Wind power pumped storage system for hydropower plants

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Magister Scientiarum degree in Sustainable Energy Business

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Abstract

In this thesis, an idea to use a wind pumped storage system to pump water from a lower reservoir to an upper reservoir and use it to reduce the construction size of a new reservoir or to increase electricity production in a hydropower plant, is presented. Instead of using a wind turbine to produce electricity to drive the pumps, a shaft is proposed to connect the wind turbine and the pumps. A profitability assessment is performed for the reservoir reduction and the electricity production. A wind pumped storage system for a hydropower plant with shaft driven pumps is not widely utilized today. Capital cost estimates and a profitability assessment reveal the feasibility of field usage. The main results of the thesis are that it is not profitable in Iceland to produce electricity from pumped water in a hydropower plant with an added wind pumped storage system and it is not profitable to build a reduced upper reservoir and a lower dam for a hydropower plant with an added wind pumped storage system.

Útdráttur

Þessi ritgerð fjallar um þá hugmynd að nota vinddælustöð til að dæla vatni í uppistöðulón til að minnka lónsstærðina á nýjum lónum eða til að auka rafmagnsframleiðslu í vatnstorkuveri. Í staðin fyrir að nota vindtúrbínu til að framleiða rafmagn sem keyrir dælurnar, er öxull notaður til að tengja vindtúrbínuna og dælurnar. Arðsemismat verður gert fyrir uppistöðulóns minnkunina og rafmagnsframleiðsluna. Vinddælustöð fyrir vantaflsver með öxuldrifnum dælum er ekki notuð í dag. Kostnaðarmat og arðsemi-útreikningar mun leiða í ljós hagkvæmni þessarar tækni til notkunar. Megin niðurstaða þessarar ritgerðar er sú að það er ekki hagkvæmt á Íslandi að framleiða rafmagn í vatnsorkuverum með auknu magni vatns dældu af vind knúnum vatnsdælum og það er ekki hagkvæmt að minnka uppistöðulón og stíflur með því að bæta við vind knúnu vatnsdælukerfi.

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Nomenclature

A	The area swept by the blades of a three bladed wind turbine, m^2
A_{pipe}	The area of a pipe, m^2
c	An average wind speed, m/s
COP	Overall measure of performance under rated conditions, about 0.3
D_{pipe}	The diameter of a pipe, m^2
f	The friction factor
g	The acceleration due to gravity, m/s^2
H	The Head of pumped water, m
Hf	The pressure drop, m
k	A Weibull constant, part of the Weibull equation, m/s
L	The length of a pipe, m
η	Efficiency, %
η_{pump}	The efficiency of the pump, %
ρ	The density of water, kg/m^3
P_{HYD}	The hydraulic power needed to pump water, kW
P_{pump}	The power needed to pump water, kW
P_{shaft}	The power at the shaft connected to the pump, kW
$P_{turbine}$	The power which one wind turbine can produce, kW
u	A wind speed, m/s
μ	The dynamic viscosity of the fluid ($1.5x10^{-3}$ kg/s m)
P()	Probability of some instance to occur, %
V	Speed of the wind, flowing perpendicular to the wind turbine blades, m/s
$V80_{power50m}$	The power of Vestas V80 in 50m height, with Weibull wind calculations, kW

$V80_{power100m}$	The power of Vestas V80 in 100m height, with Weibull wind calculations, kW
Q	The flow rate of a water, m^3/s
Q_{V80}	Flow rate. A wind turbine (Vestas V80) connected by a shaft to a pump, m^3/s
Q_{elec}	Flow rate. A pump is connected to an electricity motor, m^3/s
$Q_{shaft50m}$	Flow rate. A wind turbine at a 50 m height connected by a shaft to a pump, m^3/s
$Q_{shaft100m}$	Flow rate. A wind turbine in 100 m height connected by a shaft to a pump, m^3/s
$Q_{GE-gear90\%}$	Flow rate which one V80 can pump using two gearboxes ($\eta = 0.95$), m^3/s
Re	Reynolds number
GPM	Gallon per minute
IR	Interest rate
NPV	Net present value
RPM	Round per minute

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1 Introduction

Iceland is located in the northern Atlantic Ocean. The first hydropower plant for public use was built in 1904. After the construction of Búrfell hydropower plant in 1969, in relation to an aluminum smelter in Straumsvík, the electricity usage demand increased rapidly. Most of it, about 62-65%, has been for the industry sector (Ragnarsson, 2006). Electricity in Iceland is mostly produced in hydro- and geothermal power plants. Another renewable energy source that has not been used to produce electricity in Iceland is the wind. Iceland is located at one of the windiest location on Earth. This renewable resource is especially high, both in terms of intensity and consistency.

Electricity generated by a wind installation connected to the national grid could be just about 5% of the current total electricity production in Iceland because of high electricity usage for heavy industry (Sigurjónsson, 2009). No wind farm is now operating in Iceland because of a higher capital cost than for hydro- and geothermal power plants, unsecure electricity production and strong and irregular wind conditions. The interest has been mostly in utilizing the waterfalls and the heat from geothermal wells.

Icelandic hydropower plants do not use pumped storage systems. The extra electricity demand in the electricity grid is controlled and balanced by the hydropower plants. Some of the hydropower plants produce only constant electricity for aluminum smelters since the demand is always nearly the same. Total electricity usage in Iceland 2008 was 16,468 GWh or 2,130 MW mean power (Orkuspárnefnd, 2009).

The worldwide increasing demand for electricity at peak time has resulted in a greater need for pumped storage systems. These pumped storage systems use low cost electricity to pump water to an upper reservoir when electricity demand is low. During peak hours, when the demand for electricity is high, the water is released to a lower reservoir through a turbine, to produce electricity.

By considering the cycle of efficiency, about 4 kWh are needed to generate 3 kWh (Ibrahim et al., 2008). These plants can be designed to use either combined pump-turbines or distinct generating and pumping equipment (Davison et al., 2009).

Another implementation of a pumped storage system is a hybrid plant combined with a wind farm. Energy produced by the wind turbines at the wind farm is used to drive the pumps in the pumping station, as shown in Figure 1. The wind farm produces the electricity used to pump the water from the lower reservoir to the upper reservoir. The electricity not used to drive the pumps, is diverted into the electricity grid.

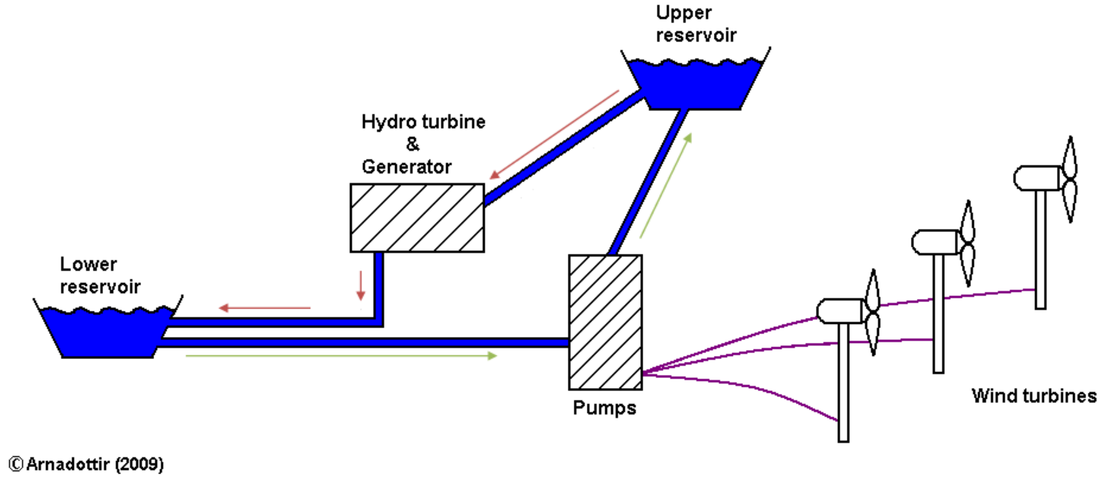

Figure 1. A pumped storage system with wind turbines producing electricity

The main objective of this thesis is to use a profitability assessment for a wind pumped storage system located at a hydropower plant in the Þjórsá area of Iceland. The question about the profitability of a wind pumped storage system will be answered in two ways:

1. Is it profitable to produce electricity from pumped water in a hydropower plant with an added wind pumped storage system?
2. Is it profitable to build a reduced upper reservoir and a lower dam for a hydropower plant with an added wind pumped storage system?

The idea in this thesis is to use a wind pumped storage system with a wind turbine directly connected with a shaft to the pumps. The wind turbines are not producing electricity. Instead the wind is used directly to drive the pumps. With a correctly selected gearbox to control the pumps, the maximum pumping performance is expected. This is called a windpump and is explained in chapter four. There is very little experience in Iceland concerning building a high wind turbine or a wind pumped storage system for a hydropower plant. No installation of a wind pumped storage system, using a three bladed horizontal wind turbine with a direct shaft connection to the pumps, for a hydro power plant, is known.

The main goal of this thesis is to explain the result from a profitability assessment used to calculate the profit for a hydropower plant with a wind pumped storage system. A profitability assessment calculation is used to estimate the profit for a hydropower plant, using a smaller upper reservoir than it is built for, to generate the same amount of electricity. A pumped storage system is widely used to create backup power to use at peak times in the electricity grid. The idea in this thesis is to minimize the land used for a reservoir and a dam with a pumped storage system and to calculate its profitability.

By gathering information available about the construction cost of a reservoir and a dam, and the cost of all the items needed for a wind pumped system, installation cost, maintenance cost, operational cost and other expected costs, an estimate will be found on profitability. Other costs not officially available will be estimated with a three point method. The land used for reservoir is not priced.

To explain further this technique, examples will be used. The main profitability assessment example in this thesis uses eight units. In each unit there are two wind turbines, gearboxes and pumps with shafts and pipes. The area used in this example is at the Sigalda power plant in the Þjórsá area, in the south of Iceland. Information from the Windatlas database of the National Energy Authority (Windatlas, 2009) is used to calculate the average wind speed at a 50 m and a 100 m height and in further calculations, to estimate the power from the wind turbines.

Authors like Bueno et al (2006) have pointed out that a system combination of a hydropower plant, a pumped storage system and a wind turbine producing electricity is based on a policy promoting clean and renewable energy from renewable energy sources at a competitive cost if costs arising from damage to health and the environment are taken into account.

In the paper from Anagnostopoulos et al (2007) it is stated that a pumping station equipped with a variable-speed pump is the most advantageous configuration and improved pumping efficiency also results in economical benefits, enhancing the overall financial prospects of the investment. This means that it is absolutely necessary for the pump to have a gearbox connected to the shaft in direct connection between the wind turbine and the pump.

According to Kazempour et al (2009), when comparing the economic merits of traditional electric energy storage technologies by their internal rate of returns, it has been shown that pumped storage plants possess a more economic merit.

A wind pumped storage system for a hydropower plant has more advantages than added electricity capacity of the power plant. It is also added security for the water level in the upper reservoir. It can be said that with a hybrid system of a wind pumped storage system and a hydropower plant, “not all eggs are put in one basket”. Combined pump and turbine as used in the Limberg II pumped storage hydropower plant in Austria, can cause severely declined pumped productivity and electricity production, in case of a one pump-turbine failure.

The SWOT analysis for a wind pumped storage system in Iceland is shown in Figure 2 and Appendix H.

Strengths	**Weaknesses**
•Average wind speed is high •Provides secure water level •Environmentally friendly •Positive social image •Persistent wind in many places in Iceland •Renewable energy source	•Wind turbine knowledge •Technology not implemented •Implementation cost inevitable •Not a profitable project in Iceland
Opportunities	**Threats**
•Electricity prices in the EU •The production of stable energy from unstable wind energy •Global trend in green energy	•To strong wind •To irregular wind •Volcanic activity •Currency instabilities •Energy policy and unstable political atmosphere

Figure 2. The SWOT analysis for a wind pumped storage system in Iceland

The SWOT analysis indicates that Iceland is a very good location for a wind turbine installation even though strong and irregular winds occur frequently. Wind turbines at a height of 50 m to 100 m are seen as environmentally friendly and are renewable, but have not been implemented in Iceland yet. Threats to this project are a new energy tax policy in Iceland and an unstable political atmosphere because the two leading parties have very different views to environmental issues and industrialization.

In a location with enough average wind speed and a suitable area for wind turbines, wind pumped storage system is a good combination with a hydropower plant. If it seems profitable to use wind turbines to produce power for pumps to pump water to a upper reservoir, and to make it reusable for hydro power plants, the next step would be to design such a system and implement it. The future will show us if a windpump system described in this thesis will be built in Iceland and what problems its designers will face.

This thesis consists of 10 chapters. Chapter 2 is an introduction to a traditional pumped storage system and how it is used today. In chapter 3, a wind turbine will be added to the discussion of a pumped storage system, where the electricity from the wind turbine is used for the pump. Chapter 4 explains a windpump, a pump driven directly with a shaft from a wind turbine, where the wind is the source of the energy. In chapter 5, the pump used will be explained and the power usage at the shaft. In chapter 6, the Windatlas located at the National Energy Authority is explained and the average wind in the Þjórsá is calculated. Weibull calculations for the stop time of the wind turbine will also be shown. Chapter 7 will explain technical calculations behind the obtained power from a wind turbine, and pipe diameter calculations are done. In chapter 8, the profitability assessment is explained and the outcome shown with graphs and photos. Chapter 9 includes more discussing of the profitability assessment related to electricity price and various usage of this technology. Chapter 10 completes the thesis, by discussing the main reason for the conclusion and what is the next step.

2 Pumped storage systems

According to International Water Power and Dam construction, the oldest pumped storage hydropower plant is in Schaffhausen, Switzerland (Douglas, 1990). It was started in 1909 and is still in operation. Another old pumped storage power plant that was commissioned in 1920 is at Walkerburn, in Scotland. A pumped storage system is a child of the twentieth century. Today there is still continuing interest in building and the usage of pumped storage systems to load balance electricity for usage at peak times. This will probably be more important in the future when countries need to balance and guarantee the stability of electricity production because of increasing installation of unpredictable or irregular energy resources such as wind and solar power generation.

The complex system of energy production stations and transmission lines has lead to little use of energy storage in the network, or roughly 2.6% (Ibrahim et al., 2008). Pumped storage power stations provide high value electricity power for peak hours to the electricity grid. Of all the countries in the world, USA uses the most of pumped storage plants but other countries like Japan and Russia are developing it too. One of the biggest stations is an 1800 MW power station at Dinorwig, U.K. It can supply about 1320 MW in twelve seconds (Douglas, 1990). A small pumped storage plant can also be useful and one of the smallest one is in West Germany, with a capacity of about half a megawatt.

At locations where there are storage lakes, a pumped storage station is an attractive option because of a rising demand for balancing electricity generation at peak times. Pumped storage stations use low price electricity when the demand is low in the grid, to pump water from a lower reservoir to an upper reservoir. A pumped storage station for a hydropower plant is one type of energy storage used to store electricity. This method of energy storage is in fact to store electricity as potential energy. At higher demands in the electricity grid, the water in the upper reservoir is released to the lower reservoir through a hydro turbine, to produce electricity.

A pumped storage station is needed for a hydropower plant station where water shortage can occur or generation and consumption of electricity is not absolutely synchronous. In all electricity networks there is a surplus or lack of electricity. A pumped storage power station can control and guarantee a safe operation in the electricity grid.

To stabilize the electricity grid a distinction is made between primary and secondary control and minute reserve in a pumped storage power station. This depends on the length of time of the variation when the reaction speed is the most important quality feature (WorldPumps, 2008). Primary control has the most priority. It restores momentarily the power balance and the stabilization of a continuous frequency by providing up to 3000 MW within 30 seconds. If not, then malfunctions follow. A primary control is replaced by a secondary control mode after 30 seconds in the case of variations lasting longer. A pumped storage power station is extremely well suited to handle minute reserve due to its broad power range.

In a classical pumped storage power station design, the turbines and the pumps are separate units. This has many advantages, like better efficiency of the pumps when operated at full capacity using low cost surplus power. But at the Limberg II power station in Austria, two combined machine sets of a pump-turbine system are installed. This solution of a reversible pump-turbine has proven to be very efficient (WorldPumps, 2008). The Limberg II hydropower station design lead up to a compact power house and thereby reducing equipment and cost. This arrangement was the best possible return for the operating utility result in a compact design, and a lower investment cost. Each of the new two machines in the cavern is rated at 240MW capacity (G. Hinteregger & Söhne, 2007).

Several advantages can be achieved when a wind park is combined with a pumped storage system. The majority of wind parks combined with pumped storage systems are both connected to the electricity grid and generate electricity to pump water from a lower reservoir to an upper reservoir. The electricity generated by the wind turbines, is used during low consumption hours to pump water to the upper reservoir. It is released again when there is the need to produce energy at peak times in the electricity network. At high demand time, when wind power is not available, the water stored in the upper reservoir is utilized. At locations where variable tariff is applied, there is the possibility to achieve significant economical benefits by deciding on an optimal turbine and pumping schedule (Vieira et al., 2008).

3 A wind pumped storage system

A wind turbine converts the kinetic energy of the wind into mechanical energy, to produce electricity. Turbines that rotate around a horizontal axis, as shown in Figure 3, are more commonly used today than turbines that rotate around vertical axis (Ipsakis el al, 2008). New power electronic semiconductor devices and advantages in electrical power conversion technique have lead to an improvement in wind turbines. Wind turbines today have more efficiency and system quality and are more reliable. By combining one or more wind turbines and a pumped storage power station, more reliable supply of electricity can be achieved.

Figure 3. Horizontal axis wind turbines (Vestas, 2009)

At a location near a pumped storage power station, where wind strength is sufficient for a wind farm installation, the wind farms electricity generation is used for both the pumps and the electricity grid. When wind is available, the wind farm produces electricity for the pumping devices and the grid. One example of a wind powered pumped storage system installation is on the Gran Canaria Island. The installation of a wind powered pumping hydro storage system increases the reliability of the electricity produced and the utilization of the wind energy is connected to the grid. The system promotes clean and renewable energy (Bueno et al., 2006).

When wind turbines are installed to generate the power for the pumps in a pumped storage power station, one possibility of a connection is a direct connection with a shaft. It is called a windpump when a wind turbine is connected with a shaft to one or more pumps. Instead of converting the energy in the wind to produce electricity, the mechanical power in the rotational motion of the blades is transferred with a shaft to drive the pump. This technique is mostly used today to pump water from underground wells in rural areas. Some types of windpumps produce electricity to pump water. The wind turbines used for this purpose are multi-bladed. It is not in the scope of this thesis to consider the usages of multi-bladed windpumps in the area of Iceland.

The commonly used term “windmill” will not be used here because a windmill is literally a wind driven machine for milling grain or some other substance (Kentfield, 1996).

4 A windpump

Wind activated water pumps use wind turbines to convert the winds kinetic energy into a motion of a shaft which again provides the power input for water pumps (Kentfield, 1996). In rural areas away from electrical power distribution, wind turbines are used for pumping water from wells or draining lands. This is called a windpump. The shaft connected to the rotor of the wind turbine is connected directly with the mechanical shaft to the pump.

Two types of connections between the wind turbine and the water pump are possible. They can be connected directly as shown in Figure 4, with or without a speed reducing or a speed increasing gearing system. The other connection can be an electrical transmission. The advantage of an electrical transmission is the remote location of the wind turbine or turbines which can be located at the best possible place for the winds access, and the generated power from the wind turbine or turbines can be directed to the grid when pumping is not required. Directly connected wind turbines will always have the disadvantage of a required location near the well and the pumps. The length of the shaft depends on the location of the pumps and other factors like the landscape. The advantage of a direct connection is both efficiency and cost related. There is no need for an expensive gearbox and a generator for the wind turbine, and operational and maintenance cost is expected to be lower. However there are two gearboxes needed to change the shafts direction. No energy is wasted in producing electricity to use it again to drive the pumps. The wind power is used directly from the rotor to the pumps.

Technology developed specifically for pumping water with combined multi-bladed wind turbines, exists in Jordan (Badran, 2003). Information from field performance reports states frequent failures of power transmission components. Also the discharge observed is much less than expected from such systems (Sathyajith et al., 2003). It seems that the windpump systems that are having problems are using piston pumps instead of centrifugal pumps.

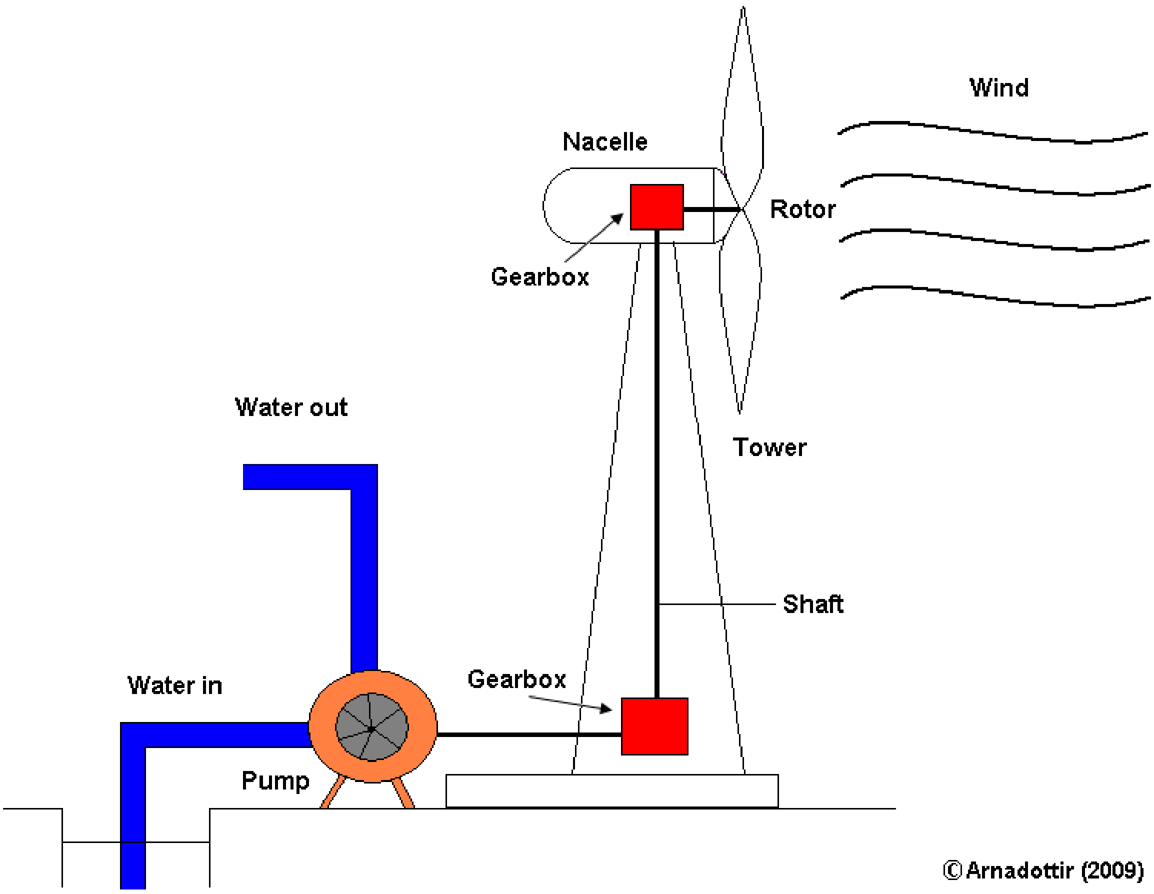

Figure 4. A horizontal axis wind turbine connected directly to a pump

A wind driven centrifugal pump system consists of the wind turbine coupled to the centrifugal pump with the power transmission mechanism, the shaft, as shown in Figure 4. The speed of the rotor of the wind turbine is stepped up many times to meet the requirement of the centrifugal pump, using suitable gear mechanism. This gear system, used to match with the speed requirement of the pump, will affect the simplicity of the windpump system (Sathyajith et al., 2003). Another important factor is that the specific diameter of the centrifugal pump should be low enough to restrict the pumps size to a reasonable limit. Major factors influencing the gear ratio required for the windpump system are the speed of the pump, the suction head and the design wind velocity (Sathyajith et al., 2003). The designer of the system has full control over the specific speed of the pump but the wind speed and pumping head is site characteristic.

5 Centrifugal pumps and pipelines

Due to their durability, versatility and simplicity, centrifugal pumps are the most popular type of pumps (Bolegoh, 2001). Pump efficiency is measured by how much of the power input to the shaft is converted to useful water pumping by the pump (Lawrence Pumps Inc, 2004). It is therefore not fixed for a centrifugal pump because it is a function of the discharge and therefore also the operating head and the frequency.

Figure 5. Goulds 316SS Centrifugal Pump 3175 XL (Bid on Equipment, 2009)

The pump will be connected with a shaft to the wind turbine. One of many producers of pumps is the Goulds pumps Corporation. The Goulds 316SS Centrifugal Pump is shown in Figure 5. The ideal power used to pump water by a pump in watts, often called hydraulic power, is as follows:

$$P_{HYD} = \rho g H Q \quad (1)$$

In equation 1 (Tester et al., 2008), P_{HYD} is the hydraulic power, ρ is the density of the fluid (water is 1,000 kg/m^3), g is the gravitational constant (9.81 m/s^2), H is the Head of the pumped water (m) and Q is the flow rate (m^3/s).

For example, the Goulds pump can pump maximum 1.83 m^3/s of water up to the height of 40 m. This information is given in the total head and capacity graph and the Goulds software in Appendix B. This pump was selected as an example, because all necessary information about the pump was available. The graph shows that a 20x24-28H Goulds pump, at the height of 40 m, can pump about 29,000 GPM. This is equal to 1.83 m^3/s. The power calculated to operate the pump with a flow rate of 1.83 m^3/s and the head equal to 40 m, is now calculated with equation 1:

$$P_{pump} = 1000 \times 9.81 \times 40 \times 1.83 = 718\ kW$$

To pump 1.83 m^3/s of water up to a height of 40 m, a minimum power of 718 kW is needed. Because the pump is not an ideal machine, the pump power is divided by the pumps efficiency and the shaft power is as follows:

$$P_{shaft} = \frac{P_{pump}}{\eta_{pump}} \quad (2)$$

In equation 2, P_{shaft} is the power at the shaft where it connects to the pump, P_{pump} is the power required to pump water and η_{pump} is the efficiency of the pump.

The manufacturers information, calculated from the Goulds software, shown in Appendix B, states that the pump power at 885 RPM is 990 kW and the efficiency is 73%. The efficiency of the pump can also be calculated with the equation 2:

$$\eta_{pump} = \frac{718\ kW}{990\ kW} = 0.73$$

The calculated pump efficiency is 0.73 or 73%.

For example, the total hydraulic power required to drive the pump when pumping 1.83 m^3/s of water up to a height of 40 m and $\eta_{pump} = 0.73$, can now be calculated with equation 2:

$$P_{shaft} = \frac{1000 \times 9.81 \times 40 \times 1.83}{0.73} = 984 \text{ kW}$$

For example, to pump water up to a height of 80 m at Sigalda power plant, two pumps have to be used and connected serially. The total power at the shaft needed to pump 1.83 m^3/s of water up to height of 80 m, with two Goulds 316SS Centrifugal Pump 3175 XL pumps, is about 2,000 kW.

6 A wind atlas for Iceland

On the website of the National Energy Authority it is possible to access weather information for Iceland through a wind atlas called Gagnavefsjá (Windatlas, 2009). This information from automatic wind stations is owned by the Icelandic Meteorological Office, The public Road Administration and the Icelandic Maritime Administration. There are a total of 142 automatic stations with more than one year of data (Windatlas, 2009).

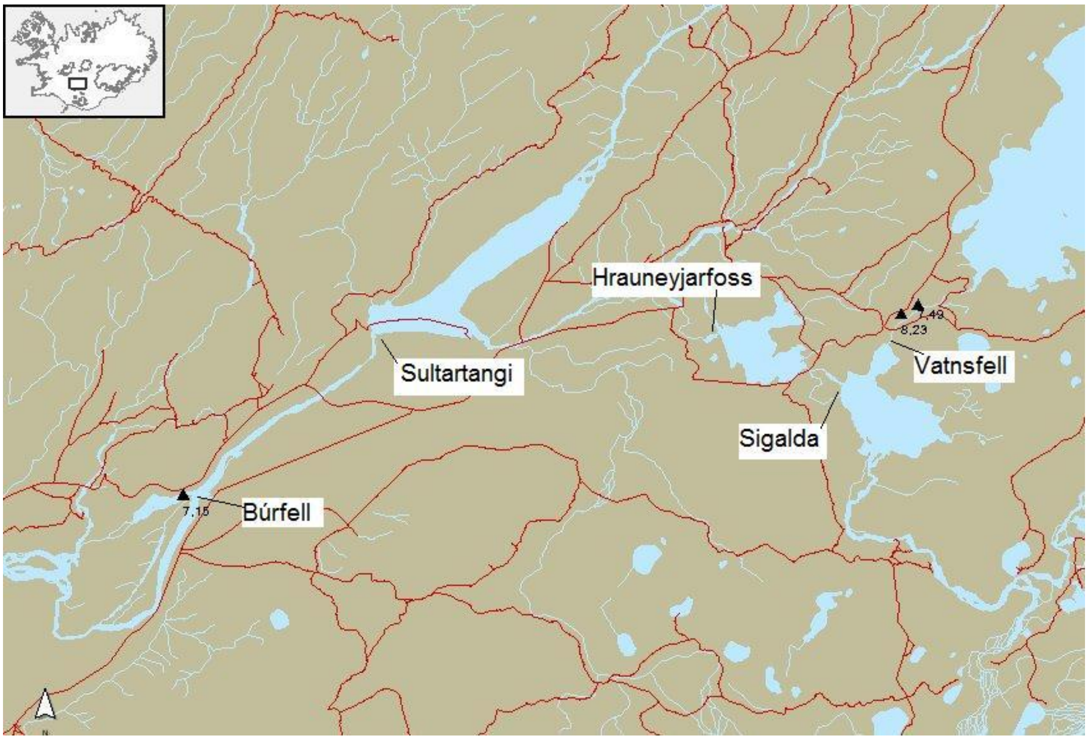

Figure 6. Landsvirkjun hydropower plants in the Þjórsá area (Windatlas, 2009)

Very few automatic weather stations are located in the area of Þjórsá where the hydropower plants are located, as shown in Figure 6. One is at the Búrfell hydropower plant and another near the Vatnsfell hydropower plant. The information from these automatic weather stations can be seen in table 1 and table 2. More detailed wind information and calculations from the Búrfell and Vatnsfell hydropower plants are given in Appendix A.

From these two automatic wind stations for the area of Þjórsá, the calculated average wind speed is 11.95 m/s at a 50 m height. This is suitable for a wind turbine installation.

Table 1. Wind information from two locations in the Þjórsá area at a 50m height			
Location	**Measured height (m)**	**Mean wind speed [m/s] (parameter *c*)**	**Weibull k (parameter *k*)**
Búrfell	50	11.55	1.96
Vatnsfell	50	12.35	1.84
Mean Value	50	11.95	1.9
Source: Author´s calculations and data based on data from Windatlas (2009)			

The two parameter Weibull distribution is used for a statistical study of the winds speed data and to describe the winds speed frequency curve (Johnson, 2001). For the winds speed *u*, the Weibull distribution probability density function is written as:

$$f(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} exp\left[-\left(\frac{u}{c}\right)^{k}\right] \quad (k > 0, u > 0, c > 1) \tag{3}$$

In equation 3, $f(u)$ represent the frequency distribution of the mean speed. The Weibull parameters c and k are the scale parameter (mean wind speed) and the shape parameter (Weibull k). As k increases, the peak moves in the direction of a higher wind speed. The shape parameter k is expected to be in the range of greater or equal to 1.5 and smaller or equal to 3.0, for most good wind regimes. It can be shown that the scale parameter c is directly proportional to the mean wind speed for this range of k (Johnson, 2001).

The starting wind speed for Vestas V80 is 4 m/s and the stopping wind speed is 25 m/s. To estimate how many hours the wind turbine will stop every year, the probability that the wind speed is greater than or equal to 25 m/s and lower than or equal to 4 m/s is calculated by using the formula (Johnson, 2001):

$$F(u) = 1 - exp\left[-\left(\frac{u}{c}\right)^{k}\right] \tag{4}$$

In equation 4, where F (0) = 0 and F (∞) = 1, it is possible to calculate the Weibull distribution. For example, to calculate how many hours the Vestas V80 wind turbine will be stopped in one year at the Þjórsá area at a 50 m height with an average wind speed of about 11.95 m/s and Weibull parameter k = 1.9:

$$P(0 \le u \le 4) = exp\left[-\left(\frac{0}{11.95}\right)^{1.9}\right] - exp\left[-\left(\frac{4}{11.95}\right)^{1.9}\right] = 0{,}1175$$

$$P(25 \le u \le \infty) = exp\left[-\left(\frac{25}{11.95}\right)^{1.9}\right] - exp\left[-\left(\frac{\infty}{11.95}\right)^{1.9}\right] = 0{,}0172$$

No wind or too excessive wind in the area of Þjórsá is about 13.5% of the time per year. The Vestas V80 had to be shut down due to low or excessive wind for about 1,180 hours per year, or about 49 days every year.

Table 2. Wind information from two locations in the Þjórsá area at a 100m height

Location	**Measured height (m)**	**Mean wind speed [m/s] (parameter *c*)**	**Weibull k (parameter *k*)**
Búrfell	100	12.29	1.96
Vatnsfell	100	13.13	1.85
Mean Value	100	12.71	1.91

Source: Author´s calculations and data based on data from Windatlas (2009)

In Table 2 there is information from the two areas i.e. Búrfell and Vatnsfell, but now for an average wind speed and a Weibull parameter k at a 100 m height (see Appendix A). The information about the wind speed and the Weibull parameter k from table 1 and 2 are used in table 3 and 4 (see chapter 7), where the power production of the Vestas V80 wind turbine is calculated for a 50 m and a 100 m height (see also Breakdown, Page 3 in Appendix E).

7 Wind Power

Today's wind turbines are based on an aerodynamic lifting. The blades interact with the wind and use both the drag force and the perpendicular force, namely the lifting forces. The lifting force is the main driving power of the rotor because it is a multiple of the drag force. The lifting force of the air flow is intercepted by the rotor blade and causes the necessary driving torque for the wind turbine (Ackermann, 2005).

Horizontal wind turbines like Vestas V80 consist of a tower, a rotor, blades and a nacelle, located on top of the tower. The nacelle contains the gearbox and the generator. In big wind turbines, a wind vane, an anemometer and a controller, control the yaw drive to point the rotor into or out of the wind. The pitch control controls the blades to capture maximum power from the wind.

A horizontal axis wind turbine used for electricity production, usually has two or three blades. A wind turbine with twenty or more blades is normally used for mechanical water pumping because of a high starting torque.

The power of an air mass captured by the wind turbine can be calculated in watts as follows:

$$P_{turbine} = COP \frac{\rho A V^3}{2} \tag{5}$$

In equation 5 (Tester et al., 2008), COP is an overall measure of performance under rated conditions, ρ is the density of the air (air is 1.225 kg/m^3), A is the area swept by the blades (m^2) and V is the speed of the wind (m/s).

In 1926, German physicist Albert Betz concluded that no wind turbine can convert more than the ratio 16/27, or 59.3% of the kinetic energy in the wind. In this thesis, COP is estimated to be 0.30 or 30% for modern wind turbines (Tester et al., 2008).

For example, the output power for Vestas V80 was calculated with Weibull formulas for the wind area at Þjórsá at a 50 m height. Each wind speed interval in table 3, consist of 3 m/s, 4 m/s to 25 m/s (see also Appendix E, Breakdown, page 3 of 3). The average wind speed used in the calculations is 11.95 m/s and Weibull *k* = 1.9.

Table 3. Wind power produce by Vestas V80 calculated at a 50 m height

Wind speed from m/s	Wind speed to m/s	Mean wind speed used	P(from) m/s %	P(to) m/s %	Total time %	Hours in one year	Mean wind power kW	Produced energy MWh/y
0	4	n/a	100.00	88.25	11.75	1,029	0	0
4	7	5.5	88.25	69.63	18.62	1,631	170	277
7	10	8.5	69.63	49.02	20.61	1,805	800	1,444
10	13	11.5	49.02	30.93	18.10	1,585	1,600	2,536
13	16	14.5	30.93	17.53	13.40	1,173	1,960	2,300
16	19	17.5	17.53	8.95	8.58	752	2,000	1,503
19	22	20.5	8.95	4.12	4.83	423	2,000	846
22	25	23.5	4.12	1.72	2.41	211	2,000	422
25	100	n/a	1.72	0.00	1.72	150	0	0
Total					**100.00**	**8,760**		**9,329**

Source: Author´s calculations and data based on data from Vestas (2009-01) (also see Appendix D)

Table 3 shows the wind speed intervals, starts with 0 to 4 m/s and ends with 25 to 100 m/s. P(from) is the probability of having wind speed from e.g. 0 m/s and P(to) is the probability of wind speed e.g. 4 m/s. Total time % is the difference of P(from) and P(to). Total time in hours is this percentage of hours in one year. Mean wind power kW is an average power produced by the Vestas V80 wind turbine. At 4 to 7 m/s the wind turbine produces 170 kW at 5.5 m/s. As shown in the power curve at Appendix D, for the wind speed interval 7 to 10 m/s, an average of 800 kW are produced at 8.5 m/s. The column, Mean wind speed used, shows average wind speed where the mean wind power was collected from the power curve for the Vestas V80. Produced energy MWh/y is the energy produced at each interval. The mean wind power is multiplied with the calculated hours in each interval. From this calculation, output energy of the Vestas V80 wind turbine is 9,329 MWh/y. Converted to average power of the year:

$$V80_{power\ 50m} = \frac{9{,}329{,}000}{8{,}760} = 1{,}065\ \text{kW}$$

Calculated power usage at the shaft for the Goulds pump from chapter 5 was 1065 kW. One Vestas V80 wind turbine could be used to drive one pump up to a 40 m height if no power was lost in the gearbox. The power lost by friction of the shafts is not included in these calculations because the efficiency of the gearbox is estimated.

For example, the output power for Vestas V80 was calculated with Weibull formulas for the wind area at Þjórsá at a 100 m height. Each wind speed interval in table 4, consist of 3 m/s, 4 m/s to 25 m/s as in table 3. The average wind speed used in the calculations is 12.71 m/s and Weibull *k* = 1.91 (see Appendix E, Breakdown, page 3 of 3).

Table 4 Wind power produce by Vestas V80 calculated at a 100 m height

Wind speed from m/s	Wind speed to m/s	Mean wind speed used	P(from) m/s %	P(to) m/s %	Total time %	Hours in one year	Mean wind power kW	Produced energy MWh/y
0	4	n/a	100.00	89.59	10.41	912	0	0
4	7	5.5	89.59	72.61	16.98	1,488	170	253
7	10	8.5	72.61	53.12	19.49	1,707	800	1,366
10	13	11.5	53.12	35.20	17.92	1,570	1,600	2,512
13	16	14.5	35.20	21.18	14.03	1,229	1,960	2,408
16	19	17.5	21.18	11.59	9.59	840	2,000	1,680
19	22	20.5	11.59	5.77	5.81	509	2,000	1,018
22	25	23.5	5.77	2.62	3.15	276	2,000	552
25	100	n/a	2.62	0.00	2.62	230	0	0
Total					**100.00**	**8,760**		**9,789**

Source: Author´s calculations and data based on data from Vestas (2009-01) (also see Appendix D)

From this calculation, output energy of the Vestas V80 wind turbine at a 100 m height is 9,789 MWh/y. Converted to power:

$$V80_{power\ 100m} = \frac{9{,}789{,}000}{8{,}760} = 1{,}117\ \text{kW}$$

To compare three different examples as shown in Figure 7, 8 and 9, power production information from Table 3 and 4 are used. As shown in Figure 7, a 50 m high wind turbine has an installed gearbox and a generator and is producing electricity. The expected efficiency of the wind turbine generator is about 95% (Nesbitt, 2006). The efficiency in the motor is estimated to be 90% (Nesbitt, 2006). The gearbox is expected to have a 95% efficiency and the estimated centrifugal pump efficiency is 73% (see calculations in Chapter 5). The power calculated at the shaft to the pump with the electricity motor is about 631 kW. The power produced with electricity is less than produced by a shaft technique as shown in Figure 8 and 9.

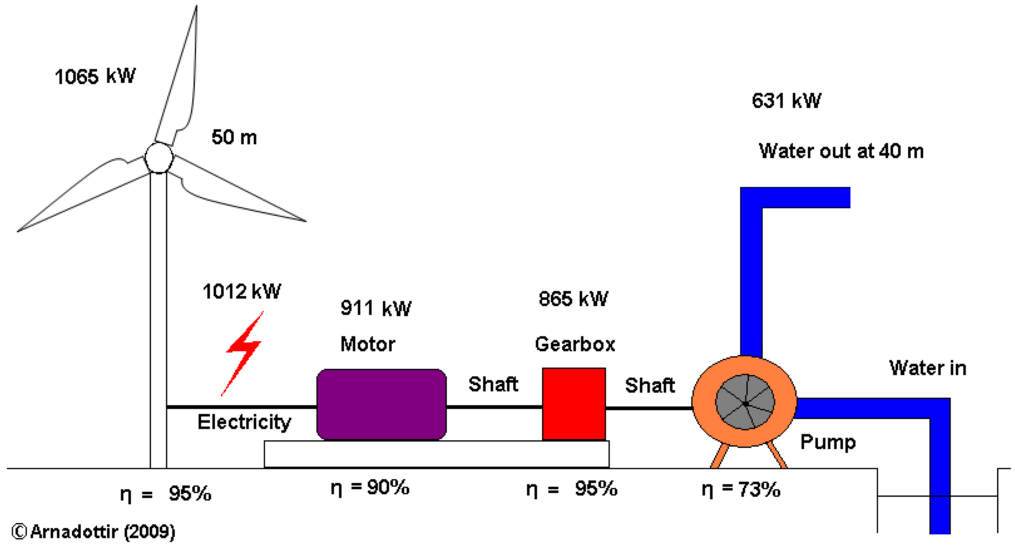

Figure 7. A wind turbine producing electricity to pump water

The flow rate can be calculated with formula 1:

$$Q = \frac{P_{pump}}{\rho g H} \tag{6}$$

In equation 6, Q is the flow rate (m^3/s), P_{pump} is the power needed to pump the water, ρ is the density of the fluid (water is 1,000 kg/m^3), g is the gravitational constant (9.81 m/s^2) and H is the head (m). For example, if one wind turbine at a 50 m height producing electricity as calculated above, has 631 kW power to pump water when the efficiency of the generator, the motor, the shaft and the pump are taken into account. Therefore the calculated flow rate for one electricity motor connected to a centrifugal pump if 631 kW is useable for pumping as shown in Figure 7 with the head at a 40 m height is:

$$Q_{elec} = \frac{631{,}000}{1000 \times 9.81 \times 40} = 1.6 \ {m^3}/{s}$$

An example of a wind turbine at a 50 m height that has a shaft connection and two gearboxes is shown in Figure 8. Each gearbox is expected to have a 95% efficiency (Nesbitt, 2006) and the calculated centrifugal pump efficiency is 73%. The hydraulic power calculated at the shaft is about 702 kW. This power is 10% more than if wind turbine producing electricity is used. To calculate the flow rate for one shaft driven centrifugal pump up to a 40 m height, if 702 kW is the power useable at the shaft, is:

$$Q_{shaft\,50m} = \frac{702{,}000}{1000 \times 9.81 \times 40} = 1.80 \ \mathrm{m^3/s}$$

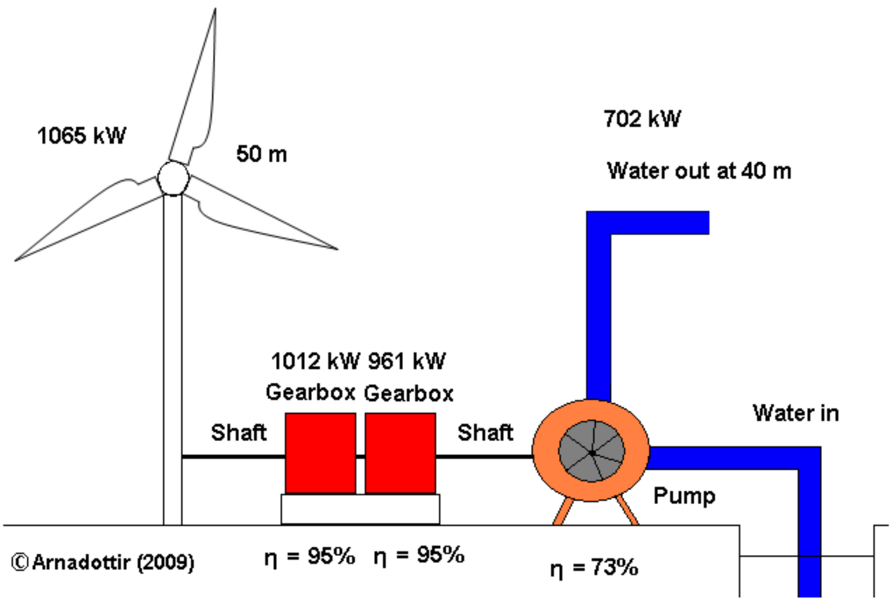

Figure 8. One 50 m high wind turbine using a shaft technique

An example of a 100 m wind turbine that has a shaft connection to the gearbox, is shown in Figure 9. Each gearbox is expected to have a 95% efficiency (Nesbitt, 2006) and the estimated centrifugal pump efficiency is 73%. The power calculated at the shaft is about 736 kW. This power is about 4,6% more than for a wind turbine at a 50 m height using a shaft technique to pump water and about 14% more than a wind turbine at a 50 m height producing electricity for pumping.

The calculated flow rate for one shaft driven pump if 736 kW is useable for pumping water, to a 40 m height, is:

$$Q_{shaft\,100m} = \frac{736{,}000}{1000 \times 9.81 \times 40} = 1.9 \ \mathrm{m^3/s}$$

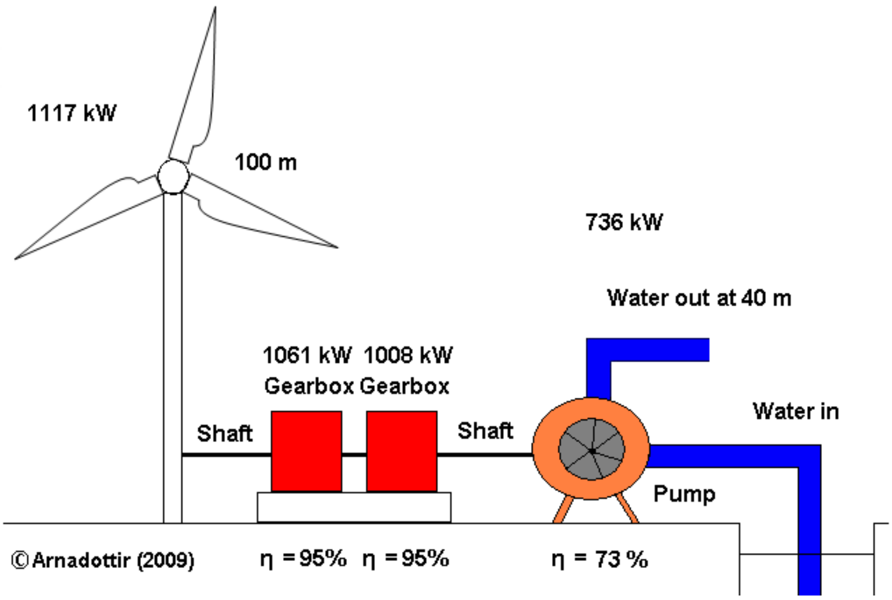

Figure 9. One 100 m high wind turbine using a shaft technique

One 100 high Vestas V80 wind turbine can produce enough power to pump water at a maximum flow rate up to a height of 40 m. For example, to pump the water up to a 80 m height at the Sigalda power plant, two pumps are connected serially as shown in Figure 10. This combination of two wind turbines, four gearboxes, two centrifugal pumps, shafts and steel pipes, is called one unit.

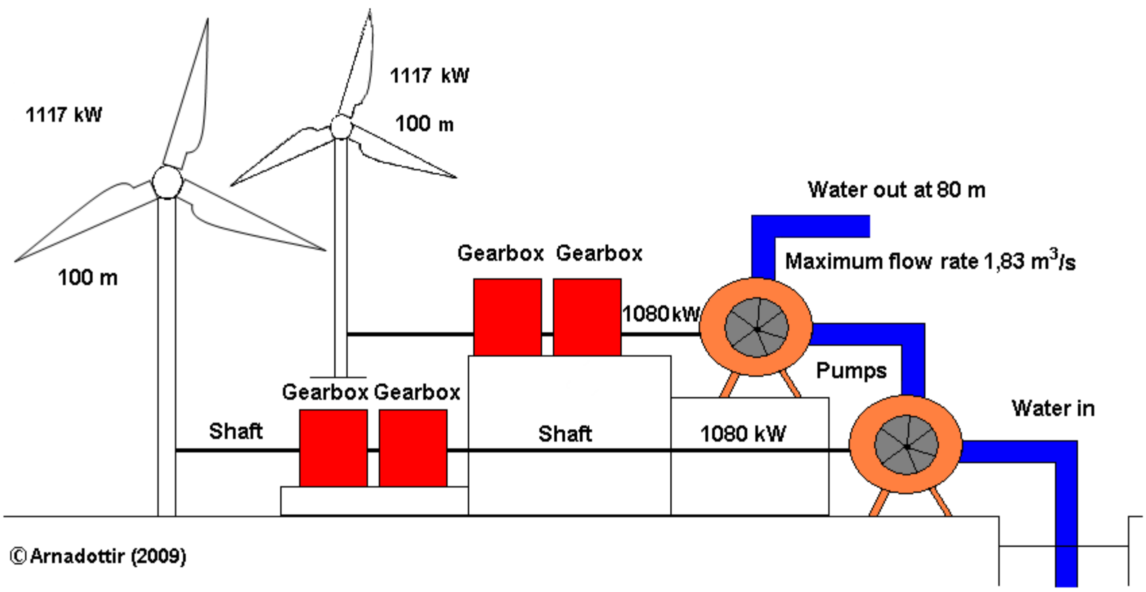

Figure 10. Two 100 m high wind turbines pumping water up to a 80 m height

When designing a fluid distribution system, three distinct steps are required. The first step is to establish the design and objectives, the second is the sizing of pipes and ducts, and the third is the calculation or determination of the pressure drop in the system (Coad, 1985). To estimate the price for pipes in the installation, calculation of the diameter is necessary.

To calculate the diameter of the pipe, the Reynolds number *Re*, the friction factor *f* and the pressure drop H_f are calculated with equations 7, 8 and 9 and then simplified in equation 10.

$$Re = \frac{4\rho Q}{\pi\mu D} \tag{7}$$

In equation 7 (Crowe et al., 2008), *Re* is the Reynolds number, ρ is the density of the fluid (water is 1,000 kg/m^3), Q is the volume of the flow rate (m^3/s), π is equal to 3.1415, μ is the dynamic viscosity of the fluid (1.5×10^{-3} kg/s m) and *D* is the diameter of the pipe (m). To calculate the friction factor (*f*) which depends on the Reynolds number *Re* of the pipe flow, the equation 8 is:

$$f = 0.316 Re^{-\frac{1}{4}} \tag{8}$$

In equation 8 (Crowe et al., 2008), *f* is the friction factor, *Re* is the Reynolds number from equation 7. The fluids flow is laminar if the Reynolds number is lower than 2000 in pipes, but if it is higher than 3000, it is turbulent (efunda, 2009).

To calculate a pressure drop, the equation 9 uses the friction factor *f* and is:

$$H_f = \frac{8fLQ^2}{\pi^2 g D^5} \tag{9}$$

In equation 9 (Crowe et al., 2008), H_f is the pressure drop, *f* is the friction factor (equation 8), L is the length of the pipe (m), Q is the volume of the flow rate (m^3/s), π is equal to 3.1415, g is the gravitational constant (9.81 m/s^2) and *D* is the diameter of the pipe (m). By simplifying equation 9, using Q= 1.83 m^3/s and L = 80 m, the diameter of the pipe can now be calculated with equation 10:

$$D = \left(\frac{0.196}{H_f}\right)^{\frac{1}{4.75}} \tag{10}$$

In equation 10, *D* is the diameter of the pipe in meters and H_f is the pressure drop. The pressure drop in equation 10, can now be calculated with equation 11.

$$H_f = \frac{\eta P}{Q} \tag{11}$$

In equation 11 (White, 2002), H_f is the pressure drop in a pipe, η is the efficiency (73%), *P* is the input horse power at the shaft (961 kW/0.746=1,288 HP) and *Q* is the volume of the flow rate (1.83 m^3/s = 1,830 l/s). The pressure drop in a pipe can now be calculated with equation 11:

$$H_f = \frac{0.73 \times 1288}{1830} = 0.5$$

The pressure drop is about 0.5. The diameter of the pipe can now be calculated by:

$$D = \left(\frac{0.196}{0.5}\right)^{\frac{1}{4.75}} = 0.82$$

The calculated diameter of the pipe is 0.82 m. The price for one meter of a 820mm steel pipe is 1,574 US dollars (Geirsson, 2009). If a plastic pipe is used instead, 1.0 m in diameter, made for 60 N/cm^2 pressure, the price is 490 US dollars per meter (Halldórsson, 2009). In the calculations, steel pipes that are about 0.82 m in diameter are used because of higher pressure capacity. The velocity of the water in the pipe can be calculated with equation 11:

$$v = \frac{4Q}{\pi D^2} \tag{11}$$

In equation 11 (LMNO Engineering, 2008), *v* is the velocity of the water in the pipe (m/s), *Q* is the volume of the flow rate (m^3/s), π is equal to 3.1415 and *D* is the diameter of the pipe (m). With a flow rate of about 1.83 m^3/s and a pipe diameter of about 0.82 m, the velocity of the water is about 3.5 m/s.

8 Economic feasibility of a windpump

In the beginning, this thesis was meant to answer the question: "Is it profitable to build a wind pumped storage system for a hydropower plant in Iceland?" By looking at two possible usages of a wind pumped storage system, an excel model for profitability assessment calculations was used. The first usage of the windpump concerned the production of electricity from the pumped water. The pumped water is used to produce more electricity from an existing hydropower plant after modification. The second usage of the windpump looked at the possibility of constructing a smaller reservoir and a dam by using a wind pumped storage at the hydropower plant. The Excel model calculates whether or not these are profitable operations. The structure of the Excel model is shown in Appendix G.

The setup in the profitability assessment uses eight windpump units. One windpump unit installed includes two V80 wind turbine from Vestas, four gearboxes, two pumps, shafts and steel pipes. The building needed is a house for the pumps. Other expensive items are the upper reservoir changes because of the pipes and foundation for the pipes and the shafts. Other investment costs are installation, designing, constitutional and insurance cost. In the estimation for the electricity price, when extra water is used to produce the electricity, modification of environment and the turbine is included within the modification part in the breakdown sheet.

The Excel model with values is shown in Appendix E. In the breakdown sheet, a three point estimated method (Goodpasture, 2004) is used to calculate expected costs for the buildings, the equipments and other investments. The confidence level is 95%. In the three point method three points are used, most pessimistic costs and optimistic costs that have some small profitability of happening and most likely costs that has the most likely value in the mode of the distribution. This three point method uses BETA distribution and calculates variance and standard deviation (see Appendix E).

For the equipment part, the wind turbine, the shaft and the gearbox costs are estimated. Installation cost is included in the wind turbine cost. The price for one kg steel type St. 52

was known. The weight of one meter of shaft was estimated at 50 kg. The estimated price of a wind turbine with installation cost for the year 2009, per kW is about 2,120 US dollars. It is about a 10% higher project cost than the price in 2008 (U.S. Department of ENERGY, 2008). The estimated calculated price of one Vestas V80 wind turbine is about 4.2 m US dollars. Because a wind turbine gearbox and a generator are not needed for the wind turbine, the wind turbine and the installation cost was reduced by 40%, to 2.5 m US dollars (see Appendix C). This is an academic cost reduced estimate by the author, because the wind turbine producer Vestas refused to give any detailed information about prices for Vestas models. Three prices for wind turbine were estimated, the optimistic, the most likely and the pessimistic. Price information for wind turbines from other producers, the same size as Vestas V80, was not possible to find on the internet. A wind turbine model V80 from Vestas was used as example in the thesis.

The building cost is mostly based on changes in the reservoir, building a shelter for the pumps and housing for the shaft from the wind turbine to the pump. Other investment cost like design cost and all other installation costs without the installation of the wind turbine, are included in the other investment part. All these estimated costs are used when the model calculates the reduced reservoir possibility. The modification part in the three point method is just added into the calculations when the model calculates the price of produced electricity from pumped water and the profit for the next 40 years. An expected lifetime of a hydro power plant is from 40 to 70 years (and even 100 years!). An expected lifetime of a wind power plant is about 20 years (Madlener et al., 2005). A wind turbine with no gearbox and no generator is expected to last longer due to lower complexity regarding electricity components and cables. Therefore it is expected that a wind turbine, with shaft technology, will last 40 years with proper maintenance. Maintenance cost is expected to be 2% annually for the wind pumped storage system.

The wind turbine is the most expensive part in the equipment part of the investment. Today's average estimated price for one MW of an installed wind turbine can vary from one million US dollars to two million US dollars. The expected cost for one Vestas V80 wind turbine is estimated in the equipment part to be 2.5 m US dollars without a gearbox and a generator. The calculated equipment cost in the Breakdown part of the profitability assessment shows that the estimated expected price of a wind turbine with installation cost is about 93% of the expected equipment cost. The gearbox, the shaft, the pumps and the pipes, without installation cost, are just 7% of the expected equipment cost. The installation cost for this equipment is categorized with other investment and is expected to be most expensive for the installation of one unit. For one unit installed, the expected estimated installation cost of the gearboxes, the shafts, the pumps and the pipes is about 34% of these equipment cost. For eight units installed, the cost is estimated about 12%, and for 20 units installed, the cost is estimated at nearly 8%.

The breakdown sheet also calculates the cost of reducing a reservoir if a wind pumped storage system is installed. This is only valid in the beginning of the process state, when a new reservoir is designed. Average capital cost of a reservoir was calculated from the cost of building four reservoirs in Iceland (Landsvirkjun, 2006). The capital cost for the four dams in September 2009 was 206,000 US dollars and the total reservoir size is 682 Gl (see Appendix C). The calculated average price for an average reservoir of a size 171 Gl with a dam, is 51,554 US dollars. Based on this information, an estimated average price of Gl in the reservoir and the amount of pumped water into the upper reservoir was used to estimate in percentages, how much the reservoir could be reduced (see Appendix E). From the estimated average price of a reservoir and a dam, the value for a reduced cost in a new project was estimated. The calculation showed that the cost of an additional pumped storage system is always higher than the reduced cost of constructing a new smaller sized reservoir and a lower dam.

The profitability assessment calculations for the electricity production of the extra pumped water are based on the profitability assessment model (see Appendix E). The planned horizon is 40 years and the loan repayment is made in 20 years. The estimated loan interest rate is 6%, which is similar to the interest rates that a large domestic energy firm like Landsvirkjun faces. In Figure 14, the effect of 3, 6 and 9% interest rate and the sales price on the NPV is compared. Equity is 30% and expected sales price in Iceland for one MWh is 29 US dollars (mills) as shown with calculation in Appendix C. The discount Rate (MARR) is 10%. The modification part in the Breakdown sheet calculates the modification necessary to produce electricity from the extra water added to the reservoir. Modification like scaling up the hydro turbine and the generator is needed. The main parts are the hydro turbine, the electricity connection and the house modification. From the wind calculation in chapter 6, no power production from the wind turbines is expected to be nearly 13.5% of the year. The model calculates expected sales quantity measured in MWh/y (mills). It is not profitable in Iceland to add a wind pumped storages system to an existing hydropower plant and to produce electricity from the extra water, based on the information in the profitability assessment.

For example, a given project of a pumped storage system with eight units, starting with a forty years lifespan, is considered to be installed at Sigalda hydropower plant in the Þjórsá area (see also Appendix E). One unit includes two wind turbines like Vestas V80, two pumps similar to Goulds 316SS, four gearboxes, 330 m of shafts and 160 m of 0.7 m wide steel pipes. Other investment costs are buildings, installation, design, constitutional and insurance cost, modification cost on a house and a hydro turbine. The total flow rate from the sixteen pumps will be about 15 m^3/s. The calculated average wind speed at a 100 m height is 12.71 m/s. The electricity production from this extra water is estimated to be 74,027 MWh/y and the sales price is 29 US dollars for MWh. The size of the added hydro turbine is about 8 MW and the head is 80 m high.

Figure 11 show the cash flow for a project of eight units. Free net cash flow and equity is an index on how much cash can be paid to the equity shareholders after all expenses. It became a positive value after 2032 because the loan was just for 20 years. At this point, it is possible that the project needs refinancing. The total cash flow and capital will be similar after 2032 due to constant electricity price and production.

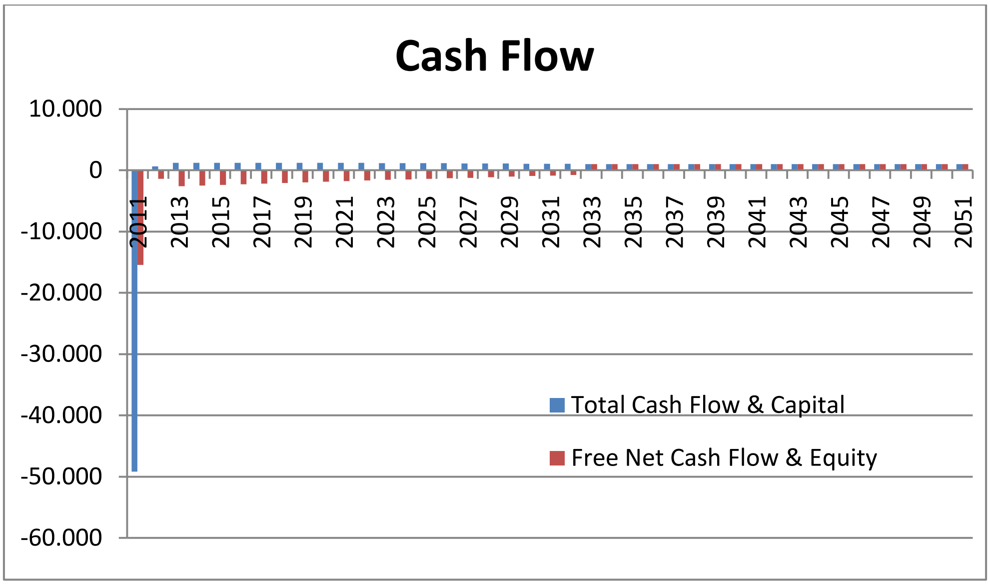

Figure 11. The cash flow for the project with eight units

The definition of NPV is the total present value of the cash flow over a certain time. It is used to measure the shortfall or excess of the cash flow for an investment. When NPV is calculated, a discount rate is used. A discount rate is the rate of return in the financial markets that could be earned with a similar risk. In the example of a wind pumped storage system with eight wind turbine units, the discounting rate is expected to be 10%. The Central Bank treasury bonds yield for 25 years is now about 8%[1] (Central Bank of Iceland, 2009). Buying bonds from the Central Bank of Iceland is, of course, a risk free investment.

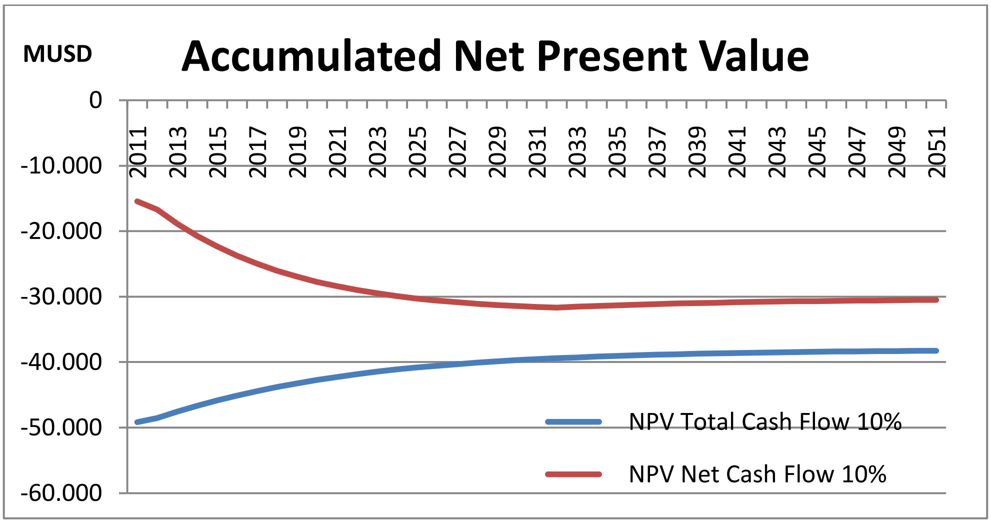

Figure 12. Accumulated Net Present Value for the eight wind turbine units

In a project like a wind pumped storage system, it is expected that investors would require at least a 3 to 5% higher rate of return than the bonds give, because of the risk. But with a discount rate equal to 10%, this project will not be profitable as shown in Figure 12.

The Internal Rate of Return or IRR is an indicator for the quality of an investment. It shows the value of the investment. It is an annualized return rate which can be earned by the invested capital. The IRR of a total cash flow shows 0%! The IRR for the net cash flow is also 0%. This quality of an investment is considered to be a very bad investment, as Figure 13 shows. The equipment and the electricity price in the calculations have a very strong influence on the IRR.

[1] The current yield of about 8% for the treasury bonds is unusually high, and most likely to become lower soon, affecting the profitability assessment.

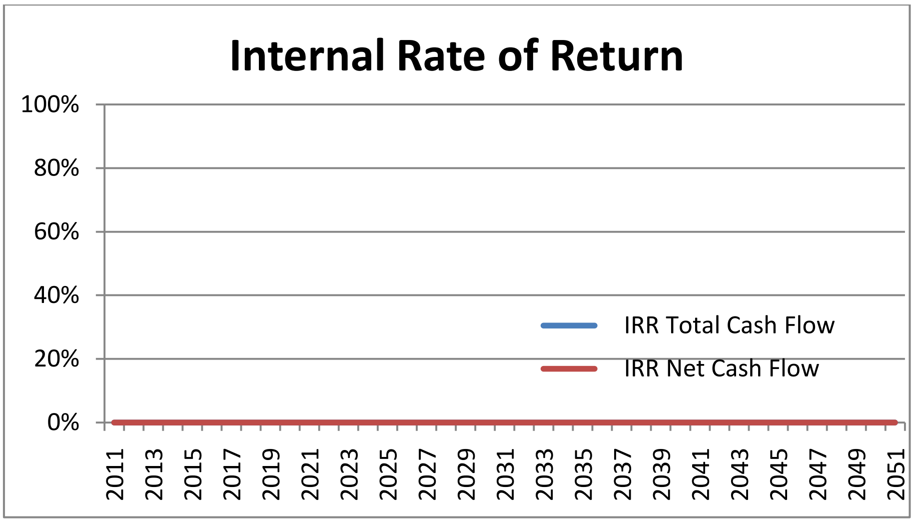

Figure 13. Internal Rate of Return for the project with eight units

In Figure 14, NPV for a project with eight wind turbine units was calculated with different sale prices and interest rates. The loan repayment is 20 years and working capital is 519,000 US dollars. About 74 GWh of electricity is produced in one year and the maintenance cost is 2%. At a 3% interest rate the NPV starts to be positive when the sale price is about 65 US dollars per MWh (mills). With an interest rate of 9%, the NPV starts to be positive when the sale price is about 83 US dollars per MWh. This is a difference of about 22%. This shows how important the interest rate is for a project this size.

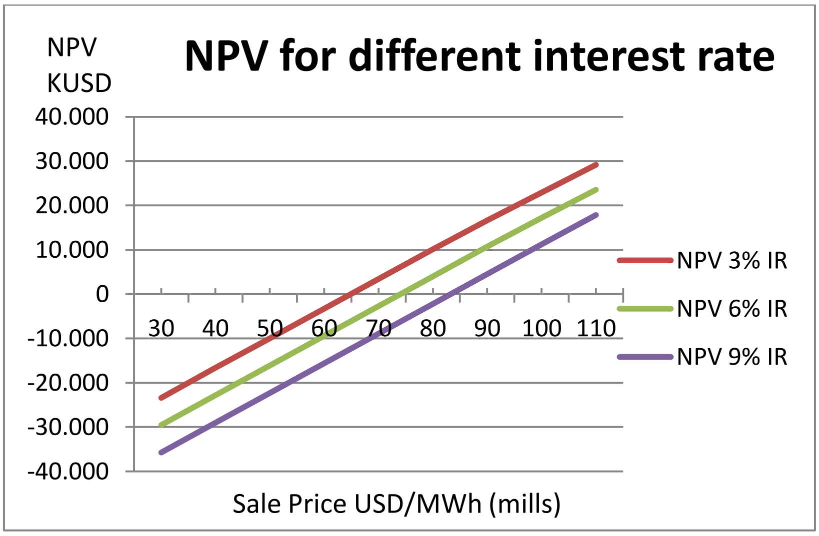

Figure 14. Comparing three different interest rates for the eight wind turbine units

9 Discussion

In many areas of the world, wind energy will play an important role in future power supply. Further improvements in wind turbines will lead to further cost reductions and a fast growing worldwide market. It will also lead to larger wind turbines and new system applications. Will wind pumped storage systems with a shaft driven technology where the water is used repeatedly be the new future possibility for hydropower plants? The future of this technology will depend mainly on the profitability of the project and the environment of where it will be built. Windpump systems added to a hydropower plant using conventional three blade horizontal wind turbines and pumping water without producing electricity, have not been implemented in this size before.

Governments are more concerned about environmental factors today than 10 years ago. Many rural areas are priceless from the tourist point of view, and some are seen as very good agricultural areas. The profitability assessment shows that it is not profitable to use a wind pumped storage system to minimize a reservoir and a dam construction. In the example from chapter 8, where eight wind turbine units are used together, it is possible to reduce an average sized reservoir by about 8%. This is calculated from an average price of four reservoirs and dams buildings in Iceland. In this case, the pumped flow rate is about 15 m^3/s, the average wind speed at a 100 m height is 12.71 m/s and there is no wind pumping for about 49 days. The estimated cost of the project is much higher than the reduced cost of building a new lower dam and a smaller sized reservoir. No calculations of other costs like loans or tax payments were consider necessary, because it was never profitable, even if the estimated price for pumped water was added (8 US dollars for Gl). Estimated price for the land was not included in the calculations. It was expected that the land used for the reservoir and the dam is free. In the case where the environment used for construction of the reservoir is priced on the grounds of e.g. cultural, agricultural or tourist’s usage, the reduced reservoir estimates can possibly start to show a profit. But in each case, the key factor will always be the environmental situation.

The profitable assessment calculations show that it is not profitable to build a wind pumped storage system for more electricity production at existing hydropower plants. Not included in these calculations is an unforeseen first time design cost. The technique of the shaft connections is well known today and multi bladed wind turbines are used instead of three bladed wind turbines. The expected sales price of one MWh of electricity in the profitability assessment is 29 US dollars. The price of electricity in Iceland for the industry and household consumers is lower than the electricity price in the EU. In the second semester 2008, the electricity price without network cost and non-recoverable taxes and levies for industrial consumers in the EU, with annual consumption between 500 and 2000 MWh, was from 42 US dollars (€2.94) to about 200 US dollars (€14) for one MWh (Goerten et al., 2009). There is a different energy and supply price for the industry in each of the member countries and the prices are even higher for household consumers. The ratio between the energy and supply costs and the network costs can differ. By changing the sale price from 29 US dollars to 90 US dollars, will have a huge impact on the profitability calculations. Even with half the pumping flow rate (due to a lower average wind speed), the same investment cost and the sales price of electricity at about 165 US dollars, the project with 8 wind turbine units installed will show a profit in the EU. A wind pumped storage system with a shaft technique for a hydropower plant is profitable in the EU because of the high electricity price.

Figure 15. The leak form the Sigalda dam captured and measured

A wind pumped storage system can be installed for security reasons. Low status of the water level in reservoirs, when there is no melting of ice from the glaziers, can occur in the winter time in Iceland. Krókslón is the reservoir for Sigalda hydropower plant. The reservoir is at maximum height 498 m over sea level. The lowest height of the water level, required for electricity production, is 491 m over sea level (Hannesdóttir, 2009). The change of the water level in Krókslón, in the year 2006, is shown in Figure 16.

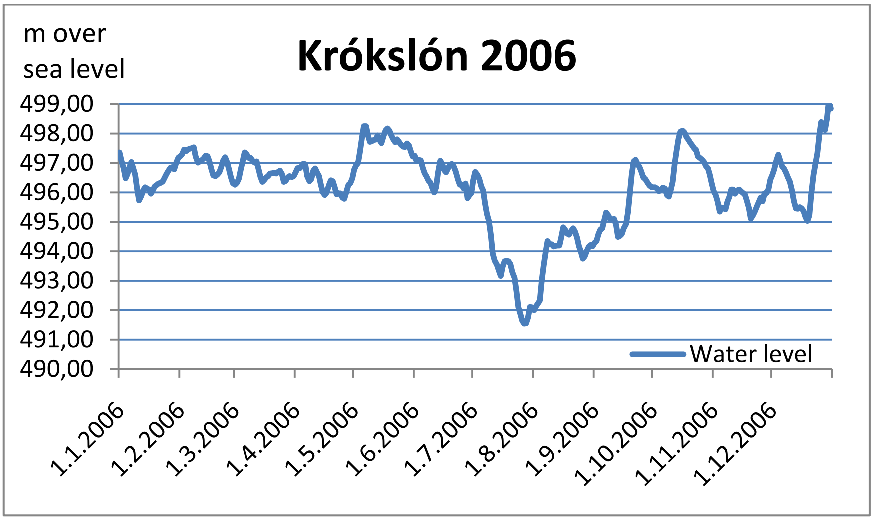

Figure 16. Water level in Krókslón 2006 (Landsvirkjun, 2009)

In late July 2006, the water level reached a critical status of 491.5 m over sea level, only 0.5 m over lowest height for electricity production. The average water level for Krókslón in the year 2006 was 496.7 m over sea level. A wind pumped storage system can help to prevent the situation when the water level reaches a critical status. How many wind turbine units one hydropower plant needs and the observed fluctuation in water level on annual basis, depends on the water usage from the reservoir.

The system can also be used to pump the water leaking from underneath the Sultartangi and Sigalda dam. This leak is from 5 m^3/s to 12 m^3/s (see Appendix J). Figure 15 shows how the leak is measured at the Sigalda dam. The leak is coming from underneath the dam through the lava. It is captured and the flow is measured. To pump a leak of about an 8 m^3/s when the height is no more than 20 m, two or more wind turbine units are expected to be used.

In an electrical system where a high level of wind sourced energy is combined, the wind power production can lead to dangerous system condition, due to variations in the wind direction and the speed. In small or medium electrical systems, where the installed wind source has reached the production limitation, a danger of interference between power demand and the energy production can occur. In a situation like this it is still possible to utilize the wind energy by installing a wind pumped storage system with shaft driven pumps combined with a hydropower plant. This can be utilized at locations where water is accessible but not in enough quantity for a conventional hydropower plant.

In the case where a wind pumped storage system uses a wind turbine to produce electricity to drive the pumps, and pumping is not necessary, the electricity is directed to the grid. This is most common in wind pumped storage systems today. In a system where electricity is produced with a hydro turbine from the pumped water, the pumps are not expected to stop except when there is none or to strong a wind, or for maintenance. For example, one Vestas V80 wind turbine can drive one pump with a shaft connection. The flow rate from electricity driven pumps will be just about 1.6 m^3/s, instead of having the pumping flow rate about 1.8 m^3/s from pumps connected with shafts to the wind turbines. This has an impact on the profitability assessment and will make this assessment, based on wind turbine producing electricity, non profitable, unless the electricity sale price for one MWh is higher than 100 US dollars or 100 mills.

10 Conclusion

The main reasons for non profitable use of a wind pumped storage system for extra electricity production in Iceland are the high price of powerful wind turbines and the low electricity sale price. In the Icelandic case, where eight units are installed with a flow rate of about 15 m^3/s and electricity price equal to 85 US dollars for MWh, the profitability assessment started to show profit. In countries where the electricity sale price is higher than 120 US dollars for one MWh, information from the profitability assessment shows that it started to be profitable to produce extra electricity with an added wind pumped storage system, even though the flow rate is 30% lower due to a lower average wind speed. Producing energy with wind turbines is categorized renewable and has nearly non CO_2 emission.

A wind pumped storage system can be used to secure the water level in a reservoir made for hydropower plants. If the water level in a hydropower plant reservoir is secured, the electricity supply from the plant is also secured. In locations where electricity sale price is higher than 90 US dollars it can probably be used with a profit to pump water into a reservoir for electricity production with hydroelectric turbines. It is also possible to use it to pump leakage water from a reservoir, where the head is just about 10 m to 25 m high. It has not been calculated in this thesis, but pumping water for security reasons is likely to be profitable in locations where a shortage of water in an upper reservoir can occur.

The next step is to design a wind pumped storage system, described in this thesis, where the wind turbines are connected to the pump with a shaft. Most important is to get a reliable price for a powerful wind turbine without a gearbox and a generator because with the installation cost it is about 93% of the equipment part in the profitability assessment. It is also important to find useable inexpensive plastic pipes to use instead of the steel pipes. Other very important factors are the sale price for the electricity and the average wind speed in the area.

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Appendix A – Information from automatic weather stations in Iceland

Source: (Windatlas, 2009)

Búrfell	**Landsvirkjun**
Location	64°07.010'N, 19°44.691'V, (64.1168, 19.7448)
Altitude	249 m
Height of measurement	10 m
Data collection started	1993

From measurement:

-	Unit	Measured	Weibull-fit	Discrepancy
Mean wind speed	m/s	7,06	7,15	1,23%
Mean power density	W/m²	475,60	476,37	0,16%

Height	Parameter	0,00 m	0,03 m	0,10 m	0,40 m
50,0 m	Weibull A [m/s]	13,0	10,6	9,8	8,5
	Weibull k	1,96	1,89	1,89	1,88
	Mean speed [m/s]	11,55	9,43	8,65	7,54
	Power density [W/m²]	1835	1039	805	532
100,0 m	Weibull A [m/s]	13,9	11,9	11,1	9,9
	Weibull k	1,96	2,01	1,99	1,97
	Mean speed [m/s]	12,29	10,57	9,82	8,76
	Power density [W/m²]	2220	1375	1114	799

Vatnsfell LV

Location 64°11.735'N, 19°02.800'V, (64.196, 19.047)

Altitude 539.5 m

Height of measurement 10 m

Data collection started 2004

From measurement:

-	Unit	Measured	Weibull-fit	Discrepancy
Mean wind speed	m/s	8,02	8,23	2,53%
Mean power density	W/m²	729,37	729,71	0,05%

Height	Parameter	0,00 m	0,03 m	0,10 m	0,40 m
50,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	13,90 1,84 12,35 2409	11,32 1,78 10,07 1352	10,39 1,78 9,25 1047	9,08 1,80 8,07 690
100,0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	14,79 1,85 13,13 2886	12,69 1,87 11,26 1791	11,80 1,87 10,47 1446	10,55 1,86 9,37 1038

Appendix B – Information for Goulds pumps

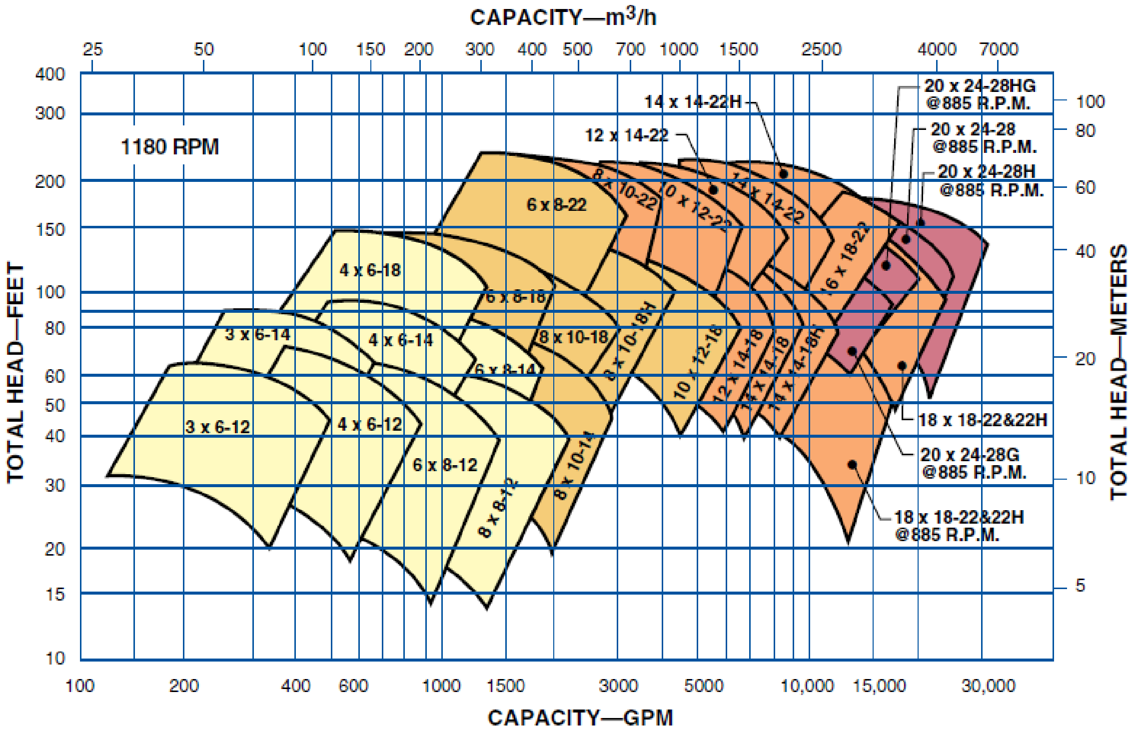
Goulds Model 3175

Designed to Handle the Toughest Jobs in the Pulp & Paper and Process Industries

- Capacities to 28,000 GPM (6360 m³/h)
- Heads to 350 feet (107 m)
- Temperatures to 450°F (232° C)
- Pressures to 285 PSIG (1965 kPa)

Design Features

Back Pull-Out



Construction Details All dimensions in inches and (mm).

		S Group	M Group	L Group	XL Group
Temperature Limits	Maximum Liquid Temperature— Oil Lubrication Without Cooling	250°F (121°C)			
	Maximum Liquid Temperature— Oil Lubrication with Frame Cooling	350°F (177°C)-Cast Iron 450°F (232°C)-Steel			
	Maximum Liquid Temperature— Grease Lubrication	250°F (121°C)			
Power Limits	HP (kW) per 100 RPM— 904L and Alloy 20 Construction	9.52 (7.10)	23.8 (17.8)	63.5 (47.4)	113.6 (84.7)
	HP (kW) per 100 RPM— Constructions other than Alloy 20	17.4 (13.0)	31.9 (23.8)	82.2 (61.3)	129.0 (96.2)
Shaft Diameter	At Impeller	1 7/8 (48)	2 3/4 (70)	3 3/8 (86)	3 7/8 (98)
	Under Shaft Sleeve	2 1/2 (64)	3 5/16 (84)	4 5/16 (109)	5 (127)
	At Coupling	1 7/8 (48)	2 3/8 (60)	3 3/8 (86)	3 7/8 (98)
	Between Bearings	3 1/8 (79)	4 (102)	4 7/8 (124)	6 (152)
Sleeve	O.D. through Stuffing Box	3 (76)	3 3/4 (95)	4 3/4 (121)	5 1/2 (140)
Bearings	Thrust (Coupling End)	SKF 7313 BECBY	SKF 7317 BEGAM	SKF 7222 BECBM	SKF 7326 BCBM
	Radial (Inboard or Pump End)	SKF 6313	SKF 6317	SKF 6222	SKF 6326
	Bearing Span	12 1/4 (311)	11 11/16 (297)	11 1/8 (283)	18 (457)
	Shaft Overhang	10 11/16 (271) to 11 27/32 (301)	11 13/32 (290) to 12 9/16 (319)	11 7/8 (302) to 13 9/16 (344)	19 (483)
Stuffing Box	Bore	4 (102)	4 3/4 (121)	5 3/4 (146)	7 1/2 (191)
	Depth—to Stuffing Box Bushing	3 11/16 (94)			6 3/4 (171)
	Packing Size	1/2 x 1/2 (13 x 13)			1 x 1 (25 x 25)
	Distance from End of Stuffing Box to Nearest Obstruction	3 1/8 (79)		3 1/4 (83)	3 3/4 (95)

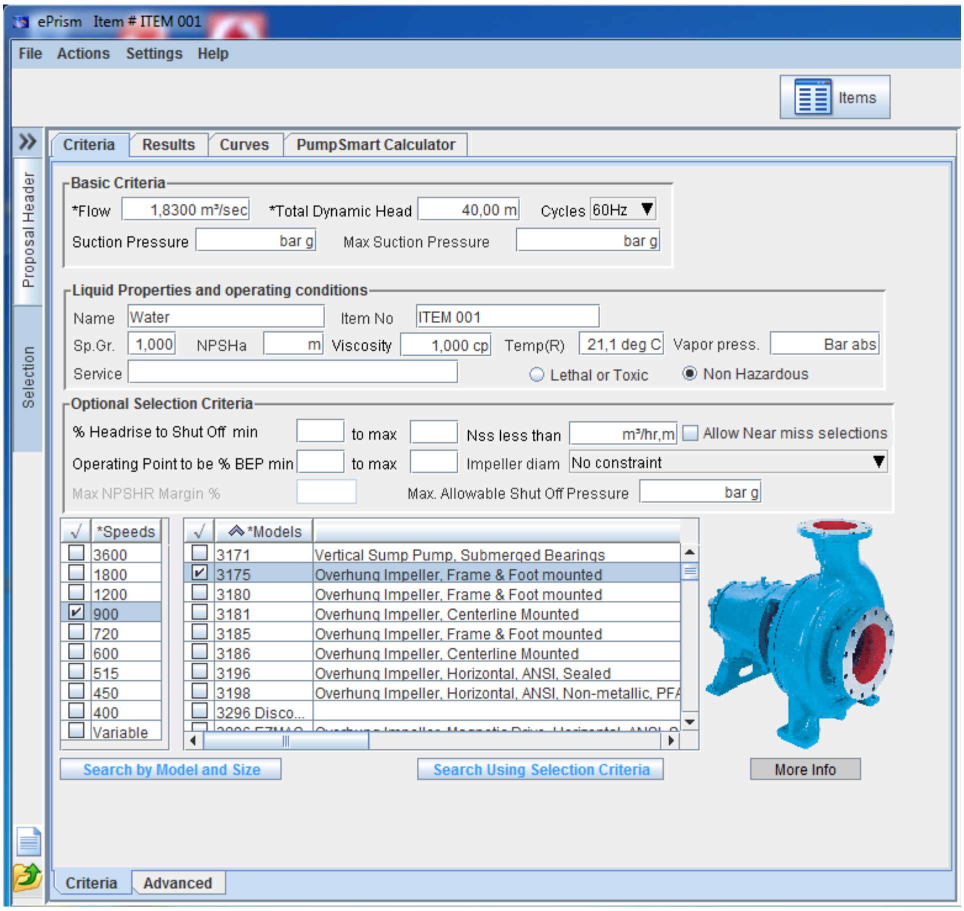
At a 40 m height, the maximum capacity of the pump is 29,000 GPM or 1,83 m^3/s.

Source: http://www.bidonequipment.info/pdf%20files/ITT%20Goulds%203175%20Paper%20Stock%20-%20Process%20Pumps.pdf

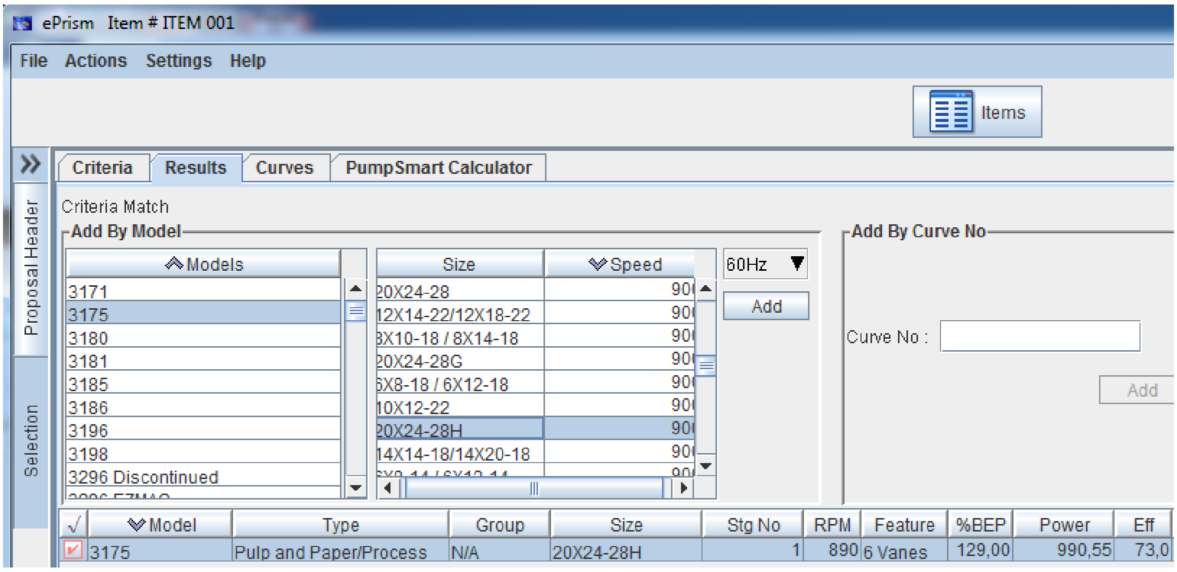
To find the efficiency of the Goulds 3172 pump the software Pump Selection System – PSS from Goulds Pumps was used (ITT, 2009).

Access was granted after installation and registration.

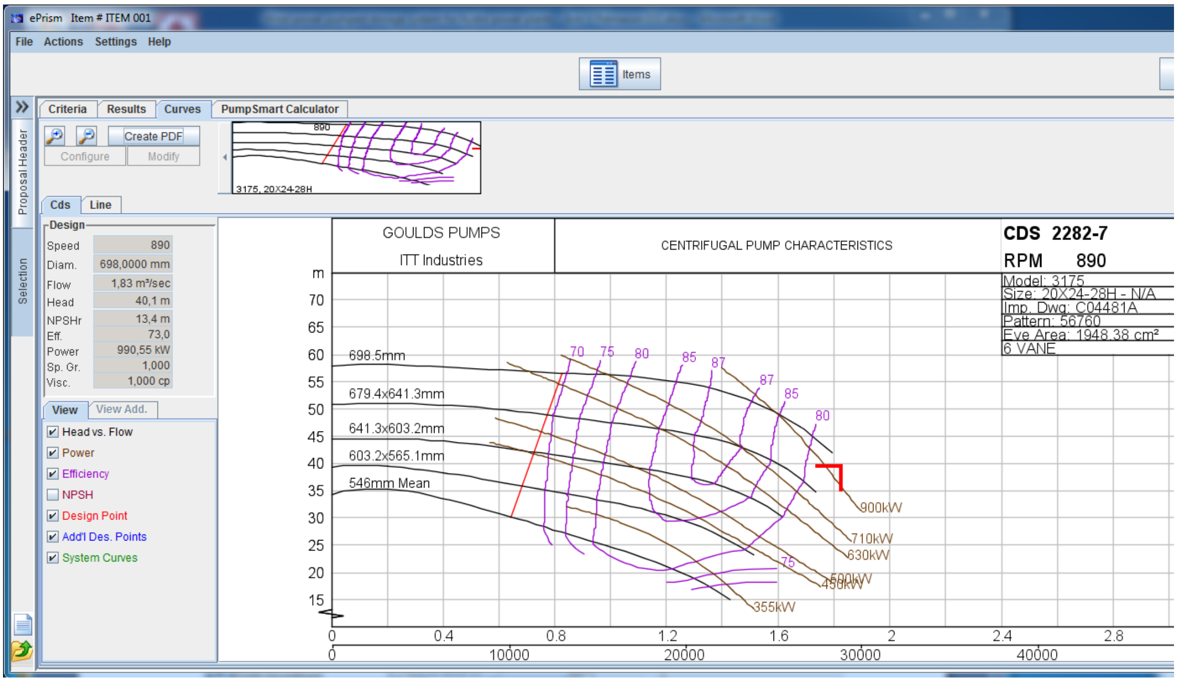
In the Basic Criteria the flow rate was set to 1.83 m^3/s and the total dynamic head to a height of 40 m.



When pressed “Search Using Selection Criteria“, the software searched for a pump which matched the criteria. One pump was found, Goulds 3175 20x24-28H.

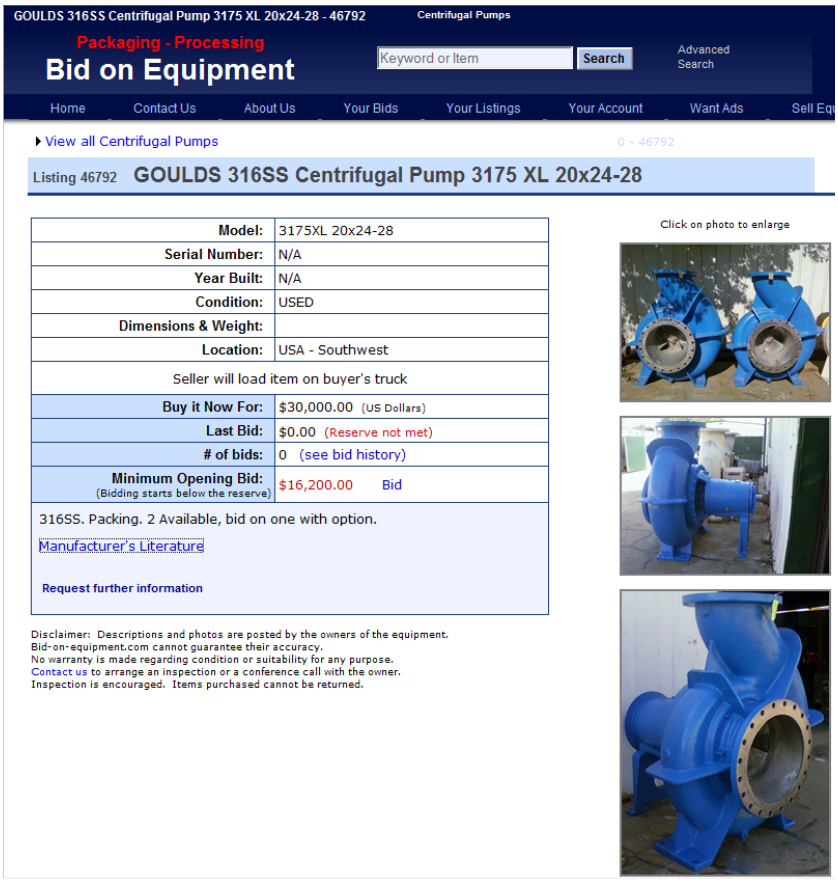


The Goulds pump of type 3172, size 20x24-28H and speed 890 RPM has efficiency of 73%. The pump uses 991 kW when pumping water up to a height of 40 m, at a flow rate of 1.83 m^3/s.



The curve for the Goulds 3175 20x24-28H pump.

The price of one Goulds 316SS Centrifugal pump 3175 XL 20x24-28 is 30,000 US dollars.



Source: http://208.11.143.12/detail~id~46792.htm

Appendix C – Calculations of dams, pipes, shafts and wind turbine cost

Dams and pipes

Prices in USD	USD =	125 ISK	1. april 2008 USD=		77,15 ISK			62%
	Euro	180 ISK					All prices without VSK	
Changes beetween 2006-01 and 2009-09	Byggingarvísistala 2006-01 =		208,5	but 2009-09 =		495,3	=	2,3755396
www.hagstofa.is								

Hydro Power Plant	Closing Overflow Dam	Just Dam	Bottom channel	height increase	condensate	owerflow	Price 2006-01 m ISK	Price 2009-09 KUSD
Blanda	2500	0	417	200	0	0	3.117	59.236
Hraueyjarfoss	1500	0	0	0	0	0	1.500	28.506
Sigalda	0	1363	656	0	940	315	3.274	62.220
Sultartangi	2800	0	0	0	160	0	2.960	56.253
Total cost for four dams and reservoirs							**10.851**	**206.216**

Hydro Power Plant	Reservoir size Gl	Station Production MW	Gross head m	Water Usage m3/s	Price per Gl m ISK	Reservoir needed in Gl for MW	Reservoir needed in Gl for m3/s	Water needed in m3/s for MW
Blanda	400	150,00	287,00	39	7,79	2,67	10,26	0,26
Hraueyjarfoss	33	210,00	88,00	154	45,45	0,16	0,21	0,73
Sigalda	140	150,00	74,00	132	23,39	0,93	1,06	0,88
Sultartangi	109	120,00	44,60	316	27,16	0,91	0,34	2,63
	682	**630**	**493,6**	**641**				

	2006-01		2006-01		2009-09	
Cost of medium size reservoir and dam	2.712,75	mISK	21.702,00	KUSD	51.553,96	KUSD
Medium size of serveroir in Gl	170,50	Gl	170,50	Gl	170,50	Gl
Medium price of one Gl in reservoir	15,91	mISK	127,28	KUSD	302,37	KUSD

Pipes	Plastic pipelines ISK	USD	Carbon steel pipelines ISK	USD	
Cost per meter for 500 mm pipe	25.127	201	196.800	1.574	Soruce: Halldórsson (2009)
Cost per meter for 700 mm pipe	42.885	343	170.000	1.360	Soruce: Geirsson (2009)
Cost per meter for 1000 mm pipe	61.264	490	240.000	1.920	

Pipe for pumping water	Type	Length m	Lines	Total len m	USD per m	KUSD per m
Pipe 1	820	1	1	1	1.574	1,5744
Pipe 2	1000	1	1	1	1.920	1,9200
Total cost of pipes		2		2		

Information on const of Wind turbine	(Vestas) Turbine type	Output power kW	+VAT Euro	USD	no gear no gener. 60%	Price in ISK	Price in USD	price for kw electr power USD	one m tower USD
Wind Turbines as Autoproducers L.D.S	V47	660	920.500	0	552.300	99.414.000	**795.312**	**1.205**	
Wind Power by Roger Rivera	?	600	0	575.000	345.000	43.125.000	**345.000**	**575**	1500
Wind Turbines as Autoproducers L.D.S	V52	850	1.127.000	0	676.200	121.716.000	**973.728**	**1.146**	
Wind turbines buyers guide july 2007	V-15	65	0	140.000	84.000	10.500.000	84.000	**1.292**	
Wind turbines buyers guide july 2007	v-17	100	0	180.000	108.000	13.500.000	108.000	**1.080**	
J.P Sayler & Associates	Nordtank	65	0	61.770	37.062	4.632.750	37.062	**570**	
U.S. Department of ENERGY, 2008	Vestas V8(	2.000		4.240.000	2.544.000	318.000.000	2.544.000	**1.272**	

Shaft and electricity price

	Tower hight	Output power kW	blade diameter	Price tower m	Price blade	Price tower total USD	Total USD	price for kw electr power USD
Just blade and tower no install V80	50	2000	80	1500	165000	75000	240000	**120**

http://www.compositesworld.com/articles/wind-turbine-blades-big-and-getting-bigger.aspx

	Price St 52 per kg ISK	Shaft for V80 Kg m	Needed m of shaft for V80 (50m)	Price of shaft in ISK	Price of shaft in m USD	Price of shaft in m KUSD	Price of shaft for V80 USD	Price of shaft for V80 KUSD
Shaft 50m height tower	200	50	130	10000	80	0,08	10400	10,4
Shaft 100m height tower	200	100	180	20000	160	0,16	28800	28,8

Energy price for the industry	**kWh ISK**	**kWh USD**	**MWh USD**	
Orkusalan	3,93	0,031	31,44	source: https://www.orkusalan.is/fyrirtaeki/verskr1
Orkuveita Reykjavíkur	3,83	0,031	30,64	Source: http://www.or.is/Einstaklingar/Verdskraogskilmalar/Rafmagn/
Average electricity price	**3,88**	0,031	31,04	
Electricity price ISK kWh - 3 years contract	**ISK**	**ISK**	**ISK**	
Landvirkjun	**2009**	**2010**	**2011**	
jan	4,157	4,364	4,474	
feb	4,157	4,364	4,474	
mars	4,157	4,364	4,474	
apríl	4,157	4,364	4,474	
may	3,117	3,273	3,355	
jun	2,079	2,183	2,237	
july	2,079	2,183	2,237	
august	2,079	2,183	2,237	
sept	3,117	3,273	3,355	
okt	4,157	4,364	4,474	
nov	4,157	4,364	4,474	
des	4,157	4,364	4,474	
Average electricity price for 12 months	**3,464**	**3,637**	**3,728**	

Source http://www.landsvirkjun.is/media/vidskiptavinir/heildsolusamningar_1-3ar_jan_2009.pdf

Landsvirkjun 2009-2011 Average price electricity

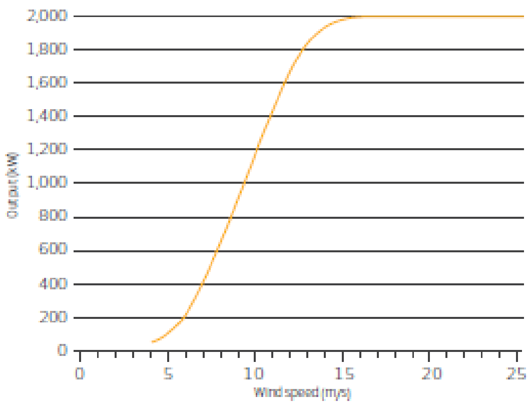
3,610	**ISK kWh**
0,029	**USD kWh**
29	**USD MWh**
0,029	**KUSD MWh**

Appendix D – Information about Vestas V80-2.0 MW wind turbine

TECHNICAL DATA FOR V80-2.0 MV

Power regulation	pitch regulated with variable speed
Operating data	
Rated power	2,000 kW
Cut-in wind speed	4 m/s
Rated wind speed	16 m/s
Cut-out wind speed	25 m/s
Wind Class	IEC IA
Operating temperature	standard range -20°C to 40°C. low temperature option -30°C to 40°C.
Rotor	
Rotor diameter	80 m
Swept area	5,027 m²
Nominal revolutions	16.7 rpm
Operational interval	10.8-19.1 rpm
Air brake	full blade feathering with 3 pitch cylinders
Tower	
Type	tubular steel tower
Hub heights	67 m and 80 m
Generator	
Type	4-pole asynchronous with variable speed
Nominal output	2,000 kW
Operational data:	60 Hz 690 V
Gearbox	
Type	3-stage planetary/helical

Power curve V80-2.0 MW

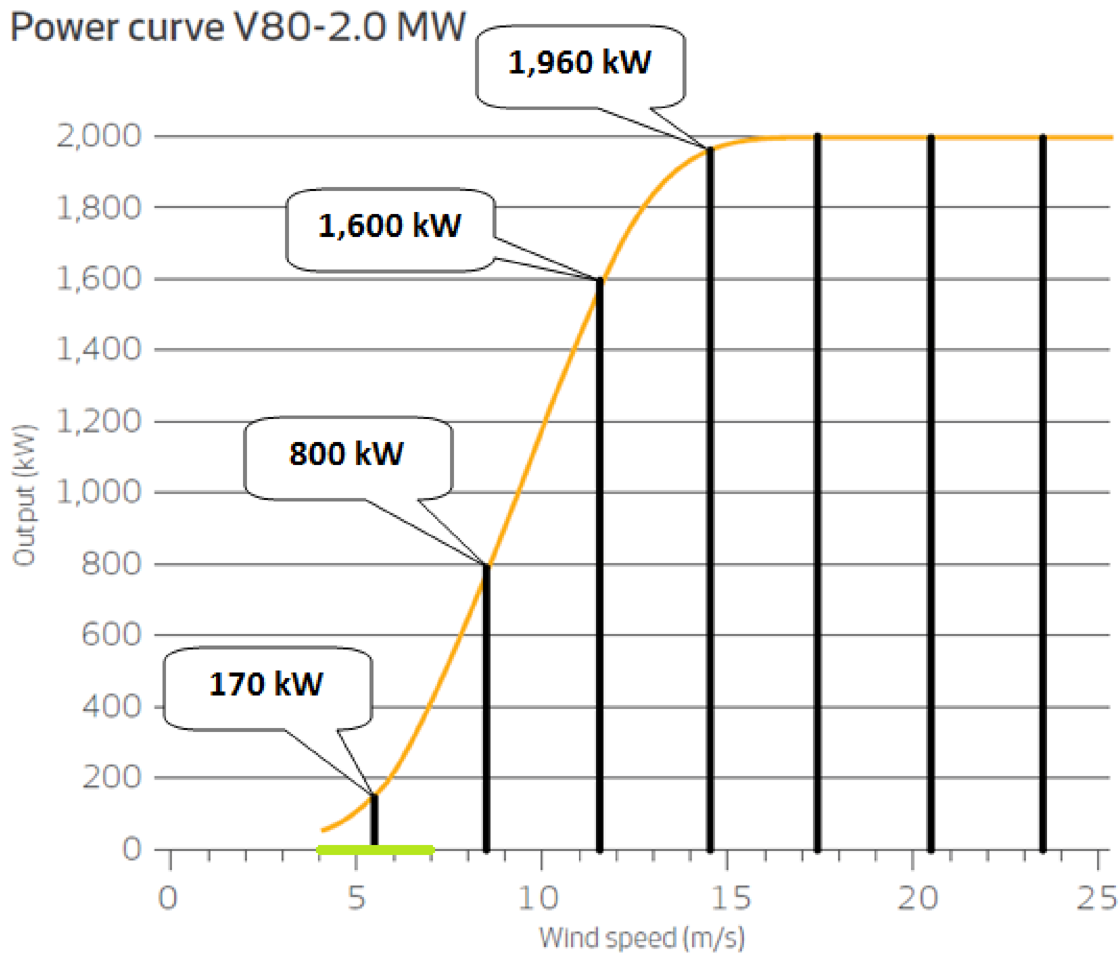


Main dimensions	
Blade	
Length	39 m
Max. chord	3.5 m
Blade	6,500 kg
Nacelle	
Height for transport	4 m
Height installed (including CoolerTop)	5.4 m
Length	10.4 m
Width	3.4 m
Weight	69 metric tonnes
Hub	
Max diameter	3.3 m
Max. width	4 m
Length	4.2 m
Weight	18 metric tonnes
Tower	
67 m	
Weight	117 metric tonnes
80 m	
Weight	155 metric tonnes

All specifications are for informational purposes and are subject to change without notice. Vestas does not make any representations or extend any warranties, expressed or implied, as to the adequacy or accuracy of this information.

Source: http://www.vestas.com/en/media/brochures.aspx

The power curve of a wind production for the Vestas V80 wind turbine.



In the power curve, the used wind range, is from 4 to 25 m/s divided into 7 intervals. Each interval is 3 m/s. The average wind power production in each interval is used. E.g. for the interval from 4 to 7 m/s, the average value of 170 kW at 5,5 m/s is used.

Appendix E – The Excel Model for the Profitability Assessment

Assumptions and Results

Number of wind turbines	16		
Start year		**2011**	
Investment:		KUSD	
Buildings		170	
Equipment	100%	46.755	
Other (+modification)		1.709	
Total investment		**48.634**	
Financing:		KUSD	
Working Capital		519	
Total Financing		**49.153**	
Equity	100%	30%	
Loan Repayments	100%	20	years
Loan Interest	100%	6%	
Operations:		**2012**	Start year
Sales Quantity	100%	74.027	MWh/y
Sales Price	100%	0,029	k$/MWh
Variable Cost	100%	0,0001	KUSD/MWh
Fixed Cost	100%	4,0000	KUSD/year
Maintenance Cost 2%	100%	935	KUSD/year
Inventory Build-up		0	of turnover
Debtors (Accounts Receivable)		25%	
Creditors (Accounts Payable)		15%	of profit
Dividend		10%	
Depreciation Buildings		4%	
Depreciation Equipm.		15%	
Depreciation Other		20%	
Loan Managem. Fees		2%	
Income Tax		15%	
Installation ratio for G/S/P/P	**11,88 %**		

Discounting Rate (MARR)	**10%**		
Planning Horizon	**40**	**years**	
Value of the company	**12.003**	KUSD	
	Total Cap.	**Equity**	
NPV of Cash Flow	**-38246**	**-30497**	
Internal Rate	**0%**	**0%**	
Minimum Cash Account =	**-34875**	KUSD	
Internal value of Shares (Capital/Equity) after 40 years			**-1**

Allocation of Funds

	KUSD	
Variable Costs	296	1%
Fund costs	160	0%
Paid taxes	4.170	9%
Loan Repayments	34.407	71%
Financial Costs	24.429	50%
Paid Divident	2.363	5%
Company cash	-17.375	-36%
	48.451	**100%**

Reduced reservoir

Number of V80 Wind turbine(s)	**8**	
Head (H)	**80**	**m**
Pumped flow rate	**14,6**	**m3/s**
Average price for one Gl	**8**	**$**
Pumped water in one year	**399**	**Gl**
Reduced reservoir (mean)	**8**	**%**
Expected gain	**7.425**	**KUSD**
Expected project cost	**47.672**	**KUSD**
Total expected cost (cost - gain)	**40.247**	**KUSD**
Gain as percentage of the cost	**16**	**%**

Breakdown

Page 1 of 3
Three point Method

Numer of WT	8	1 = 2 x Vestas V80 , pump, shaft, gearbox, pipes	
Head (m) =	80	H = 80 for Sigalda hydro power plant station	

Assuming Beta distribution

Exp value= (a+4*m + b)/6 | Stdev=(b-a)/6

Confidence level: 95%
Z= 1,64

KUSD	Optimistic	Most likely	Pessimistic	Ex Value	Stdev	Variance	Cost estimate	
Buildings	a	m	b	E	s	s^2		
Reservoir change	28	57	99	59	12	139		
Housing for the shaft	17	33	66	36	8	68		
House for pumps	28	42	85	47	9	89		
Total	73	132	250	142	17	296	170	KUSD

KUSD	Optimistic	Most likely	Pessimistic	Ex Value	Stdev	Variance	Cost estimate	
Equipment	a	m	b	E	s	s^2		
Wind turbine w/install	30.528	40.704	44.928	39.712	2.400	5.760.000		
Gearbox	320	384	480	389	27	711		
Shaft	211	211	211	211	0	0		
Could 316SS	480	480	480	480	0	0		
Steel pipe dia=0.82m	2.015	2.015	2.015	2.015	0	0		
Total	33.554	43.794	48.114	42.807	2.400	5.760.711	46.755	KUSD

KUSD	Optimistic	Most likely	Pessimistic	Ex Value	Stdev	Variance	Cost estimate	
Other investment	a	m	b	E	s	s^2		
Constitutional	28	35	49	37	4	13		
Installation (not WT)	311	368	424	368	19	356		
Designing	141	198	269	200	21	450		
Insurance	57	85	141	90	14	200		
Total	537	686	884	694	32	1.018	747	KUSD

KUSD	Optimistic	Most likely	Pessimistic	Ex Value	Stdev	Variance	Cost estimate	
Modification	a	m	b	E	s	s^2		
Electricity cable modif	80	160	240	160	27	711		
Modification of turbine	400	640	800	627	67	4.444		
House modification	40	56	80	57	7	44		
Total	520	856	1.120	844	72	5.200	963	KUSD

Breakdown

Page 2 of 3

Production calculation	η	One year calculated no wind %	Head (m)	Q (l/s)	P=ρgHQη MW	Power production with no wind MW	Total energy production MWh/y
	85%	13	80	14.640	10	8	74.027

For Vestas V80 pumped flow rate m3/s 1,83 Reservoir calculation	Medium size Gl	2009-09 Medium size reservoir KUSD	Wind pumped flow rate m3/s	Medium Price on one Gl USD	Pumped in one year -no wind Gl	Reduced reservour %	2009-09 Reduced cost for new reservoir KUSD	Total cost B / E / O KUSD	Reduced cost of full size reservoir %
	171	51.554	14,6	8	399	8	7.425	47.398	16

Hydro Power Plant	Water usage m3/s	usage per day Gl/day	usage per year Gl/year	Pumped m3/s per day Gl/day	Orginal size of reservoir Gl	Usage of orginal size reservoir %	Usage % of medium size reservoir
Blanda	39	3	1.230	1.265	400	307	721
Hrauneyjarfoss	154	13	4.857	1.265	33	14.717	2.848
Sigalda	132	11	4.163	1.265	140	2.973	2.441
Sultartangi	316	27	9.965	1.265	109	9.143	5.845
Average value	160	14	5.054	1.265	171		

Hydro Power Plant	Energy price for kWh estim. USD	Plant usage per day Gl/day	Station usage per day Gl/year	Station electricty production MW	Produced electricty per year kWh	Water usage per kWh Gl/kwh	Price per Gl used for kWh USD
Blanda	20	140	1.370.304	150	1.314.000.000	0,0010	19
Hrauneyjarfoss	20	554	5.410.944	210	1.839.600.000	0,0029	7
Sigalda	20	475	4.637.952	150	1.314.000.000	0,0035	6
Sultartangi	20	1.138	11.102.976	120	1.051.200.000	0,0106	2
Average value	20	577	5.630.544	158	1.379.700.000	0,0045	8

Breakdown

Calculated power for V80 (50m height) **1.065 kW** Calculated power for V80 (100m height) **1.117 kW**

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Vestas V80 Weibull calculations Height 50m Wind pumped	From wind speed m/s	To wind speed m/s	Mean wind speed m/s	k m/s	P(from m/s) %	P(to m/s) %	Total time in one year %	Total time in one year hours	Wind power kW	Total energy product one year MWh
Out of range of V80	0	4	11,95	1,90	100,00	88,25	11,75	1.029	0	0
Wind speed interval 1	4	7	11,95	1,90	88,25	69,63	18,62	1.631	170	277
Wind speed interval 2	7	10	11,95	1,90	69,63	49,02	20,61	1.805	800	1.444
Wind speed interval 3	10	13	11,95	1,90	49,02	30,93	18,10	1.585	1.600	2.536
Wind speed interval 4	13	16	11,95	1,90	30,93	17,53	13,40	1.173	1.960	2.300
Wind speed interval 5	16	19	11,95	1,90	17,53	8,95	8,58	752	2.000	1.503
Wind speed interval 6	19	22	11,95	1,90	8,95	4,12	4,83	423	2.000	846
Wind speed interval 7	22	25	11,95	1,90	4,12	1,72	2,41	211	2.000	422
Out of range of V80	25	100	11,95	1,90	1,72	0,00	1,72	150	0	0
							100,00	8.760		9.329

Vestas V80 Weibull calculations Height 100m Wind pumped	From wind speed m/s	To wind speed m/s	Mean wind speed m/s	k m/s	P(from m/s) %	P(to m/s) %	Total time in one year %	Total time in one year hours	Total power product MW	Total power one year MWh
Out of range of V80	0	4	12,71	1,91	100,00	89,59	10,41	912	0	0
Wind speed interval 1	4	7	12,71	1,91	89,59	72,61	16,98	1.488	170	253
Wind speed interval 2	7	10	12,71	1,91	72,61	53,12	19,49	1.707	800	1.366
Wind speed interval 3	10	13	12,71	1,91	53,12	35,20	17,92	1.570	1.600	2.512
Wind speed interval 4	13	16	12,71	1,91	35,20	21,18	14,03	1.229	1.960	2.408
Wind speed interval 5	16	19	12,71	1,91	21,18	11,59	9,59	840	2.000	1.680
Wind speed interval 6	19	22	12,71	1,91	11,59	5,77	5,81	509	2.000	1.018
Wind speed interval 7	22	25	12,71	1,91	5,77	2,62	3,15	276	2.000	552
Out of range of V80	25	100	12,71	1,91	2,62	0,00	2,62	230	0	0
							100,00	8.760		9.789

GOULD 316SS 20x20-28 Pump	Shaft speed R.P.M	Head m	Capacity GPM	For 1.83 m3/s Needed power kW	Given for 3175 η	Capacity m3/s	Calculated power usage kW	Calculated η	Power usage from Goulds kW
GOULD 316SS	885	40	29.000	990,00	0,73	1,83	718	0,73	718

Investment

KUSD														
Years		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Investment and Financing			1	2	3	4	5	6	7	8	9	10	11	12
Investment														
Buildings		170	163	156	150	143	136	129	122	116	109	102	95	88
Equipment		46.755	39.742	32.729	25.715	18.702	11.689	4.676	4.676	4.676	4.676	4.676	4.676	4.676
Other		1.709	1.367	1.026	684	342	0	0	0	0	0	0	0	0
Booked Value		**48.634**	**41.273**	**33.911**	**26.549**	**19.187**	**11.825**	**4.805**	**4.798**	**4.791**	**4.784**	**4.778**	**4.771**	**4.764**
Depreciation														
Depreciation Buildings	4%		7	7	7	7	7	7	7	7	7	7	7	7
Depreciation Equipm.	15%		7.013	7.013	7.013	7.013	7.013	7.013						
Depreciation Other	20%		342	342	342	342	342	0	0	0	0	0	0	0
Total Depreciation			**7.362**	**7.362**	**7.362**	**7.362**	**7.362**	**7.020**	**7**	**7**	**7**	**7**	**7**	**7**
Financing		**49.153**												
Equity KUSD	30%	**14.746**												
Loans KUSD	70%	**34.407**												
Repayment (years)	20			1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720
Principal KUSD		34.407	34.407	32.687	30.967	29.246	27.526	25.806	24.085	22.365	20.644	18.924	17.204	15.483
Interest	6%		2.064	2.064	1.961	1.858	1.755	1.652	1.548	1.445	1.342	1.239	1.135	1.032
Loan Management Fee	2%	688												
Total Payments per year		**688**	**2.064**	**3.785**	**3.682**	**3.578**	**3.475**	**3.372**	**3.269**	**3.165**	**3.062**	**2.959**	**2.856**	**2.753**
Annuity Loan														
Repayment				935	991	1.051	1.114	1.181	1.252	1.327	1.406	1.491	1.580	1.675
Principal		34.407	34.407	33.472	32.481	31.430	30.316	29.135	27.883	26.556	25.150	23.659	22.079	20.404
Interest			2.064	2.064	2.008	1.949	1.886	1.819	1.748	1.673	1.593	1.509	1.420	1.325
Annual Payment		688	2.064	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000

Operations

No repayment of loan	KUSD												
	Years	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Operations Statement													
Sales MWh			74.027	74.027	74.027	74.027	74.027	74.027	74.027	74.027	74.027	74.027	74.027
Price MWh			0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029
Revenue			**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**	**2.147**
Variable Cost KUSD	0,0001		7	7	7	7	7	7	7	7	7	7	7
Net profit contributrion			2.139	2.139	2.139	2.139	2.139	2.139	2.139	2.139	2.139	2.139	2.139
Fixed Cost KUSD	4		4	4	4	4	4	4	4	4	4	4	4
Maintenance Cost	935		935	935	935	935	935	935	935	935	935	935	935
Diverse Taxes													
Operating Surplus (EBITDA)			**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**
Inventory Movement			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Depreciation (just numbers)			**7.362**	**7.362**	**7.362**	**7.362**	**7.362**	**7.020**	**7**	**7**	**7**	**7**	**7**
Operating Gain/Loss			**-6.162**	**-6.162**	**-6.162**	**-6.162**	**-6.162**	**-5.820**	**1.193**	**1.193**	**1.193**	**1.193**	**1.193**
Financial costs (Interest & LMF)		688	2.064	2.064	1.961	1.858	1.755	1.652	1.548	1.445	1.342	1.239	1.135
Profit before Tax		**-688**	**-8.226**	**-8.226**	**-8.123**	**-8.020**	**-7.916**	**-7.471**	**-355**	**-252**	**-148**	**-45**	**58**
Loss Transfer	0	-688	-8.914	-17.140	-25.263	-33.283	-41.199	-48.671	-49.026	-49.277	-49.426	0	0
Taxable Profit		0	0	0	0	0	0	0	0	0	0	0	58
Income Tax	15%	0	0	0	0	0	0	0	0	0	0	0	9
Profit after Tax		**-688**	**-8.226**	**-8.226**	**-8.123**	**-8.020**	**-7.916**	**-7.471**	**-355**	**-252**	**-148**	**-45**	**49**
Divident	**10%**	0	0	0	0	0	0	0	0	0	0	0	5
Net Profit/Loss		**-688**	**-8.226**	**-8.226**	**-8.123**	**-8.020**	**-7.916**	**-7.471**	**-355**	**-252**	**-148**	**-45**	**44**

Cash Flow

KUSD Years	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Cash Flow												
Operating Surplus (EBIDTA)	**0**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**
Debtor Changes		537	0	0	0	0	0	0	0	0	0	0
Creditor Changes		1	0	0	0	0	0	0	0	0	0	0
Inventory Changes		0	0	0	0	0	0	0	0	0	0	0
Cash Flow before Tax	**0**	**665**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**
Paid Taxes		0	0	0	0	0	0	0	0	0	0	0
Cash Flow after Tax	**0**	**665**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**
Financial costs (Interest+LMF)	688	2.064	2.064	1.961	1.858	1.755	1.652	1.548	1.445	1.342	1.239	1.135
Repayment	0	0	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720
Free (NET) Cash Flow	-688	-1.400	-2.585	-2.481	-2.378	-2.275	-2.172	-2.068	-1.965	-1.862	-1.759	-1.656
Paid Dividend		0	0	0	0	0	0	0	0	0	0	0
Financing - Expenditure (Working capital)	519											
Cash Movement	-169	-1.400	-2.585	-2.481	-2.378	-2.275	-2.172	-2.068	-1.965	-1.862	-1.759	-1.656

Source and Allocation of Funds

KUSD Years	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Source of Funds												
Profit before Tax	-688	-8.226	-8.226	-8.123	-8.020	-7.916	-7.471	-355	-252	-148	-45	58
Depreciation	0	7.362	7.362	7.362	7.362	7.362	7.020	7	7	7	7	7
Funds from Operations	**-688**	**-864**	**-864**	**-761**	**-658**	**-555**	**-451**	**-348**	**-245**	**-142**	**-38**	**65**
Loan Drawdown	34.407											
Equity Drawdown	14.746											
Funds for allocation	**48.465**	**-864**	**-864**	**-761**	**-658**	**-555**	**-451**	**-348**	**-245**	**-142**	**-38**	**65**
Alloction of Funds												
Investment	48.634											
Repayment	0	0	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720
Paid Taxes	0	0	0	0	0	0	0	0	0	0	0	0
Paid Dividend	0	0	0	0	0	0	0	0	0	0	0	0
Total allocation	**48.634**	**0**	**1.720**	**1.720**	**1.720**	**1.720**	**1.720**	**1.720**	**1.720**	**1.720**	**1.720**	**1.720**
Changes Net Curr. Assets	**-169**	**-864**	**-2.585**	**-2.481**	**-2.378**	**-2.275**	**-2.172**	**-2.068**	**-1.965**	**-1.862**	**-1.759**	**-1.656**
Analysis of Changes												
Current Assets												
Cash at start of year	0	-169	-1.569	-4.153	-6.635	-9.013	-11.288	-13.459	-15.528	-17.493	-19.355	-21.114
Cash at end of year	-169	-1.569	-4.153	-6.635	-9.013	-11.288	-13.459	-15.528	-17.493	-19.355	-21.114	-22.769
Changes in Cash	**-169**	**-1.400**	**-2.585**	**-2.481**	**-2.378**	**-2.275**	**-2.172**	**-2.068**	**-1.965**	**-1.862**	**-1.759**	**-1.656**
Debtor changes	0	537	0	0	0	0	0	0	0	0	0	0
Stock Movements	0	0	0	0	0	0	0	0	0	0	0	0
Changes in Current Assets	**-169**	**-863**	**-2.585**	**-2.481**	**-2.378**	**-2.275**	**-2.172**	**-2.068**	**-1.965**	**-1.862**	**-1.759**	**-1.656**
Liabilities												
Creditor changes	0	1	0	0	0	0	0	0	0	0	0	0
Changes Net Curr. Assets	**-169**	**-864**	**-2.585**	**-2.481**	**-2.378**	**-2.275**	**-2.172**	**-2.068**	**-1.965**	**-1.862**	**-1.759**	**-1.656**

Balance

Balance Sheet	KUSD Years	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Assets													
Cash Account	0	-169	-1.569	-4.153	-6.635	-9.013	-11.288	-13.459	-15.528	-17.493	-19.355	-21.114	-22.769
Debtors (accounts receveable)	25%	0	537	537	537	537	537	537	537	537	537	537	537
Stock (inventory)	0	0	0	0	0	0	0	0	0	0	0	0	0
Current Assets		**-169**	**-1.032**	**-3.617**	**-6.098**	**-8.476**	**-10.751**	**-12.923**	**-14.991**	**-16.956**	**-18.818**	**-20.577**	**-22.233**
Fixed Assets		48.634	41.273	33.911	26.549	19.187	11.825	4.805	4.798	4.791	4.784	4.778	4.771
Total Assets		**48.465**	**40.240**	**30.294**	**20.451**	**10.711**	**1.074**	**-8.118**	**-10.193**	**-12.165**	**-14.034**	**-15.800**	**-17.462**
Debts													
Dividend Payable		0	0	0	0	0	0	0	0	0	0	0	5
Taxes Payable		0	0	0	0	0	0	0	0	0	0	0	9
Creditors (acc payment)	15%	0	1	1	1	1	1	1	1	1	1	1	1
Next Year Repayment		0	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720	1.720
Current Liabilities (Short term debt)		**0**	**1.721**	**1.721**	**1.721**	**1.721**	**1.721**	**1.721**	**1.721**	**1.721**	**1.721**	**1.721**	**1.735**
Long Term Loans		34.407	32.687	30.967	29.246	27.526	25.806	24.085	22.365	20.644	18.924	17.204	15.483
Total Debt		**34.407**	**34.409**	**32.688**	**30.968**	**29.247**	**27.527**	**25.807**	**24.086**	**22.366**	**20.646**	**18.925**	**17.218**
Equity	0	14.746	14.746	14.746	14.746	14.746	14.746	14.746	14.746	14.746	14.746	14.746	14.746
Profit & Loss Balance	0	-688	-8.914	-17.140	-25.263	-33.283	-41.199	-48.671	-49.026	-49.277	-49.426	-49.471	-49.426
Total Capital		**14.058**	**5.832**	**-2.394**	**-10.517**	**-18.537**	**-26.453**	**-33.925**	**-34.279**	**-34.531**	**-34.680**	**-34.725**	**-34.680**
Debts and Capital		**48.465**	**40.240**	**30.294**	**20.451**	**10.711**	**1.074**	**-8.118**	**-10.193**	**-12.165**	**-14.034**	**-15.800**	**-17.462**

Profitability

	KUSD Years	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Profitability Measurements													
NPV and IRR of Total Cash Flow													
Cash Flow after Taxes		0	665	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200
Loans		-34.407											
Equity		-14.746											
Total Cash Flow & Capital		**-49.153**	**665**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**	**1.200**
NPV Total Cash Flow	10%	**-49.153**	**-48.549**	**-47.557**	**-46.655**	**-45.836**	**-45.090**	**-44.413**	**-43.797**	**-43.237**	**-42.728**	**-42.265**	**-41.845**
IRR Total Cash Flow		**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
MIRR Total Cash Flow									**-20%**	**-16%**	**-12%**	**-10%**	**-7%**
NPV and IRR of Net Cash Flow													
Free (Net) Cash Flow		-688	-1.400	-2.585	-2.481	-2.378	-2.275	-2.172	-2.068	-1.965	-1.862	-1.759	-1.656
Equity		-14.746											
Free Net Cash Flow & Equity		**-15.434**	**-1.400**	**-2.585**	**-2.481**	**-2.378**	**-2.275**	**-2.172**	**-2.068**	**-1.965**	**-1.862**	**-1.759**	**-1.656**
NPV Net Cash Flow	10%	**-15.434**	**-16.707**	**-18.843**	**-20.707**	**-22.331**	**-23.744**	**-24.970**	**-26.031**	**-26.948**	**-27.737**	**-28.416**	**-28.996**
IRR Net Cash Flow		**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
MIRR Net Cash Flow													**-100%**
Financial Ratios													
ROI (Return on Investment Profit+Interest/Debt+Capita			-13%	-15%	-20%	-30%	-58%	-542%	-15%	-12%	-10%	-9%	-8%
ROE (Return on Equity Profit/Shareh. Capital)			-59%	-141%	339%	76%	43%	28%	1%	1%	0%	0%	0%
Turnover (Revenue/Debt+Capital)			4%	5%	7%	10%	20%	200%	-26%	-21%	-18%	-15%	-14%
Eiginfjárstaða - Capital/Debt+Capital			14%	-8%	-51%	-173%	-2463%	418%	336%	284%	247%	220%	199%
Net Current Ratio			-1	-2	-4	-5	-6	-8	-9	-10	-11	-12	-13
Liquid Current Ratio			-1	-2	-4	-5	-6	-8	-9	-10	-11	-12	-13
Internal value of Shares (Total Capital/Equity)			0	0	-1	-1	-2	-2	-2	-2	-2	-2	-2
Debt Service Coverage			0	0	0	0	0	0	0	0	0	0	0
Principal of Loans			34.407	32.687	30.967	29.246	27.526	25.806	24.085	22.365	20.644	18.924	17.204
NPV of Future cash Flow (The loan ends there)			4.741	4.550	3.805	2.985	2.083	1.091	2.083	2.985	3.805	4.550	5.228
Loan Live Cover Ration			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Acceptable Minimum			2	2	2	2	2	2	2	2	2	2	2

Exit Policy

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
MARR=		10%																				
Free Cash Flow		**-1.400**	**-2.585**	**-2.481**	**-2.378**	**-2.275**	**-2.172**	**-2.068**	**-1.965**	**-1.862**	**-1.759**	**-1.656**	**-1.561**	**-1.473**	**-1.386**	**-1.298**	**-1.210**	**-1.122**	**-1.035**	**-947**	**-859**	**-771**
Market Value (Salvage Value)																						
1. Accounting: (capital in the comp		5.832	-2.394	-10.517	-18.537	-26.453	-33.925	-34.279	-34.531	-34.680	-34.725	-34.680	-34.557	-34.355	-34.073	-33.713	-33.274	-32.756	-32.159	-31.482	-30.727	-29.893
2. NPV inf of EBITDA		12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003	12.003
3. NPV 40 Years of free Cash Flow		-16.115	-16.442	-15.347	-14.249	-13.144	-12.032	-10.911	-9.782	-8.643	-7.494	-6.333	-5.159	-3.962	-2.733	-1.469	-166	1.179	2.572	4.015	5.515	7.078
Paid Dividend		0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
Equity	-14746																					
Value if Exit year: **1**	-14746	-16.115																				
2	-14746	0	-16.442																			
3	-14746	0	0	-15.347																		
4	-14746	0	0	0	-14.249																	
5	-14746	0	0	0	0	-13.144																
6	-14746	0	0	0	0	0	-12.032															
7	-14746	0	0	0	0	0	0	-10.911														
8	-14746	0	0	0	0	0	0	0	-9.782													
9	-14746	0	0	0	0	0	0	0	0	-8.643												
10	-14746	0	0	0	0	0	0	0	0	0	-7.494											
11	-14746	0	0	0	0	0	0	0	0	0	0	-6.333										
12	-14746	0	0	0	0	0	0	0	0	0	0	0	-5.154									
13	-14746	0	0	0	0	0	0	0	0	0	0	0	5	-3.948								
14	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	-2.710							
15	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	-1.437						
16	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	-126					
17	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	1.228				
18	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	2.629			
19	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	4.081		
20	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	5.590	
21	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	7.162
22	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
23	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
24	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
25	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
26	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
27	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
28	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
29	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
30	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
31	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
32	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
33	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
34	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
35	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
36	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
37	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
38	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
39	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84
40	-14746	0	0	0	0	0	0	0	0	0	0	0	5	14	22	31	40	49	58	66	75	84

Appendix F – Permissions to use data in the thesis

Email sent 19.10.2009

From: Sigurður Ingi Friðleifsson [mailto:sif@os.is]
Sent: 19. október 2009 12:12
To: Árni V. Pálmason
Subject: vindaatlas

Sæll Árni

Ég veit ekki alveg á hvaða formi þú þarft leyfi til að nýta þessar myndir úr Vindatlasi Orkustofnunar.

Það er hinsvegar þannig að Vindatlasinn er ætlaður til almmenra nota óg á að vera opinn fyrir alla. Svo framalega sem vitnað er í heimildir þá er öllum heimil not af Vindatlasi Orkustofnunar

Bestu kveðjur / best regards
Sigurður Ingi Friðleifsson
Framkvæmdarstjóri / Manager
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sif@os.is

Email sent 20.11.2009

From: Sara Árnadóttir [mailto:saraarna@internet.is]
Sent: 20. nóvember 2009 15:24
To: 'Árni V. Pálmason'
Subject: Vegna myndanna

Þú færð leyfi til þess að nota þær myndir sem ég hef teiknað í ritgerðinni þinni.

Þær eru merktar á þennan hátt: © Arnadottir (2009)

Sara Árnadóttir

From: Henriette Juul [mailto:HER@vestas.com]
Sent: 19. október 2009 06:10
To: Árni V. Pálmason
Subject: RE: Price for Vestas wind turbines

Hi again – yes you may! As long as it is published information you may use it for you thesis – once again I wish you good wind!

Yours sincerely / Med venlig hilsen

Henriette Juul
Marketing Director
Marketing Northern Europe

Vestas Northern Europe
T: +45 97302834
M: +45 23682834
her@vestas.com

From: Árni V. Pálmason [mailto:arnipalma@internet.is]
Sent: 17. oktober 2009 15:10
To: Henriette Juul
Subject: RE: Price for Vestas wind turbines

Dear Henriette

Can I have permission from Vestas to use photos and informations from brochures at the page http://www.vestas.com/en/media/brochures.aspx in my thesis?

Best regards
Kærar kveðjur

Árni V. Pálmason
MSc í sjálfbærum orkuvísindum
Reykjavik Energy Graduate School of Sustainable Systems

----

gsm 824 4715

arnipalma@internet.is

Email sent 28.12.2009

Sæll Árni
Nokkrum sinnum hefur vatnshæðin í Sigöldulóni verið lækkun enn neðar en 491 mys eins og gert var í sumar vegna viðgerða. Lægsta rekstrarvatnshæð er 491 mys.

Kv. Laufey

Framangreind gögn eru í samræmi við gagnagrunn Vatnamælingakerfis Landsvirkjunar 28. desember 2009.
Landsvirkjun áskilur sér allan rétt til að endurskoða gögnin hvenær sem er. Hvorki gögnum né nöfnum mælistaða má breyta eftir að gögnin hafa verið afgreidd.

Vitna má þannig í gögnin:
Landsvirkjun, 2009: Vatnamælingakerfi Landsvirkjunar, 2009.12.28.

Laufey B. Hannesdóttir
Vatnaverkfræðingur/ Hydrologist
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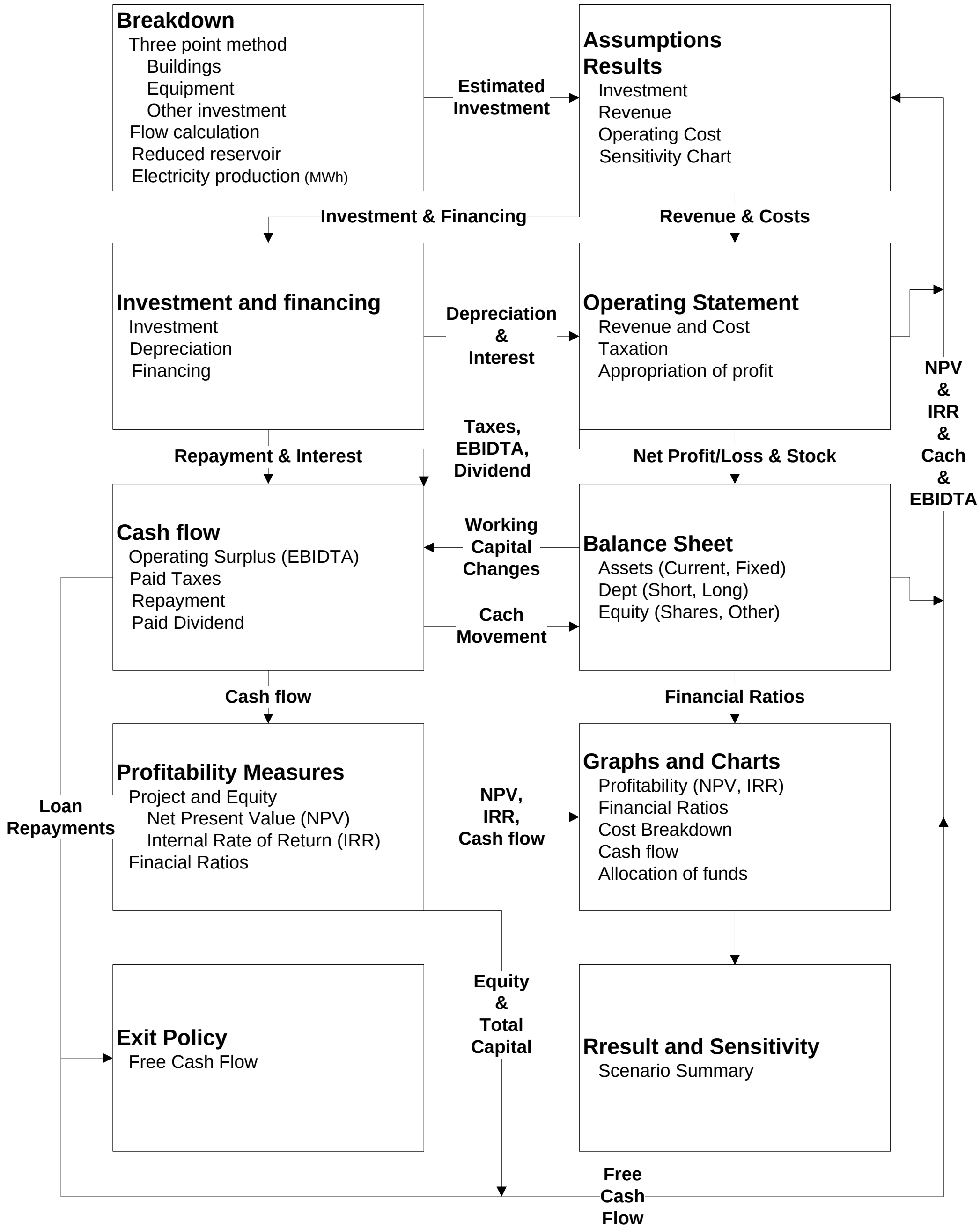
www.lvpower.is ·

Appendix G – The Profitability Assessment model

The Excel Model for Profitability Assessment

Model Components



Source: Author´s dawning based on Jensson (2006).

Appendix H – The SWOT analysis

Strengths

- ✓ It can provide secure water level, if needed.
- ✓ At the Þjórsá area in south Iceland there is a high average wind speed. This gives more power from a wind turbine.
- ✓ No CO_2 emission is from a wind turbine.
- ✓ A wind turbine is a symbol for renewable energy production today and has a positive global image.
- ✓ There is persistent wind in many places in Iceland.
- ✓ The power comes from renewable energy source.

Weaknesses

- ✓ No wind turbine in the size of Vestas V80 has been installed in Iceland. There is little knowledge or experiment in this field.
- ✓ The technique for a pumped storage system with a shaft connecting wind turbine and pumps and using a 3 blade wind turbine has not been implemented yet. First it has to be designed, then built and tested.
- ✓ It is inevitable to expect an extra implementation cost.
- ✓ Not a profitable project to install a wind pumped storage system, for electricity production from the extra water, at hydro power plant in Iceland.

Opportunities

- ✓ The average electricity price in the EU is higher than in Iceland. Building a wind pumped storage system for electricity production from the pumped water will most likely be profitable. It will depend on local situation like average wind speed and head of the water.
- ✓ Wind power is not always usable because of the reliability on the wind. No wind, no power! But with a windpump and a hydropower plant, hydro turbines produce the electricity but the wind turbine and the pumps provide the water.
- ✓ Many countries are now focusing on green technology energy production.

Threats

- ✓ Iceland is on one of the windiest part on earth. This can cause a problem if weather is stormy and causing an irregular wind.
- ✓ Volcano activity can cause a problem for a wind turbine by damaging the blades.
- ✓ The Icelandic currency is still recovering from the bank crash in 2008.
- ✓ Today there is an uncertainty about new energy taxes in Iceland. The political atmosphere is adding more risk to the construction of bigger projects, than before.

Appendix I – The leak from the Sigalda dam

Email sent 10.09.2009

From: Sigurður P Ásólfsson [mailto:siggip@lv.is]
Sent: 10. september 2009 14:58
To: Árni V. Pálmason
Subject: Re: Leki úr lónum Sultartanga og Sigöldu

Sæll Árni
Ég biðst afsökunar hvað ég svara þér seint en ég hef verið á fjöllum. Ég er ekki búinn að afla mér upplýsinga um verð á vatninu en get skoðað það fljótlega .Hvað varðar lekann get ég sagt þér að við Sultartanga er mælanlegur leki í gamla Tungnaár farveginum er hann á bilinu 0,5- 1 m3/s og neðan við Sigöldustíflu er lekinn nálægt 5 m3/s við stífluna en niður við Sigöldufoss er hann 9-12 m3/s.
Ég skal leita að verði á þessu vatni fljólega.

kv
Sig. P. Ásólfsson