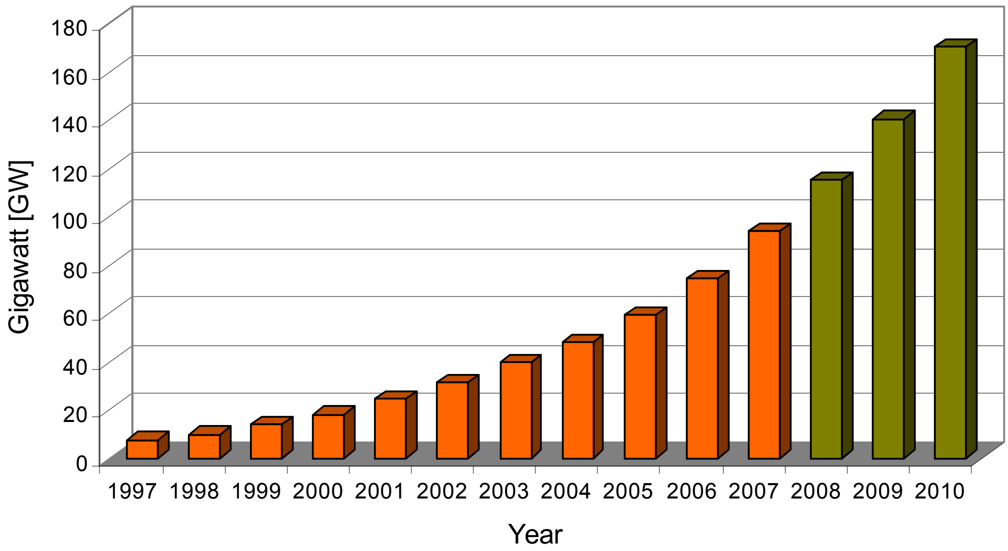

Figure 1. Total installed capacity 1997-2007 in orange, green predicted [4].

Technological advances have been enormous in the last decades and increased rotor diameter, tower height and modern electronic components have increased the power generated from each wind turbine dramatically. Simultaneously the cost per installed kWh has decreased and thus increased the feasibility of harnessing wind power even from an economical viewpoint. The growth in the turbines capacity is represented in Figure 2 below. One of the largest wind turbine produced today is the E-126 from the German manufacturer Enercon, it has a hub height of 135 m and a rotor diameter of 126 m. Estimated total capacity is 6 MW [1], [5].

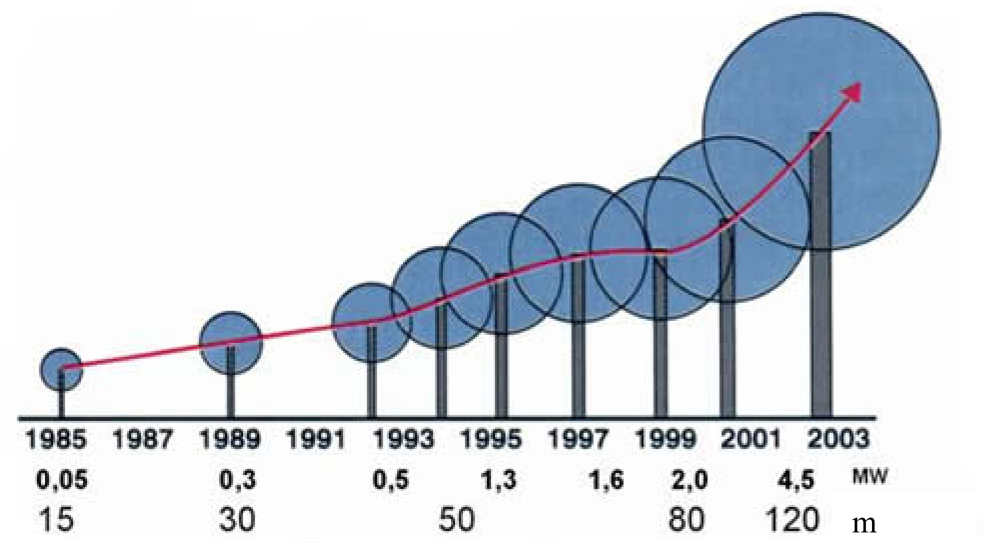

Figure 2. Turbine size enlargement [5].

In the year 2010 the total installed capacity is expected to reach 170 GW [4]. The market drives the development towards increasing size, less visual impact and economies of scale. This fast development is expected to continue in the future as the need for a renewable energy source continues to increase. Locations with favorable wind resources may become more important in the future, even though they may be far away from large interconnected power systems such as those in Europe.

1.2 The Power Supply Situation in Iceland

Despite the world wide growing utilization of wind energy no wind farms or even a single wind turbine larger than 100 kW have been built in Iceland, and none of the smaller ones are connected to the electricity grid. There are a few models of wind chargers, at locations far away from the grid where direct connection to electricity is impossible, and these are designed for a predetermined application.

The natural energy resources harnessed in Iceland are hydropower that accounts for more than 80% of the electrical energy produced, the rest being mainly geothermal, and still, the availability of unused energy resources residing in hydro and geothermal power, is abundant. There are no nuclear power plants or large-scale fossil fuel plants in Iceland, neither has tidal power been harnessed yet in this Atlantic Ocean island. This is also the case with wind power, wind measurements clearly show that its windy climate contains a large amount of energy, but as yet, this has not been utilized. Figure 3 is a pie chart showing all power plants in Iceland and Figure 4 their respective energy production. The total electrical power capacity in Iceland is around 2400 MWh [6].

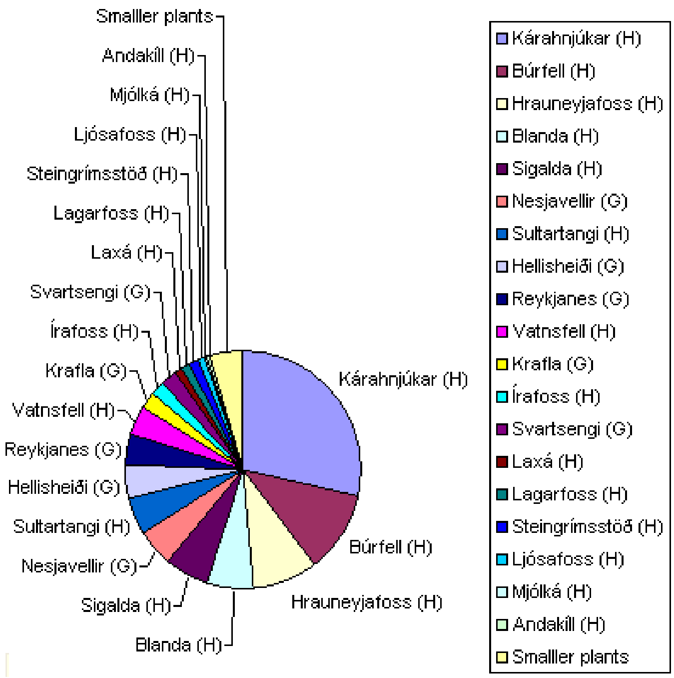

Figure 3. Power plants in Iceland and their respective energy production. Names of stations followed by parenthesis where G = geothermal and H = hydropower.

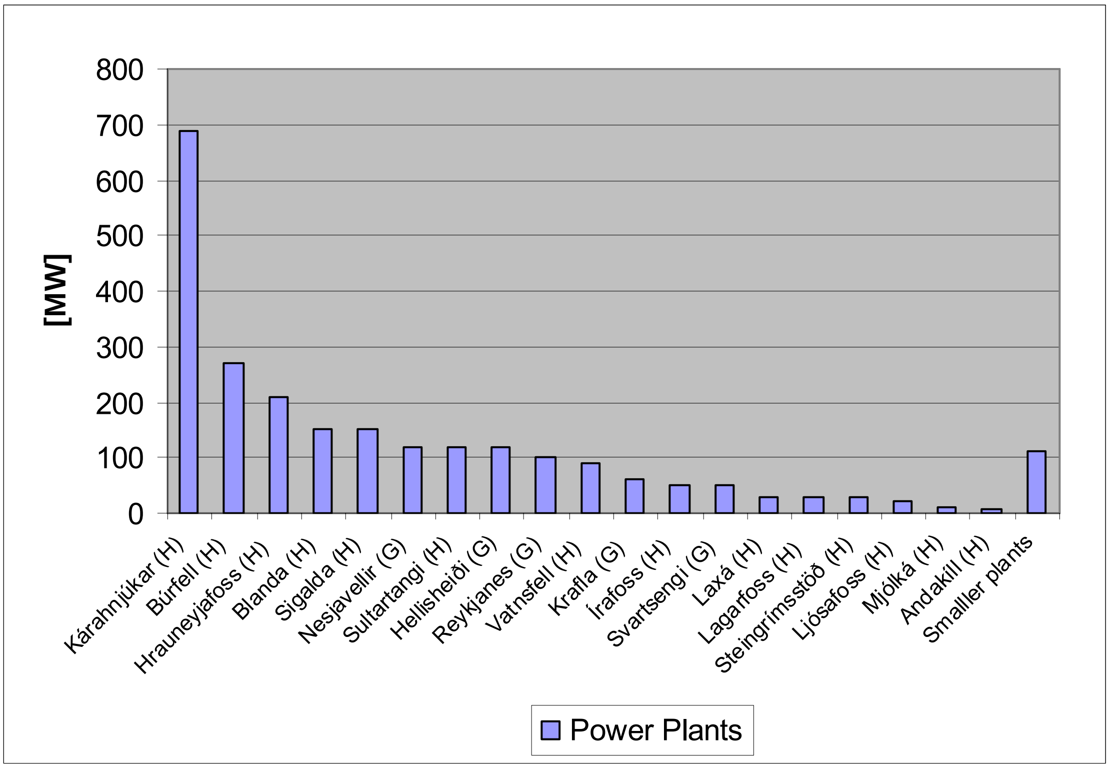

Figure 4. The Electrical Power Capacity.

1.3 Motivations

Wind Power utilization is growing world-wide and despite the richness of other environmentally friendly energy resources in Iceland it is interesting to investigate further the possibility of harnessing the unlimited energy of the wind. It was also interesting to try to define when, or, essentially, at what price per kWh, the equation becomes positive and the building of a wind farm becomes realistic.

In this thesis the feasibility of harnessing wind power in Iceland will be analyzed. Using existing wind measurements from the Icelandic wind atlas three feasible locations will be identified and a preliminary analysis done regarding estimated annual energy production, the technical construction of a wind farm including grid connection will be discussed, and finally an economical analysis of the feasibility of such a project for the best location will be performed.

1.4 Problem Analysis

The project has many different and important elements that need to be discussed and analyzed. Below is a list of the main factors that will be dealt with in the project.

1. Technical analysis:
    a. The adequate size, type and properties of the wind turbine.
    b. The location of the wind farm, the influence of the climate.
    c. The general design and structure of the wind farm.
    d. The connection to the main electrical grid or other smaller electric grids.

2. Laws and regulation analysis:
    a. General laws and regulations regarding electricity production and its environmental influence.
    b. Actual laws and regulations regarding wind turbines and wind farms in Iceland.

3. Economic analysis:
    a. The selling of electricity from a wind farm.
    b. Risk management, analysis of possible risks associated with investment in wind farms.
    c. The possible profitability of the wind power farm including:
        - A sensitivity analysis of the most economical size and infrastructure.
        - Governmental subsidies and the prevailing political policy and its effect on the project.
        - Calculation using estimated values of different preconditions such as energy price, interest rate, the cost etc. giving IRR, payback period, benefit/cost ratio and present value of revenue.

1.5 Methods

A feasibility analysis of building a wind farm is a task that is dependent upon gathering relevant information from a variety of sources. This included reviewing relevant literature in the field, searching the internet as well as trying to establish contact with a number of organizations and companies. In Sweden contact with Vestas, a wind turbine producer; Falkenberg energy, a company that runs a wind farm in Falkenberg was initialized but unfortunately proved unfruitful. In Iceland contact with the large energy firms and grid owners has been taken, such as Landsnet, Rarik, Landsvirkjun as well as a governmental organizations, Orkusetrið and Orkustofnun (The national energy authority of Iceland).

Calculation programs used to analyze the general economical aspects, wind power as well as the energy content of the wind, have been created in Excel, see Appendix A. Unfortunately it was not possible to access any advanced computer programs during the project period. A number of advanced specific computer programs exist today dealing with wind analysis as well as the design of a wind farm as well as calculations regarding the economical aspects of building a wind farm. In order to estimate the energy production from the three locations in the project a calculator from the homepage of The Danish Wind Industry Association was used [7].

1.6 Scope of Work

The project has a number of limitations, some of them obvious from the start, while some have emerged since the beginning of data collection. Information from various sources proved difficult to acquire. For example price ranges for wind turbines from the producers are not available, and neither is information about what service is included in the price. Though, price figures are available from different organizations, and these are used in the economical analysis of this project. This is however never as exact as a final offer from a producer such as would have been optimal to receive. Another imprecise figure is the price per sold kWh, even this had to be approximated through various other sources than an offer direct from the possible buyer. The same is valid for many figures used in the project such as interest rates, various parts of the operational and maintenance costs etc.

When designing and building a wind farm it is necessary to use specific computer programs, i.e. WAsP or Windpro, to calculate various outcomes using data from a wind atlas. No such program has been available during the thesis work. The programs present detailed valuable information such as the production capacity of every wind turbine at a given location, the most efficient size of every turbine, the adequate number of wind turbines and their location within a given landscape. In this project approximations have been done regarding certain factors using information from the Icelandic wind atlas [8] and simpler calculations.

Without these specific computer programs and with a lack of detailed information from the manufacturer of the wind turbines it is difficult to estimate the most efficient and thereby economical size of the wind turbines, that is, choosing the right MW and hub height for a location. As a result a decision was made to base the calculations on building 10 wind turbines 2 MW each with hub height of 100 meters.

Three locations are analyzed in the project. One of them, Bláfeldur, has only been included in the wind atlas for a period of 2 years 2004-2006, where a longer registration period would be desirable. The other locations, Hvanney/Stokksnes and Rauðinúpur, see Appendix 2, 3 and 4; contain information from 1995 and 1997 respectively [9], [10], [11].

A connection of a wind farm to a grid has to be simulated to get realistic data about what can happen when connecting a wind farm to it. This kind of a simulation is out the scope of this project, possible locations for the connection to the Icelandic main electrical grid are chosen according to the grids capacity, further investigation and simulation is then needed in a more detailed analysis.

1.7 Disposition

Chapter 2	Discusses the principles of wind energy and the Icelandic wind atlas.
Chapter 3	Reviews the laws and regulations related to the eventual harness of wind power.
Chapter 4	Deals with the technical aspects of raising a wind farms; its infrastructure, turbine technology as well as a discussing grid connection.
Chapter 5	Analyzes the costs as well as the possible revenue with economical calculations in order to determine the feasibility of the project, including a sensitivity analysis. It even contains a short discussion of risk management.
Chapter 6	Conclusions are drawn from the projects outcome. Final discussion of the project and future possibilities.

Chapter 2: Wind Energy

This chapter focuses on the available wind energy in Iceland and the selection of favorable locations for a wind farm. The Icelandic wind atlas is introduced and results from the three locations chosen are discussed and explained.

2.1 Basic Principles

According to the first law of thermodynamics energy can neither be created nor destroyed, it can only be transformed from one form to another. The energy content of a moving mass is related to its velocity according to Equation 1 below:

$$E_{kin} = \frac{1}{2} m v^2 \qquad (1)$$

Where: E_{kin} Kinetic Energy (J)
m Mass (kg)
v Velocity (m/s)

The power contained in wind, i.e. moving air, flowing at speed v through the area A (for example the swept rotor area) is therefore as in Equation 2:

$$P_{wind} = \frac{1}{2} \rho A_r v^3 \qquad (2)$$

Where: P_{wind} Power in the wind (W)
ρ Air Density (kg/m^3)
A_r Swept Rotor Area (m^2)
v Velocity (m/s)

This law is the basic principle of modern energy extraction from the wind. Of course, in order to build a wind farm, a research on the wind's energy content at any given location is fundamental [1].

2.2 Selection of the Location

In order to determine the annual energy content in the wind detailed wind measurements are required. In Iceland a wind atlas has been established. A total of 142 anemometers are shown in the wind atlas, see Figure 5 below. For a number of locations detailed information about the wind exists over the period of many years, whereas other measurements have been going on for a shorter period of time, though not shorter than one year. Information is continuously added to the wind atlas as measurements continue. The governmental organizations Orkustofnun (The national energy authority of Iceland) and Veðurstofan (The Icelandic meteorological office), are the owners of the wind atlas but the information is made available to the public on the internet [8].

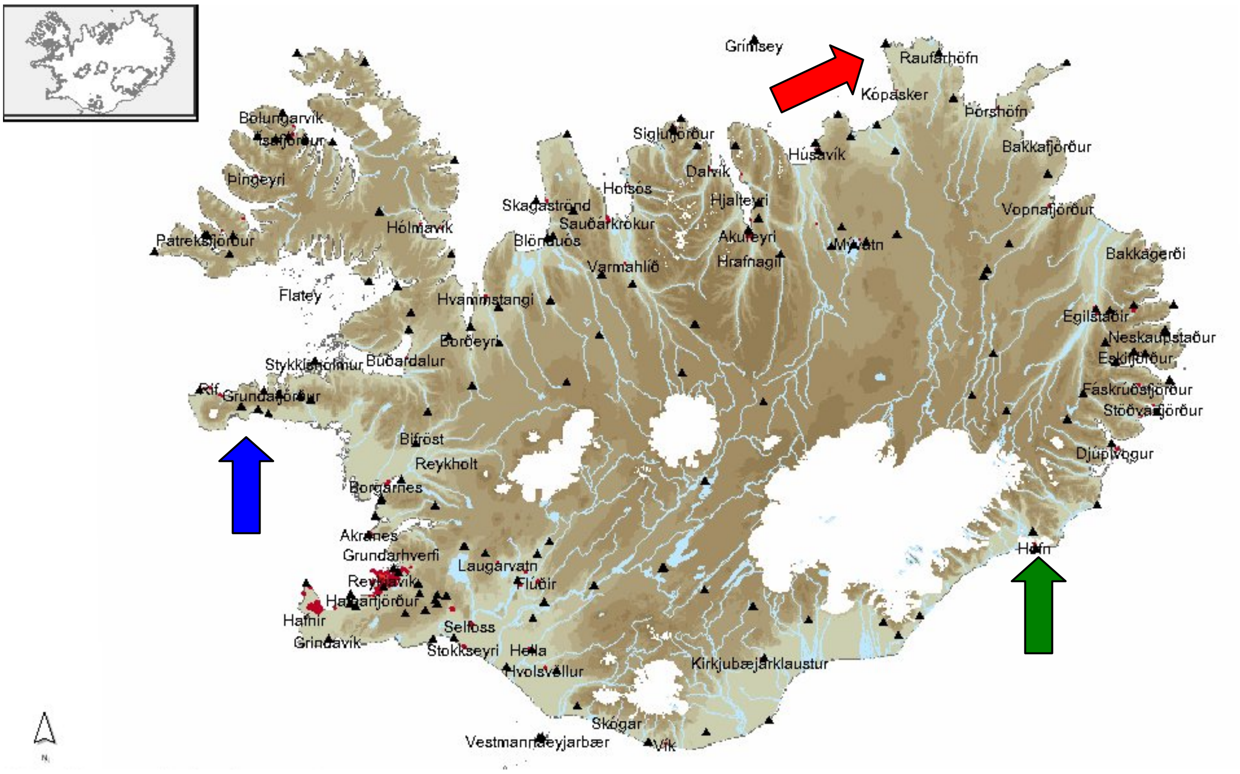

Figure 5. Shows the locations of the 142 anemometers from the Icelandic wind atlas. The locations selected in this project are shown with arrows, blue Bláfeldur, green Hvanney/ Stokksnes and red Rauðinúpur.

Three factors were important when choosing the best locations; firstly the mean wind speed, secondly the closeness to the main grid and thirdly that the area was near the coast where access is easier. Three locations were selected, after reviewing a number of results from the wind atlas, that were considered possible and feasible locations for a wind farm; Stokknes, Bláfeldur and Rauðinúpur. The first location, Stokksnes (measurement station named Hvanney) on the southeast coast, is a deserted area previously used by the US army as a radar tracking station. The land is a private property and within the area there are no inhabitants or other obvious obstacles or contra-indications to the construction of a wind farm. The closest substation is about 13 km away and connected to the main 132 kV grid. The second location, Bláfeldur, on the south side of the west-coast peninsula Snæfellsnes, is a thinly populated area along the coast line and a 66 kV overhead line is in the vicinity, around 3 km away. The third location, Rauðinúpur, on the northeast coast, is also thinly populated and in the vicinity of large areas of open-spaced landscape. The closest 66 kV line is approximately 20 km away [8], [9], [10], [11].

2.3 The Icelandic Wind Atlas

The Icelandic wind atlas contains information about the exact location of the anemometer, elevation above sea level and the wind meter's height above the ground. It uses the Danish software WAsP in analyzing the results of the measurements. WAsP was developed by the National Laboratory for Sustainable Energy at the Technical University of Denmark, more precisely the Wind Energy Department at Risø. It is a PC program that analyzes wind climate statistics. It describes wind flow over different terrains and close to sheltering obstacles. Amongst other things it gives information about mean wind speed, mean power density, and predicts the wind climate and the annual energy production [8 - 12].

A classification of the landscape's roughness is even included in the WAsP program. It is classified according to a so-called RIX, Ruggedness Index described by Bowen and Mortensen (1996), that is often used when analyzing the landscapes influence on wind behavior. It gives the proportion of the landscape that has a slope greater than 30%, as these slopes will significantly affect the wind flow in the area and thereby the possible energy production [13]. The example below in Table 1 shows calculated parameters from one of the chosen locations, Bláfeldur [10]. It shows the difference in the Weibull parameters, mean wind speed and power density at different heights and roughness classes. As can be seen both the height of the wind turbine as well as the roughness class impact the power density substantially.

Table 1. Shows the calculated parameters for each of the standard heights and roughness class, 5 heights and 4 roughness classes. The Weibull-A parameter is given in m/s. U gives estimated (calculated) mean wind speed in m/s and power density gives the total mean power of the wind in W/m², for each of the standard five heights and roughness classes.

Height	Parameter	0,00 m	0,03 m	0,10 m	0,40 m
10,0 m	Weibull A [m/s]	10,8	7,7	6,8	5,3
	Weibull k	1,19	1,14	1,15	1,16
	Mean speed [m/s]	10,17	7,38	6,43	5,05
	Power density [W/m²]	2632	1085	709	339
25,0 m	Weibull A [m/s]	11,7	9,1	8,2	6,9
	Weibull k	1,19	1,16	1,17	1,17
	Mean speed [m/s]	11,06	8,62	7,78	6,54
	Power density [W/m²]	3366	1673	1218	714
50,0 m	Weibull A [m/s]	12,5	10,2	9,4	8,2
	Weibull k	1,20	1,19	1,19	1,19
	Mean speed [m/s]	11,76	9,65	8,86	7,71
	Power density [W/m²]	3998	2252	1732	1133
100,0 m	Weibull A [m/s]	13,3	11,6	10,8	9,6
	Weibull k	1,21	1,23	1,23	1,22
	Mean speed [m/s]	12,52	10,83	10,07	8,97
	Power density [W/m²]	4732	2951	2386	1694
200,0 m	Weibull A [m/s]	14,3	13,3	12,4	11,2
	Weibull k	1,22	1,29	1,28	1,27
	Mean speed [m/s]	13,39	12,32	11,52	10,37
	Power density [W/m²]	5679	3959	3288	2455

The distribution of wind speed and the frequency of varying wind directions is customarily shown as a wind rose. The Icelandic wind atlas shows wind roses divided to 12 sectors, each 30°, the radius of which gives the relative frequency (%) of each of the 12 wind directions, i.e. how many percent of the time the wind is blowing from that direction. Wind from the north is set as 0°, east 90°, south 180°and west 270°. When multiplied with the average wind speed in each direction it shows each sectors contribution to the average wind speed and consequently how much it contributes to the expected energy production [14].

The Weibull distribution curve is used when calculating mean wind speed. For each direction a Weibull curve is shown where the relative frequency of wind speeds on the y-axis is plotted against the wind speed in m/s on the x-axis. Two parameters derived from the Weibull distribution curve are given, Weibull-k and Weibull-A (m/s). The Weibull distribution curve has different looks depending on the distribution of wind speeds. The form of the curve will be more peaked if the wind speeds tend to be close to a certain value, on the other hand if the distribution of wind speed is large the curve's peak will be less marked. Weibull-k is a parameter that describes the look of the curve and has a value between 1and 3, and the higher the number the more peaked the curve is. A low k indicates increased presence of very high wind speeds that contain a lot of energy. Another parameter given in the Weibull distribution curve is Weibull-A and this is the calculated mean wind speed in m/s. Results are shown in one or all sectors as preferred by the user [15].

The mean wind speed derived from the Weibull distribution curve is then used to calculate the estimated annual energy production in Wh/year according to Equation 3 shown below.

$$P_{el} = \frac{1}{2} * \rho * C_P * A_r * V^3 * \eta * H_Y \tag{3}$$

Where:	P_{el}	Electrical power [W]
	ρ	Air density [kg/m^3]
	C_P	Power Coefficient (<59%)
	A_r	Rotor Swept Area (πr^2 [m^2])
	V	Wind Speed [m/s]
	η	Efficiency (≈0.9)
	H_Y	Hours/year (8760)

This equation is the mathematical basis for the calculations but as can be seen from the equation a number of variables are determined for example by the turbines characteristics such as the power coefficient and approximated running time in hours/year. The power coefficient even varies with varying wind speed and this complicates the calculations even further. Theoretically the maximum power yield from a wind turbine is less than 59%, in reality this figure is always lower, for large turbines around 45%. The efficiency, η, is the difference between input and output power or Pel/Pmec. The losses in the generator system that converts mechanical power into electrical power are estimated to give $\eta \approx 0.9$ Because of the complexity of the equation it was not possible to reproduce the results from the Icelandic Wind Atlas in order to upgrade them to a larger wind turbine, instead the use of a commercially available power calculator from The Danish Wind Industry Association was necessary. It should be highlighted that the power produced varies with the mean wind speed at a factor of three, as can be seen in the equation, thus doubling the wind speed increases the power output at a factor of eight. Therefore, relatively small changes in mean wind speed alter the power production substantially; it is also clear that very high wind speeds contain a large amount of energy but when the speed exceeds a certain value the wind turbine will be switched off and thus no power production will occur [1], [7], [16].

The results from the wind atlas for each location are shown below in Figure 6, Figure 7 and Figure 8. The wind rose is to the left, shaded areas show the relative frequency of wind blowing from that direction. To the right a Weibull distribution curve where measured wind speed, U, is used to calculate the wind power density, P. By using the Weibull distribution curve and its shape factor, k, the annual mean wind speed is estimated as A.

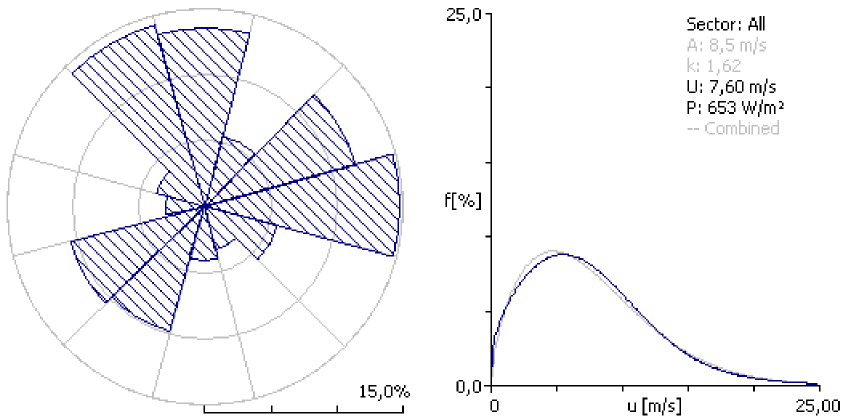

Figure 6. Hvanney/Stokksnes, wind rose and a Weibull curve. A = Weibull-A parameter m/s, k = Weibull-k, U = mean wind speed m/s, P = power density W/m2, the blue curve represents calculations using mean wind speed, the gray curve combines the mean wind speed and the Weibull-k.

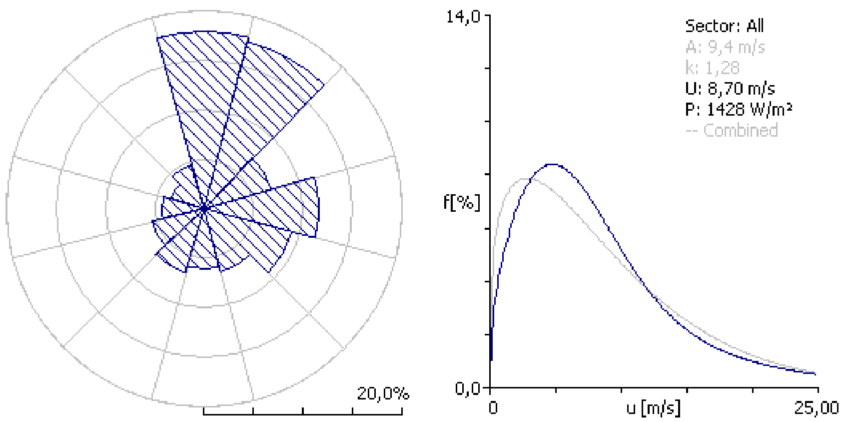

Figure 7. Bláfeldur, wind rose and a Weibull curve. A = Weibull-A parameter m/s, k = Weibull-k, U = mean wind speed m/s, P = power density W/m2, the blue curve represents calculations using mean wind speed, the gray curve combines the mean wind speed and the Weibull-k.

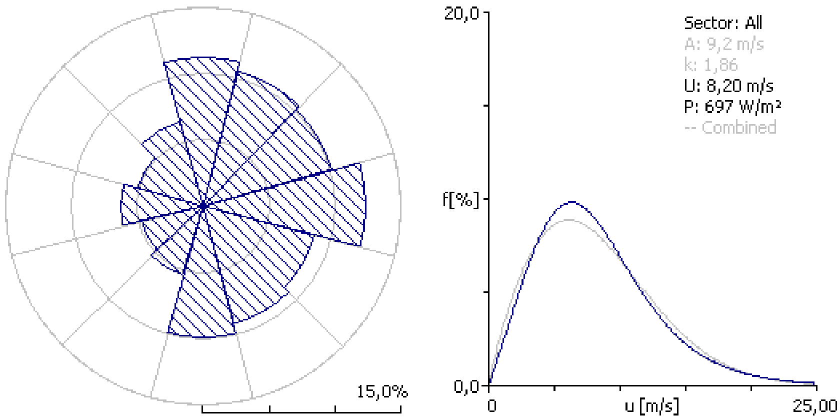

Figure 8. Rauðinúpur, wind rose and a Weibull curve. A = Weibul-A parameter m/s, k = Weibull-k, U = mean wind speed m/s, P = power density W/m2, the blue curve represents calculations using mean wind speed, the gray curve combines the mean wind speed and the Weibull-k.

Table 2 below shows the results from all three locations. The figures are based on the 660 kW turbine Vestas V47 with hub height 45 meters.

Table 2. The results for Weibull parameters, mean wind speed and power density.

Component:	Hvanney/Stokksnes	Bláfeldur	Rauðinúpur
Weibull-A [m/s]	8.50	9.40	9.20
Weibull-k	1.62	1.28	1.86
Mean wind speed, U [m/s]	7.60	8.70	8.20
Power density, P [W/m^2]	653	1426	697

It is important to notice that the power density is highest at Bláfeldur but because of the low value of Weibull-k, indicating relatively frequent very high wind speeds, this does not necessarily mean that power production at this site will be the largest. When analyzing information from a wind atlas the next step is defining what type of wind turbine would be most advantageous at the given location. This is done in previously named software programs such as WAsP as has been used in the Icelandic database. This project has no access to this software or other similar, but existing information in the wind atlas specifies results for the 660 kW Vestas V47 with hub height 45 meters. Specific calculation regarding this turbine is shown where the mean wind speed gives the estimated annual energy production [9 - 11].

Combining the information from the wind atlas and WAsP about wind speed and power density at different heights and roughness classes an approximation of the possible annual energy production for a different wind turbine has been done as is shown later in chapter 4.4, The structure of the wind farm.

Chapter 3: Laws and Regulations

In this chapter official statements regarding wind power in Iceland are discussed. Then the current laws and regulations are reviewed, both retaining to The Electricity Act as well as laws regarding environmental issues.

3.1 Public Statements

The content of public information about wind turbines in Iceland is to say the least sparse. Only a few documents were found after searching the internet. The majority of these are written by individuals with an interest in the subject, sometimes professionals with a connection to energy companies or related organizations. Many favor an extended research into the matter of harnessing wind power in Iceland. Though, in a recent statement about electrical energy in Iceland from the ministry of industry wind power is only briefly mentioned, below is a translation of this short text:

> *6.4. Other energy sources.*
> *Among projects discussed in the last statement about electrical energy was the creation of a wind atlas. The goal of the project is to research the possibility of wind power production. This project is finished and allows evaluation of building wind farms. Few have so far shown any interest in this possibility, and it is also unlikely that wind power will be, in the near future, a more inexpensive source of electricity than the traditional energy sources* [6].

No other direct statement or vision regarding wind power and its utilization in the future could be found at public governmental homepages.

The rules and regulations to consider when building and running a wind farm in Iceland are reviewed below. It is important to know the rules of the game before you start playing, not only the specific laws regarding wind turbines but also general rules regarding the electrical system as well as those related to environmental aspects.

3.2 The Electricity Act

The Electricity Act from the Ministry of Industry is presented below in an official translation [17]. It states among other things that before building a power plant a power development license is needed. This will be granted by the Minister of Industry. An agreement must even be concluded with the land owners regarding compensation before applying and receiving such a license, as well as an agreement with the owner of the transmission system. It states that for power plants exceeding 7 MW in size a direct connection to the main transmission system is an obligation, but smaller plants can be connected to the distribution system. The minister may even with a governmental regulation establish special conditions before granting such a license for example regarding the supply of electricity to the grid, security, reliability and efficiency as well as the utilization of renewable energy sources. The minister can also set

conditions in relation to environmental protection, land use and the technical and financial capacity of the power development license holder. A fee has to be paid to the Ministry for the issue of the license. It comprises a fixed charge of ISK (Icelandic krona) 100,000 plus ISK 10,000 per MW [17].
Below is a direct reference to the part of the Electricity Act that states what a power development license issued by the Minister of Industry should include.

Article 6
Substance of the Power Development Licence

A power development licence shall specify, inter alia:

1. *The size of the power station and the demarcations of the power development area.*
2. *The time at which the development shall begin at the latest and when it shall be completed.*
3. *The obligation of the power development licence holder to provide information and report to Orkustofnun and to the transmission system operator, to the extent necessary for those parties to perform their respective roles.*
4. *Safety and environmental protection measures.*
5. *Conditions relating to the technical and financial capacity of the licence holder.*
6. *Disposal of facilities and equipment when their use is discontinued.*
7. *Other matters pertaining to the conditions of the licence and the licence holder's obligations hereunder.*

A provision may be included stipulating that the power development licence shall be reviewed after a specified period of time in the event that the grounds for the conditions of the licence have changed materially [17].

3.3 Provision of the Regulation regarding the Act of Electricity

This regulation block gives among other things a detailed account of what information is required in the application for a power development license. The application has to be quite extensive including research results regarding the type of energy to be harnessed, a description of the power plants infrastructure and location, an economical analysis, contracts with both grid owner as well as land owner as well as an environmental impact report in accordance with The Environmental Impact Assessment Act [18].

On next page is a translation by the author of this thesis of Article 4 of this regulation [19]:

Article 4
The application for a Power Development License.
The application shall be written and accompanied with the following:
1. *Name of the applicant, personal identification number, address and information about the management of the company.*
2. *Research results regarding the type of energy to be harnessed.*
3. *A description of the power plant, including a plan or a map showing the position and arrangement of buildings, the principal numerical information regarding the power plant and the demarcation of the area to be used.*
4. *A plan of implementation, inclusive when the building process will start, when the power plant will be finished and when it will start running.*
5. *An economical plan for the project.*
6. *A contract with the owner of the transmission system in the area regarding connection to the grid.*
7. *Information about whether an agreement with land owners or owners of natural resources has been reached regarding compensation for the utilization of the land/resources.*
8. *Information about the main environmental issues of the power plant and its influence on the respective natural resources and area, inclusive influence on any utilization previously located in the area, as appropriate. Information about whether the process is a subject to obligatory evaluation according to the law of environmental influence. If so, a report about the evaluation of the environmental impact must accompany the application as well as the decision of the environmental authorities about the environmental impact.*
9. *Information about other possible licenses that the applicant believes he needs from other authorities, and if the process is consistent with the current local planning of the area* [19].

3.4 Environmental Laws and Regulations

The Environmental impact assessment act [18] deals with the impact of different projects on the environment; it ensures that before consent is granted an assessment of the impact has been carried out, it aims to minimize as far as possible the negative impact, it promotes co-operation between concerned parties and aids in informing the public of the project. It states that an Environmental impact assessment is obligatory for all power plants exceeding 10 MW in size as in this project. Another act deals specifically with the process of doing an initial environmental impact statement and later, if this is approved, a full-scaled environmental impact assessment [20].
Briefly, the process consists of first doing an initial environmental impact statement and this is the responsibility of the developer. This should include a description of the project, the area, the design within the area and if the project is in consistency with current development plans. It shall state which part of the project and environment will be emphasized in the subsequent environmental impact assessment, what data exists and a plan on the presentation and co-operation with others concerned as well as the public. Consult with the Icelandic

National Planning Agency (Skipulagsstofnun) is obligatory and this agency either approves or declines the environmental impact statement. If it approves the second step is doing an environmental impact assessment that is a more detailed report. The developer is also responsible for this report and must stand for the cost. Finally, it is the minister of Industry that either approves or declines the project, after consulting the National Planning Agency [18], [20].

3.5 Taxes

The taxes for an electrical generating company are set at 18% of the profit if any. Value-added tax (VAT) in Iceland is 24.5%. A special industrial tax is paid of all income, irrespective of profit, and is set at 0.08% [21].

No subsidies exist for power plants producing renewable environmentally friendly energy such as the green certificate used in Sweden and other countries [1] or a fixed higher price as in for example Germany where a law since 1990 obliged power utilities to buy all electricity produced with renewable energy source at a fixed price decided by the authorities, at the same time grid owners were obliged to adjust their system to accommodate for this green electricity [22]. The reason for the absence of any subsidy is probably the fact that Iceland’s energy production is either hydropower or geothermal power and is considered, just as wind power, a renewable environmentally friendly source of energy.

3.6 Problems

A number of potential problems can be foreseen in this area. Both the lack of specific laws and regulations dealing with wind energy as well as the lack of experience in the governmental organizations will almost certainly delay the project and add cost. Undesirable environmental influences will have to be evaluated in detail as well as the aspects of visual and auditory pollution, wildlife and nature conservation. This will be time consuming delaying the eventual authorization of a wind farm. It is even unclear regarding a pioneering project like this if it will have public support or the opposite, and this will of course influence the bureaucratic process.

Chapter 4: Wind Power in Power Systems

This chapter reviews the technical aspects of raising a wind farm. First a general description of a wind turbine is presented, then the power production of the turbine is explained and results from the power calculator regarding the three locations selected shown. A description of the surroundings and infrastructure follows, including a discussion on land leasing. Lastly a general discussion about power system integration including power quality issues as well as a specific description of the situation in Iceland regarding integration into the Icelandic power system.

4.1 Wind Turbine

The advances in wind power technology have been enormous in the last three decades. Newer "state of the art" turbines constantly replace older models and many of the main problems related to wind power have been diminished to such a level that they no longer hinder the continuing progress of wind power. In this thesis focus is on recent turbine models as these have replaced older ones. Misconceptions are common regarding these earlier problem areas and therefore they are discussed shortly.

A general model of a traditional modern wind turbine is presented in Figure 9 below. The main parts of a wind turbine are foundation, tower, nacelle with a generator and traditionally gearbox and rotor blades. The hub height of a wind turbine is the height from the ground to the center of the nacelle. The hub height is a very important aspect as the energy of the wind increases with increasing elevation above the ground. Following the rotor blades outwards from the nacelle gives the radius of the swept area formed when the turbine is spinning and thus, by πr^2, the swept area, A (m^2), can be defined. The swept area is, as hub height, a very important element in the turbines efficiency as seen in equation 3 in chapter 2.3. The producer usually presents this information as the rotor diameter, rather than radius [1], [23].

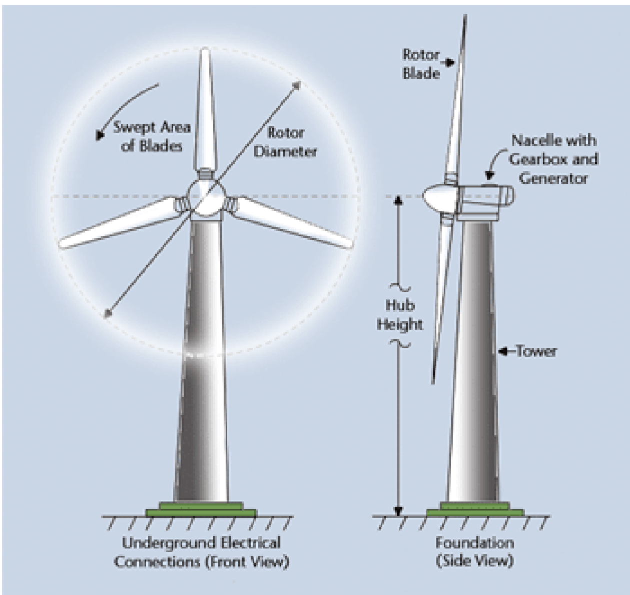

Figure 9. A schematic representation of a wind turbine.

4.2 Power Generation

The power generation of a wind turbine is dependent on a number of factors. Important terms regarding a wind turbines power generation are the wind speed, the turbines efficiency and power co-efficient, the rotor (or the generator) speed and the effect regulation.

The power curve of a wind turbine is defined by four speeds. The start up speed is the critical speed level needed to turn the rotor but still no power output occurs. The cut-in speed is the speed where power output begins and this output rises linearly as wind speed increases until it reaches the nominal speed where the turbine is at its maximal power output where the output remains constant despite continuously increasing wind speed. At last the cut-out speed is reached where the turbine is switched off to prevent damage due to excess forces; this is usually at wind speed ~ 25 m/s. A power curve for a wind turbine is shown in figure 10, when cut-out speed is reached the power curve will of course decline to zero [16].

The turbines efficiency is presented as the maximal power output, in this project 2 MW. With less wind speeds the efficiency is lower. Only a part of the total wind energy contained in the wind can be extracted. That fraction of energy depends on wind speed, rotor speed, blade position and turbine quality, as a result every wind turbine has its own power co-efficient defined according to Equation 4 below [22].

$$C_P = \frac{P_{turbine}}{P_{wind}} \tag{4}$$

Where:	C_P	Power Co-efficient.
	$P_{turbine}$	The maximal energy extraction capacity of the wind turbine.
	P_{wind}	The total power in the wind.

A power curve for a 2 MW wind turbine is shown in Figure 10 [24].

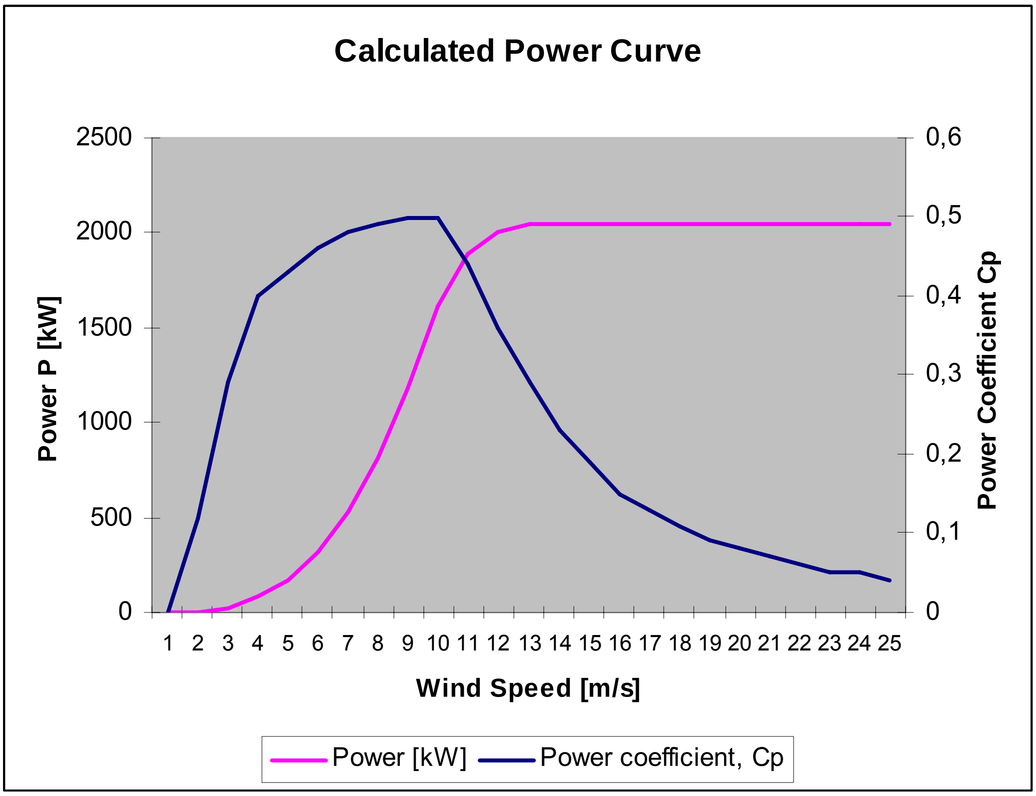

Figure 10. Wind power curve showing wind speed and power co-efficient.

The rotor speed refers to the generator's revolutions per minute, rpm. This speed can either be constant, or, as is more common in modern wind turbines, variable, and thus increasing as the wind speed increases. Modern variable speed large turbines contain either a so-called doubly-fed induction generator (DFIG) or a synchronous generator as shown in Figure 11 below. The DFIG is more widely used at present. The electronic converter is composed of two voltage source inverters with a common DC link that enables it to produce bi-directional power flow and thus allowing the induction generator to run at variable speeds, up to ±30% of its inherent synchronous speed. This can increase the annual energy production of up to 5%. The main disadvantage of the DFIG is it's gearbox that is prone to failure and requires considerable maintenance. The other generator type, the synchronous generator does not necessarily require a gearbox although this is shown in Figure 11, rather, it is connected to the main grid via a converter that has to be designed for all operating speeds of the turbine and thus adding considerable weight and increased cost compared with the DFIG. The DFIG's converter only handles the power needed to control the rotor speed (Up to 1/3 of the operating wind speed of turbine) and as a result is lighter and less expensive [22], [25], [26].

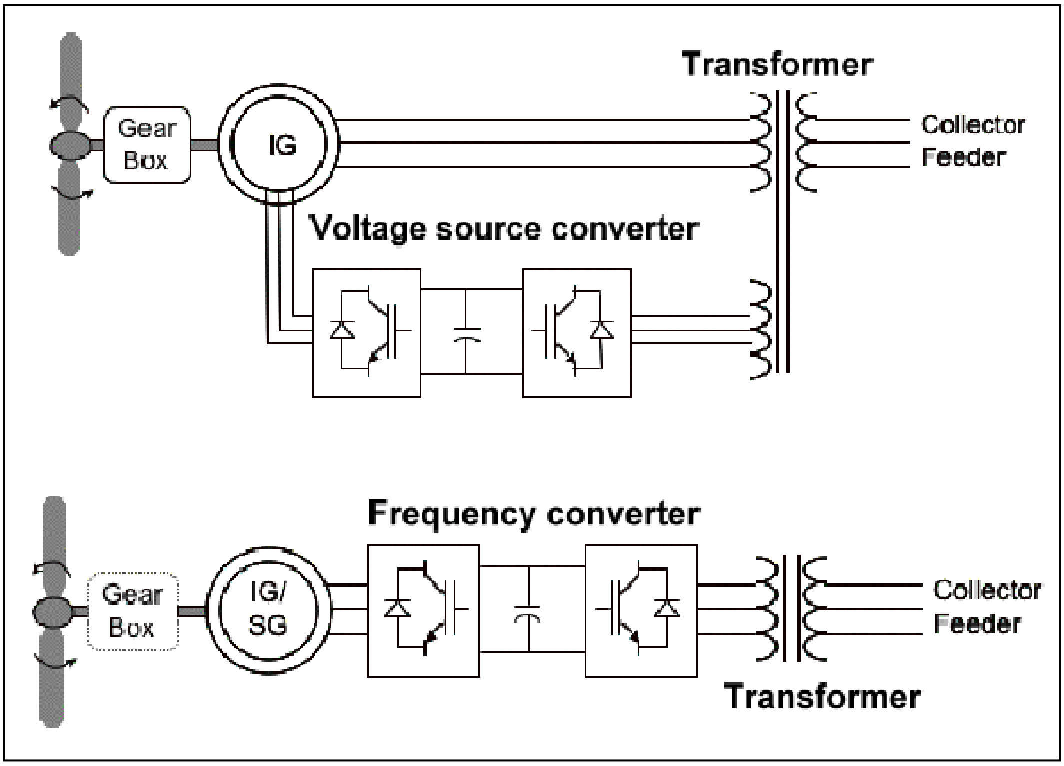

Figure 11. Modern variable speed turbines, above a doubly-fed induction generator, below a synchronous generator. IG = induction generator, SG = synchronous generator.

The effect regulation seeks to maximize the power output from the turbine by controlling the speed at which the turbine rotates. The main mechanisms used are either active control of the blades position, called pitch control, or passive as in stall controlled machines. Pitch control mechanism is relatively easily understood; when the wind force increases and stresses the turbine the blades are actively turned away, letting more wind pass by and subsequently the power delivered by the wind decreases and the turbine slows down again. In stall control the blades are aerodynamically designed in such a way that when the wind speed reaches a certain level a turbulence in the air flow on the backside of the blades arises and causes the blades to slow down. In addition the blades are twisted from the base to the apex in such a way that as the wind successively increases the larger area of the blades begin to stall and act to slow the turbine down, this gives a more even slowing of the turbine and acts to optimize the energy output over an extended interval of wind speeds. The latest technology has combined these two into so-called active stall control where the blades are aerodynamically designed to cause passive stall as described above as well as being able to turn around their axis, all intended to further increase the turbines effect [1],[7].

4.3 Wind Farm Infrastructure

The geographical infrastructure of a wind farm is highly dependent upon local lay of the land and type of wind turbine and as a result could not be analyzed in this project. The power of the wind farm in this project was set at 10 x 2 MW wind turbines as stated above. The general internal electrical connection of a wind farm is shown in Figure 12 below. The connection to the main grid is either 66 or 132 kV in this project; this will be discussed later in chapter 4.6.3. A common output for the generator is 690 V, though some larger turbines have an output that is 10-12 kV, and the generator is connected, through a transformer located inside the tower, to the local distribution grid at a 10 kV voltage or more. In the substation all turbines are collected to the same bus and with another transformer the voltage is elevated to the main grid voltage in the area [3].

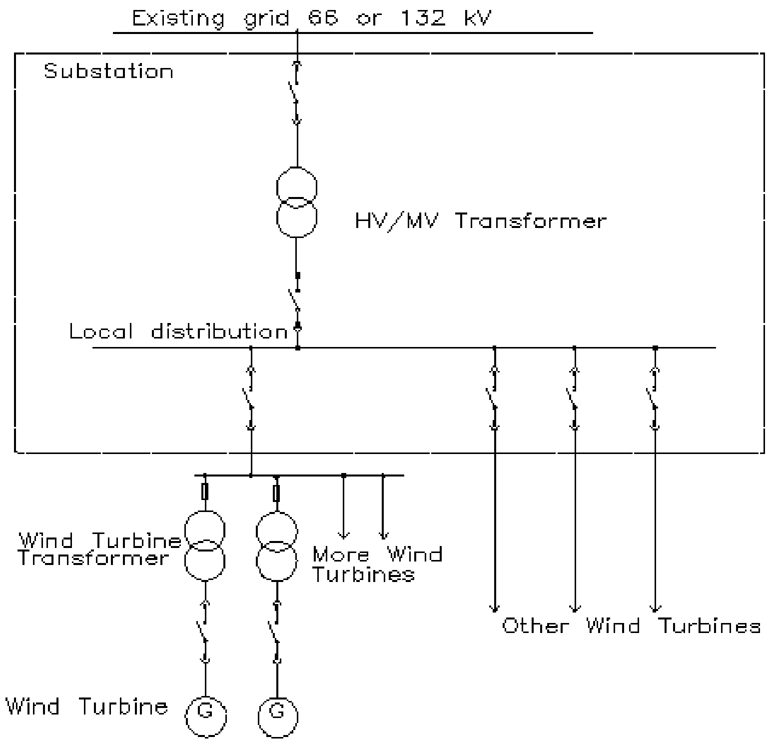

Figure 12. Internal electrical connection for a wind farm. HV = high voltage, MV = medium voltage, G = wind turbine generator.

In addition to a control system and protection relays an important component for a wind farm is a communication system, SCADA (Supervisory Control and Data Acquisition). It connects individual wind turbines, the substation and meteorological stations to a central computer as well as the control and protection systems. This allows the system operator to monitor and operate the wind farm through the SCADA system if needed [3].

4.4 The Power Calculator

Initially it was the intention to analyze different sizes and structures of wind farm and then choose the one most appropriate and economically favorable for each location. Because of lack of information from the wind turbine producer and lack of access to the specific wind programs such as WAsP, this was not possible. Therefore, the size and structure of the wind farm analyzed in this project was set at 10 x 2 MW wind turbines with a hub height of 100 meters.

By using a power calculator from the homepage of The Danish Wind Industry Association [7] combined with the results from the Icelandic wind atlas, that used a Vestas 47 660 kW wind turbine in its calculations, the results from the wind atlas were upgraded to a 2 MW wind turbine with hub height 100m. The variables to be inserted to the power calculator were temperature, Weibull k, mean wind speed, hub height and roughness class. Practically the same results were obtained when comparing 660 kW Vestas V47 in this calculator program as presented in the Icelandic wind atlas. In the Icelandic database neither the temperature nor the roughness class is specified and thus had to be estimated. When deciding the variable for temperature the mean yearly temperature from the closest weather station was used. It was approximately 5°C for all three stations. The roughness classes in the areas were derived by feeding data to the power calculator using the Vestas V47 for comparison and then approximating roughness class depending on how near the results were to the Icelandic wind atlas. This roughness class could then be used to upgrade the calculation for a larger wind turbine. From the wind atlas accurate data about Weibull k as well as mean wind speed could be obtained, hub height is 100 m in this project as stated above.

Measurements and results for 2 MW wind turbines with hub height 100 m for all locations, Hvanney/Stokksnes [9], Bláfeldur [10] and Rauðinúpur [11], are shown in Figure 13, Figure 14 and Figure 15 below. Roughness class is set at 0 for Hvanney/Stokksnes and Rauðinúpur but 2 for Bláfeldur, for all stations their mean temperature is 5°C. Other chosen variables are derived from the Icelandic wind atlas and are shown in Table 2 in chapter 2.3.

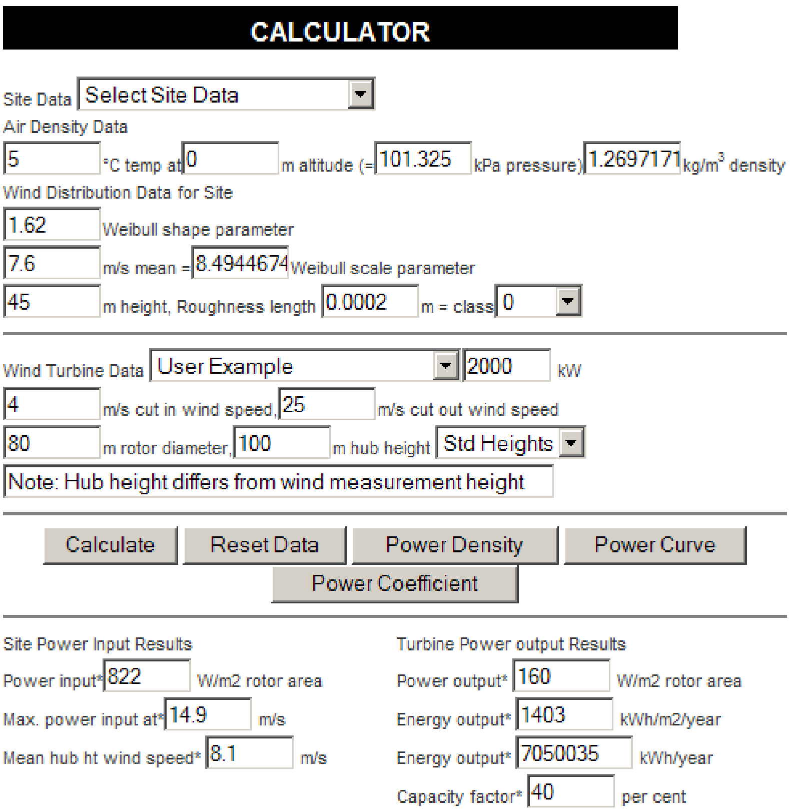

Figure 13. Hvanney/Stokksnes. Variables and results from the power calculator [9], [7].

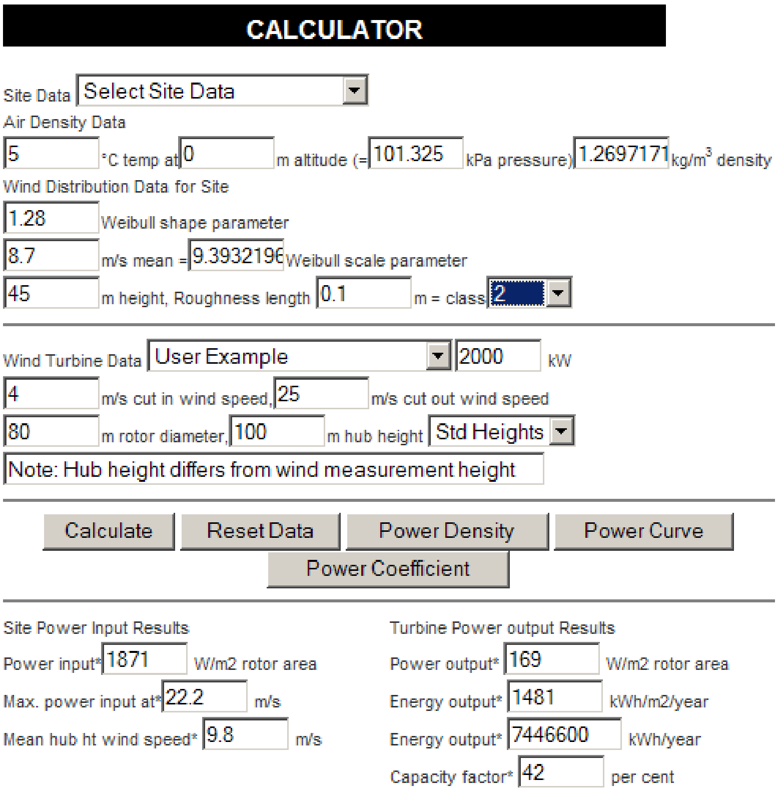

Figure 14. Bláfeldur. Variables and results from the power calculator [10], [7].

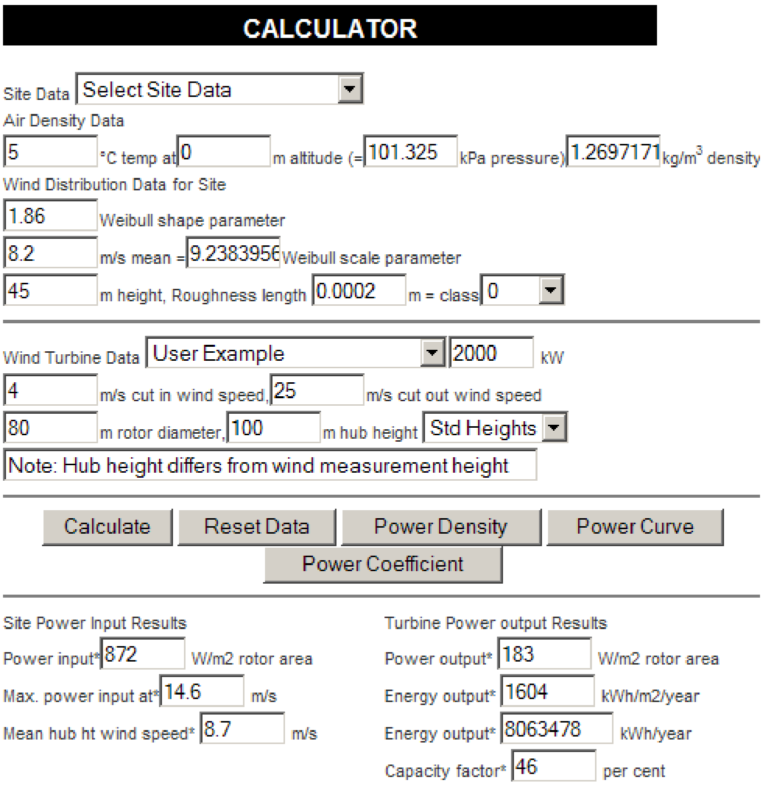

Figure 15. Rauðinúpur. Variables and results from the power calculator [11], [7].

The results from the power calculator give the production capacity in kWh/year among other things. For Hvanney/Stokksnes approximately 7.0 GWh/year, for Bláfeldur 7.5 GWh/year and for Rauðinúpur 8.0 GWh/year. The result from the highest production capacity, Rauðinúpur, forms the basis of the economical calculation in chapter 5.

The Capacity factor is the proportion between the expected annual power production and the nominal capacity (in this project 2 MW x 8760). As can be seen above all three locations show very high values of capacity factor, 40%, 42% and 46% whereas values between 20-40% are most common for on-shore wind farms [27].

Interestingly, Bláfeldur, with highest mean wind speed and power density, gives less expected annual power production than the other locations. The cause of this must be that the Weibull-k parameter is low, indicating more frequent very high wind speeds than for the other locations. The very high wind speeds with their large amount of energy will switch the turbine off for security reasons and as a result cannot be used to extract energy for electrical power production. For Hvanney/Stokksnes the results are similar with higher energy content in the wind but lower Weibull-k parameter decreasing the calculated production capacity.

It is necessary to analyze further the right type, i.e. size, design etc. of a wind turbine that would suit the area best if the building of a wind farm becomes a reality.

4.5 The Location

The location of the wind farm at these chosen areas in Iceland needs further analysis. The locations have not been directly inspected with this purpose in mind and no images or pictures are available at this time. Although, it is certain that all locations have spacious areas above the 2 km^2 needed (a thumb rule of 1 km^2/10 MW) and are sufficiently far away from other buildings or structures. The internal arrangement of the wind turbines cannot be decided until a detailed investigation of the area has been performed [1], [3].

Analysis of the geology of the locations is also needed. Foundations will have to be built to support the turbine but their needed strength, i.e. capacity to withstand extreme forces of nature such as wind, ice or earthquakes, remains obscure.

The cold climate is also a point to consider as icing of the wind turbine blades causes diminished power output, both by aerodynamically slowing the rotor down as well as potentially causing a major malfunction stopping the turbine completely. To prevent this the blades of wind turbines operating in cold climates are customarily equipped with some kind of a heating system that prevents icing from occurring [1].

As there are to date no wind turbines in Iceland it is difficult to estimate what price land owners in Iceland will accept for leasing land for the construction of a 20 MW wind farm. Most of the land owned by farmers is either grassland or cultivated land and could therefore continue to serve the farmer after the construction period. Generally royalty rates as a proportion of the annual income (revenue) vary from a low of 1.5% in Germany to 10% in France and can therefore be estimated to lie somewhere in-between [28]. In Sweden it was not possible to get exact information about leasing costs; the contracts with land owners were not official. Furthermore, one can assume that because of the large supply of sparsely populated areas in Iceland the cost will probably be closer to the lower number. Another possibility is to buy land but the price varies and when the exact location of a wind farm in unknown it is impossible to know if there is any land to buy, and even harder to know how much it will cost.

4.6 Power System Integration

Wind power integration into the existing power system is essential to analyze in detail in an early phase when designing a wind farm. This is done using specialized computer programs that analyze power system dynamics. It is important to be aware that the integration of wind farms has an influence on the transmission system in a variety of ways. The intermittent and uncontrollable energy production that characterizes wind farms needs to be dealt with in the power system they connect to and it becomes even more important with increasing amount of integrated wind power. Because of the intermittent nature of wind power a larger reserve is needed in case the wind doesn't blow to maintain system capacity. It is estimated that if wind power accounts for 10% of the total energy production in a system, it requires an extra reserve corresponding to 2-10% of the installed wind power capacity. With decreasing wind power proportion the less reserve is needed. With very small proportions the effect on reserve requirements in large power systems is minimal. A 20 MW wind farm in Iceland would generate around 0.8% of the total energy production and would therefore have a minimal impact in the system as a whole regarding system capacity [29].

The location of wind farms is also a main factor to consider when analyzing grid connection. Wind farms are typically clustered at windy locations and the grid's transmission capacity in the area has to be sufficient to serve the wind farm. This is not always the case and can cause a considerable increase in cost that individual wind farms cannot afford. The grid's capacity locally thus limits the possible locations when planning for a wind farm [1], [25], [29].

4.6.1 Power Quality

Wind turbines interfere with the system they connect to in a number of ways. In the past problems related to the integration of wind power were substantial but technological advances have diminished them substantially. The main problem areas are related to power peaks, the absorption of reactive power, flicker problems, the causation of harmonics and switching operations [1], [27].

Power peaks occur with sudden changes in the turbines output, for example this could happen during a sudden increase in wind speed. In modern variable speed turbines with better control over the power output of the inverter system using control mechanisms described before (stall, pitch or combined) this problem has been minimized. Also, the habit of building a wind farm with many turbines adds a smoothing effect to this phenomenon as the occurrence of a sudden increase in wind generally does not happen at exactly the same time at all turbines [27].

Advanced power electronic equipment in modern wind turbines can control both the capacitive and inductive reactive power of the turbines thereby keeping the voltage level delivered to the grid stable. This feature of wind turbines can even be used to increase power quality at weak points in the transmission system [27].

Sudden changes in the turbines active and reactive power causes flickers and these still occur with modern turbines. As technology has advanced giving better control over active power peaks and reactive power the flickers have decreased. Even here the number of turbines gives a smoothing effect to the occurrence of flickers where the flicker of the farm is √(number of turbines) x flicker of a single turbine [27].

The drawback with the power electronic equipment in modern turbines is its tendency to produce harmonic currents in the system. The turbine transformer reduces this effect; filters are even used with the same purpose [27].

In-rush currents and changes in active and reactive power associated with the turbines switching operations, such as for example occurs at cut-in speed, can cause voltage changes in the output. As discussed before newer technology has decreased this problem [27].

Combining the above it has been concluded that modern technology in wind turbine design and construction has decreased problems regarding power quality to such a level that the power system is no longer threatened by the expansion of wind derived energy [1], [25], [27] [29], [30].

4.6.2 Ancillary Service

In power systems it is essential to establish a balance between supply and demand. This is done using complex control and surveillance systems that automatically adjust the production of electricity to the usage. Every power system has its own characteristics and its management seeks to optimize the efficiency in the system by adjusting the power supplied to the system from all connected power plants. The costs associated with maintaining system balance are referred to as ancillary-services costs.

The production of wind power cannot be controlled in the same way as for example hydropower. Instead it is dependent on the weather. This creates a need for compensating actions elsewhere in the system and thereby increases the ancillary-services cost. How much the cost increases has been investigated in a number of researches. The cost has been estimated to lie somewhere between 1 and 3.6 €/MWh of installed wind power. In general the effect on the cost is small when wind turbines account for low levels of the total energy production but increases with higher penetration levels. This is a cost that the system operator has to expect when installing wind turbines to the system. Though, it is obvious that no generation, whether hydropower, geothermal power or other, can be connected to a grid without any cost [29].

4.6.3 Possibilities of Grid Connection in Iceland

Landsnet hf is the owner of the Icelandic transmission grid from 33 to 220 kV, the highest voltage level in Iceland. Figure 16 schematically represents their transmission system in year 2007. Landsnet is owned by 4 of the largest energy companies in Iceland, Landsvirkjun, Orkuveita Reykjavíkur, Rarik and Orkubú vestfjarða. Before the deregulation of the electrical market in year 2003 the main grid was largely owned by these companies that were controlled by different authorities. Landsnet is under the surveillance of Orkustofnun, a governmental organization, which sees to that the company operates according to laws and regulations [31].

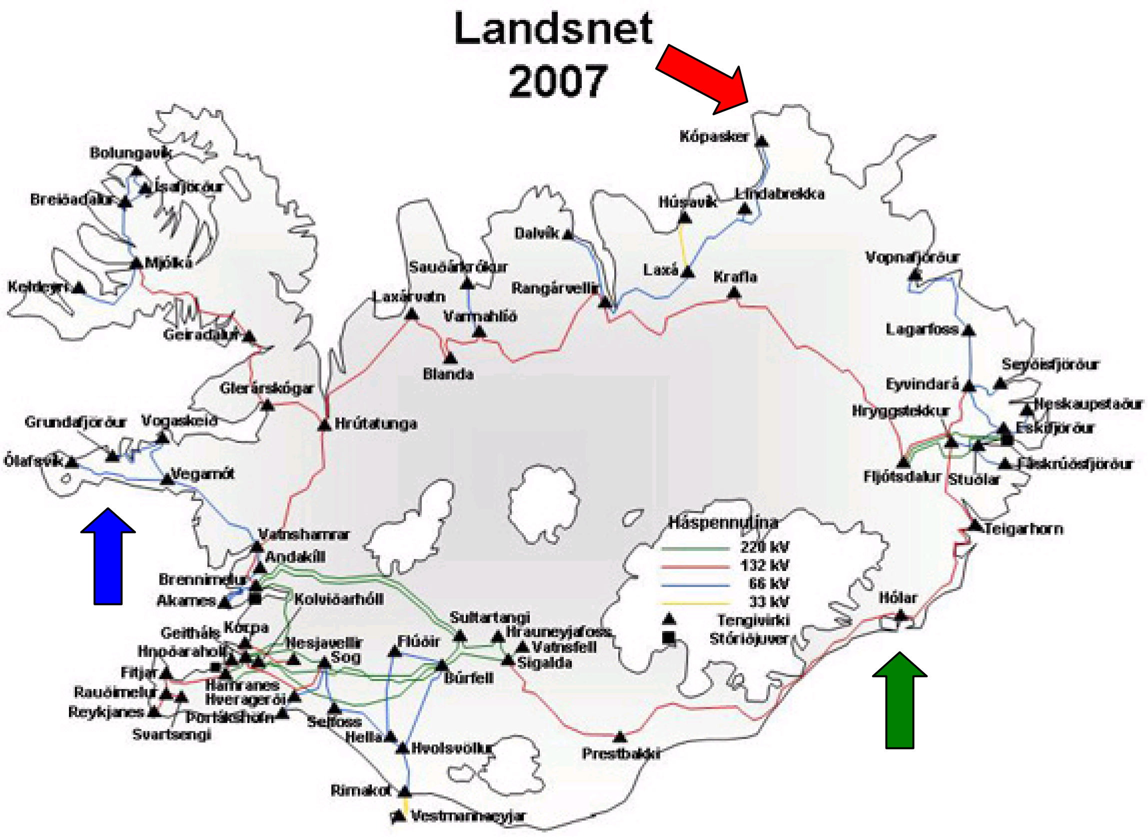

Figure 16. The Icelandic transmission system. Háspennulína = high voltage line, different voltage levels shown in different colors as shown in figure, ▲= substation, ■ = large industry. Colored arrows show the possible wind farm locations of this project, blue = Bláfeldur, red = Rauðinúpur, green = Hvanney/Stokksnes [32].

Landsnet is obligated by the law to connect all applicants to the main grid unless the grid's capacity is too low, or if the grid's safety or power quality is threatened. If any applicant is denied connection, Landsnet is obligated to rationalize the denial in writing [17], [19].

The three possible wind farm locations are shown in Figure 16 with arrows. As can be seen two locations, Bláfeldur and Rauðinúpur, need a connection to 66 kV transmission line at a distance of 3 and 20 km respectively, no substation is located within that radius and the third one, Hvanney/Stokksnes needs a connection to a 132 kV transmission line where the closest substation is located some 13 km away. Landsnet, the grid owner, requires a computerized simulation of the impact of such a connection before allowing connection to the grid; therefore, the company needs a detailed model of both the wind farm and it's technical characteristics as well as its planned connection to the grid in forehand.

4.6.4 Requirements

Landsnet sets different terms that all power plants that connect to its grid system have to fulfill. These are general terms related to the power plants design and structure and its behavior in different circumstances such as a transmission system failure. There are also rules regarding frequency regulation, static excitation equipment, frequency and voltage variations and protection systems. Because no information could be obtained from the wind turbine producer it is unclear if the wind turbines withstand Landsnet's demands regarding these issues. Although, it is likely that the requirements are met as wind farms are connected to similar power systems world-wide [33].

Terms are even set regarding processing schedules where the generation companies have to deliver plans on how much energy they plan to produce over the next week; obviously, these terms are hard to fulfill for a wind farm. These terms would probably have to be revised before connecting a wind farm to Landsnet's grid [34].

As energy production using wind turbines so far does not exist in Iceland, an analysis of the conditions for reserve power for a wind farm will be needed although this is unlikely for a wind farm producing only 0.8% of the total power capacity as discussed before.

4.6.5 Fee Collection

Landsnet issues a rate list on its services where the prices are set within the boundaries of a certain profit value for the company as the law stipulates that the profit of Landsnet cannot exceed a certain level. This rate list contains price information about transmission charges, ancillary services and transmission losses for distribution system operators and power intensive users. Power producers pay a delivery charge but the fee for ancillary service is according to a private contract with Landsnet rather than this rate list. Producers do not have to pay for transmission losses.

According to the most recent rate list available, dated 1st of February 2008, customers will be charged as follows [35]:

Delivery charge:	3,925,033 ISK per year.
Ancillary services:	25.80 ISK/MWh.
Transmission losses:	79.80 ISK/MWh.

Chapter 5: Financial Analysis

This chapter deals with the economical aspects of wind power technology. First a general discussion on the subject that is then divided into risk management, costs (investment, O&M), electricity price, a description of the Icelandic electricity market, economical calculations with results presented as PV, IRR, B/C ratio and Pay-back time and lastly a sensitivity analysis regarding price, discount rate, investment cost, number of turbines and exchange rate.

5.1 Economics of Wind Energy

In projects such as building a wind farm a preliminary investigation of the projects economical feasibility is customarily performed before constructing a more detailed plan of implementation that requires vast resources. The results of a preliminary investigation then form the basis for further decision-making by determining if the project is realistic. Three major factors are vital when planning and designing wind farms. There must be adequate wind resource, the wind turbines have to be reliable and, last but not least, they must be cost-effective. This chapter deals with the economical aspects of building and running a wind farm at the site with highest power production, Rauðinúpur, giving a production capacity of 8.0 GWh/year.

An overview of wind energy economics is shown in Figure 17 where a rough division is made between different costs to the left weighed against the market value of wind energy to the right. Derived aspects of wind energy value such as costs avoided with the building of the wind farm, for example the saving of fuel costs are not considered in this project as they would be close to zero in Iceland. The environmental benefits are difficult to estimate in figures of money, and as other energy sources in Iceland also are environmentally friendly no attempt is made to include this in the analysis in this project. Rather, the focus is on the generating costs and the pure market value of wind energy in ISK/kWh.

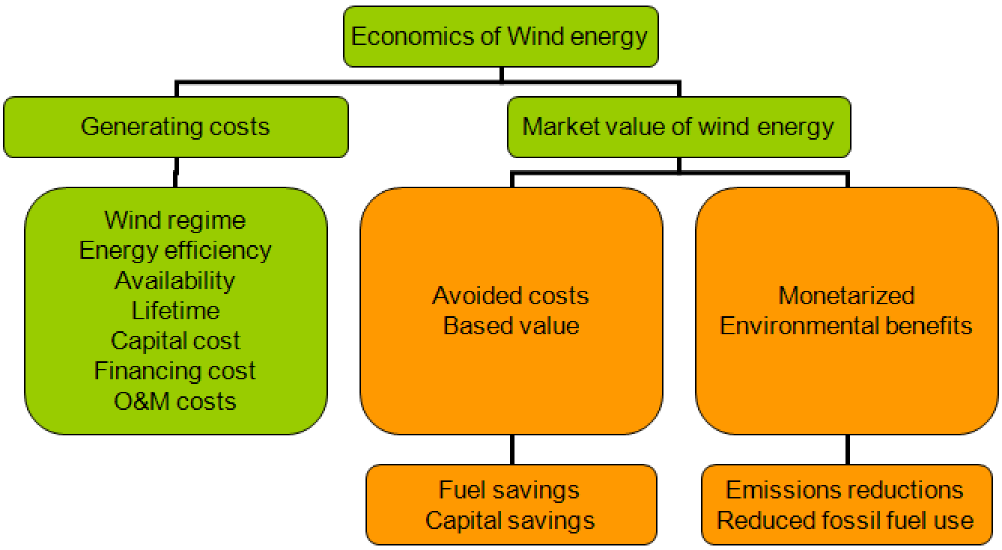

Figure 17. The economics of wind energy [36].

5.2 Risk Management

Risk management deals with identifying, assessing and controlling risks associated with different projects. Raising a wind farm is accompanied by many risks and it is essential to deal with these. The risks can be divided to three main types, the ones associated with governmental as well as public approval, then risks related to the wind turbine and it's energy production and lastly, financial risks [1], [37].

5.2.1 Approval

As stated previously a number of permits from the authorities are needed for the construction. Before seeking different permits a substantial amount of time has been spent with associated costs. Extensive work in this area will probably be related to the environmental impact, both because of the lack of experience regarding wind turbine farms in Iceland and because of the growing public concerns for the environment. Also, it is essential to obtain expert opinion in the field and this will both be time consuming as well as costly. It is vital that the quality of the work presented in the permissions needed is of adequate quality, as this will reduce the risk of a denial. In general, the risk of a denial for building the wind farm at nearly any selected location must be considered substantial.

A different aspect is the public's approval of the project. In general the public opinion on wind farms is positive but a few things are important to remember. The acceptance from the local population can usually be achieved if the project is presented in the right way, giving early and preliminary information about the planned project allowing public discussion and if needed an influence regarding parts of the project. Another group to manage are individuals with a special interest in the area, it could be those living nearby or those utilizing the area in various ways. It is vital to gain their acceptance as private lawsuits could slow the project enormously or inhibit it. Of course, the land owner's acceptance is a necessity [1], [37].

5.2.2 Energy Production

Wind energy varies and when the wind doesn't blow no energy production occurs. Before raising a wind farm anemometers have measured the wind in the area usually for a few years at least. This forms the basis in estimating the amount of energy that can be harnessed from the wind at a given location. If these measurements have overestimated the annual energy production the profitability of the project is threatened. It is therefore vital to have access to as accurate assessments as possible.

The process of harnessing wind power is through dependent on complex machinery, the wind turbine. As with any other equipment a failure to operate properly causes less achievement and therefore less power production. This affects the profitability of the wind farm. In order to decrease the risk of malfunction regular and qualified maintenance is needed. A major turbine fault is sometimes the manufacturer's responsibility but not always. Insurance of the farm against major breakdowns and a so-called "force major" (a failure associated with extreme acts of nature such as an earthquake or ice storms) is necessary to guard against the total loss of a turbine, it is also probable that financing will be difficult without proper insurance [1], [37].

5.2.3 Financial Risks

The value of the wind energy is only an estimation and not a fact and therefore the risk remains that this value will be overestimated. It is not only the price that is estimated, all the costs related to building as well as running and maintaining a wind farm are estimated figures and this must be borne in mind throughout the project planning. A thorough high quality planning is vital in order to diminish the risk of overestimation of the possible profitability. The tax system is often complicated and a good knowledge of it is necessary when running a wind farm. It can be expensive either to pay more tax than obligated or to neglect the tax payment and then be forced to pay penalties. Also, the tax system is not always in a status quo, an establishment (or discontinuation) of a green certificate system or similar tax subsidies would impact the economical calculations substantially. The transmission company also influences the economic equation, price changes for their services can have a negative impact [1], [37].

5.3 Costs

When analyzing the costs it is useful to divide the generating costs into capital investment costs versus operation and maintenance costs. Approximately 75% of the generating costs lie in the investment cost and therefore wind farms are regarded as capital intensive, i.e. most of the costs emerge at the beginning, before the wind farm starts its energy production. The rest, 25%, is accounted for by operation and maintenance. In general the expected life-time of a wind turbine is about 20 years [3].

5.3.1 Capital Investment Costs

Capital investment cost has a number of components but the turbine price is the single largest factor. It is estimated that the turbine alone stands for 65% to 80% of this capital cost [36], [38]. As mentioned before the actual prices for wind turbines are confidential and therefore this poses a major obstacle in determining the cost. In a recent document, dated the 22nd of November 2007, from the Commission of the European Communities the total capital investment cost is estimated to be of the order of €1000 to €1200 per kW for onshore wind farms [39]. Those figures are used in further calculations in this project.

The discount rate can be assumed to range from 5% to 10% for projects such as this [3]. The different components of the capital investment costs are shown in Table 3 below. The first column shows the variations according to different sources of information. The second shows the estimated proportion of the cost used in this project [36], [38]. The estimations were considered probable by the author of this project but are not a detailed analysis of these cost items.

Table 3. Wind farm capital cost breakdown.

Component	Total cost [%]	Estimation [%]
Turbine	65-80	70.0
Foundation	5-11	7.0
Electrical installation	5-11	5.0
Grid connection	6-15	6.0
Road construction	1-5	1.5
Land purchase	0-6	0.0
Approvals	3-8	3.0
Planning costs (consultancy)	3-5	3.5
Financial cost	3-5	3.0
Infrastructure	1-5	1.0
Total:		**100.0**

All these factors will of course need further investigation before the eventual building of a wind farm as mentioned above. They are explained shortly hereafter. Later in this chapter economical analyses are done using these proportional values.

The wind turbine is delivered by the manufacturer and is the single largest cost.

The foundation has to be built on the ground to support the wind turbine; its extent depends upon the location's terrestrial and meteorological characteristics.

Electrical installation estimates the costs for the internal distribution network between individual wind turbines.

The bulk of the grid connection cost lies in the building of an overhead line or an underground cable from the wind farm to the main grid's connection site. Eventually, a transformer will have to be purchased.

The cost for road construction emerges because of the customary somewhat distant location chosen for wind farms. This calls for the construction of roads leading to the wind farm as well as to each individual wind turbine. The dimension of the road construction varies from place to place depending upon previous conditions. It is necessary for the roads to be structurally engineered in such a way that their bearing capacity will correspond to the load to be transported, i.e. heavy structural units of the wind turbine.

Land purchase can be a part of the capital cost if the decision is to buy land instead of leasing. It is unclear if it is more economical to buy or lease land; in this project the calculations are based on leased land as it is impossible to know if land-owners would be ready to sell land, and if so to what price. It is easier to estimate a probable rent for the usage of land, compared to what is known from experience in other countries.

Approval is the cost derived from fee collection by the authorities for different licenses and approvals needed before the construction. An example is a license for producing electricity and for building a power plant in general involving both the Ministry of Environmental issues as well as the Ministry of Industry.
Planning costs include all costs retaining to consultancy under mainly planning but even construction period as it is clear that expert advice is needed in a number of fields. As an example the environmental influence rapport is a very complex object that has to be done by the projector and it is evident that this necessitates the cooperation between a number of different specialized consultants. It is unclear how much consultancy directly related to the design and construction of the wind farm is included in the price for the wind turbine, but in this field expert knowledge of wind turbines is essential.

Financial cost is related to financing the project that will be largely done with loans, this part even account for fee collection by loan institutions etc.

Infrastructure cost means cost apart from direct wind turbines construction cost (that is included in the turbine prices) and roads, for example connections between individual wind turbines, installation of specific systems required for the optimal running of the wind farm such as a SCADA system for better and safer operation, an anemometer on location to improve weather forecasting etc [3].

5.3.2 Operation and Maintenance Costs

The estimation of the costs associated with the project proved difficult. A number of sources have been reviewed but the results varied widely and were seldom sufficiently clear as too what cost items were included. In addition this kind of information is often unofficial. In this project the information for the total O/M cost where estimated to be 1.2 c€/kWh as an average over the life time of the wind turbine. An attempt to estimate different aspects of the costs is represented below in Table 4, information about the actual cost is included if known. Further discussion in chapter 5.6 The outcome of the financial analysis [3], [36], [38], [40], [41].

Table 4. Wind farm operation and maintenance cost breakdown.

Operation:	**Cost information**
Land lease	1.5-10% of the revenue
Local taxes	1% estimated, without VAT and tax of possible revenue
Insurance	400,000 ISK/MW installed
Administration	NN*
Local utilities	NN*
Delivery charge	3,925,033 ISK/year
Ancillary services	25.8 ISK/MW produced
Maintenance:	
Regular maintenance (Scheduled)	NN*
Maintenance (Unscheduled)	NN*
Long-term replacement	NN*
Total:	1.2 c€/kWh

*NN = no number available

Land lease is estimated from praxis in other countries as well as knowledge of the market in Iceland and is set at 3% of the revenue.

Local taxes are difficult to estimate. The taxes for an electrical generating company are low as long as the debt counterweights the income thus affecting the profitability negatively. When there will be a net inflow the tax rate of the profit is 18%, operational and maintenance costs act to reduce this profit, and therefore the tax to be paid. The income tax will not take effect until after the payback time has passed, the payback is discussed later in this chapter. A special industrial tax to be paid of all income independent of debt is set at 0.08%. The estimation of 1% was set low, although higher than 0.08% as the project is expected, at some time, to become profitable.

Insurance cost is estimated from figures published in Sweden. By calculating the exchange rate the figure is represented in ISK [1].

Administration is the cost associated with the daily running of the company after the construction period. Local utilities means for example accommodation, transport vehicles, telephones etc. The proportions of this cost are not shown here as scarce information about them were found. They are roughly estimated later in a specific example with certain other values predetermined; see Table 7 in chapter 5.6 [3].

Landsnet charges all those that are connected to their grid a delivery charge 3,925,033 ISK to be paid annually.

It is customary in Iceland for the energy companies to each make a contract with Landsnet where the amount charged for ancillary services is decided. This contract is confidential and therefore an assumption has to be made regarding the cost for ancillary service. For users the cost for ancillary service is known and is set at 25.8 ISK/MWh and this figure will be used in the economical analysis assuming a similar cost for a power producer [35].

Certain costs for maintenance are known from the beginning, the wind turbines need to be checked at specific intervals. Not all costs relating to maintenance and repair are known and it will have to be anticipated that certain parts of the wind farm will have to be repaired or replaced in case of malfunction or operating failure. These costs are difficult to estimate, certain wind turbines may have a low rate of failure whereas a great deal of bad luck could generate huge reparation costs. The proportion estimated in this project assumes an even division between scheduled and unscheduled maintenance as well as a payment to a reserve fund as is generally recommended, but no numbers are shown above because that the prerequisites used in the calculations change depending upon various factors. Actual figures are shown later in Table 7 with figures derived from the total cost but somewhat higher, this is because of Iceland's isolation that increases the cost of consultancy from abroad, as well as the high price level. The estimated proportions are also shown there, these vary with changing the predetermined values in the calculation and are therefore not presented in Table 4 [3], [40].

5.4 Sale of the Electricity

The Icelandic energy market is in the process of deregulation. Previously the electricity sector was a regulated monopoly owned by the state; there was only one provider of electricity to all customers, the sector had an obligation to serve all and the price was set by governmental regulatory agencies. This was the customary system in most countries but a deregulated market has now become the norm. In a deregulated power market generation, transmission and distribution are separate businesses. The vision with deregulation was to enable the customer to choose between different producers and distributors; this should induce a competitive market and ultimately lower energy prices to the customer. Transmission is still a regulated monopoly, in Iceland run by the company Landsnet that also is the system operator as well as the market operator. On the market the contracts between producers and distributors or large-scale users are bilateral but at the end of year 2008 a spot market will be activated, this will make the energy prices from the producer more obvious, the effects on the market as a whole are difficult to predict.

Figure 18 below schematically describes the structure of the electricity sector in Iceland including generation, transmission and distribution of energy as well as the market infrastructure [42].

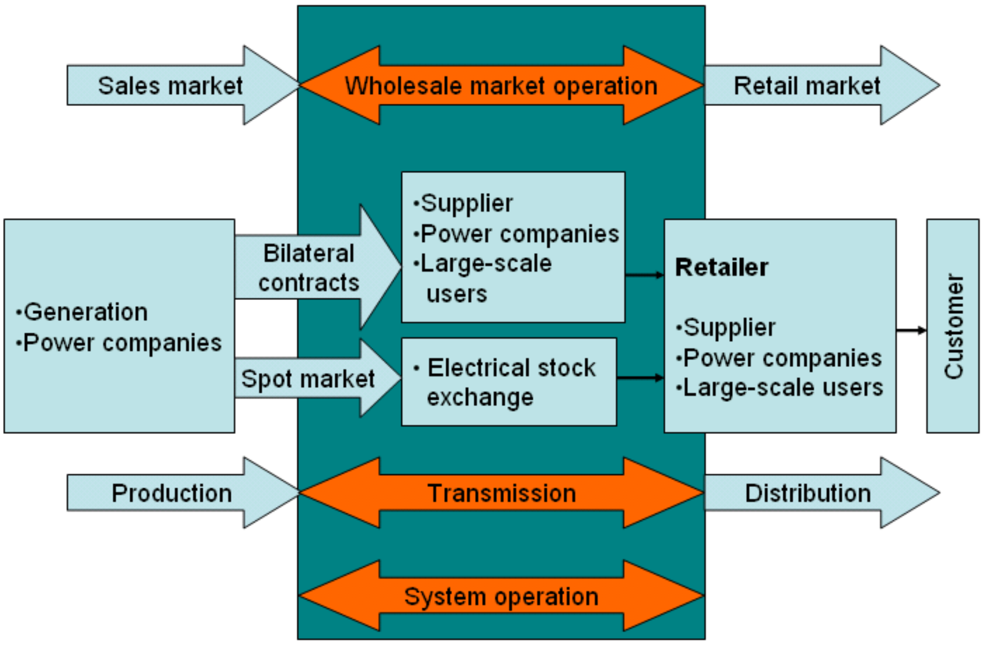

Figure 18. Schematic representation of the Icelandic electrical sector.

5.4.1 Price

The largest energy producing and selling company in Iceland is Landsvirkjun and their price list for electricity is available to all. This price list is valid for regular users, but special contracts are usually made with large-scale users where price can assumed to be somewhat lower. The prices are given for variable time periods; 1, 3, 7 and 12 years, where a longer contract period gives lower energy prices. The shortest period, 1 year, yields an energy price slightly above 3 ISK/kWh on average where the prices are higher in the winter period and lower in the summer. All prices are presented without VAT. No other companies publish their price list publicly [43].

At a conference in year 2001 held by Samorka it was estimated that the price for energy derived from wind turbines could be somewhere between 3-4 ISK/kWh [2]. Samorka is a federation of the Icelandic electricity industry, district heating, waterworks and sewage utilities.

The price used in the economical calculations varies between 3-4.5 ISK/kWh.

5.5 The Economical Calculations

The economical calculation is based on the assumptions previously discussed in the project. All results appear in euro, €.
Table 5 shows the variables used in the calculations done in Excel. The program created in Excel is shown in more detail in Appendix A.

Table 5. Variables to insert into the economical calculations, interval shown in information column if appropriate.

Component	Chosen values	Unit	Information
Turbine size	2.0	MW	
Number of turbines	10.0	(Max 100)	
From Wind turbine Power Calculator	8000	MWh/year	For one turbine
Annual production	80,000	MWh/year	Total production for one year
Electricity price	3000	Krona/MW	2500-4000 ISK/MW
Green Certificate	0	Krona/MW	
Total investment cost per kW	1000	€/kW	1000-1200 €/kW
Discount rate	7.5	%/year	5%-10%
Life time of the wind farm	20.0	Year	
O/M cost	1.2	c€/kWh	Average over the life time of the wind turbine
Royalty rate (land lease)	3.0	%	1.5-10% of revenue
Delivery charge	3,925,033	Krona/year	In Iceland
Ancillary services	25.8	Krona/MW	In Iceland
Exchange rate ISK	110	ISK	
Exchange rate SEK	0.0	SEK	

Changing the variables will of course affect the outcome. It is clear that the turbine size and number drastically affect the outcome but in order to simplify the situation the decision was made to do calculations based on 2 MW turbines. It is not possible to alter the wind turbines effect to for example 2.5 MW as this changes the basis of the calculated annual power production results from the power calculator. On the other hand, it is possible to alter the multiplication factor, in this project set as 10 turbines. In chapter 4.4 the annual production for a 2 MW wind turbine was determined for all three locations in this project. In the economical analysis the highest power yield, 8000 MWh/year, from Rauðinúpur, is used. In the calculator it is possible to insert values in ISK or SEK and an exchange rate calculator gives the results in euro, €. This is applicable for values of electricity price, green certificate, delivery charge and ancillary services. Here, the electricity price is shown as 3000 ISK/MWh but this can be varied in the calculator. Of course, the green certificate is zero, as this does not exist in Iceland, so far. The total investment cost per kW was discussed in chapter 5.3.1. And is estimated to be of the order of €1000 to €1200 per kW. The discount rate is estimated to lie between 5-10% and can be varied in the calculator [3], [41]. The life time of wind turbines is generally regarded as 20 years. The cost for operation and maintenance is set as 1.2 c€ per MW using 10 wind turbines but the calculator diminishes this cost linearly to 0.8 c€ per MW when the turbine number has reached 100.

The royalty rate, i.e. the cost for leasing land, is estimated to lie between 1.5-10% of the revenue as discussed before in chapter 4.5. The values for delivery charge and the ancillary services were discussed in chapter 5.3.2. The exchange rate for ISK to euro is set at 110. The rate for the ISK has for the last three years varied around 90 but its value has now decreased and it is expected to stabilize at a new level around 110 according to a personal contact source in the Icelandic financial sector.

5.6 The Outcomes of the Financial Analysis

Below in Table 6 and Table 7 the results of the cost analysis are represented with the amount in € for different values earlier represented in the cost analysis as proportions. These values are valid with the electric price set at 4000 ISK/MWh, the discount rate at 5%, the investment cost 1100 €/kW and 10x2 MW turbines with an annual production of 80,000 MWh. Table 6 shows the capital investment cost while Table 7 shows the operation and maintenance costs.

Table 6. The capital investment cost breakdown.

Component	Total cost [%]	Estimation [%]	Cost [€]
Turbine	65-80	70.0	15,400,000
Foundation	5-11	7.0	1,540,000
Electrical installation	5-11	5.0	1,100,000
Grid connection	6-15	6.0	1,320,000
Road construction	1-5	1.5	330,000
Land purchase	0-6	0.0	0
Approvals	3-8	3.0	660,000
Planning costs (consultancy)	3-5	3.5	770,000
Financial cost	3-5	3.0	660,000
Infrastructure	1-5	1.0	220,000
Total:		**100.0**	**22,000,000**

Table 7. Operation and maintenance cost breakdown.

Operation:	Cost information	Proportion [%]	Total annual Cost [€]
Land lease	1.5-10% of the revenue	9.09	87,273
Local taxes	1% estimated, without VAT and tax of possible revenue	3.03	29,091
Insurance	400,000 ISK/MW installed	7.58	72,744
Administration	NN*	25.00	239,920
Local utilities	NN*	8.00	76,774
Delivery charge	3,925,033 ISK/year	3.72	35,682
Ancillary services	25.8 ISK/MW produced	1.96	18,764
Maintenance:			
Regular maintenance (Scheduled)	NN*	14.00	134,355
Maintenance (Unscheduled)	NN*	14.00	134,355
Long-term replacement	NN*	13.62	130,708
Total:	1.2 c€/kWh	**100.00**	**959,666**

*NN = no number available

A number of methods are used in economical analyses. All are based on assumptions regarding the costs and price. In this project the results are presented as the internal rate of return IRR, present value PV, Benefit to Cost ratio and Pay-back period.

The IRR is a percentage that indicates the relative yield on the investment, or the annualized effective compounded return rate. Mathematically the IRR is the determined value of discount rate for PV to equal zero. In this project an internal calculator in Excel was used to determine IRR. The higher the IRR the more yield the investment will give. The IRR should exceed the interest rate for the investment loan and the higher level of IRR the better, i.e. the higher the yield of the project.

Present value is the value on a given date of a future payment (or series of payments), given an interest or a discount rate to reflect the changing value of money over time. A loan to be repaid with annual amortisations can be considered as a sum of loans, one for each year where the PV of the loan equals the sum of the present values of all loan payments as shown in Equation 5 below [36].

$$PV = \frac{A}{1+r} + \frac{A}{(1+r)^2} + \ldots + \frac{A}{(1+r)^N} = A\sum_{j=1}^{N} \frac{1}{(1+r)^j} \qquad (5)$$

This can also be shown with a geometric series shown in Equation 6:

$$PV = A\frac{\left[1-(1+r)^{-N}\right]}{r} \tag{6}$$

Where:	PV	Present Value
	A	Equal Annual Payment
	r	Discount Rate
	N	Economic Life of Project (years)

The benefit-to-cost analysis gives the B/C ratio; where B is the present value of the income and C the present value of the investment cost or $PV_{income}/PV_{investment}$. If B/C > 1 the project is economically feasible but if < 1 it is not.

Pay-back period is the period of time required to repay the investment capital. In this project the number of years needed to pay back the initial loan has been solved from Equation 3 above and thus includes the interest rate factor. The equation for payback time used is shown in Equation 7 below.

$$N = \frac{\ln\left(-\frac{A}{PV * r - A}\right)}{\ln(1+r)} \tag{7}$$

The results from the economical analysis are shown below in Table 8 where the production is set at 80,000 MWh/year and the electricity price at 4000 ISK/MWh. If the result is obviously far out of the frame of reference the results are shown as NN, this applies for a B/C ratio below 0.85, a payback time longer than 25 years and a present value of revenue less than €19,600,000. The total investment cost varies depending on the estimation chosen, for 1000 €/kW it is €20,000,000; for 1100 €/kW €22,000,000; and for 1200 €/kW €24,000,000.

Table 8. The economical analysis 1. IRR= internal rate of return, B/C ratio=benefit/cost ratio.

Component:									
Production [MWh/year]	80,000								
Electricity price [ISK/MWh]	4000								
Discount rate [%]	5			7.5			10		
Investment cost [€/kW]	1000	1100	1200	1000	1100	1200	1000	1100	1200
IRR [%]	7.42	6.2	5.14	7.42	6.2	5.14	7.42	NN	NN
B/C ratio	1.22	1.1	1.01	0.99	0.9	NN	NN	NN	NN
Pay-back time [Y]	14.75	17.03	19.59	20.3	NN	NN	NN	NN	NN
Present value of revenue [€]	24,293,969			19,873,283			NN		

Table 9 shows a calculation where the electricity price is lower, 3500 ISK/MWh excluding the interest rate of 10% because of obviously uninteresting results.

Table 9. The economical analysis 2.

Component:						
Production [MW/year]	80,000					
Electricity price [ISK/MWh]	3500					
Discount rate [%]	5			7.5		
Investment cost [€/kW]	1000	1100	1200	1000	1100	1200
IRR [%]	4.86	3.77	2.82	NN	NN	NN
B/C ratio	0.988	0.898	NN	NN	NN	NN
Pay-back time [Y]	20.41	24.25	NN	NN	NN	NN
Present value of revenue [€]	19,762,256			NN		

In the excel calculator it is possible to change the number of wind turbines. With increasing size the O/M cost per turbine become lower, in the calculator this cost reduces linearly as discussed above. Table 10 shows the calculations with 100 turbines as it was interesting to see what effect the enlargement of the wind farm to 200 MW could have.

Table 10. The economical analysis 3. Enlargement of wind farm to 200 MW.

Component:									
Production [MWh/year]	800,000								
Electricity price [ISK/MWh]	4000								
Discount rate [%]	5			7.5			10		
Investment cost [€/kW]	1000	1100	1200	1000	1100	1200	1000	1100	1200
IRR [%]	9.3	7.98	6.84	9.3	7.98	6.84	9.3	7.98	X
B/C ratio	1.39	1.27	1.16	1.14	1.04	0.95	0.95	0.87	X
Pay-back time [Y]	12.14	13.87	15.75	15.35	18.49	22.57	23.54	X	X
Present value of revenue [€]	278,830,854			228,092,662			190,483,403		

5.7 Sensitivity Analysis

In the sensitivity analysis the projects economical calculations are presented in charts where different components of the calculations are highlighted and their effect on the final outcome is discussed.

5.7.1 Price and Number

Figure 19 shows different electricity prices and their effect on IRR. In this case the investment cost was set as 1000 €/kW. A cost reduction occurs for O/M with increasing number of turbines as stated earlier. As can be seen the IRR doubles for a change in price from 3500 to 4500 ISK/MWh for 10 turbines. The rise in IRR associated with increased turbine number from 10 to 100 is more modest. Additionally, it isn't until the price exceeds 4000 ISK/MWh that the IRR has reached a economically interesting level.

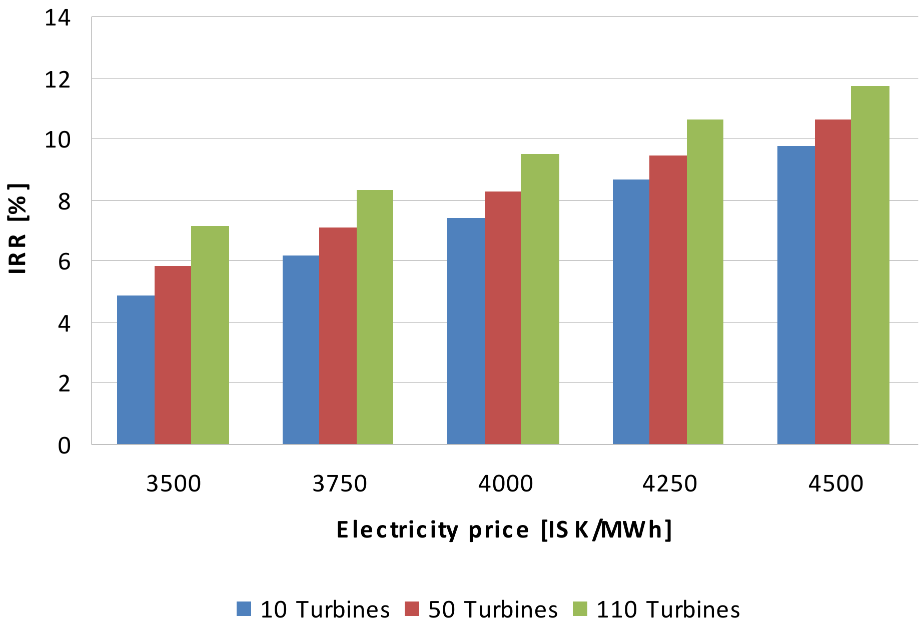

Figure 19. Turbine number effect on IRR.

5.7.2 Discount Rate

It is very important to seek to minimize the discount rate when financing a project of this scale as the influence on the projects economics is large. Figure 20 shows the price and discount rate effect on B/C ratio where investment cost is set at 1000 €/kW and 10 turbines. At a mean discount rate 7.5% the B/C ratio becomes 1 at an electricity price of 4000 ISK/MWh, thus, lower prices or higher discount rate will decrease the B/C ratio to a level below 1.

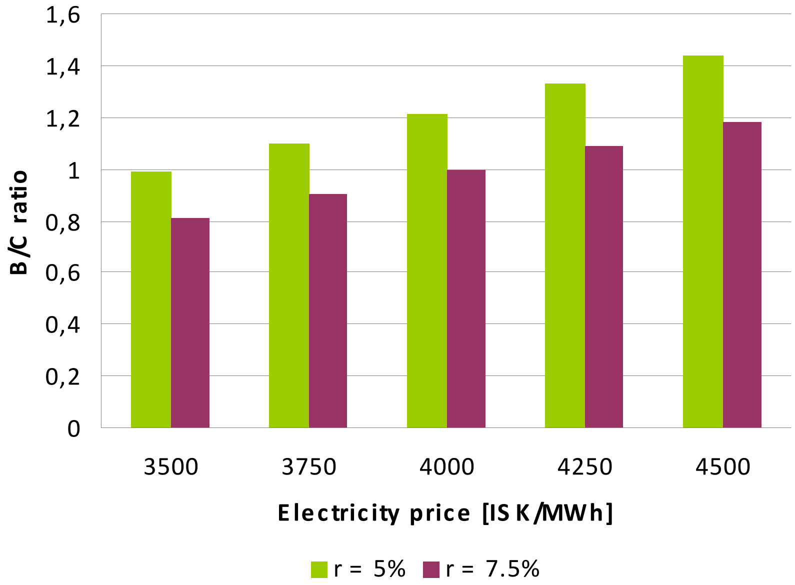

Figure 20. Discount Rate Effect on B/C ratio.

Figure 21 shows the discount rate effect on pay-back time with investment cost set at 1000 €/kW and 10 turbines as before. With decreasing electricity price the pay-back time increases, the discount rate impact on the pay-back time being largest at lower electricity prices. Assuming a mean interest rate of 7.5% the pay-back time equals the expected life-time of the wind farm at an electricity price of 4000 ISK/MWh, and it is obviously preferable to have the pay-back time shorter than this.

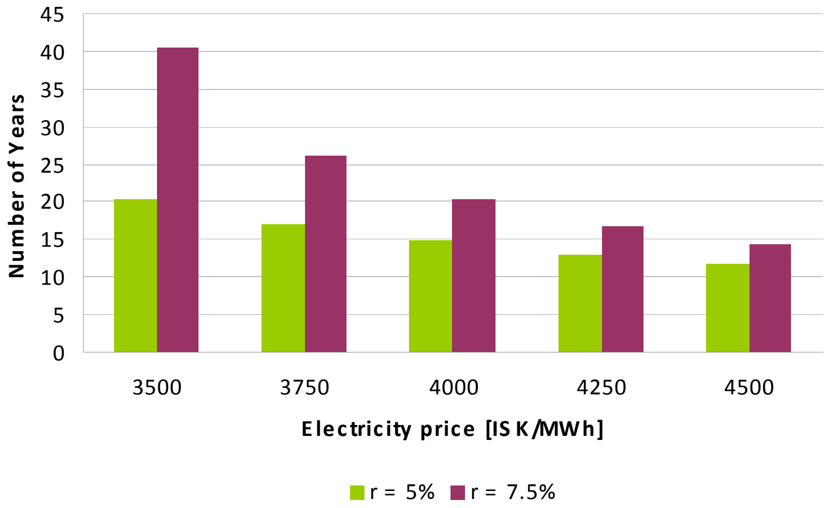

Figure 21. Discount Rate Effect on Pay-back time.

5.7.3 Investment Cost

Figure 22 shows the effect of investment cost on IRR, number of turbines 10. Even assuming high electricity prices of 4250 and 4500 ISK/MWh the IRR is below 10% with the lowest estimated investment cost.

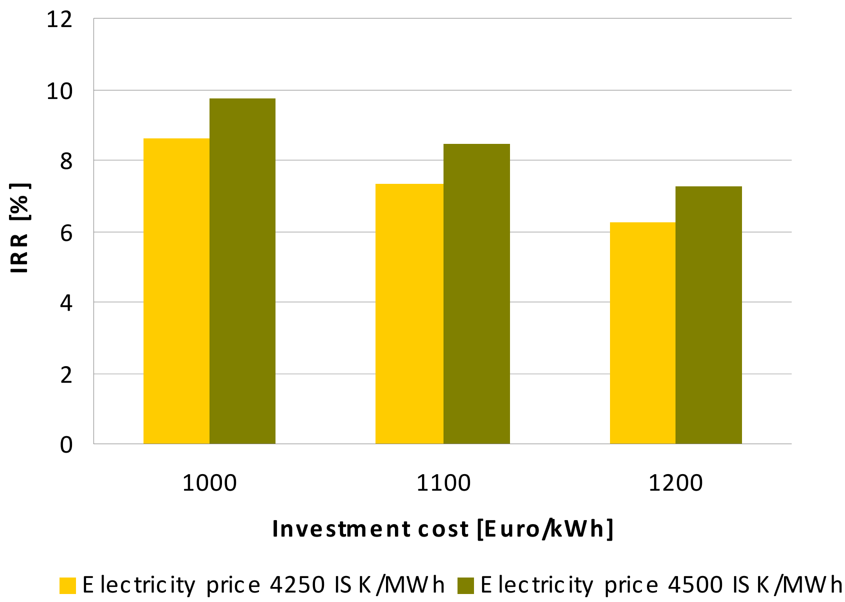

Figure 22. Investment Cost Effect on IRR.

The investment cost effect on B/C ratio at different discount rates is shown in Figure 23. The electricity price is set at 4250 ISK/MWh and the number of turbines is 10. As can be seen at this high electricity price the economical feasibility according to the B/C ratio is acceptable at a low discount rate 5%, as the discount rate increases to 7.5% the B/C ratio declines and only the lowest investment cost is > 1.

Figure 23. Investment Cost Effect on B/C ratio.

5.7.4 Number

With increasing size the economical conditions improve. The three figures presented below show the turbine number effect on B/C ratio with different discount rates, 5%, 7.5% and 10%, respectively. All examples presume an investment cost of 1000 €/kW.

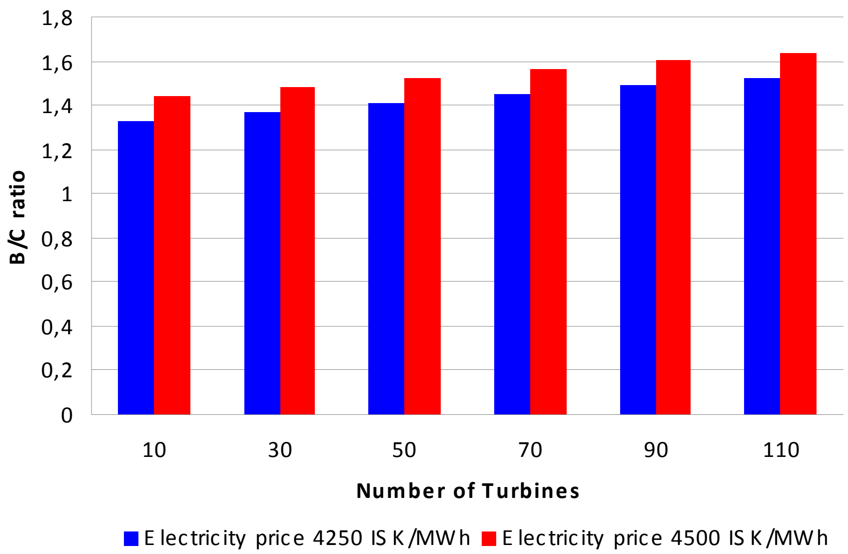

Figure 24. Turbine Number Effect on B/C Ratio. Discount Rate 5%.

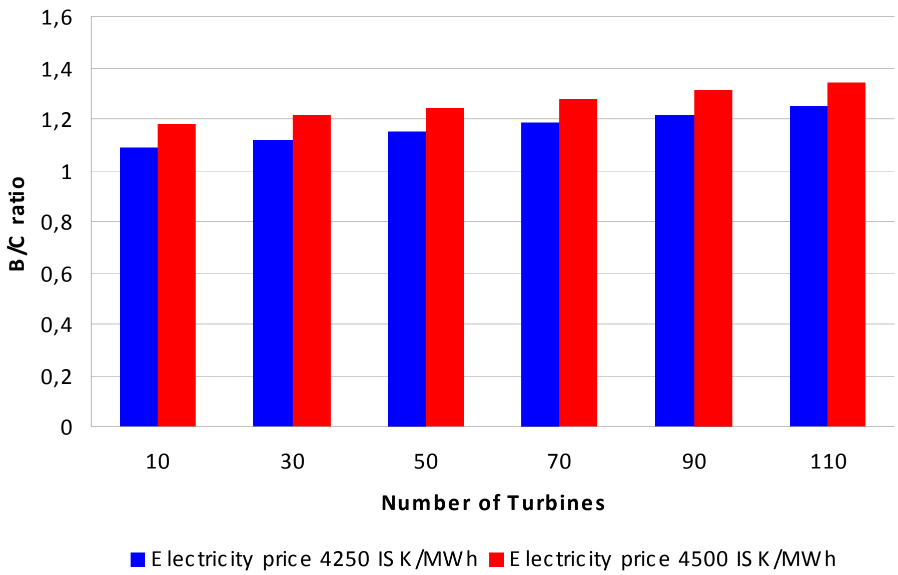

Figure 25. Turbine Number Effect on B/C Ratio. Discount Rate 7.5%.

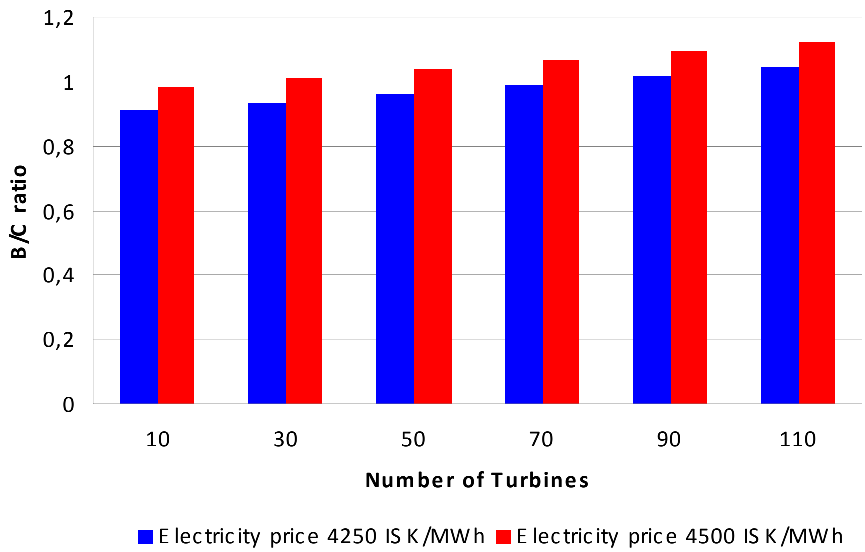

Figure 26. Turbine Number Effect on B/C Ratio. Discount Rate 10%.

As can be seen increasing size improves the resulting B/C ratio, as does the discount rate reduction for the two cases of the electricity prices of 4250 and 4500 ISK/MWh. At lower electricity prices no number of turbines (up to 110) would have resulted in a B/C ratio > 1 at a 10% discount rate.

5.7.5 Exchange Rate

Exchange rate variations have a large impact on the economical calculation as the electricity is paid for in ISK but the loan payments are presumably in €. In Figure 27 below the exchange rate effect on IRR is shown at different electricity prices. The investment cost is set at 1000 €/kW, turbine number at 10. A large impact can be seen, especially at low electricity prices where the IRR is nearly doubled as exchange rate changes from 110 to 90.

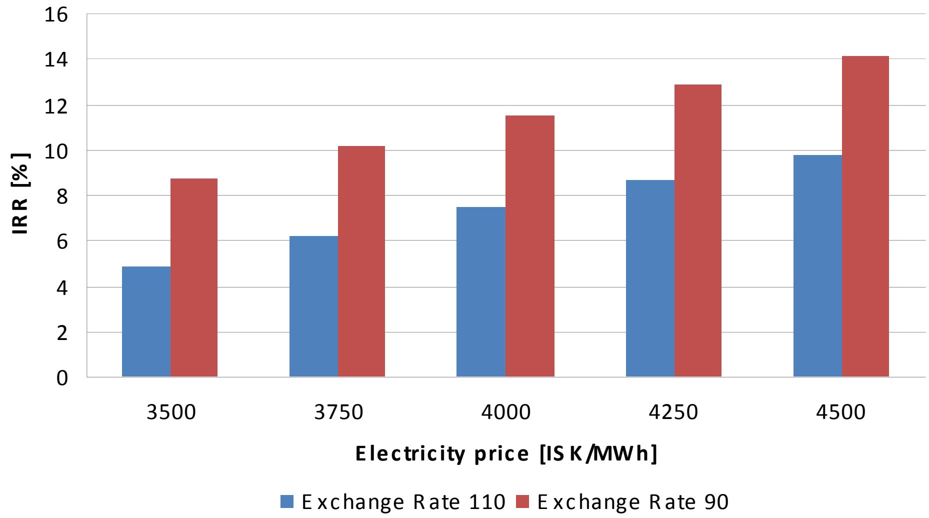

Figure 27. Exchange Rate Effect on IRR.

Using the same conditions as before the exchange rate effect on B/C ratio is shown in Figure 28. With discount rate (not relevant in IRR calculation) set at 7.5% it can be seen that the exchange rate also influences the B/C ratio substantially. At exchange rate 90 the project can always be considered feasible whereas the electricity price would have to exceed 4000 ISK/MWh for the project to be feasible at exchange rate 110.

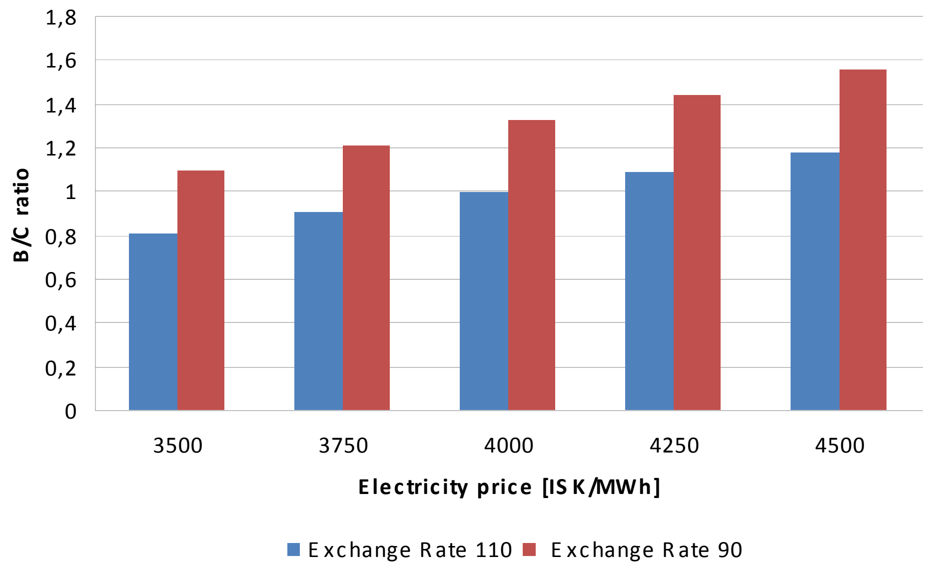

Figure 28. Exchange Rate Effect on B/C Ratio.

Chapter 6: Conclusions and Recommendations

This chapter presents the conclusions drawn as well as a discussion of the results and future aspects of wind power development in Iceland.

6.1 Conclusions:

This project has attempted to estimate the possible profitability of raising a wind farm in Iceland. It is clear that with certain conditions fulfilled the project may yield an acceptable profit but at the present it is doubtful that such a project would interest developers working in this field. The conditions in Iceland have to change substantially in order to make harnessing wind power economically feasible.

The large available amount of unused green energy sources in form of hydro and geothermal power and the low price for electricity on the market are presumably the main causes of the slow development in wind power in Iceland. The national energy authority of Iceland, Orkustofnun, estimates that only 20% to 25% of the technically and environmentally feasible hydropower, and only 20% of the conventional geothermal potential available for electricity production in Iceland, have been harnessed [44]. The harvest of these energy sources produces a larger profit and in a competitive environment wind energy isn't, at the present, competitive enough. Other possible causes for the slow development of wind farms in Iceland are the lack of experience in the field where developers are reluctant to deal with a completely new project. Political influence is even important, no governmental subsidies exist and neither do plans to establish such a system.

The project has dealt with different aspects of raising a wind farm as initially shown in chapter 1.4. Problem Analysis. These aspects can be divided into three categories:

- A technical analysis of raising a wind farm.
- An analysis of existing laws and regulations regarding the power sector focusing on wind turbines.
- An economical analysis trying to determine the profitability of the project.

In the technical analysis the intention was from the beginning to estimate both the right size of the wind turbines and their most appropriate number for a given location as well as the general design of the farm. It soon became clear that this was an impossible task without the advanced specialized computer programs designed with this purpose in mind, in addition to this was the lack of information from the wind turbine producer that posed a major obstacle. Three locations were analyzed in this project, these locations were chosen because of favorable wind measurements from the Icelandic wind atlas, two of them even because of closeness to the transmission system. Only the best result was used in the economical evaluation. In general it can be said that there is no lack of wind energy to be harvested but information is needed from the wind turbine producer to determine if the turbines tolerate the high wind speeds and the cold climate with the occasional ice storms in Iceland. This is a question that remains to be answered. The connection to the grid will presumably not be problematical, the grid's capacity seems to be sufficient but of course a detailed computerized analysis in forehand will be needed. Here, as always, the cost related to grid connection will have a considerable effect when deciding between different possible locations of the farm. The consultancy for the integration of the wind farm will be costly, as well as the actual connection.

Reviewing the current laws and regulations has revealed considerable shortage in the field of wind energy harnessing. General laws and regulations are often transferable to wind power harvest but not always. A great deal of work in reviewing and interpreting existing laws will be required but also the need will arise for specific regulations, for example regarding environmental issues where the main concerns with wind turbines such as noise and shadows are not mentioned at all in the Icelandic laws and regulations. The main electrical regulation problems seem to more be a concern between the transmission company and the developer where no previous contracts in this field can be used as a reference. This will cause a great deal of work with associated costs and risk for mistakes that then can affect the management of a wind farm at later stages.

The economical analysis included cost estimation, estimation of electricity price, risk management and a calculation of the possible profitability expressed as IRR, B/C ratio, PV and Pay-back time and a sensitivity analysis. It is important to remember that the calculations cannot become more correct than the assumptions they are based on.

The project of building a wind farm is generally accepted to carry a substantial amount of risk; these were discussed in more detail in chapter 5.2 Risk management. The conclusion to be drawn is that it is essential to be aware of this high risk when planning for such a project and that it is necessary to analyze more exactly what factors generate the largest risk and have a plan to deal with these in the appropriate way.

The selling of the electricity is dependent on the actual market price where the largest provider of electrical power in Iceland, Landsvirkjun, is selling electricity at a price slightly below 3 ISK/kWh. One can assume that the energy price from other producers is not substantially higher than this. A public price list for retail sale of electricity in Iceland published at the Orkustofnun homepage [45] shows that retail companies are selling at a rate of 3.52 ISK/kWh and it is therefore clear that they are not buying the energy at a higher price than this.

The economical calculation has given disappointing results regarding the feasibility of raising a wind farm in Iceland. It is unlikely within the nearest future that the electricity price increases to a level of 4000 ISK/MWh or more. The results from the calculation in Table 8 shows that the profitability is limited even when the price is set at this high level and the cost factors including the discount rate set at a minimum. The highest IRR is 7.42%, C/B 1.22 and payback period 14.73 years and a present value of revenue 24,293,969 with an investment cost of 20,000,000. Using these figures the raising of a wind farm could very well be considered as an interesting investment opportunity but then one is assuming a “best case scenario” that in reality isn’t always the case. The effect of lowering the electricity price to 3.5 ISK/kWh changes the equation substantially as shown in Table 9 and the benefit-cost analysis is no longer > 1. Reciprocally, using another exchange rate than 110 as is done in this analysis will increase the profitability. If the exchange rate in the example presented in Table

8 is set at 90 but other variables remain unchanged the IRR rises to 11.51%, B/C to 1.618 and a payback period of 9.97 years that are obviously very promising results.

The sensitivity analysis emphasizes that the electricity price has to exceed 4000 ISK/MWh in order to make the project economically feasible in almost all cases with mean investment cost at 1100 €/kW, also, the project is very sensitive to discount rate and exchange rate value. Increasing the turbine number will also yield more profit.

Governmental subsidies could drastically alter the equation of profitability, in general such systems give the wind energy a higher market value. For example a green certificate could generate an energy price of 4000 ISK/MWh instead of 3000 – 3500 ISK/MWh and therefore make the building of a wind farm in Iceland feasible from an economical viewpoint. The environmental impact of harnessing of wind power is even less that the impact associated with hydropower or geothermal stations and therefore it is not unthinkable that a situation will arise in the future where public and political influence will cause such a change in the energy market.

6.2 Recommendations:

As the work with the project has evolved it has become clear that an extensive detailed analysis is needed before the construction of a wind farm. Further research is needed in this area, for example:

- Analysis of the transmission system and the interaction between a wind farm and the system.
- Further analysis of existing wind data from the Icelandic wind atlas as the lack of access to the programs used caused a considerable limitation to this study.
- Extended economical calculation with an increased size and number of turbines as this could yield better results, as shown in Table 10. This benefit is counterweighed by the increased investment risk and financing could prove to be difficult.
- In order to investigate further the possibility of raising a wind farm in Iceland a good start would be to raise one or a few experimental turbines that could provide information, knowledge and experience necessary for the progress of wind power in Iceland.
- In order to minimize delays in the bureaucratic processes inevitable accompanying a project such as raising a wind farm, and to assist wind power progress in Iceland, a thorough review and refinement of existing laws and regulations is necessary.

The work with this project has been interesting. I have speculated a lot in the past years as to why there are no wind farms in Iceland as well as discussed the matter with a number of individuals, both persons with a connection to the electrical field and others, without obtaining a reasonable answer in the matter. But now I know more and I hope that this report can provide a few answers to other keen enthusiasts.

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Appendix 1: The Economic Calculator

Mean wind speed	9	m/s
Rotor diameter	82	m
Power coefficient, C_p	0,5	
Mechanical/electrical efficiency, η	1	
Air density	1,225	kg/m^3
Hours in year, T	8760	h/year
Number of 2 MW turbines	10	pcs
Power distribution for one year	103.282	MWh/year

Bláfeldur	7500	MWh/year
Hvanney	7000	MWh/year
Rauðinúpur	8000	MWh/year
Size of turbines	2	MW
Number of 2 MW turbines	10	pcs (MAX 110)
Wind turbine power calculator result	8000	MWh/year
Power distribution for one year	80.000	MWh/year

Exchange rate, Icelandic krona	110	ISK	
Exchange rate, Swedish krona	0	SEK	
Exchange rate, euro	1	Euro	**Information:**
Electricity price	3000	krona/MW	2500-4000 ISK/MW
Green certificate	1000	krona/MW	
Total investment cost per kW	1000	€/kW	1000-1200 €/kW
Discount rate	5,00%	%/year	5%-10%
Life time of the wind park	20	year	
O/M costs	1,2	c€/kWh	Average over the lifetime of the wind turbine
Royalty rate (land lease)	3%	%	1,5-10% of the revenue
Delivery charge	3.925.033	krona/year	3.925.033 ISK/year in Iceland
Ancillary services	25,80	krona/MW	25,8 ISK/MW in Iceland
Local taxes	1%	%	
Insurance	400.000	krona/year	400.000 ISK/MW

O/M costs	1,20	c€/kWh
Electricity price	36,364	€/MWh
Delivery charge	35.682	€/year
Ancillary services	0,235	€/MWh
Insurance	72.727	€

Internal Rate of Return [IRR] 7,42%	Pay-back time [years] 14,75
Benefit to cost ratio [B/C] € 1,215	Present Value of revenue € 24.293.969

Period	Investment	Production (MWh)	O/M cost	Revenue	Net Cash Flow	Present value of revenue	Pay-back
0	€ 20.000.000	0	€ -	€ -	-€ 20.000.000		-€ 20.000.000
1		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.856.582	-€ 19.050.589
2		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.768.173	-€ 18.053.708
3		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.683.974	-€ 17.006.982
4		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.603.785	-€ 15.907.920
5		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.527.414	-€ 14.753.905
6		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.454.680	-€ 13.542.190
7		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.385.410	-€ 12.269.888
8		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.319.438	-€ 10.933.972
9		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.256.608	-€ 9.531.260
10		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.196.769	-€ 8.058.412
11		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.139.780	-€ 6.511.921
12		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.085.505	-€ 4.888.106
13		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 1.033.814	-€ 3.183.101
14		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 984.585	-€ 1.392.845
15		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 937.700	€ 486.924
16		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 893.048	€ 2.460.681
17		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 850.522	€ 4.533.126
18		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 810.020	€ 6.709.193
19		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 771.448	€ 8.994.063
20		80.000	€ 959.680	€ 2.909.091	€ 1.949.411	€ 734.712	€ 11.393.178
						€ 24.293.969	

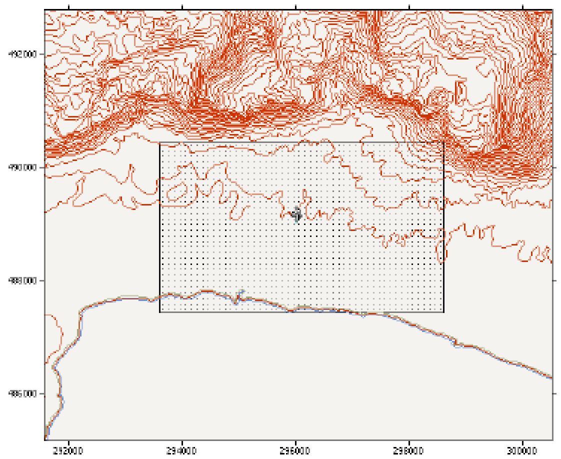
Cost breakdown for a wind turbine farm			
Turbine	70,0%	65-80%	€ 14.000.000
Foundation	7,0%	5-11%	€ 1.400.000
Electrical installation	5,0%	5-11%	€ 1.000.000
Grid connection	6,0%	6-15%	€ 1.200.000
Road construction	1,5%	1-5%	€ 300.000
Land purchase	0,0%	0-6%	€ -
Approvals	3,0%	3-8%	€ 600.000
Planning costs (consultancy)	3,5%	3-5%	€ 700.000
Financial cost	3,0%	3-5%	€ 600.000
Infrastructure	1,0%	1-5%	€ 200.000
	100,0%		€ **20.000.000**

Operations:			
Land lease	9,09%	€	87.273
Local taxes	3,03%	€	29.091
Insurance	7,58%	€	72.727
Administration	25,00%	€	239.920
Local utilities	8,00%	€	76.774
Delivery charge	3,72%	€	35.682
Ancillary services	1,96%	€	18.764
Maintenance:			
Regular maintenance (scheduled)	14,00%	€	134.355
Maintenance (unscheduled)	14,00%	€	134.355
Long term replacement	13,62%	€	130.708
	100,00%	€	959.650

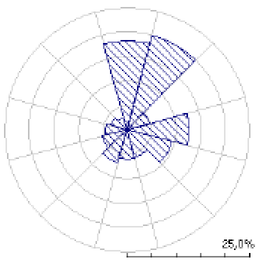
Appendix 2: Bláfeldur

Skýringar á töflum og myndum er hægt að nálgast

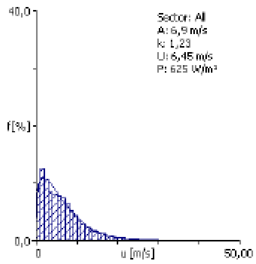
Bláfeldur
Staðsetning 64°50.36'N, 23°18.07'V, (64.839, 23.301)
Hæð mælis 10 m
Hæð yfir sjó 13 m
Tímaraðir 2004-2006



-	Unit	Measured	Weibull-fit	Discrepancy
Mean wind speed	m/s	6,36	6,45	1,27%
Mean power density	W/m²	624,03	624,79	0,12%



Wind rose at 10 meters



Distribution at 10 meters

This table shows the calculated parameters for each of the standard heights and roughness class, 5 heights and 4 roughness classes for 12 sectors. The Weibull A-parameter is given in m/s. U gives estimated (calculated) mean wind speed in m/s and power density gives the total mean power of the wind in W/m², for each of the standard five heights and roughness class.

Height	Parameter	0,00 m	0,03 m	0,10 m	0,40 m
10,0 m	Weibull A [m/s]	10,8	7,7	6,8	5,3
	Weibull k	1,19	1,14	1,15	1,16
	Mean speed [m/s]	10,17	7,38	6,43	5,05
	Power density [W/m²]	2632	1085	709	339
25,0 m	Weibull A [m/s]	11,7	9,1	8,2	6,9
	Weibull k	1,19	1,16	1,17	1,17
	Mean speed [m/s]	11,06	8,62	7,78	6,54
	Power density [W/m²]	3366	1673	1218	714
50,0 m	Weibull A [m/s]	12,5	10,2	9,4	8,2
	Weibull k	1,20	1,19	1,19	1,19
	Mean speed [m/s]	11,76	9,65	8,86	7,71
	Power density [W/m²]	3998	2252	1732	1133
100,0 m	Weibull A [m/s]	13,3	11,6	10,8	9,6
	Weibull k	1,21	1,23	1,23	1,22
	Mean speed [m/s]	12,52	10,83	10,07	8,97
	Power density [W/m²]	4732	2951	2386	1694
200,0 m	Weibull A [m/s]	14,3	13,3	12,4	11,2
	Weibull k	1,22	1,29	1,28	1,27
	Mean speed [m/s]	13,39	12,32	11,52	10,37
	Power density [W/m²]	5679	3959	3288	2455

-	0	30	60	90	120	150	180	210	240	270	300	330	Total
A	12,9	8,8	2,4	5,7	5,7	5,3	4,9	5,1	6,2	5,0	4,8	3,5	6,9
k	1,72	1,67	1,20	1,84	1,79	1,54	1,49	1,40	1,72	1,45	1,29	0,90	1,23
U	11,47	7,87	2,28	5,03	5,04	4,78	4,46	4,61	5,54	4,51	4,45	3,73	6,45
P	2086	700	29	163	170	175	149	180	235	160	188	254	625
Freq	18	20	5	13	9	6	6	7	5	5	4	3	100

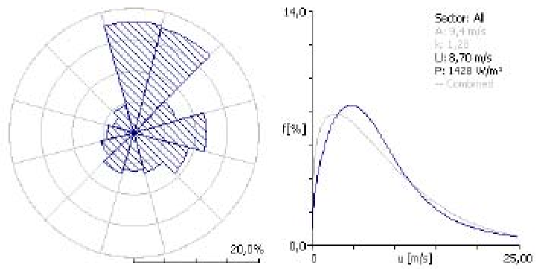
U	0	30	60	90	120	150	180	210	240	270	300	330	Total
1	59	61	207	74	66	95	92	77	94	146	199	293	92
2	58	109	348	144	112	113	130	109	107	160	202	232	126
3	27	87	182	118	128	144	179	183	104	130	91	80	106
4	28	55	95	107	111	140	125	154	104	99	60	61	85
5	41	58	70	102	133	105	112	102	95	81	85	79	82
6	55	66	41	104	123	71	81	88	98	88	87	44	78
7	58	66	23	99	98	80	80	80	106	85	72	40	75
8	56	65	14	84	78	80	72	57	82	57	57	32	65
9	55	63	12	68	46	54	47	45	63	40	42	29	53
10	48	60	6	46	39	42	34	34	37	41	22	20	43
11	51	51	1	27	26	37	19	20	41	29	20	9	35
12	47	52	0	14	15	14	14	15	27	24	14	21	29
13	46	46	0	5	12	11	5	12	19	7	15	9	23
14	41	42	0	3	7	5	4	10	12	6	11	6	20
15	40	30	0	3	5	4	2	5	4	4	6	10	16
16	32	21	0	1	1	2	2	3	2	0	6	5	11
17	35	19	0	1	0	3	1	4	1	0	5	5	11
18	30	16	0	0	0	0	1	1	0	1	3	3	9
19	31	9	0	0	0	0	1	1	2	0	1	8	8
20	24	7	0	0	0	0	0	0	0	0	1	4	6
21	22	3	0	0	0	0	0	1	0	1	0	6	5
22	20	3	0	0	0	0	0	0	1	0	0	1	5
23	18	3	0	0	0	0	0	0	0	0	0	2	4
24	18	1	0	0	0	0	0	0	1	0	0	1	4
25	16	2	0	0	0	0	0	0	0	0	0	0	3
26	10	2	0	0	0	0	0	0	0	0	0	0	2
27	8	1	0	0	0	0	0	0	0	0	0	0	2
28	7	0	0	0	0	0	0	0	0	0	0	0	1
29	5	0	0	0	0	0	0	0	0	0	0	0	1
30	6	0	0	0	0	0	0	0	0	0	0	0	1
31	3	0	0	0	0	0	0	0	0	0	0	0	1
32	1	0	0	0	0	0	0	0	0	0	0	0	0
33	1	0	0	0	0	0	0	0	0	0	0	0	0
34	1	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0

Results from Turbine Vestas V47 (660 kW):

Sector	Wind climate				Power			
#	a [deg]	f [%]	W-A	Weib-k	U	P [W/m2]	AEP	l [%]
1	0	17,9	16,2	1,66	14,50	4421	0,586	0,0
2	30	17,3	11,5	1,60	10,32	1669	0,502	0,0
3	60	7,0	6,1	1,16	5,78	509	0,095	0,0
4	90	11,5	7,6	2,08	6,75	347	0,203	0,0
5	120	9,1	7,7	2,10	6,79	349	0,162	0,0
6	150	6,6	7,4	1,71	6,56	395	0,111	0,0
7	180	6,0	6,9	1,58	6,18	366	0,092	0,0
8	210	6,7	7,0	1,51	6,32	414	0,106	0,0
9	240	5,4	8,0	1,80	7,13	475	0,105	0,0
10	270	4,3	6,8	1,61	6,11	345	0,064	0,0
11	300	3,5	6,5	1,20	6,07	547	0,052	0,0
12	330	4,6	9,5	1,10	9,18	2290	0,096	0,0
All			(9,4)	(1,28)	8,70	1428	2,173	0,0

Site	Location [m]	Turbine	Height [m]	Net AEP [GWh]	Wake loss [%]
Bláfeldur	(296017,3, 489085,8)	Vestas V47 (660 kW)	45	2,173	0,0

-	Total	Wind with maximum power density
Mean wind speed	8,70 m/s	19,65 m/s
Mean power density	1431 W/m²	59 W/m²



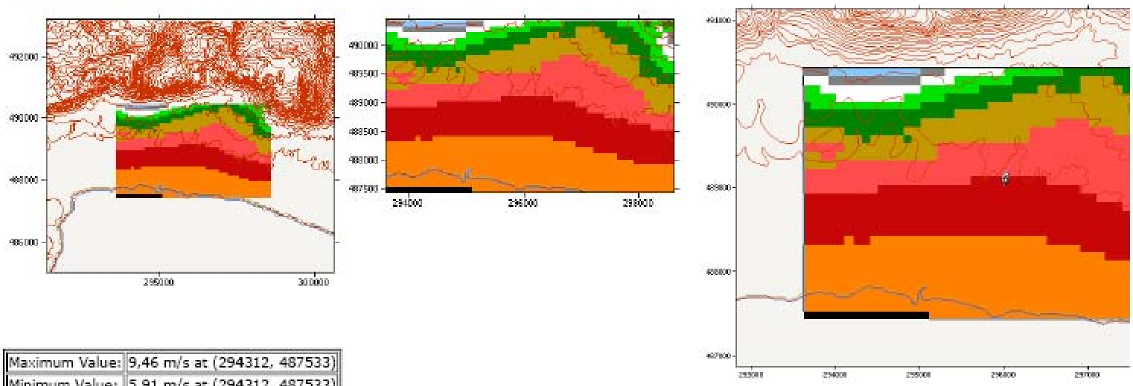
The combined (omnidirectional) Weibull distribution predicts a gross AEP of 2,223 GWh and the emergent (sum of sectors) distribution predicts a gross AEP of 2,173 GWh. (The difference is 2,3%)

Grid Setup

Structure: 50 columns and 30 rows at 100 resolution gives 1500 calculation sites.
Boundary: (293612, 487433) to (298612, 490433)
Nodes: (293662, 487483) to (298562, 490383)

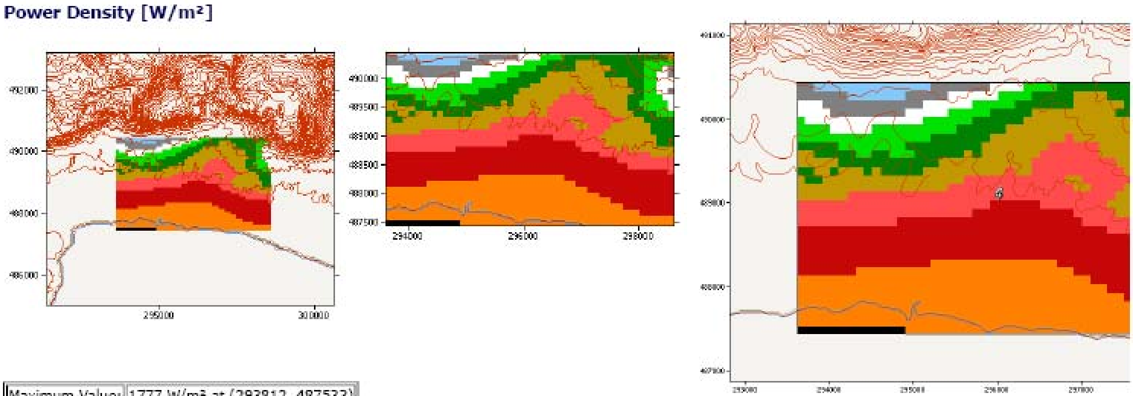
Results

Mean Speed [m/s]



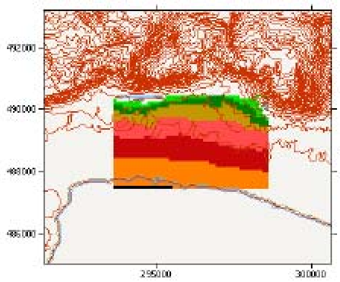
Maximum Value:	9,46 m/s at (294312, 487533)
Minimum Value:	5,91 m/s at (294312, 487533)
Mean Value:	8,48 m/s at (294312, 487533)

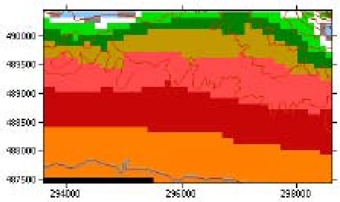
Power Density [W/m²]

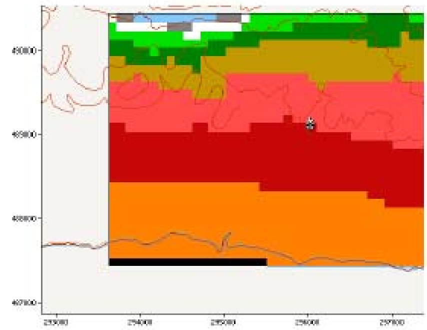


Maximum Value:	1777 W/m² at (293812, 487533)
Minimum Value:	343 W/m² at (293812, 487533)
Mean Value:	1315 W/m² at (293812, 487533)

AEP [Wh]

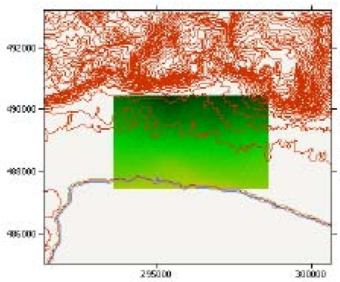


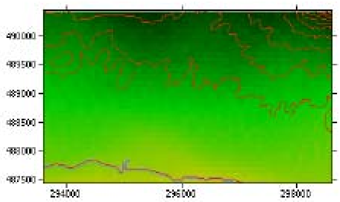


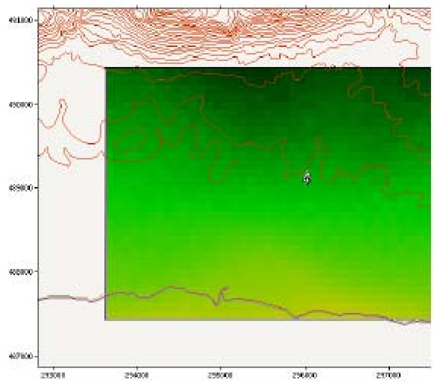


Maximum Value:	2,399 GWh at (294312, 487533)
Minimum Value:	1,407 GWh at (294312, 487533)
Mean Value:	2,138 GWh at (294312, 487533)

RIX [Rix]





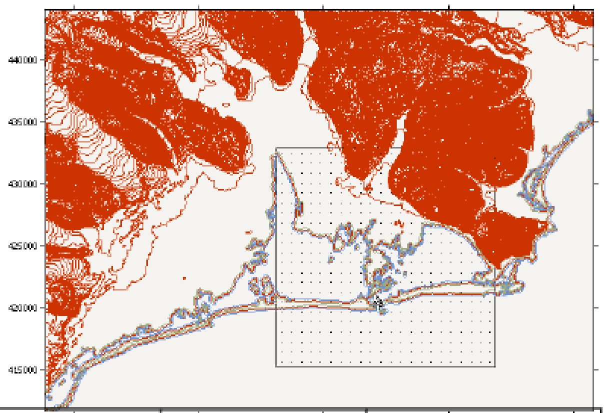


Maximum Value:	1233,2% at (298512, 490433)
Minimum Value:	37,3% at (298512, 490433)
Mean Value:	574,9% at (298512, 490433)

Appendix 3: Hvanney/Stokksnes

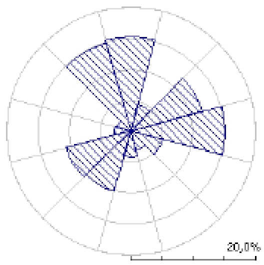
Skýringar á töflum og myndum er hægt að nálgast

Hvanney	Höfn í Hornafirði
Staðsetning	64°14'N, 15°12'V, (64.233, 15.2)
Hæð yfir sjó	4 m
Hæð vindmælis yfir jörð	10 m
Upphaf veðurathugana	1995

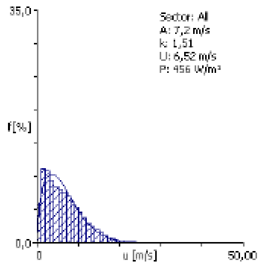


Frá mæli:

-	Unit	Measured	Weibull-fit	Discrepancy
Mean wind speed	m/s	6,43	6,52	1,39%
Mean power density	W/m²	455,59	455,72	0,03%



Wind rose at 10 meters



Distribution at 10 meters

This table shows the calculated parameters for each of the standard heights and roughness class, 5 heights and 4 roughness classes for 12 sectors. The Weibull A- parameter is given in m/s. U gives estimated (calculated) mean wind speed in m/s and power density gives the total mean power of the wind in W/m², for each of the standard five heights and roughness class.

Height	Parameter	0,00 m	0,03 m	0,10 m	0,40 m
10,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	7,71 1,58 6,92 514	5,42 1,41 4,93 219	4,72 1,41 4,30 145	3,72 1,42 3,39 71
25,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	8,42 1,60 7,55 655	6,44 1,47 5,83 338	5,80 1,47 5,25 249	4,88 1,47 4,42 148
50,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	9,02 1,64 8,07 774	7,38 1,58 6,63 452	6,75 1,56 6,07 353	5,85 1,54 5,27 235
100,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	9,69 1,62 8,67 973	8,57 1,70 7,65 630	7,91 1,70 7,06 496	6,99 1,67 6,25 350
200,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	10,51 1,58 9,44 1294	10,20 1,67 9,11 1081	9,40 1,68 8,40 842	8,32 1,69 7,43 580

-	0	30	60	90	120	150	180	210	240	270	300	330	Total
A	7,8	5,5	8,3	7,1	4,3	3,6	5,5	8,2	9,7	2,8	2,5	8,1	7,2
k	1,77	1,29	2,29	2,09	1,50	1,07	1,29	1,58	1,62	0,91	0,87	1,55	1,51
U	6,9	5,12	7,31	6,32	3,89	3,49	5,13	7,38	8,71	2,91	2,64	7,27	6,52
P	440	285	405	283	98	131	288	619	985	115	99	612	456
Freq	15	4	12	15	5	3	4	10	11	3	2	15	100
U	0	30	60	90	120	150	180	210	240	270	300	330	Total
1	45	132	38	27	72	130	109	40	42	152	179	43	57

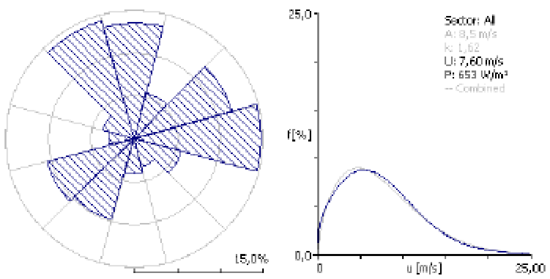
2	111	188	51	51	141	254	177	86	83	279	304	120	112
3	109	114	46	66	186	184	135	97	92	226	213	131	109
4	84	83	62	96	195	110	91	92	85	109	98	92	93
5	73	68	81	124	152	77	74	84	71	66	50	59	84
6	65	68	105	136	93	58	67	78	63	42	34	54	80
7	70	61	111	132	52	48	59	67	50	31	29	55	75
8	74	52	117	109	35	38	49	63	44	19	23	51	69
9	76	42	101	85	28	25	48	53	44	15	12	49	61
10	71	45	83	58	15	20	39	54	41	12	12	52	53
11	59	37	70	40	12	15	36	50	42	9	12	53	45
12	47	27	48	24	7	11	37	45	46	11	9	51	37
13	36	23	30	18	4	7	25	47	43	7	10	42	30
14	27	19	19	13	4	8	17	32	45	6	5	39	24
15	19	17	12	9	2	6	15	31	40	8	4	31	20
16	11	10	9	6	1	5	7	25	39	2	1	23	15
17	9	5	6	3	2	2	6	16	31	3	3	17	11
18	5	4	4	2	0	1	3	12	29	2	2	12	8
19	3	1	2	1	0	1	3	10	21	2	1	9	6
20	1	1	2	1	0	0	1	6	16	0	0	5	4
21	3	1	1	0	0	0	1	5	11	1	0	5	3
22	1	0	0	0	0	0	0	3	8	0	0	3	2
23	1	0	0	0	0	0	0	2	5	0	0	2	1
24	1	0	0	0	0	0	0	1	4	0	0	1	1
25	0	0	0	0	0	0	0	1	2	0	0	1	0
26	0	0	0	0	0	0	0	0	1	0	0	0	0
27	0	0	0	0	0	0	0	0	1	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0

Results from Turbine Vestas V47 (660 kW):

Sector	Wind climate					Power		
#	a [deg]	f [%]	W-A	Weib-k	U	P [W/m2]	AEP	l [%]
1	0	13,6	8,9	1,95	7,87	586	0,313	0,0
2	30	5,6	7,8	1,73	6,95	462	0,104	0,0
3	60	11,8	9,6	2,53	8,53	596	0,318	0,0
4	90	14,8	8,4	2,19	7,40	435	0,309	0,0
5	120	5,6	5,7	1,61	5,12	202	0,058	0,0
6	150	3,3	4,4	1,17	4,20	189	0,026	0,0
7	180	4,1	6,4	1,33	5,89	410	0,058	0,0
8	210	9,8	9,5	1,63	8,52	915	0,242	0,0
9	240	10,4	11,0	1,65	9,88	1409	0,297	0,0
10	270	3,0	4,3	0,99	4,33	306	0,026	0,0
11	300	3,8	4,9	1,08	4,78	334	0,038	0,0
12	330	14,2	9,4	1,69	8,40	841	0,349	0,0
All			(8,5)	(1,62)	7,60	653	2,138	0,0

Site	Location [m]	Turbine	Height [m]	Net AEP [GWh]	Wake loss [%]
Hvanney	(684200,1, 419937,5)	Vestas V47 (660 kW)	45	2,138	0,0

-	Total	Wind with maximum power density
Mean wind speed	7,60 m/s	13,91 m/s
Mean power density	653 W/m²	46 W/m²



The combined (omnidirectional) Weibull distribution predicts a gross AEP of 2,128 GWh and the emergent (sum of sectors) distribution predicts a gross AEP of 2,138 GWh. (The difference is 0,46%)

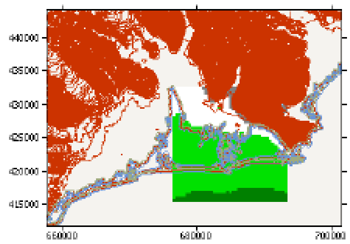
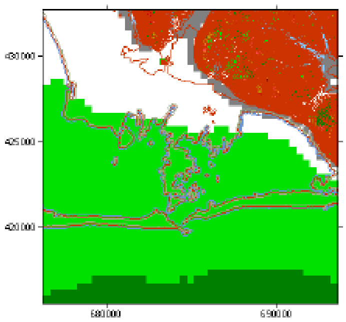
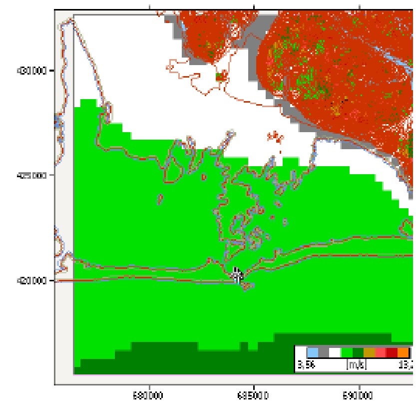
Grid Setup

Structure: 43 columns and 43 rows at 400 resolution gives 1849 calculation sites.
Boundary: (676358, 415475) to (693558, 432675)

Nodes: (676558, 415675) to (693358, 432475)

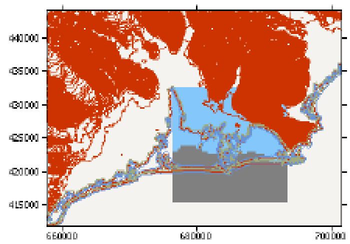
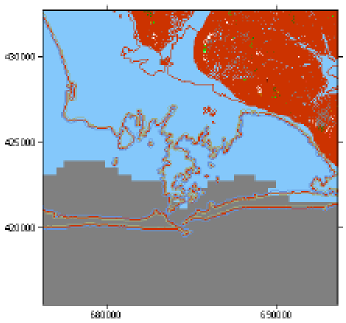
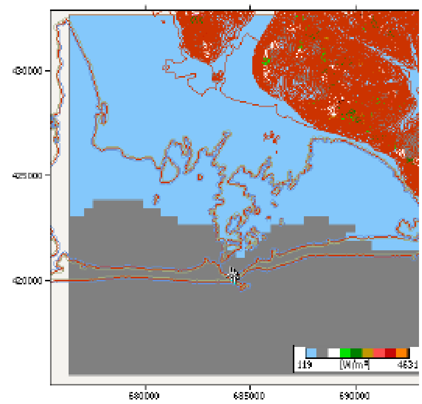
Results

Mean Speed [m/s]

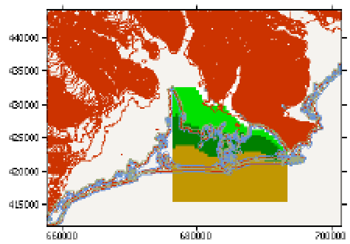
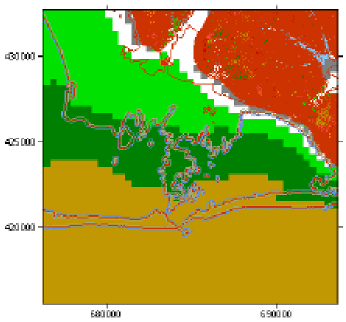
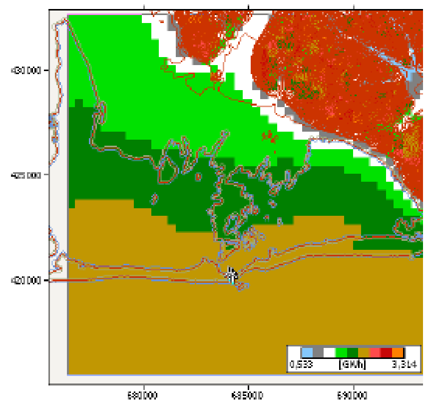
Maximum Value:	13,23 m/s at (688758, 428675)
Minimum Value:	3,56 m/s at (688758, 428675)
Mean Value:	7,24 m/s at (688758, 428675)

Power Density [W/m²]

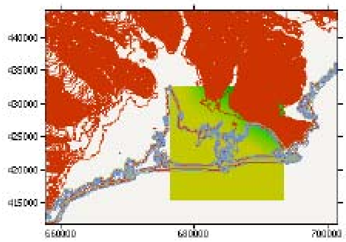
Maximum Value:	4631 W/m² at (689558, 428675)
Minimum Value:	119 W/m² at (689558, 428675)
Mean Value:	632 W/m² at (689558, 428675)

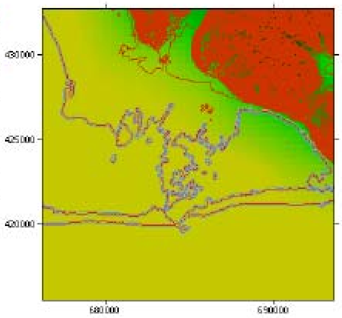
AEP [Wh]

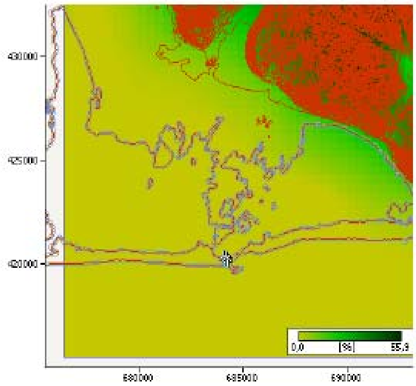




Maximum Value:	3,314 GWh at (693558, 425475)
Minimum Value:	0,533 GWh at (693558, 425475)
Mean Value:	1,945 GWh at (693558, 425475)

RIX [%]





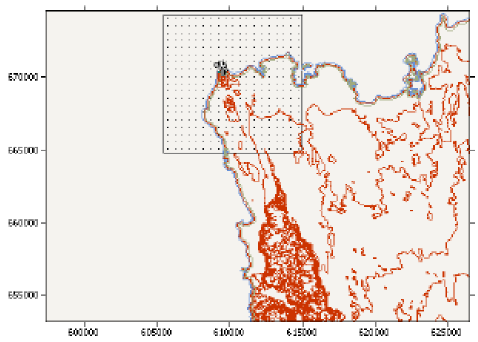


Maximum Value:	5591,9% at (690358, 430275)
Minimum Value:	0,0% at (690358, 430275)
Mean Value:	795,8% at (690358, 430275)

Appendix 4: Rauðinúpur

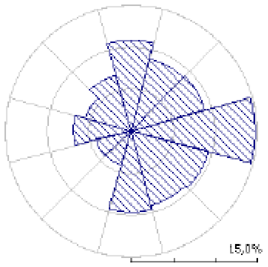
Skýringar á töflum og myndum er hægt að nálgast

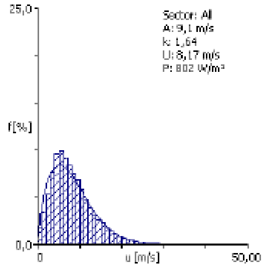
Rauðinúpur	VÍ
Staðsetning	66°30.492'N, 16°32.663'V, (66.508, 16.544)
Hæð yfir sjó	59.3 m
Hæð vindmælis yfir jörð	9.5 m
Upphaf veðurathugana	1997



Frá mæli:

-	Unit	Measured	Weibull-fit	Discrepancy
Mean wind speed	m/s	8,31	8,17	1,68%
Mean power density	W/m²	801,02	801,70	0,08%





Wind rose at 10 meters Distribution at 10 meters

This table shows the calculated parameters for each of the standard heights and roughness class, 5 heights and 4 roughness classes for 12 sectors. The Weibull A- parameter is given in m/s. U gives estimated (calculated) mean wind speed in m/s and power density gives the total mean power of the wind in W/m², for each of the standard five heights and roughness class.

Height	Parameter	0,00 m	0,03 m	0,10 m	0,40 m
10,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	7,44 1,87 6,61 362	5,20 1,62 4,66 151	4,53 1,62 4,06 100	3,57 1,62 3,20 49
25,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	8,15 1,92 7,23 460	6,22 1,72 5,55 236	5,59 1,71 4,99 173	4,70 1,70 4,20 104
50,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	8,74 1,97 7,75 552	7,18 1,89 6,37 321	6,55 1,85 5,82 250	5,67 1,82 5,04 166
100,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	9,44 1,93 8,37 711	8,44 2,04 7,48 480	7,75 2,05 6,87 370	6,82 2,04 6,04 253
200,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	10,36 1,86 9,20 981	10,32 1,99 9,14 899	9,42 2,00 8,35 682	8,24 2,02 7,30 451

-	0	30	60	90	120	150	180	210	240	270	300	330	Total
A	12,0	9,3	9,1	9,2	5,9	6,7	9,2	7,8	9,2	11,7	10,7	11,9	9,1
k	1,89	1,87	1,87	2,22	2,27	2,05	2,27	1,69	1,40	1,81	1,69	1,91	1,64
U	10,63	8,29	8,09	8,16	5,22	5,97	8,17	6,94	8,38	10,44	9,54	10,51	8,17
P	1495	716	666	576	148	243	568	473	1088	1484	1224	1429	802
Freq	11	9	9	15	10	9	10	4	4	7	6	7	100
U	0	30	60	90	120	150	180	210	240	270	300	330	Total
1	14	15	14	9	17	15	31	31	31	15	25	16	18
2	31	34	28	21	34	39	38	57	56	33	38	34	34
3	41	63	46	32	74	78	45	83	75	46	42	43	53
4	54	82	71	54	147	112	60	108	84	58	57	52	77
5	53	82	90	81	215	150	82	102	103	64	70	53	96
6	61	90	97	102	186	151	81	102	85	71	72	62	99

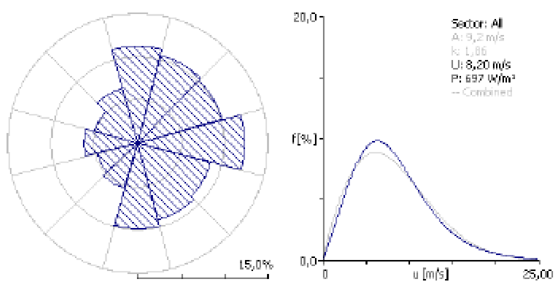
7	61	86	103	105	128	135	81	83	74	64	76	68	92
8	65	81	94	111	87	102	98	75	56	63	73	60	84
9	64	71	87	115	51	70	87	65	57	58	70	67	76
10	68	71	73	99	27	52	88	61	51	56	70	64	68
11	59	63	61	79	16	37	88	55	50	56	59	59	58
12	56	60	49	53	8	26	66	44	46	55	55	54	48
13	53	46	42	40	4	14	48	33	39	52	48	49	39
14	50	37	34	24	2	10	37	28	32	46	41	51	32
15	43	31	29	21	1	4	25	23	23	44	37	45	26
16	39	24	23	15	1	3	15	16	25	40	34	45	22
17	35	19	17	11	1	1	10	13	18	35	25	35	18
18	29	13	13	9	0	1	8	7	16	28	28	30	14
19	25	11	9	6	0	1	3	5	16	23	17	21	11
20	21	7	7	3	0	0	3	4	12	18	11	23	8
21	15	6	5	2	0	0	3	3	6	16	13	19	7
22	16	3	4	2	0	0	1	0	8	14	9	14	6
23	12	2	2	2	0	0	1	1	7	10	6	11	4
24	8	1	1	1	0	0	1	0	6	8	6	8	3
25	9	1	1	0	0	0	0	0	5	6	4	2	2
26	6	0	0	0	0	0	0	0	3	4	3	4	2
27	5	0	0	0	0	0	0	0	3	4	2	3	1
28	3	0	0	0	0	0	0	0	4	3	0	4	1
29	2	1	0	0	0	0	0	0	3	2	2	2	1
30	0	0	0	0	0	0	0	0	3	2	2	1	1
31	0	0	0	0	0	0	0	0	1	2	1	1	0
32	0	0	0	0	0	0	0	0	1	1	1	0	0
33	0	0	0	0	0	0	0	0	0	1	1	0	0
34	0	0	0	0	0	0	0	0	0	0	1	0	0
35	0	0	0	0	0	0	0	0	0	1	0	0	0
36	0	0	0	0	0	0	0	0	0	0	1	0	0
37	0	0	0	0	0	0	0	0	0	0	1	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0

Results from Turbine Vestas V47 (660 kW):

Sector	Wind climate				Power			
#	a [deg]	f [%]	W-A	Weib-k	U	P [W/m2]	AEP	I [%]
1	0	11,2	11,9	1,96	10,57	1415	0,365	0,0
2	30	10,5	9,8	1,93	8,73	808	0,279	0,0
3	60	10,1	9,0	2,03	7,94	578	0,238	0,0
4	90	12,3	8,6	2,69	7,64	410	0,273	0,0
5	120	8,7	6,1	2,44	5,44	158	0,084	0,0
6	150	9,2	7,3	2,38	6,49	274	0,144	0,0
7	180	9,9	9,5	2,50	8,43	579	0,262	0,0
8	210	5,4	8,5	1,82	7,56	558	0,116	0,0
9	240	4,8	9,2	1,53	8,26	908	0,111	0,0
10	270	6,2	10,4	1,87	9,26	998	0,175	0,0
11	300	5,1	9,6	1,78	8,50	814	0,129	0,0
12	330	6,6	11,0	1,96	9,72	1094	0,202	0,0
All			(9,2)	(1,86)	8,20	697	2,379	0,0

Site	Location [m]	Turbine	Height [m]	Net AEP [GWh]	Wake loss [%]
Rauðinúpur	(609525,9, 670211,2)	Vestas V47 (660 kW)	45	2,379	0,0

-	Total	Wind with maximum power density
Mean wind speed	8,20 m/s	13,69 m/s
Mean power density	697 W/m²	55 W/m²



The combined (omnidirectional) Weibull distribution predicts a gross AEP of 2,433 GWh and the emergent (sum of sectors) distribution predicts a gross AEP of 2,379 GWh. (The difference is 2,29%)

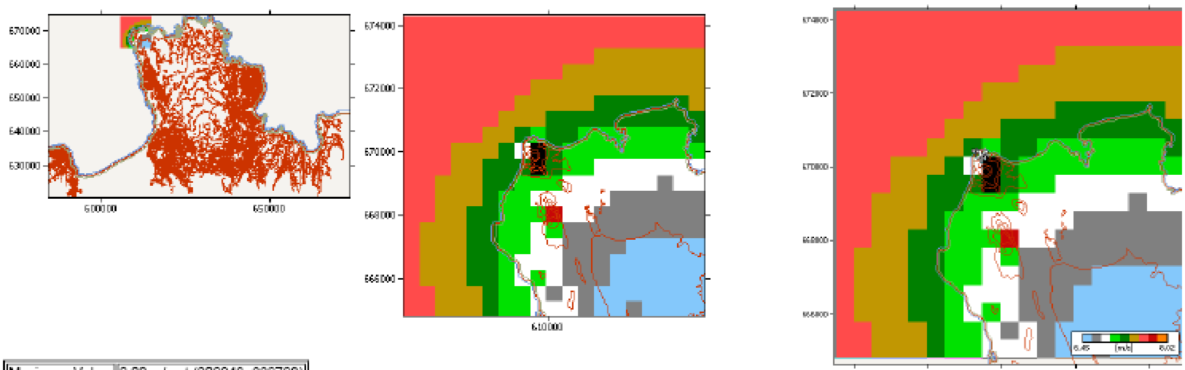
Grid Setup

Structure: 19 columns and 19 rows at 500 resolution gives 361 calculation sites.
Boundary: (605448, 664793) to (614948, 674293)

Nodes: (605698, 665043) to (614698, 674043)

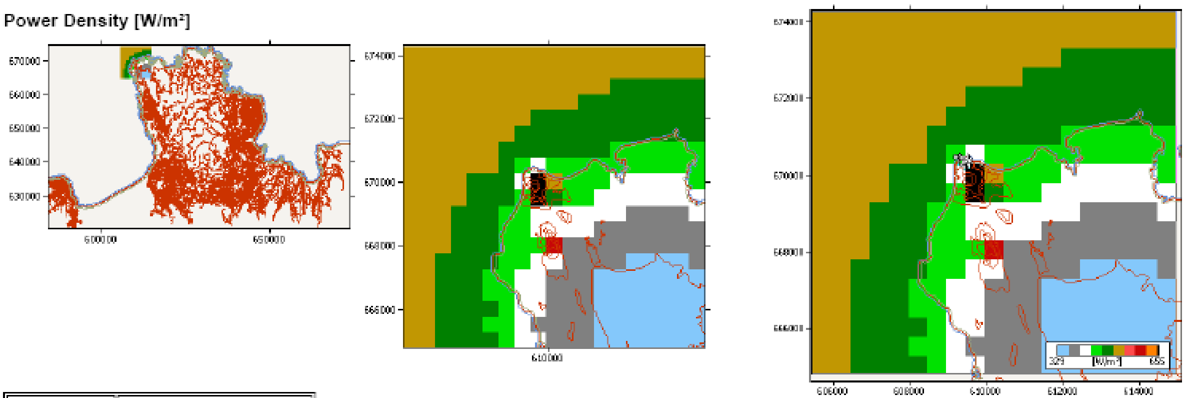
Results

Mean Speed [m/s]



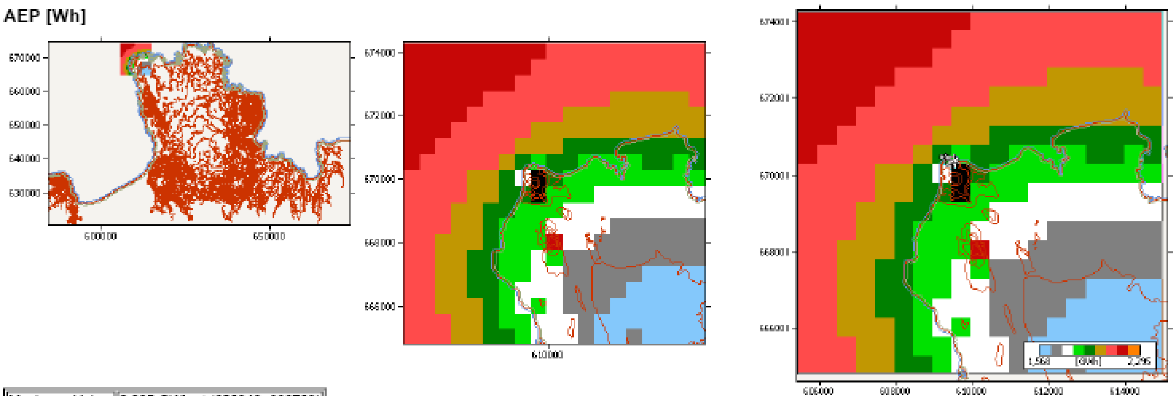
Maximum Value:	8,02 m/s at (609948, 669793)
Minimum Value:	6,45 m/s at (609948, 669793)
Mean Value:	7,20 m/s at (609948, 669793)

Power Density [W/m²]



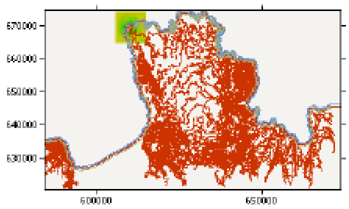
Maximum Value:	655 W/m² at (609948, 670293)
Minimum Value:	329 W/m² at (609948, 670293)
Mean Value:	463 W/m² at (609948, 670293)

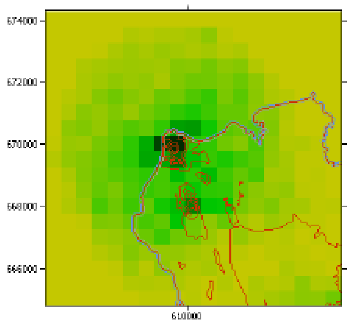
AEP [Wh]

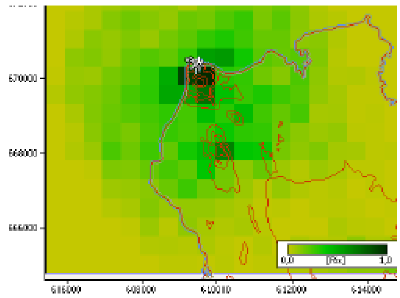


Maximum Value:	2,295 GWh at (609948, 669793)
Minimum Value:	1,568 GWh at (609948, 669793)
Mean Value:	1,933 GWh at (609948, 669793)

RIX [Rix]







Maximum Value:	103,9% at (609948, 670293)
Minimum Value:	0,0% at (609948, 670293)
Mean Value:	10,3% at (609948, 670293)