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Profitability Assessment for a Tidal Power Plant at the Mouth of Hvammsfjörður, Iceland.

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ABSTRACT

With a maximum current speed of 8.7 meters per second, the mouth of Hvammsfjörður is currently at the forefront of sites under consideration that have potential of utilizing a tidal current conversion technology for electricity generation. With research completed and a model created of the area, calculations show the total annual kinetic energy at the mouth of Hvammsfjörður to be about 1,000 GWh. Röst accounts for about 75% of all flow traveling through the mouth of Hvammsfjörður and if harnessed at 30% efficiency it would provide enough energy to power all homes in Iceland, given the homes average electricity usage.

However, it is not a profitable project to date due to low electricity prices in Iceland. The cost of generating electricity is only 32.2% lower at the tidal power plant start-up than the electricity price received, but moving to 61.8% in 20 years and 101% in 30 years. Starting the project with 50% higher electricity price, the project provides a positive NPV from total cash flow of 16,274 MISK.

At the end of the thesis, a value added to the project is presented for the county of Dalabyggð, that being a tourist attraction design of the plant from day one, keeping in mind the 1,000,000 annual visits to all of the facilities of the company Reykjavík Energy.

Keywords: Tidal Power Plant, Tidal Energy, Tidal Current, Ocean Energy, Hvammsfjörður, Sjávarfallavirkjun, Sjávarorka

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LIST OF ABBREVIATIONS

AMSL	Above Mean Sea Level
BULB unit	Turbine Type
CFD	Computational Fluid Dynamics
Cm	Centimeter
CO2	Carbon Dioxide
Ehf.	Iceland's Abbreviation for Ltd.
EMEC	European Marine Energy Centre
EU	European Union
Gl	Giga liter
GWh	Gigawatt hour
IRR	Internal Rate of Return
ISK	Icelandic Krona
Km	Kilometer
kW	Kilowatt
kWh	Kilowatt hour
LEC	Leverlized Energy Cost
m/sec.	Meter per Second
m3/sec.	Cubicmeter per Second
MCED	Marine Current Energy Device
MIRR	Modified Internal Rate of Return
MISK	Million Icelandic Krona's
MROI	Modified Return On Investment
MTC	Marine Current Turbine
MW	Megawatt
MWh	Megawatt hour
NPV	Net Present Value
O&M	Operaration and Maintenence
Orthogonal	Name of RusHydro's turbine
p/kWh	Pence (£) per kilowatt hour
R1	Röst 1. Measurement point 1 in Röst
R2	Röst 2. Measurement point 2 in Röst
ROE	Return on Equity
ROI	Return on Investment
RTT	Rotech Tidal Turbine (Lunar Energy)
RÖST	Name of the main channel at the mouth of Hvammsfjörður
TEC	Tidal Energy Converter
TPP	Tidal Power Plant

I dedicate this thesis to my son, Adam Ernir,

who is by far, my biggest achievement.

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Throughout my work I enjoyed the help of many and my sincere gratitude goes to all of them. I want to mention few: Páll Jensson, my co-advisor for his valuable help and availability 24/7 at the end, also during the holiday's and my supervisor Ingjaldur Hannibalsson for his time and valuable input. Also Helga Kristjánsdóttir and Ólöf Rós Káradóttir, my advisors, for their input.

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In particular I want to thank my family for their endless patience and contributions of both help and food to my son and I, during the busy times. "Tiny" thanks also go to my good luck troll.

1.0 INTRODUCTION

This paper's goal is to shed some light on the question of whether a tidal power plant located at the mouth of Hvammsfjörður in Iceland might be a feasible option for Iceland, which is rich in both conventional hydro- and geothermal energy. The literature review chapter will provide insight into two of the oldest tidal power plants in the world, the La Rance plant in France and the Kislogubskaya tidal plant in Russia. The focus, however, will be kept on the new orthogonal turbine introduced in the Kislogubskaya plant in 2004 since that turbine will be used in the suggested ways of harnessing Hvammsfjörður tidal energy. Insight is given into different tidal energy conversion technology (TECs) to harness tidal energy as defined by the European Marine Energy Centre (EMEC). Some discussion is provided about the environmental effect that those two tidal power plants have on their surroundings as based on four decades of study. The economics of tidal energy conversion is analyzed and is, to some degree, compared to the decrement of wind energy cost due to the learning curve of that technology. The data chapter discusses the relative data collected from the research, calculations and measurements on the research area, how they are found, the area they represent and the story they tell. A new approach to harness kinetic energy from the moving sea is introduced and is based on well-developed technology; argument is offered for particular choice rather than utilizing the technology being commercialized today. Finally the project's outcome, given the assumptions used, will be presented.

The author of this paper has a background in electricity, commercial diving and has a bachelor's degree in business, which in turn inspired and influenced the decision to undertake study related to the profitability of ocean energy. An Iceland-based company, Sjávarorka Ehf., has been doing research and taking measurements on the Hvammsfjörður area since 2001 and with a report created from the results in 2008, a profitability assessment was the next logical step. A co-operation for a feasibility study on a tidal power plant at the mouth of Hvammsfjörður seemed to be the obvious route to take and would be beneficial for all parties.

How well the topic of harnessing ocean energy was in tune with the author's background, along with common interest in the energy sector, also played a significant role in the decision on the topic for this thesis. The energy sector has been and still is going through radical changes. Some changes are due to great strides in technical development and others result from the necessity brought forward by the awareness of climate change. When the small, energy-rich island of Iceland is factored out and the energy sector in Europe is reviewed, the picture is serious.

The concern over global climate change has increased dramatically over the past decades and many policy makers worldwide recognize the need of reducing greenhouse gas emission, shifting the focus to sustainable and environmentally friendly energy (Charlier, 2006). A related concerning factor is that if nothing is done, about 70% of the total European energy consumption will be imported within 20-30 years. This places great pressure on European counties to harness domestic energy in a more competitive way (Denny, 2009). In Europe alone it is estimated that around one trillion euros will be needed over the next 20 years to cope with the expected energy demand and replacement of an ageing infrastructure. Global oil consumption alone has increased by 20% since 1994 and global energy demand, along with CO_2 emission, is expected to rise by some 60% by 2030 (Commission of the European Communities, 2006). The European Union places pressure on its member countries to reach a goal of a percentage of its primary energy use to be from sustainable and environmental friendly energy sources. Of that list, 7 countries have a bigger gap to fill than the average member countries (10.8%) for the goal set at 2020, placing the United Kingdom at the top of the list with 13.5% and Ireland in second place with 13.1% to fill (Europe's Energy Portal, 2010). Iceland is only a fraction away, less than 0.1%, from having 100% environmentally friendly electricity generation, as compared to Europe, which generates about one-third of its electricity with coal (Commission of the European Communities, 2006).

The picture is quite different when looking at the domestic energy sector. Electricity accounted for about 80% of primary energy use in Iceland in 2009 (National Energy Authority, 2009). Although environmentally friendly resources currently generate almost all electricity in Iceland, growth, as in any other country, calls for increased electricity consumption in most cases. Every year the National Energy Authority in Iceland publishes a forecast about the electricity consumption and the predictions for 2009-2030 support this statement. The increased electricity consumption is utilized by different sources and for different reasons. A population growth of 16% calls for more electricity, the service sector will need 81% more, homes 40%, industry only 2% but agriculture 22% more (National Energy Authority, 2009). Along with the domestic increase for the need of electricity, the CEO of Landsvirkjun, the national energy company, has mentioned at the last two annual meetings that it is not a question of if, but rather when, a subsea cable will connect Iceland to Europe's energy market. If, or when, that happens, the information about the European energy market will be very relevant for a project like this and will most likely improve the feasibility of the project since the price of electricity in Iceland is significantly lower than the average price in northern Europe.

Iceland's geographical location offers a large potential for geothermal energy and the land also offers a large potential for hydroelectricity generation. A great deal of knowledge and experience has been gathered in both fields, making both choices very economically feasible in many locations. However, not all locations are economically feasible for harnessing energy and for the rest, it is increasingly more difficult to get governmental approval for utilization of the resources, largely due to environmental aspects but political issues are also a factor. Norðlingaölduveita is a good example to use in that regard. In 1980 an agreement was made between Iceland's energy companies and the Environmental Agency of Iceland for the Norðlingaölduveita reservoir up to 581 meters above mean sea level (amsl), With Norðlingaölduveita being not a power plant, but only a distribution system and a reservoir to utilize in more economic manner the power plants located in the Þjórsá- and Tungnaár area. The Þjórsárver area was granted environmental protection in the year 1981 and was partly referred or linked to the agreement mentioned above. The results of nearly 20 years of study and research showed more environmental disturbance than initially thought, so a more modest plan was put forward, that being a reservoir up to 575-578 meters amsl. This plan was agreed to by the Icelandic National Planning Agency. The committee, Iceland's Highlands Planning Authority, did not however agree to Norðlingaölduveita until it was scaled down to a reservoir up to 566-567.5 meters amsl., with little to no environmental disturbance (Verkfræðistofa Sigurðar Thoroddsen Hf., 2003). The Minister of the Environment is still currently planning to enlarge the protected area of Þjórsárver eliminating Norðlingaölduveita as an option for Landsvirkjun (Landsvirkjun Hf., 2002). How and if Norðlingaölduveita will be utilized is yet to be seen.

The debate is also ongoing on many other planned power plants, both geothermal and hydro, resulting in a very different working environment than the energy sector previously experience in Iceland. The changes are largely due to knowledge and experienced gained over the past decades on how human influence of different forms into the Earth’s energy resources can affect the inhabitant biosphere in such a way that it will change or destroy its potential for life. In addition, to some degree extremists and politics also play a role in that new working environment. In many ways this is understandable since the environmental aspects of power plants are in most cases not an exact science and their effect on the local biosphere cannot be precisely mapped. A balance between economic and environmental benefits in society is difficult for many reasons. This is normal and will be an ongoing challenge for the energy sector just as it is a challenge for so many other sectors.

However the need for more energy is still a reality and with continuant usage of today’s dominant energy resources, namely fossil fuel, coal and gas, the pollution and its harmful effects on Earths ecosystem is also an ongoing reality. Most agree with this statement, so the need for new and clean energy is a common global goal. Tidal energy can contribute to this need but yet, just as when addressing environmental issues, there is no one right answer that can be offered as an energy resource. The approach taken should be one of a global-scale mindset, while utilizing local energy sources when possible and economically feasible.

Many resources are available to harness renewable energy for electricity generation, such as solar, wind, tidal and wave, but not all are suitable for Iceland for obvious reasons, solar energy being the most obvious one. All of the resources have one thing in common, that being a variable output, meaning that their output depends on weather conditions or forces of nature, like gravity and the rotation of the Earth. Wind energy extraction is linked to wind speed and sun energy is dependent on the intensity of sunlight, for example. Those conditions cannot be controlled by the operator. When electricity generation is unpredictable to some degree it puts strains on the operator of the electricity network, resulting in requirements to alter the operation of the system to accommodate the variability of these generators. While these unpredictable energy resources create challenges for the operator of the network, tidal energy has a significant advantage of being predictable over long periods of time. This result in less of a challenge associated with incorporating tidal generation into an electricity network (Denny, 2009).

As mentioned earlier, Sjávarorka Ehf. has been gathering information on the kinetic energy at the mouth of Hvammsfjörður with focus on a specific area, Röst, while trying to determine the amount of kinetic energy available to harness for electricity generation. The results (Verkís, 2008) are straight forward as there is an abundance of energy available in the area's ocean current, bringing forward the question of whether it is feasible to harness that energy for electricity generation. Even if the area holds great potential for TECs, with a maximum current speed of 8.7 meters/sec, there is more to consider. The location's surroundings guide about 75% of the flow through a natural funnel named Röst, an area where the ocean depth is not deep enough for many of the TECs that currently lead the race to harness the waters kinetic energy. This might, to some extent, limit the options for technology used and with that, how feasible it is to harness the ocean current at the mouth of Hvammsfjörður.

TECs are a technology in the developing phase and manufacturers are protective of technical information because they are hoping to get to, or stay, at the forefront of this expanding market. This increases the challenge faced by authors of papers like this one since very little information based on experience is available to the public or even available at all. As such, the gap of uncertainty will be bigger than if the topic were a well-developed energy utilization method.

This paper offers information on a few relative factors that will have a large effect on the amount of kinetic energy available to harness in any specific area along with how that energy is calculated. Some of the factors will be presented in more detail later on in the paper but are offered here for the reader without any technical or relative background insight into the factors affecting tidal power plants' feasibility. Seawater is about 830 times denser than air so for an ocean current turbine to harness the same amount of energy as a wind-mill, much less area and current speed are needed than wind speed. The formula to calculate the amount of kinetic energy available to harness from an ocean current can be described as follows:

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

In Equation (1) P is the kinetic power (W), Cp is a measure of the overall hydrodynamic efficiency of the device, the percentage of power that the turbine can extract from the current, ρ is the density of water (kg/m^3), A is the square measure of area harnessed athwart on current direction (m^2) and V is current speed (m/s).

Power produced from kinetic energy is in proportion to the current speed, to the power of 3, so when current speed is doubled the power will increase eight fold. Only 10% error in calculated current speed will give 30% error in calculated power (Verkís, 2008). This is demonstrated in Figure 1. The efficiency of turbines used is also an important factor, as the chart clearly shows. The square measure of the harnessed area has to be decided before the amount of power can be estimated. This will be answered with the square meters covered by the turbine type used and number of turbines used.

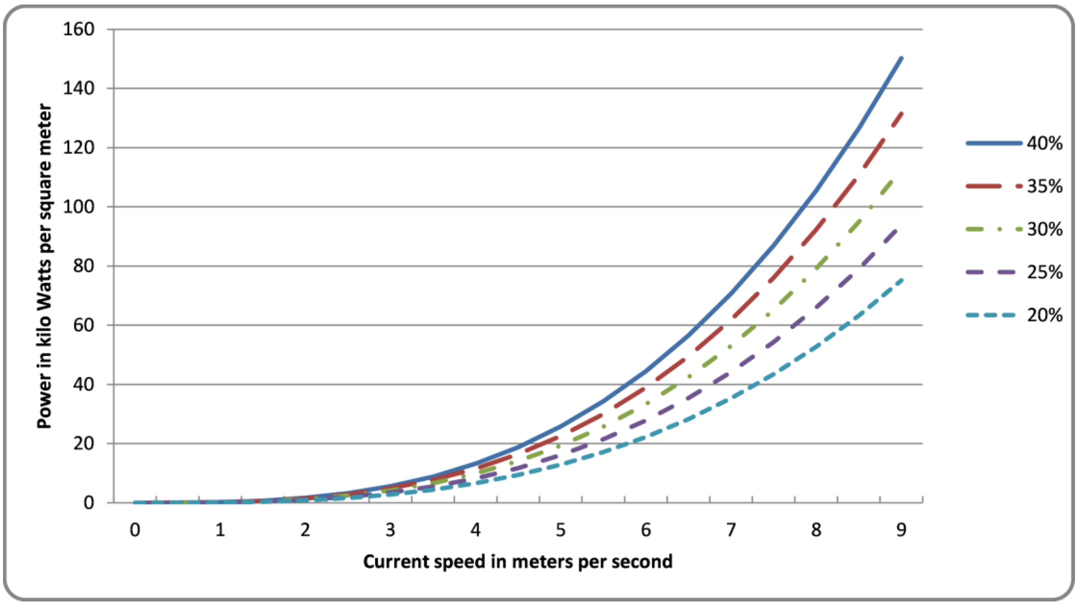


Figure 1. Relation between current speed (m/sec.) and tidal energy (kW), given different turbine efficiency (20-40%).

Source: Author

This thesis investigates the profitability of a tidal current power plant at the mouth of Hvammsfjörður based on the research information previously mentioned and better described in Chapter 3. The work makes a suggestion as to the technology thought to be the most suitable for the area based on the information available. For the revenue estimations of the tidal plant, information from the energy sector will be used and that information will be, with help from specialists, transferred to this specific project creating as realistic a situation as possible.

Following this introduction on the thesis topic and its approach, Chapter 2 provides a literature review. Insight into EMEC is given where companies designing and testing TECs enjoy an advance testing site and a simulating electricity grid connection for their technology. EMEC's definition of different types of TECs is also covered. Two of the oldest Tidal Power Plants (TPP), the La Rance TPP in France and the Kislogubskaya TPP near Murmansk, Russia are covered, due to their 40 years of experience. Extra attention is paid to the new orthogonal turbine used in the Kislogubskaya TPP since it will be the technology used for this profitability assessment. Additionally, companies developing stand-alone turbines are discussed as they are reviewed as a possible technology used for the Hvammsfjörður TPP. Economics of tidal energy are shown, including estimated production cost of electricity and the learning curve of related technologies. Chapter 3 covers the TPP site being considered at the mouth of Hvammsfjörður and includes information on available energy offered by the site and how it was gathered. The site's specific surroundings and how they might rule out some technologies as an option to use for the TPP are also addressed. Chapter 4 explains the profitability model used and gives some insight into the Net Present Value (NPV) method used. The assumptions used in the model are also explained in that chapter. Chapter 5 shows the profitability assessment outcome through the model results as well as also some sensitivity analyses that are done on factors most greatly affecting the projects outcome. Finally Chapter 6 provides the thesis's conclusion, adding some further thoughts on how the project might add value to the area in addition to being a new workplace and a tax payer.

2.0 LITERATURE REVIEW

In this chapter different approaches to harnessing tidal energy will be discussed, keeping the focus on how they might fit into the Hvammsfjörður tidal plant scheme. Several aspects of such a project must be looked at. The economic viewpoint must of course have a place in the discussion, since the efficiency of the plant plays a major part in the financial outcome. As previously mentioned environmental aspects cannot be overlooked and the attempt will be made to link that discussion to the recent activity and the political environment towards the Icelandic energy sector's plans for new power plants.

There are four basic schemes used to harness the abundance of energy associated with the ocean tides. The first is a system that has been used in different ways for centuries and consists of a basin that fills up at flood tide and can only generate at ebb tide. The second one consists of multiple basins and simple turbines, where continuous generation is possible. The third one involves a single basin but includes the use of pump-turbines, making ebb and flood generation possible. In this case power can be generated on demand and is not tide-connected. The fourth approach includes a single basin and simple turbines but includes a high head pumped-storage arrangement. Given the possibility for continuous and not tide-connected generation with maximum efficiency, this scheme is also the most expensive to operate (Charlier, 2006). In more recent years, schemes that utilize the ocean currents in open waters without any dams and minimal construction work needed at the site, have added to the possibilities offered to the tidal power plant designers today. That approach includes no basin or pumping system, only turbines that work as a "stand alone units", harnessing the kinetic energy in moving water or the sea, utilizing its natural flow. No reservoir or height difference (head) of water is used.

A strong motivation for innovation in the energy sector is the steady rising of oil and gas prices, along with the knowledge about the world's need for clean energy due to climate change. However this was not as strong of a motivator forty years ago when the Rance River tidal power plant, near St Malo in Brittany, France was in its infancy as an electricity generator (Charlier, 2006). The same can be said about the Kislogubskaya tidal power plant, situated on the Arctic shoreline in Russia (Shpolyanskij, Usachev, & Istorik, 2009). The Rance TPP celebrated the 40th

anniversary of its reliable and productive service in the year 2006 and the Kislogubskaya in the year 2008. Those tidal plants, however, harness the potential energy of the sea by utilizing the height difference (water head) created by the tides and not the kinetic energy it offers. As described earlier, this method requires barrage and the blocking of large areas for reservoir purposes with much greater environmental issues involved than harnessing the kinetic energy in open water. This is not a method feasible to Sjávarorka Ehf. at Hvammsfjörður and therefore little attention is devoted in this thesis. But it is not fair to do extensive coverage on tidal electricity generation without mentioning the La Rance tidal power plant. Following the information on the La Rance tidal power plant, greater attention will be placed on the Kislogubskaya tidal power plant in Russia. Both of those tidal plants used the same scheme at the start, bulb unit turbines, harnessing the ocean's potential energy generated by the tides.

The Kislogubskaya plant, however, replaced its turbines in 2004 with a new design referred to as the orthogonal hydropower units or orthogonal turbine. The turbine is simple in design and is a modification of an older rotor called the Darrieus rotor (Sobolev, Shpolyanski, Istorik, & Usachev, 2009). That design is now included in all Russian designs of future tidal schemes (Abonnel & Louis, 2009). It is designed to work both in working fluid and gases, whereby fluid can refer to seawater and gas to air (Shpolyanskij et al., 2009). The focus of this thesis will be more on the experience gained with the new orthogonal turbine replacing the bulb unit in 2004. As can be seen in Figures 6 and 7 the simplicity of the orthogonal turbine's rotor is much greater than in the bulb-unit.

2.1 The European Marine Energy Centre

The European Marine Energy Centre (EMEC) offers a home to technologies that generate clean electricity for homes and businesses by harnessing the power of waves and tidal streams. EMEC is the first research center to be created anywhere in the world that offers developers the opportunity to test full-scale grid-connected prototype devices in unrivalled wave and tidal conditions. It is a strong indicator of the extensive worldwide excitement about utilizing the oceans kinetic energy that there are 76 TEC developers listed at EMEC (European Marine Energy Centre Ltd., 2010). Understandably they are in various stages with their device design, some of them not yet built, some in laboratory testing, some in full-scale testing and a few already connected to a national grid. Many of the designs have very different characteristics and not all are suitable for all locations

There are four main types of TECs as defined by EMEC (The European Marine Energy Centre Ltd., 2010), as can be seen in Figure 2. This refers to a wider range of designs but not all thought to be suitable to harness the ocean current at the mouth of Hvammsfjörður.

2.1.1 Horizontal axis turbine (A)

A horizontal axis turbine is similar to a wind turbine and is the most common type of tidal stream turbine. The moving currents spin the turbine's blades as Figure 2A illustrates. Devices can be housed within ducts to create secondary flow effects by concentrating the flow and producing a pressure difference. The blades drive a generator, which converts energy harnessed from the ocean currents into power.

2.1.2 Vertical axis turbine (B)

A vertical axis turbine looks like a large eggbeater. The turbine has large blades that rotate like a washing machine as currents move past as Figure 2B illustrates. It is similar to Figure 2A, however the turbine is mounted on a vertical axis.

2.1.3 Venturi effect (C)

Figure 2C illustrates a bi-symmetrical horizontal axis turbine in a symmetrical venturi duct. The shroud increases the water flow through the turbine, and as it is bi-directional yawing is now required for ebb and flow.

2.1.4 Oscillating Hydrofoil (D)

By attaching a hydrofoil to an oscillating arm it is possible to harness the motion caused by the tidal current flow on either side of a wing, which results in lift. This motion can then drive fluid in a hydraulic system to be converted into electricity, as Figure 2D illustrates.

2.1.5 Other designs

This section covers devices with a unique and very different design to the more well-established types of technology or if information on the device's characteristics could not be determined.

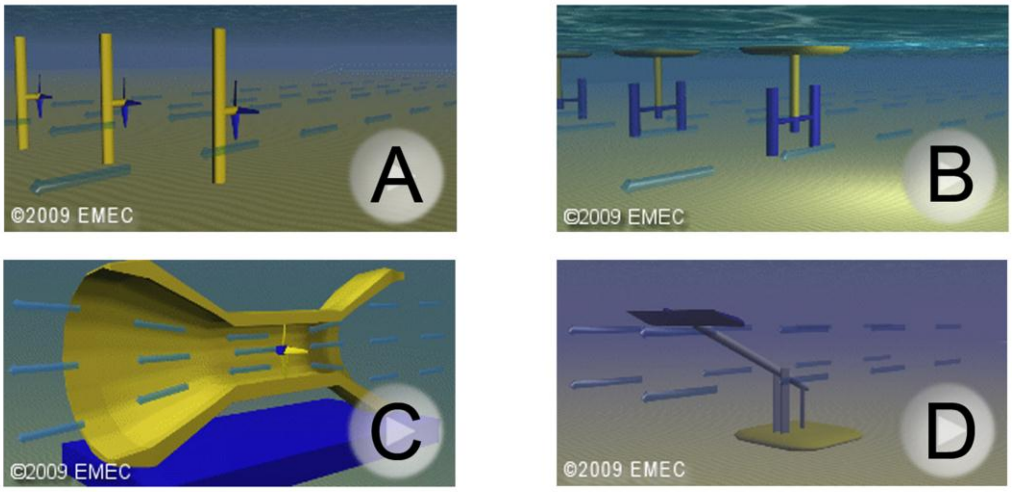


Figure 2. Tidal Energy Convertors definition from EMEC.

Source: (The European Marine Energy Centre Ltd., 2010)

There are also designs that can fit into both the horizontal and vertical axis turbine categories as they are described by EMEC. Figure 3 shows the Darrieus rotor, a vertical axis wind turbine design, patented in 1931 by a French aeronautical engineer named Georges Jean Marie Darrieus (Wikipedia, 2010), which has inspired many modifications that work both as vertical axis and horizontal axis turbines. The orthogonal turbine is an example of such a design. The most successful orthogonal design turbine is stated to be able to compete with classic axial turbines used in the wind power industry. Fundamentally the design is a modification of the Darrieus rotor with straight blades and a wing profile. Through the connection disks on each end the turbine axis passes through the center, parallel to the blades. The turbine can be used at low-head hydropower plants and as free-flow in-stream devices in various locations (Sobolev et al., 2009).

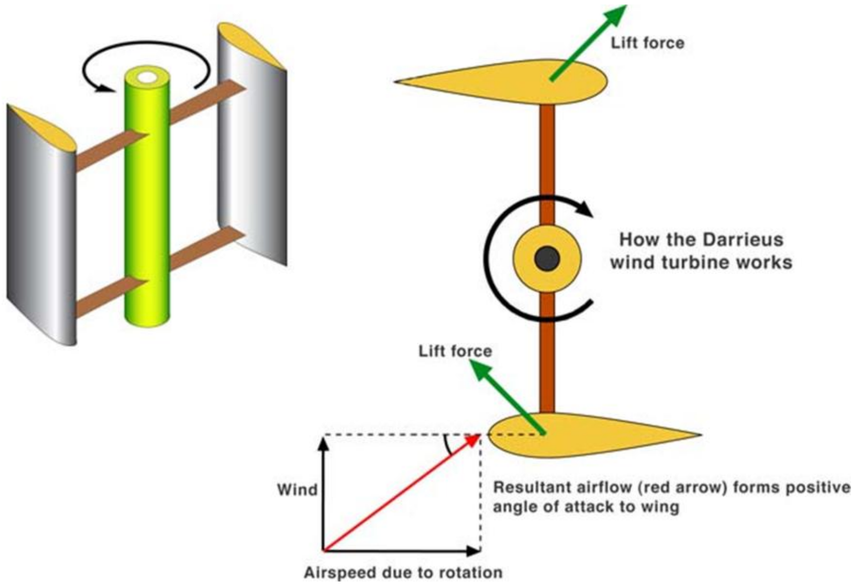


Figure 3. The Darrieus rotor.

Source: English Wikipedia, original upload July 8, 2003 by GRAHAMUK

2.2 La Rance tidal power plant

The forty-year-old tidal power plant not only represented a new way of large capacity electricity generation but at the same time the end of how the tidal energy had been utilized in the La Rance estuary for centuries, with watermills. The last water mill that was operated in the region was shut down in order to make room for the big innovative achievement that the La Rance tidal plant surely was at the time (Charlier, 2006).

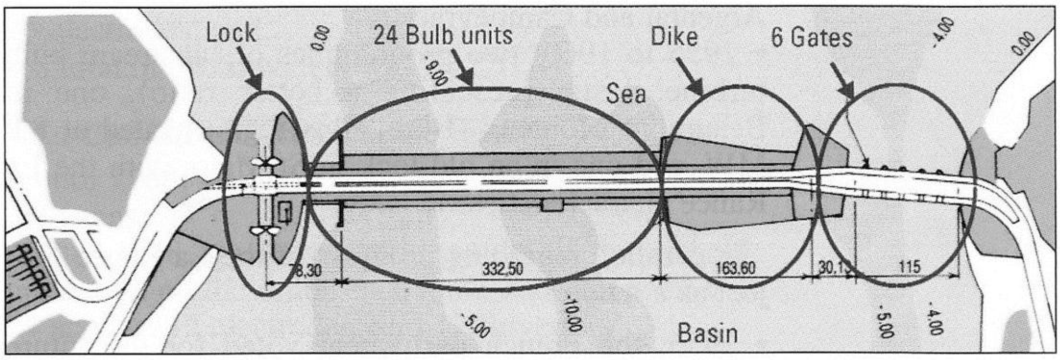


Figure 4. Schematic view of the La Rance tidal power plant with its main elements.

Source: (Abonnel & Louis, 2009)

As shown in Figure 4 the Rance River plant consists of four main zones: The lock, the plant itself that holds the 24 bulb turbines, the dyke and the six gate barrage. An overview picture of the power plant is featured in Figure 5 (Abonnel & Louis, 2009).

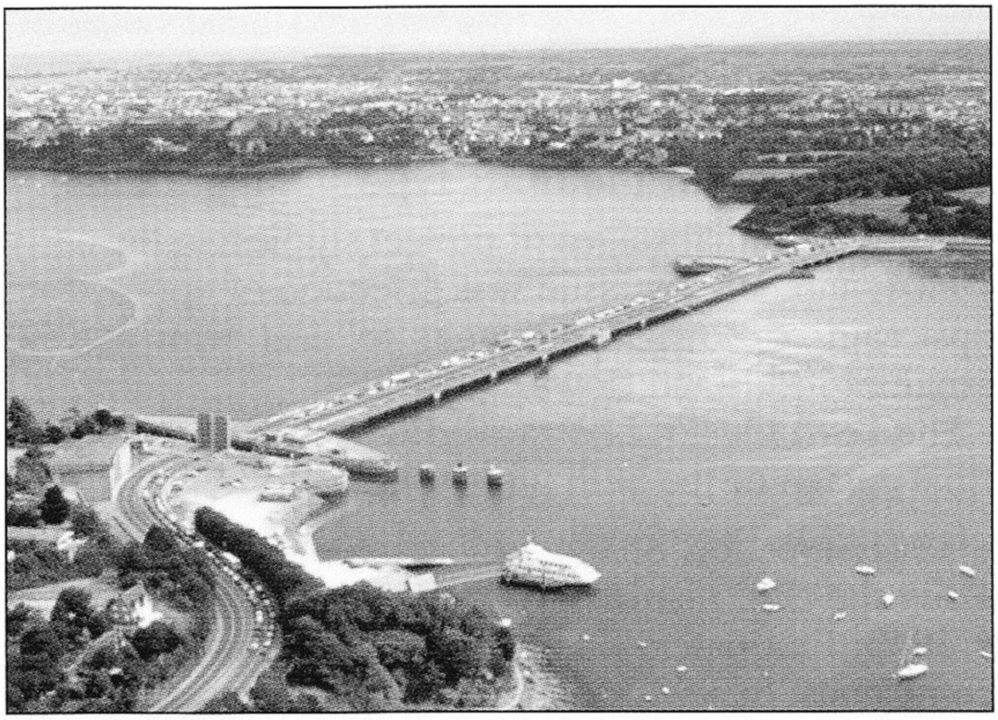


Figure 5. The La Rance tidal power plant in France.
Source: (Abonnel & Louis, 2009)

When the plant was built, aside from wiping local tide mills off the map, some 1,500,000 m^3 of water was removed in order to dry up about 75 hectares of the estuary to allow the construction to proceed under normal conditions. The total length of the hollow concrete dyke is 390 meters and 53 meters wide. The foundation goes down 10 meters below sea-level and reaches 15 meters above it. The 750 meter long TTP was built between 1961 and 1966, including 24 identical 10 MW bulb turbine units, as can be seen in Figure 6, providing installed capacity of 240 MW. On average the annual amount of electricity generated is about 540 GWh, giving approximately around 25.6% efficiency of installed capacity (Charlier, 2006). In comparison, the conventional hydro power plant, Búrfellsvirkjun in Iceland, holds an installed capacity of 270 MW and generated 2.093 GWh in the year 2000, giving an 88.4% efficiency of installed capacity (Landsvirkjun Hf., 2010).

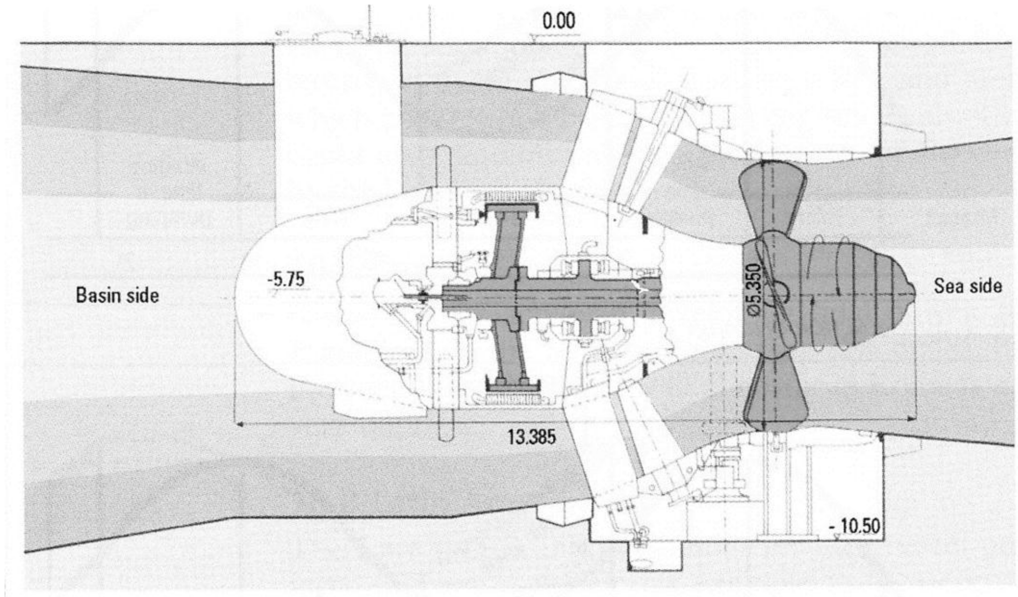


Figure 6. A cross section of a bulb-unit.

Source: (Abonnel & Louis, 2009)

This demonstrates how much difference the uneven production curve makes due to the tides. But also the height difference from the basin and the turbines (the waterhead) will give every m^3 of water much greater potential energy, with the Búrfell power plant having 115 meters (Landsvirkjun Hf., 2010) while the La Range tidal plant maximum about 5.5 meters (Abonnel & Louis, 2009). This difference is demonstrated in equation (2) outlining the link between the potential power of water and the waterhead, so logically when water falls from a greater height, greater potential energy can transfer into kinetic energy due to gravitational forces.

Power = (total hydraulic head) x (volumetric flow rate) x (efficiency)

$$Power = (\rho g Z + \frac{1}{2}\rho\Delta(v^2))\ x\ Q\ x\ \varepsilon \qquad (2)$$

The first part on the left, ρgZ, contains the static head and $\frac{1}{2}\rho\Delta(v^2)$ the dynamic head. Q is the volumetric flow rate in units of m^3/sec., Z is the net height of the waterhead in meters, ρ is density of water in kg/m^3, g is the acceleration of gravity 9.8 m/sec.^{2}, and $\Delta(v^2)$ is the difference in the square of the inlet and exiting fluid velocity across the energy converter (Tester, Drake, & Driscoll, 2005).

The story of the La Range TPP is also quite an interesting story on innovation, development and the learning curve needed to put it into action. In 1978 and the following years, 9,500 measurements were taken per year (current, voltage, electro-chemical potential) and 874 hours per year where used for maintenance.

2.2.1 Ecological aspects of the La Rance TPP

The ocean’s enormous reservoir of energy is not only clean, it is continuously available. But yet, as nature is being disturbed in some way, the law of cause and effect must take place to some degree. Even if some species lost their habitat at the time of construction and did not return to their original home, with other species having colonized the abandoned space, no “major” biological-ecosystem modifications occurred. However, some of the environmental changes realized in the Rance estuary area during the time after construction include sand banks disappearing and during construction the beach of St. Servan was badly damaged and only partially regained its former luster. Near the sluices and the powerhouse, high-speed currents have developed causing sudden surges to occur in the nearby area. Also the tidal range has been reduced, dropping the maxima from 13.5 to 12.8 meters and roughly increasing the minima proportionally (Charlier, 2006).

2.3 Kislogubskaya tidal plant

In the year 2008, at the same time as the Russian school of tidal power engineering celebrated its 70th anniversary the Kislogubskaya tidal plant celebrated forty years since the beginning of its operation, as it was built between 1964 and 1968. As in the case of the La Rance TPP, the Kislogubskaya plant incorporated the French bulb turbine unit with a running diameter of 3.3 meters (Borodin, Zhepetov, & Sivkov, 2009), which proved to be a success for 35 years (Shpolyanskij et al., 2009). Even if installed capacity was not as large in the beginning, only 0.4 MW, the experience and knowledge gained have proven to be enormous. When constructed, the Kislogubskaya plant design involved two water conduits. Initially one of them was left empty with the plan to install an additional, domestically manufactured, generating unit at a later date. The viewpoint taken with the design was to significantly decrease the cost of equipment used at future tidal power plant schemes (Borodin et al., 2009).

As the Kislogubskaya power plant is located on the Arctic shoreline, along with providing ecologically safe and reliable power to the Russian electricity grid it also faces extremely harsh environmental conditions creating new challenges to overcome.

The result of forty years of study on durable and frost-resistant concrete on the shores of the Barents showed the beginning of deterioration after only three to five years of exposure. At Murmansk, the area where the Kislogubskaya TPP is located, the climate conditions expose the area to around 650 wet-dry cycles and 450 freeze-thaw cycles during the nine months of sub-zero temperatures (Shpolyanskij et al., 2009). Also, the ambient air temperature in the area ranges from -40°C to +30°C (Borodin et al., 2009), ocean temperature ranged between -1.6°C to +10.5°C with salinity up to 35% and air humidity higher than 80%. This resulted in the concrete deteriorating during the first winter season (Shpolyanskij et al., 2009).

As the Kislogubskaya TPP was one of the first of its kind in the world, it assumed the role as the world's first floating hydropower plant with the TPP powerhouse constructed inland and then towed by sea to its location and mounted on a pre-constructed seabed foundation. But the story behind the power plant including its design, construction, construction method, along with its exploitation model, have the Kislogubskaya plant protected by the Russian state as it is considered a technical monument (Shpolyanskij et al., 2009).

This shows even further how big an achievement the Kislogubskaya TPP was at the time, but since the harsh climate conditions do not compare on a large-scale to the conditions at hand in the Hvammsfjörður are, the research and results of the concrete and material used will not be covered in detail in this thesis. More focus will be spent on its new role as a test site for the new orthogonal turbine. Along with that turbine being included in all Russian designs of future tidal schemes, its results are very promising and it seems to be very suitable for the Hvammsfjörður TPP scheme.

The Russian JSC PO Sevmash Design Bureau's first major contribution to the development of tidal power engineering was the design of a 2.5 meter diameter orthogonal horizontal turbine in 2004 (Figure 7). This design finally gave the empty water conduit in the Kislogubskaya TPP a role to play, housing the new turbine. As a result of the turbine successfully passing all operational tests, the decision was made for Sevmash to begin a joint manufacturing project including the first of its kind floating generating unit holding a 5 meter diameter orthogonal vertical turbine. Given a very ambitious time frame to work with, the specialists from the Design Bureau of JSC Sevmash got their pens, paper and computers working overtime in preparing technical and production plans for the construction of the floating unit. Incorporating prior designs, lessons learned and experience gained from the 2.5 meter in diameter turbine, the result was a largely enhanced efficiency of the new unit. Before the final design and equipment was specified, more than 1,500 design documents were drawn up and different variants for the hydraulic units were proposed (Borodin et al., 2009).

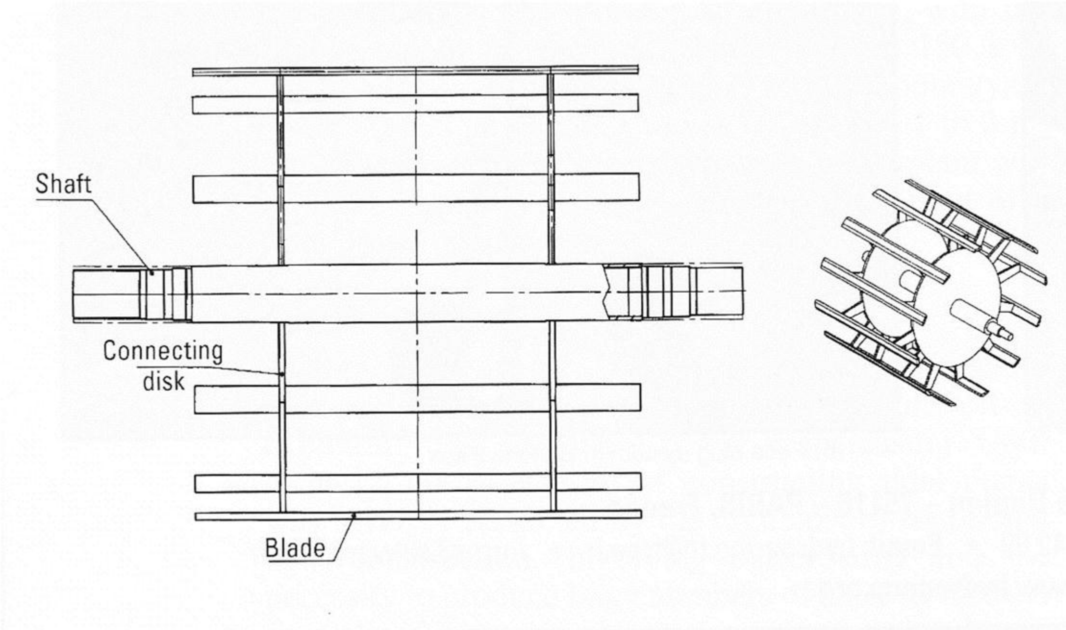


Figure 7. The Orthogonal turbine.
Source: (Sobolev et al., 2009)

The orthogonal turbine has been developed during the past two decades in Russia with tidal and wave power plants in mind. The thought is to achieve considerable gains in power plant economic efficiency and is a significant Russian contribution and support to wide-scale utilization of renewable and clean energy derived from ocean tides and waves. The turbine is fundamentally a modification of the Darrieus rotor as mentioned before, with straight blades and a wing profile which is parallel to the turbine axis and can be classified as a reaction cross-flow unit, fully immersed in the flow of gas or fluid. Along with being suitable for low-head hydropower plants and as a free-flow in-stream device in rivers, seas and oceans, the orthogonal turbine's design characteristics hold a maximum efficiency of 0.75 allowing the design to compete with classic axial turbines used in the wind power industry (Sobolev et al., 2009). Also, when compared with traditional designs of tidal bulb units, the orthogonal turbines have a larger throughput capacity which projects to partially, or even completely, avoid construction of a barrage resulting in great savings in construction cost (Shpolyanskij et al., 2009).

Due to the success of a greatly simplified design, the orthogonal turbine offers considerable cost savings. As a result the production period of each generating unit is reduced, lower metal consumption is needed and technical efficiency is greater. This opens up the possibility to mass-produce units in general purpose machine-building factories, with savings in both time and manufacturing facility overhead. Additionally, a typical orthogonal turbine power-house is only about half the size of a conventional hydro plant. An example of this is the Russian plan for the Mezenskaya TPP, which is about 52 meters in length when equipped with orthogonal units as opposed to about 105 meters if equipped as an equivalent bulb turbine plant (Shpolyanskij et al., 2009). Further advantages of the orthogonal turbine design are described in the article by Shpolyanski et.al (2009). Not only does the placing of the turbine shaft laterally to the flow allow for possible placement of a generator and a step-up gear outside of the turbine chamber (Figure 8), when located in a penstock, it also provides the possibility of placing more than one turbine on a single shaft using one common generator. The fact that the rotation direction of the runner will remain the same despite flow direction is also considered a big design advantage. So when used in a chamber, given that the chamber is symmetrical, the power characteristic stays the same for both flow directions. Therefore, the article states that the orthogonal turbine is ideally suited for two-way operation, which is the most effective way of producing

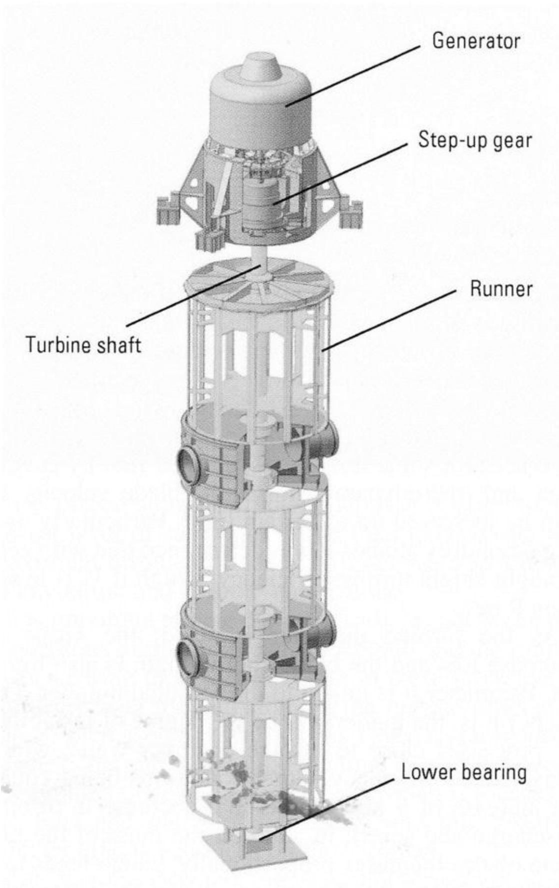


Figure 8. Three orthogonal turbines placed on a single vertical axis with the gearbox placed outside the turbine chamber.

Source: (Sobolev et al., 2009)

energy at tidal or wave power plants (Sobolev et al., 2009).

2.3.1 History of the orthogonal turbine

About twenty years ago, Canadian scientists placed themselves at the forefront of researchers studying and developing the orthogonal turbines. During laboratory studies, the model chosen was 0.63 meters in diameter and used several types of runners combined with a uniflow turbine chamber and converging inlet and diverging outlet penstocks. The findings were not that encouraging, resulting in a maximum efficiency of the turbine to be only 0.37. Furthermore, to diminish the world's interest in the orthogonal turbine, around the same time Japanese scientists were studying small-scale models of orthogonal turbine, with diameter of only 0.20 meter in rectangular tunnel. When the water head exceeded 1.5 meters, their findings revealed early cavitations of these turbines (Sobolev et al., 2009).

However, human nature and innovative drive does not allow for one answer or design to be the final one. There will always be someone to challenge today's ways of doing things and often new designs and improvements are developed. It was in this innovative spirit that a simplified mathematical model of an orthogonal turbine was created, the grounds being the numerical solutions for motion equations of the ideal fluid (Sobolev et al., 2009). Going into details of the method used would not support the overall goal of this paper and so the focus will be on the main results and how that work has changed the efficiency of the orthogonal turbine in operation. After comprehensive numerical studies, computations findings using universal dimensionless characteristic of the orthogonal turbine and the typical distributions of velocity vectors and pressures, the new orthogonal turbine's theoretical efficiency was close to 0.90 (Sobolev et al., 2009). Going from 0.37 to about 0.90 in efficiency is significant and has the potential to create a completely new outlook for a profitability study when the orthogonal turbines are factored in, keeping in mind that they could also contribute great savings in construction cost. This was, however, only in theory and so how closely it relates to reality remains a question not yet answered. At the Kislogubskaya plant the first orthogonal turbine, a design of 2.5 meter in diameter, generated efficiency of 0.37 with waterhead of 3 to 4 meters and zero draught head. Based on the results of the research described above, the efficiency of the turbine was increased to 0.58, a staggering increase of approximately 58% in efficiency (Sobolev et al., 2009). A generation increase such as that also represents an increase in a company's income, something that would without a doubt be welcomed by shareholders. The increase is also an important step in the developers' aim for a competitive tidal and wave turbine and would result in ambitions to do even better with the new 5 meter diameter orthogonal turbine. Using the patent in addition to experience and knowledge gained from field studies on the 2.5 meter turbine and making some changes to the near-side guiding vanes, a maximum efficiency of 0.71 was achieved during a field study carried out in the summer of 2008. This provided another 11% increase in turbine efficiency since the turbine had not previously reached efficiency above 0.64 (Sobolev et al., 2009). It should however be noted that these results are linked to waterhead, turbine diameter, penstock design, structure and other factors so the numbers cannot be directly related to other possible tidal power plant sites. Still, this does not change the fact that a very positive development has been made on the orthogonal turbine, creating an interesting choice for tidal power plant designers today.

2.3.2 Ecological aspects of the Kislogubskaya tidal plant

Tidal power plants have the advantages of generating clean energy without demanding large amounts of land or the need for resettlement, although this is not always the case as it will be true for some conventional hydro-power plant reservoirs. Beyond those advantages there lies the need to study other environmental aspects of possible effects on eco-life in the basin area. In the opening of the article: "Ecological aspects of tidal power plants" (Fedorov, Usachev, Suzdaleva, Sultanova, & Demidenko, 2009), it is said that the conclusion can be made that blocking off the basin from the sea by the tidal barrage has had almost no long-term effects on environmental conditions in the area, referring to the Kislogubskaya tidal plant and its basin. When the article is looked at in more detail, some questions might arise about that statement. However, it must be noted that studies on the environmental aspects of the Kislaya Gulf began in 1924 by Institute Lengidroproekt and the Polar Institute of Fishing and Oceanography (PIFO) of Russian Academy of Sciences (RAS) carried out studies of the flora and fauna in the area between 1960 and 1970. In 1983 a detailed study of the environmental impacts of the Kislogubskaya plant was carried out and involved experts from the Murmansk Sea Biological Institute (MSBI), PIFO, Moscow State University, St. Petersburg Polytechnic University and the Kola Branch of the Russian

Academy of Sciences (Fedorov et al., 2009). One finding of the research was that regular water exchange from the sea to the basin was essential to the hydrological regime in the basin blocked by the barrage. During 4 years of construction, the gulf inlet was blocked resulting in a basin of freshwater-marine meromictic pool. Having the water change in a basin decrease 5 to 7 times, as happened during construction and the first years of operation before the plant was working in its normal regime; one would expect changes to the hydrological characteristics of the reservoir, as was the result. Tidal range and cycle decreased, the surface layer of water was greatly modified, the water exchange between the surface and deep waters stopped and the ice regime changed. The result of this was an overall change to ecological condition in the Kisloaya Gulf (Fedorov et al., 2009). This last sentence can quite easily be interpreted as a contradiction to the first statements in the article.

In the year 1984 the plant began to work in accordance with its design operating regime and with that, the water exchange in the basin became equivalent to 25 per cent of its natural amount. After two years of operation, positive changes to the ecosystem where revealed and within the three years of the beginning of those changes, some repairs have been made to the power plant and if spoken in terms of water exchange, it created even more favorable conditions for the sea biota. An assumption made in the article (Fedorov et al., 2009) is that if non-biological conditions in the Kislaya Gulf are kept at a stable level, it would be fair to expect further development in the lower associations. Having said this, it is also expected that they will inevitably differ from initial associations since the change which occurred will remain: The reduction in water exchange between the basin and the sea. Expected results would be that the ecosystem being formed would be different from the original one. The conclusion after the extensive research which has been carried out at Kislogubskaya is that the gulf is almost ecologically stable, but not fully (Fedorov et al., 2009).

The eco-system formulating is different from the one that was present before the building of the Kislogubskaya TPP. Recommendations are offered to optimize the ecological situation in the Kislogubskaya tidal basin and adopting, the following engineering technical measures are included in those recommendations:

> *"Tidal power units should work only in the most ecologically safe design mode."*
>
> *"In the littoral zone, it is beneficial to create artificial biotopes in the form of synthetic seaweed which will not reach to the desalination and will attract mobile forms of hydrobionts."*
>
> *"Cold aerated water should be supplied to the hollows which are deficient in oxygen: this is done by pipeline from the Ura Gulf."*
>
> *"Centres can be created to develop mariculture. At the Kislogubskaya tidal plant, based on operational experience of experimental fish-breeding facilities (PIFO), rainbow trout, salmon and cod were cultivated on either side of the tidal plant. "*

In Russia, the following ecological optimization methods are used for the design of tidal power schemes and the related trends can be noted:

> *"Taking ecological aspects into account at the stage when the layout of tidal facilities is being determined, as well as during the design and selection of an appropriate construction method."*
>
> *"Use of equipment and industrial technologies which minimize negative impacts on the environment."*
>
> *"Adoption and maintenance of an operating regime which prevents degradation of the marine ecosystem."*
>
> *"Development and implementation of some special measures (such as environmental land reclamation, nature protection, general environmental protection)."*
>
> *"Recognition that the environmental impacts of tidal power schemes are site specific, and not global in character."*

2.4 Tidal Current Conversion Technology

Much of the history of harnessing tidal current aims to create waterhead which is then utilized by various means. In electricity generation low head turbines are used, such as the Bulb units used in the La Rance tidal power plant covered earlier in this thesis. That technology is however not thought to be feasible by Sjávarorka for the Hvammsfjörður project, mainly due to environmental issues and is not the focus of EMEC. The development in recent years has been in technology that harnesses the ocean's kinetic energy in open sea, rather than its potential energy by creating waterhead. There are a number of various turbine tidal producers; EMEC has a list of 76 TEC developers from all over the world. Of these almost half (32) are based in the UK and 19 in the USA (European Marine Energy Centre Ltd., 2010).

Among all the developers, a closer look is taken at three companies that all have created commercial-sized turbines, rated in power from 1–1.2 MW. They all have been tested onto a virtual grid but the Open Hydro's open center turbine and the Marine Current Turbines' SeaGen have also been connected to a national grid with good results. The third company is Lunar Energy Ltd.

2.4.2 Lunar Energy

Lunar Energy holds a worldwide license to a technology known as the Rotech Tidal Turbine (RTT). The RTT is a bi-directional horizontal axis turbine housed in a symmetrical venturi duct (Figure 9).

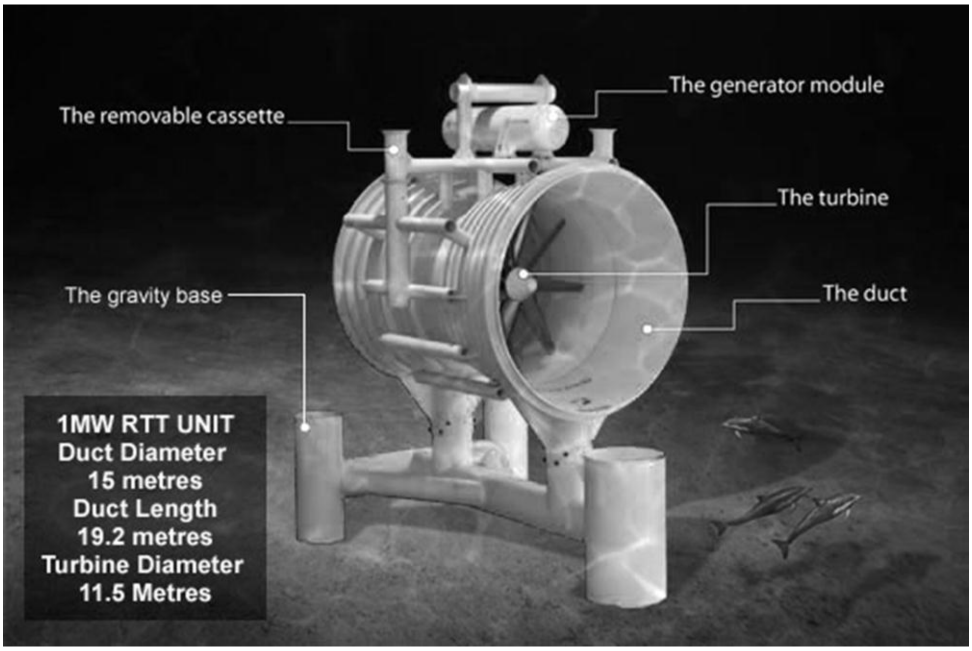


Figure 9. RTT turbine by Lunar Energy.
Source: (Lunar Energy Ltd., 2009)

Use of a gravity foundation will allow the RTT to be deployed anywhere at a fairly even seabed, at depths in excess of 40 meters. This foundation design allows for a rapid installation process and options for less expensive changes of location. In its design and fabrication of the duct and its supporting structure Rotech has used technology and experience gained in the offshore oil and gas fabrication and installation industry. As seen in Figure 9, the foundation of the duct is 3 ballast filled legs on which the main frame, duct and turbine are positioned. Once in position, the bi-directional ducted rotor with its symmetrical turbine blades uses the venturi-shaped duct to accelerate tidal flows through the turbine, thereby increasing the energy that can be captured by the turbine. The design of the RTT and its use of a venturi duct remove's the need for a yawing mechanism at the turn of each tide to keep the device pointing directly into the tidal flow. The venture-shaped duct directs the tidal flow as it approaches the turbine blades ensuring the optimum angle of approach as well as maximum power extraction of the energy available in the flow. It also removes the need for blade pitch control. There can be significant cost savings in design, construction and maintenance. In a harsh marine environment the use of less complicated mechanisms reduces the technical risks and associated rectification costs (Wikipedia, 2009).

Figure 10 illustrates the simplicity of RTT technology design which focused on simple and robust technique.

Figure 10. Demonstrating how the turbine can be removed from the duct and foundation for maintenance.

Source: (Lunar Energy Ltd., 2009)

This concept, which involves a removable cassette, means lower operation and maintenance cost (O&M cost) than similar techniques. This is the technology favored by Lunar Energy (Tidestream, 2009). The UK Company Lunar Energy and the Korean firm Midland Power have agreed to build a giant 300 turbine power plant in the

Wando Hoenggan Water Way, off the South Korean coast. This contract is worth 500 million British pounds. The plant is expected to provide 300 megawatts of renewable power to Korea by December 2015 (Lunar Energy Ltd., 2008).

2.4.3 Ducted and Non-Ducted turbines

According to a study executed in 2004 by Lunar Energy in the Glasgow Test Tank, the Venturi effect can have considerable and positive effect on turbine efficiency.

Figure 11A shows a turbine with venture duct in the same current flow. The duct directs the flow with respect to the turbine. Figures 11B shows an un-ducted turbine with flow shown from left to right. According to the Lunar Energy website those diagrams are taken from Computational Fluid Dynamics (CFD) analysis and show fluid approaching a ducted and un-ducted turbine at 30 degrees of axis. With the duct directing the flow perpendicularly to the turbine blades the turbine is helped to maintain its optimum efficiency.

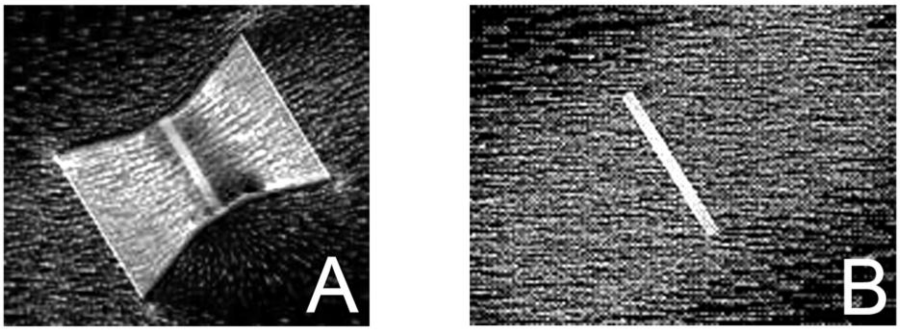


Figure 11. Ducted- and un-ducted turbines.
Source: (Lunar Energy Ltd., 2009)

The study shows that with this particular design of turbine blades and venture ducts, the output is maximized with the flow at about 25 degrees off angle. At that angle the difference in power output between the ducted and the un-ducted turbine is 23%, in favor of the ducted one. This is shown in Figure 12.

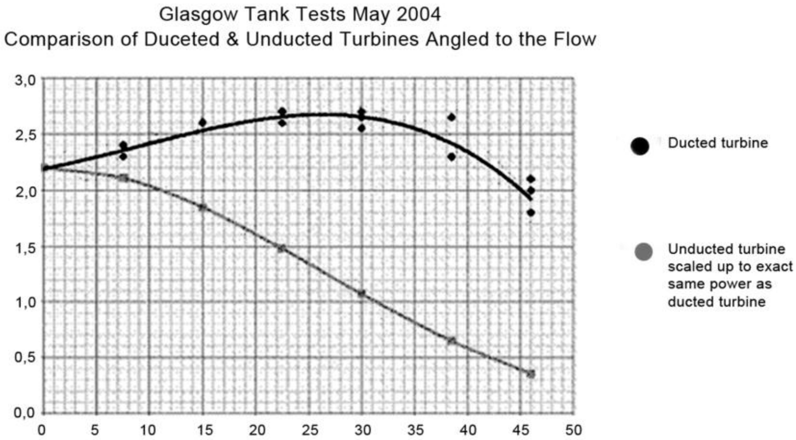


Figure 12. The development of power outlet (vertical axis, power in kW) with increased angle of flow (horizontal axis, yawing angle), starting perpendicularly at the turbine blades.

Source: (Lunar Energy Ltd., 2009)

2.4.4 Open Hydro

Figure 13. Open Hydro commercial-sized turbine.

Source: (OpenHydro Group Limited., 2010)

Open Hydro is an Irish company and in co-operation with Nova Scotia Power Inc. (NS Power), the main Nova Scotia power company, they have placed in operation a 1 MW turbine located in the Bay of Fundy, Canada (Global Energy Network Institute, 2009). Today NS Power provides 10 percent of all its electricity from renewable sources and have the goal to double that amount by the year 2013.

According to Open Hydro's announcement, they are the first company to complete the connection of a tidal turbine to the UK national grid and commence electricity generation (Global Energy Network Institute, 2008). November 12th, 2010, NS Power and Open Hydro successfully deployed the first commercial-scale in-stream tidal turbine (one-megawatt) in the Bay of Fundy (Figure 13). The Open-Centre Turbine uses the same idea as Lunar Energy for the foundation of its turbine, three ballast-filled legs on which the main frame, duct and turbine are positioned. It is designed to be deployed directly on the seabed as Figure 13 illustrates.

As with the Lunar Energy turbine (RTT) this one is not visible from the surface which, in the case of the Hvammsfjörður location, has been described by Sjávarorka to be a big advantage. The depth will of course be decided upon to minimize any chance of navigational hazards. The Open Hydro turbine has a large central hole which is more than one meter in diameter. It also has a low frequency noise that will minimize the effect on sea wildlife. The turbine is similar to the Lunar Energy design, a bi-directional turbine, so no turning mechanism is needed.

2.4.5 Marine Current turbines

Figure 14. Sea Gen turbine.
Source: (Marine Current Turbines Ltd., 2009)

SeaGen has two 2-bladed, horizontal-axis rotors, 16 meter in diameter mounted on the end of a cross beam (Figure 14). The rotors are directly mounted onto shafts of speed-increasing gearboxes, which in turn drive the generators.

The orientations of the rotors are fixed, but the blades can be pitched through 180° so that they can be used for currents in both directions, either on the ebb or the flood tide. In the proposed installation, the turbines will be facing down the lough, facing directly into the flood tide. The cross arm is mounted on a steel tube or “monopile” which is fixed into the seabed. The power trains (rotors, gearboxes and generators) are mounted on the cross beam that is equipped with a collar which can slide up and down the pile. With the cross beam out of the water, there is easy access to the working components for inspection and maintenance. Apart from the power trains, all the other systems are housed in a ‘pod’ on the top of the pile. This means that they can be kept in a controlled, dry environment, which is especially important for the electrical and control components (Ainsworth & Thake, 2006, pg. 23). The main structural element of SeaGen is the tubular steel pile. This carries the weight of all the other components, the operating forces on the rotor and the environmental loads. A maximum diameter and weight has to be imposed on the pile design by the capabilities of the jack-up barge used to install it. Working within these limits, the pile is designed to carry all acceptable loads. The pile is a steel tube 3.5 meter in diameter below the mud line and 3.0 meter diameter above, circa 55m long, and weighs circa 270 tones (Ainsworth & Thake, 2006, pg. 27). Like wind turbines, Marine Current Turbine's SeaGen tidal turbine is a modular technology. A number of SeaGen units will be deployed together much like wind turbines in wind farms. Just like wind utilizing technology, this technology will benefit from economies of scale and learning curve effects to reduce costs and improve efficiency (Marine Current Turbines Ltd., 2009).

2.5 Economics of tidal energy

As there is no actual tidal current power plant up and running and only few trial models that are connected to a national grid, it would not be incorrect to state that the tidal current energy conversion technology is still in its infancy (Rourke, Boyle, & Reynolds, 2009). This is important to recognize since it also offers great financial benefits for those at the forefront of this fast-moving technology. However, it is equally important to mention that in TPP there will not be one solution for all locations and situations so there will be room for different versions of technology to harness the oceans' kinetic energy. Tidal energy enjoys the same characteristic as the current electricity generating resources in Iceland, hydro and geothermal witch is very low fuel cost but at the same time new technology tends to have greater maintenance cost. This also means that when a renewable power plant of this sort is constructed, the society is effectively pre-paying for the next twenty to forty years of electricity generation it provides and might indicate that long-term financing would be appropriate and seem fair (Heal, 2009). This will however also be affected by the economic environment on each occasion and general, the financing is most likely to be tuned in with expected revenue generated by the plant, aiming for economical balance for the project as a whole and its stakeholders.

As previously mentioned, Iceland enjoys the privilege of being only a fraction away from having 100% of the country's electricity generation from renewable resources and with hydro counting for 72.9% and geothermal for 27.0% (National Energy

Authority, 2009) the issue of coal or fuel cost for electricity generation is not applicable. The same can be said about the CO_2 emission taxes or the possibility of generating income through the European Union's emission trading market. This might however change if or when Iceland becomes an EU member state. Both of the resources housed and harnessed in this small island in the north are evenly-generating resources, meaning that the issue of balancing irregular supply to regular demand on the electricity grid has never been a challenge to the grids operator. This challenge can be quite a handful if the portion of electricity generated from irregular resources is substantial. This would include resources such as sun, wind, tidal and wave. Sun, for quite obvious reasons is not expected to play a role in Iceland's electricity generation and of the other three, tidal has garnered the most attention. This is not to say that the other two might not be options worth exploring in the near future. One of the biggest benefits for tidal stream utilization is how regular it is, in its irregularity. More specifically, the duration of one tide circle, from ebb tide to ebb tide again, is just over 12 hours, stopping electricity generation four times every 24 hours but at the same time is very predictable over a long period of time. The same predictability cannot be enjoyed when harnessing wind or wave energy and therefore, electricity generated from the tides results in less of a challenge to the grid operator. This reveals one of the biggest obstacles facing utilization of those and any other irregular energy resource, the lack of energy storing technology.

Figure 15 exhibits straight lines but both axes are logarithms. Moving along each line from left to right means successively greater increases in cumulative output are required to give successively smaller absolute reductions in costs (House of Lords: Committee on Economic Affairs, 2008). Despite its challenges, using the tidal stream as an energy source for electricity generation has many benefits. As discussed earlier, the penetration of irregular electricity into the grid comes with challenges, but those challenges are not new and so extensive experience and knowledge have been gathered on the subject. Wind energy is, for obvious reasons, not available unless the wind is blowing; yet harnessing the wind is the most developed technology of intermittent and renewable energy sources. The experience and knowledge gained on the subject can clearly be seen when the effect it has had on the cost of generated electricity like presented in the learning curve over the past decades (Figure 15).

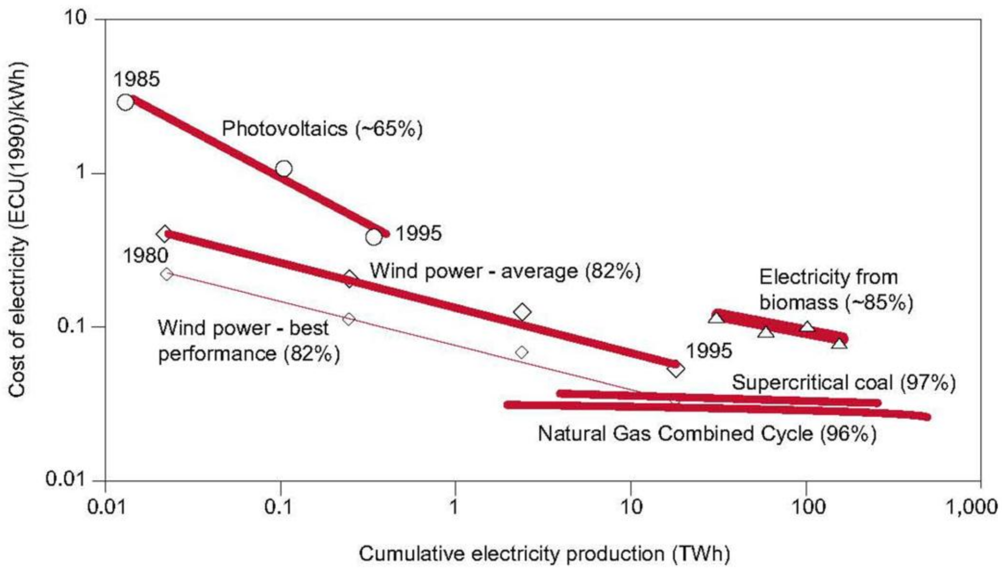


Figure 15. Learning curve for different types of electricity generation from renewables.

Source: (House of Lords: Committee on Economic Affairs, 2008).

As can be seen, the cost of electricity generated by wind is represented by a steady downward slope from 1980 to 1995. The same can be said about solar energy even if its total electricity generated is less that when compared to wind. The cost per unit of electricity generated by a new wind power plant in 1995 is 82% of what it was when generated with 1985 technology, representing a drop in production cost of 18% over the period of 15 years, or a little over 1% per year.

Estimations put production cost of tidal electricity is given in the area of 9 to 26 pence per kWh according, on 2006 price level, on page 23 in the paper: The economics of renewable energy (2008) (Figure 16). The fact is, however, that the cost of generation can vary substantially from one power plant to another. It is very dependent on the capital cost, the rate of return required by the power plants owners, the cost of fuel (which is not relevant in the case of tidal energy) and the amount of output that the plant is expected to generate (load factor) (House of Lords: Committee on Economic Affairs, 2008).

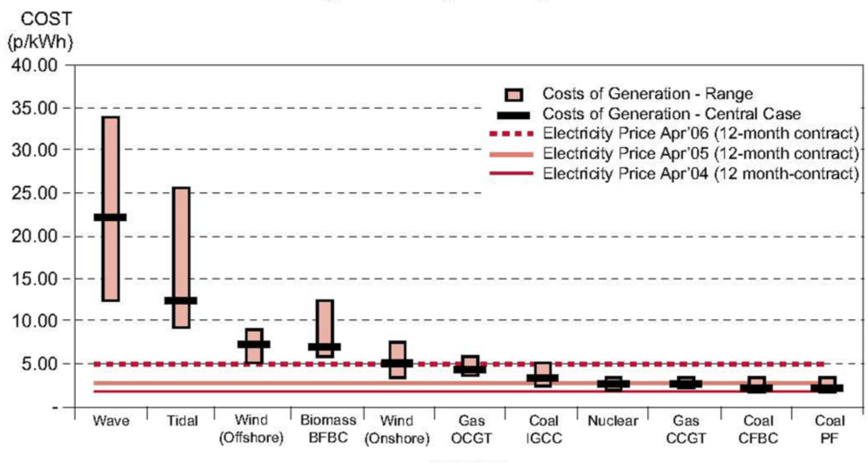


Figure 16. Cost of electricity generation from different energy resources.

Source: (House of Lords: Committee on Economic Affairs, 2008, pg. 23)

There is not one way of correctly calculating the cost of marine current energy devices (MCEDs). Different methods have been used, the cost per rated power of the device (cost/MW) being one of them. Even if this is the simplest way of expressing the cost it might lack reliability and be in some way misleading. This basic method of calculating MCEDs cost uses the following criteria:

> *"Capital cost: This category will count for all cost associated with machinery and control system, basically everything needed for the physical aspect of the plant enabling it to run and generate electricity, including all licenses needed."*
>
> *"Operation & maintenance (O&M) cost: Counts for all running cost, salary, insurance, ongoing research, phone bill, taxes and so on."*
>
> *"Financing cost: Cost related to the financial means used to pay for the power plant. Loan/s repayment may be required and/or investor/s may demand a return on their investment."*
>
> (Rourke et al., 2009)

In order to get a more accurate picture of the cost per rated power, a commonly used method of evaluating the economics of energy technologies should be used, such as life-cycle costing (LCC). For many renewables the fuel cost is zero and that applies to MCEDs, so when the capital cost is paid off the only operating cost is the running cost of the plant. At that time the change in revenue might change considerably and if it is not taken into consideration when comparing different methods of generating electricity the outcome might be misleading.

The LCC method takes into consideration all cost over the planned lifetime of the project into a single number. To convert a live-time cost into a single number, all future cost has to be converted to a present value (pv) using a percentage ratio, which might either be linked to inflation or required rate of return or MARR, as decided by the investor/s. Equation for calculating the LCC of any particular energy technology is given as:

$$LCC = Cpv + Mpv + Fpv + Xpv - Spv \qquad (3)$$

In Equation (3) Cpv is the capital cost of the total technology which is considered as a single payment (present value) occurring in the initial year of the project, regardless of the finance conditions. Mpv is the O&M costs on a yearly basis, including salaries, inspections and insurance. Fpv is the yearly fuel costs. Xpv is the external costs which includes damage cost and damage prevention. Spv is the salvage value of the technology in its final year of lifetime. In all cases, pv stands for present value.

In order to see cost per rated power, the calculated LCC, as described above, is divided by the rated power of the power plant. This way of expressing the cost of MCED in relation to any site can be misleading, as mentioned before, since the rated power is a function of the design marine current speed (Rourke et al., 2009). Also, since efficiency of technologies are very different the calculated outcome might not be useful in comparing two different technologies. The efficiency of stand-alone turbines, harnessing ocean current is around 25-50% while a conventional hydro power plant might be expected to deliver about 90% efficiency. Comparing those two technologies on a cost per rated power basis would for that reason give investor very misleading information about the profitability of the investment.

The most accurate method and best suited to compare one technique to another is to calculate the cost of a generated unit of electricity. Therefore the cost per kWh is a much better way of economically assessing the cost of a MCED (Rourke et al., 2009). Levelised Energy Cost (LEC) is an excellent method to calculate the cost per kWh since it takes into account all cost accumulated by generating electricity over a certain period of time. Any irregular cost is treated as equivalent equal payments on a regular basis and is therefore expressed as equal annual payments. The devices unit cost, defined as unit cost/kWh, is calculated as the annual LEC divided by the annual electricity generation. This method is often used to compare emerging energy technologies against those already in widespread use. There are various reasons for using this method of cost comparison rather than using the capital cost of each technology. Since accumulating cost over the lifetime, including fuel cost, O&M cost and all other cost, is taken into consideration a more realistic assessment of the MECD actual cost is received. An obvious example of this is comparing a gas or gasoline-fueled power plant with high and accelerating fuel cost to a tidal power plant with no fuel cost (Rourke et al., 2009).

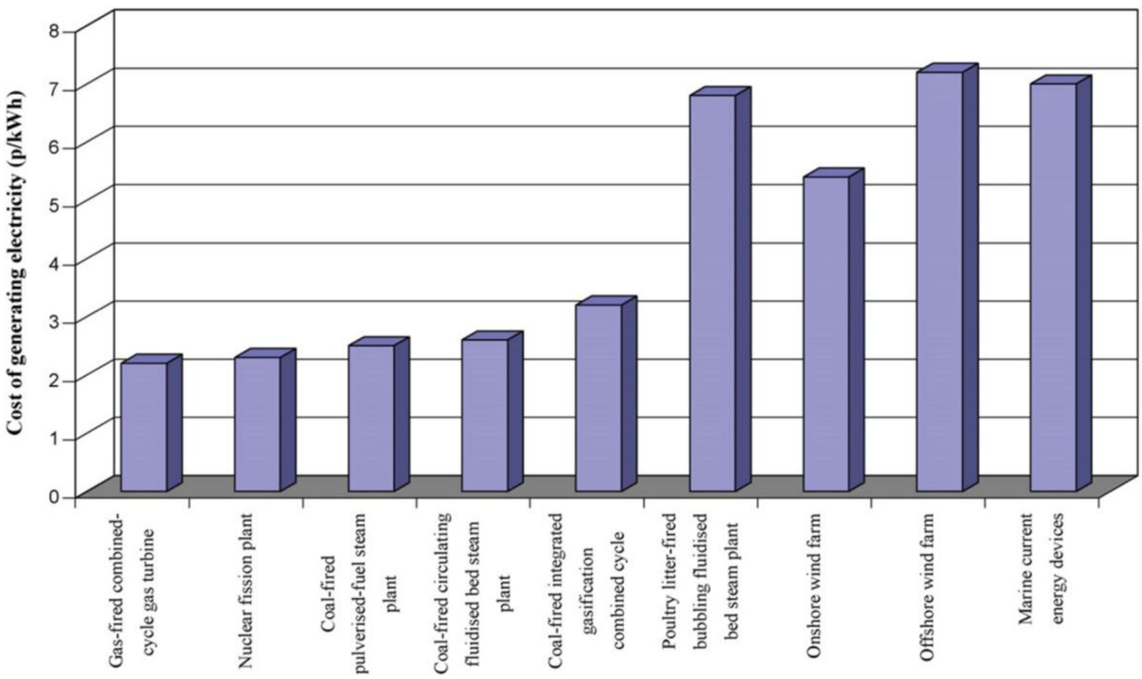


Figure 17. LEC comparison of generating electricity using various technologies excluding the cost of CO2 emissions.

Source: (Rourke et al., 2010)

The Carbon Thrust is an independent company set up by the UK government in 2001 with the objective of assisting with the creation of a low carbon economy and development of clean renewable technologies. A report was compiled in 2005 stating that if LEC cost analysis is used, the cost of generated electricity by MCEDs in the UK, utilizing the best viable resource, will be approximately 7 p/kWh. Furthermore, when 3,000 MW capacity is installed the cost would fall to approximately 3 p/kWh. (Rourke et al., 2009).

As can be seen, the difference in estimated cost of generated electricity by tidal energy is substantial, which can in many ways be a normal outcome for a technology still in its infancy. Therefore the generating cost is highly related to the technology used and the site characteristics. Those cost numbers are almost fully comparable, the latter being on 2005 price level and the first one on 2006 price level. The difference isn't that big when the currency rate of the pound is compared between those two years, with the annual average index rate being 100.38 in 2005 (set at 100 on January 1st 2005) and 101.21 in 2006 (Bank of England, 2010).

3.0 HVAMMSFJÖRÐUR TIDAL ENERGY

For obvious reasons the numbers used for the kinetic energy available to harness at the mouth of Hvammsfjörður are critical to the subject of profitability assessment of a TPP in that area. The Verkís report (2008) is the only source of information about the kinetic energy available to harness. This chapter will give some insight into the numbers used to create the profitability assessment. It is also stated that if the project is realized, further measurements will be necessary, for example current speeds need to be measured in order to make comparisons and verifications of the model outcome (Verkís, 2008).

Since a TPP as recommended in this chapter has not yet, or, to the author's knowledge, ever been created, reliable cost information is not available. Some help was therefore needed from RusHydro in order to create as realistic cost estimations as possible on given construction methods and other given assumptions.

With regards on building construction cost estimations, the Verkís engineering firm offered the assistance of Einar Bjarndal Jónsson and Ólöf Rós Káradóttir which proved to be of great help. Ólöf Rós also being one of the thesis advisors and a specialist in ocean current did oversee assumptions made on available energy. In estimating if a construction of this sort could be possible on site, the assistance of two of the most experienced Icelandic divers was useful, Ómar Hafliðason and Arnoddur Erlendsson.

3.1 Information background

In the year 2001 Sjávarorka received a grant from Iðntæknistofnun, now part of the Innovation Center of Iceland, to investigate the possibility of harnessing tidal energy at the mouth of Hvammsfjörður. The engineering company Vista was given the task of taking sea level measurements in three places, Stykkishólmi, Búðardal and Brokey with measurements taken every 10 minutes. The tidal model initially developed for the Icelandic Maritime Administration predicts sea level variations and depth averaged tidal currents due to astronomical forcing (Tómasson et al., 2005). It solves the shallow water equations numerically on á 50x50 m^2 grid in Hvammsfjörður. The model is calibrated to the sea level measurements (Verkís 2008). Those numbers are used for this profitability assessment but it is stated in the report that the numbers tend to be underestimations rather than overestimations.

As previously stated, Sjávarorka Ehf. is a company founded in 2001 and based in Stykkishólmur, a village located at the mouth of Hvammsfjörður. The company was founded to investigate the possibility of utilizing the ocean currents at the mouth of Hvammsfjörður and if feasible, harness that energy for electricity generation. As its founders are local to the area, knowledge about the vast energy available was available from day one. The next step would be to express that idea with numbers. At first there were no available ocean maps of the area investigated, so a contract was made with a company that is now a part of the Icelandic coastguard to create a map of the area. The map was ready by the summer of 2002 (Sjávarorka Ehf., 2010).

Taking measurements of tidal currents was the next step, starting in April 2005 and finishing the first phase by the spring of 2008. A report was created containing the results of the measurements. The report, "Sjávarfallastraumar í Breiðafirði, Orka í sjávarföllum, 1. Áfangi" was finished late April 2008. All numbers stated in this thesis about Hvammsfjörður are a result of those calculations and are stated in that report, referred to as the Verkís report (2008).

As seen on the map in Figure 18, there is a cluster of islands at the mouth of Hvammsfjörður, creating a natural funnel that the sea has to travel through on its way in and out of Hvammsfjörður. According to the Verkís report (2008) about 75% of that amount of ocean water goes through Röst, about 10% though the channels between Norðurey and Brokey, another 10% between Brokey and Skógarströnd and about 5% between Röst and the land in Dagverðarnes. This amounts to 800 Gl. of ocean water on a spring tide and about 400 Gl. on neap tide, every 6.2 hours.

On the map two points are marked, R1 (Röst 1) and R2 (Röst 2). R1 is on the inside of the actual Röst, at a depth of about 11 meters. R2 is 2.3 km from R1 outside of the Röst, at about a 20 meter depth. Due to the natural funnel created by the islands, the height difference of the sea on the inside and outside of Röst can be up to one meter at spring tide. This is a strong indicator that the current speed through Röst will be substantial.

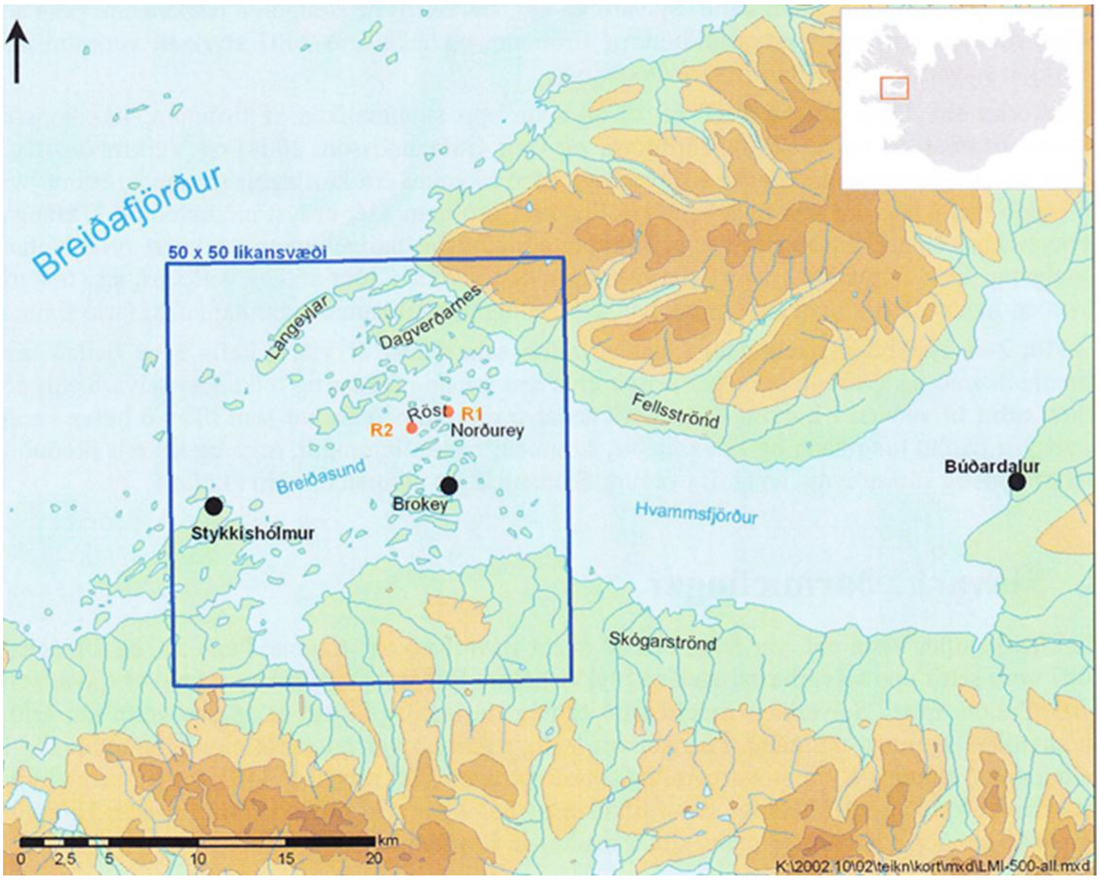
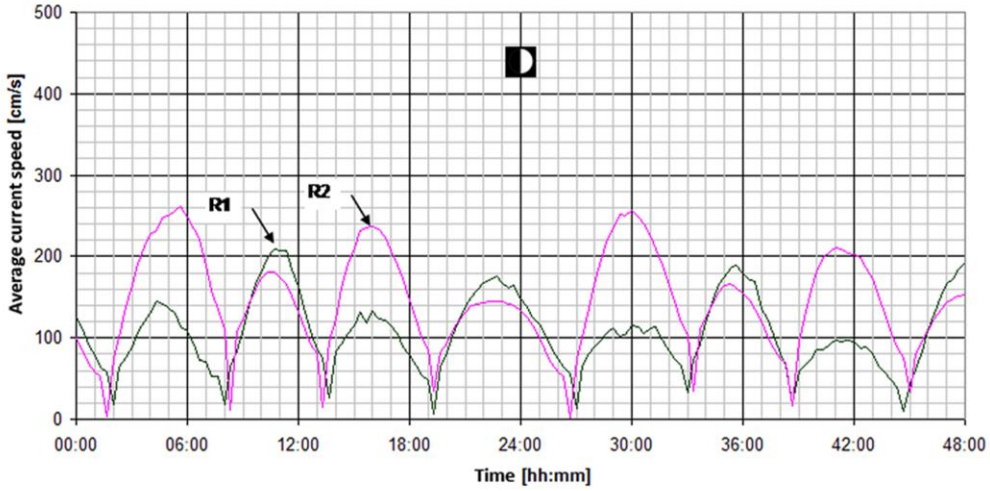


Figure 18. The mouth of Hvammsfjörður and the research area.
Source: (Verkís, 2008)

3.1.1 Hvammsfjörður kinetic energy

It is stated in the Verkís report (2008) that the mathematical model used has tendency to under estimate the current speed, so all numbers given in the report are more likely to be under estimations rather than over-estimations. The calculated depth averaged current speed in Röst 1 and Röst 2 is shown in Figure 19. During spring tide, the maximum current speed in Röst is calculated at 8.7 m/sec and the concurrent cross-section averaged speed about 3.3 m/sec. However, when the current speed is looked at over period of 7 days, the cross-section averaged speed is 1.8 m/sec from neap tide to spring tide. It is also worth mentioning that the maximum current speed can be greater than mentioned here, and was calculated up to 11 m/sec in certain points at the mouth of Hvammsfjörður.



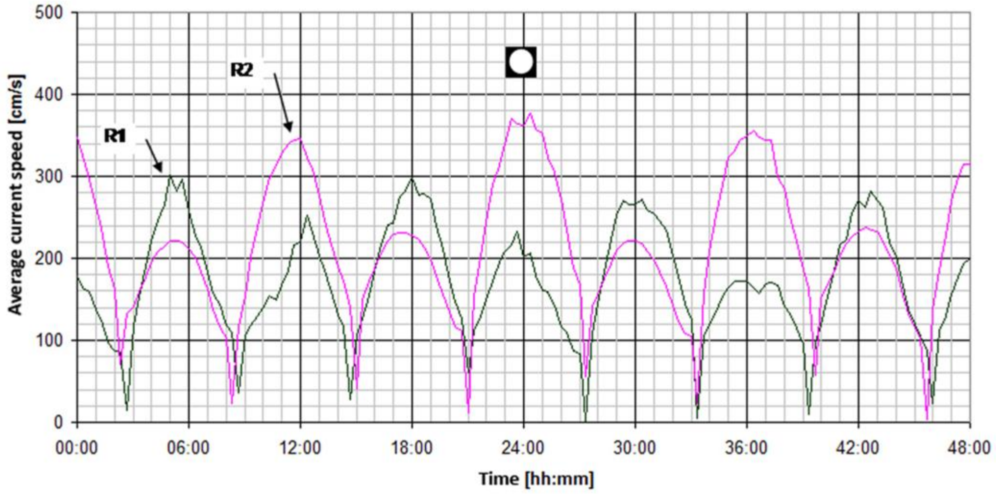
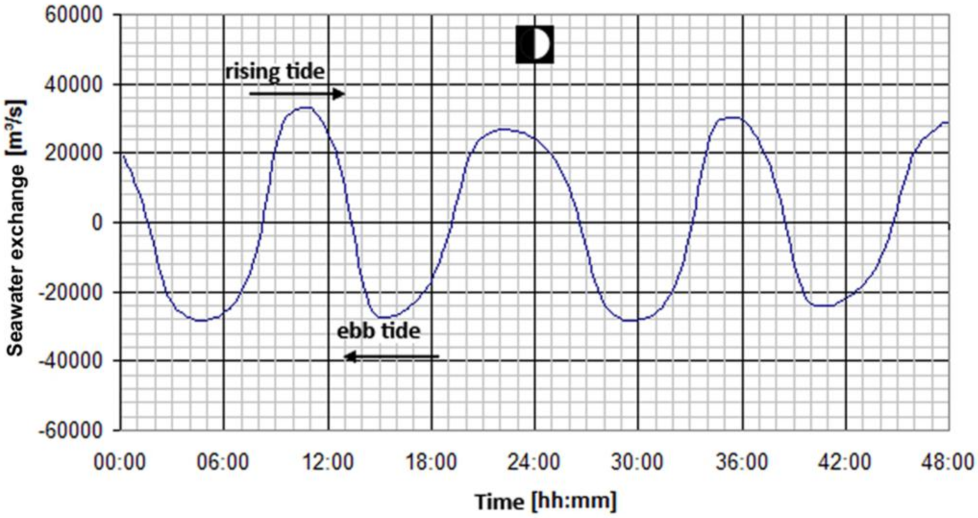


Figure 19. Calculated depth averaged current speed at spring- and neap tide in Röst.

Source: (Verkís, 2008)

The amount of sea-water moving through Röst (Figure 20) is from about 30,000 m^3/sec at low (neap) tide to about 50,000 m^3/sec at high (spring) tide.



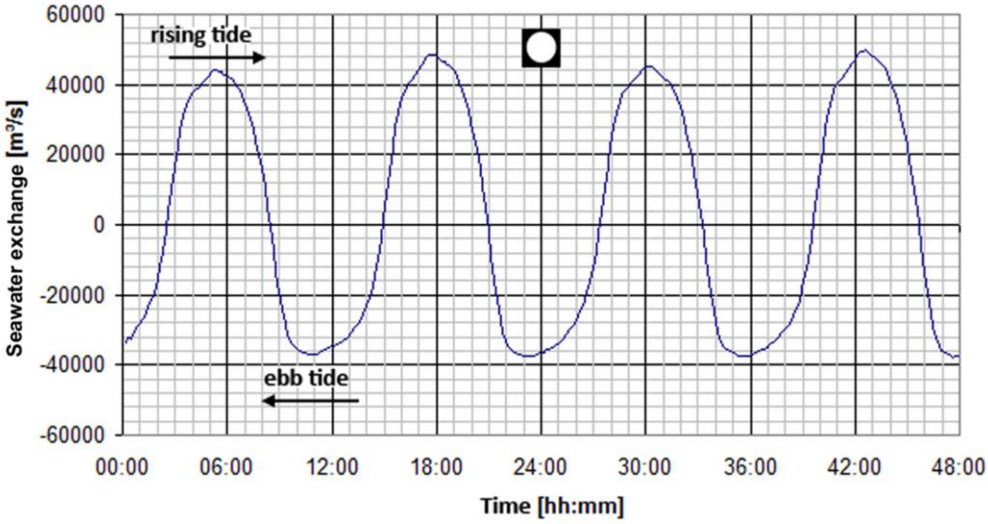


Figure 20. Showing the calculated amount of seawater exchange in and out of Hvammsfjörður, both during spring- and neap tide.

Source: (Verkís, 2008)

According to the report, the kinetic energy going through the mouth of Hvammsfjörður, is about 1,000 GWh/year in total with about 650 GWh/year from the seabed up to 3 meters below average surface level. The kinetic energy moving through Röst, in one cross-section is about 800 GWh/year with the power capacity of about 240 MW and about 550 GWh/year from seabed up to 3 meters below the average surface level. More energy is available as the sea also travel's other route's into Hvammsfjörður, for example about 30 GWh/year is generated in a channel south of

Brokey. However only a limited amount of that energy can be harnessed, when energy is harnessed in one place, the energy in other places is affected.

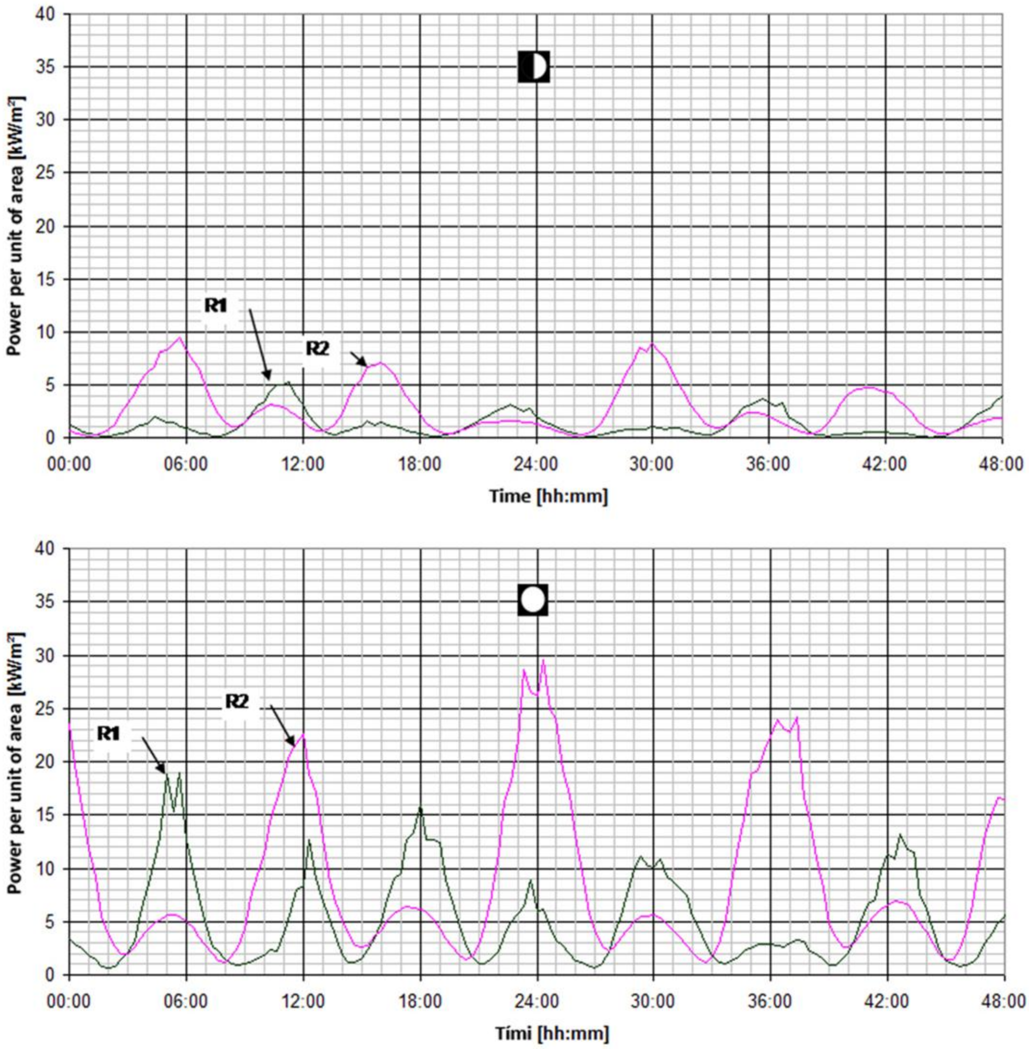


Figure 21. Showing the calculated power over a unit of area in Röst, both at spring- and neap tide.

Source: (Verkís, 2008)

The distribution of the kinetic energy over a two-day period, both at neap- and spring tide, in R1 and R2 can be seen in Figure 21. In comparison, the rated capacity of the Sultartangi hydro power plant is 120 MW and electricity generation is about 880 GWh/year (Verkís, 2008).

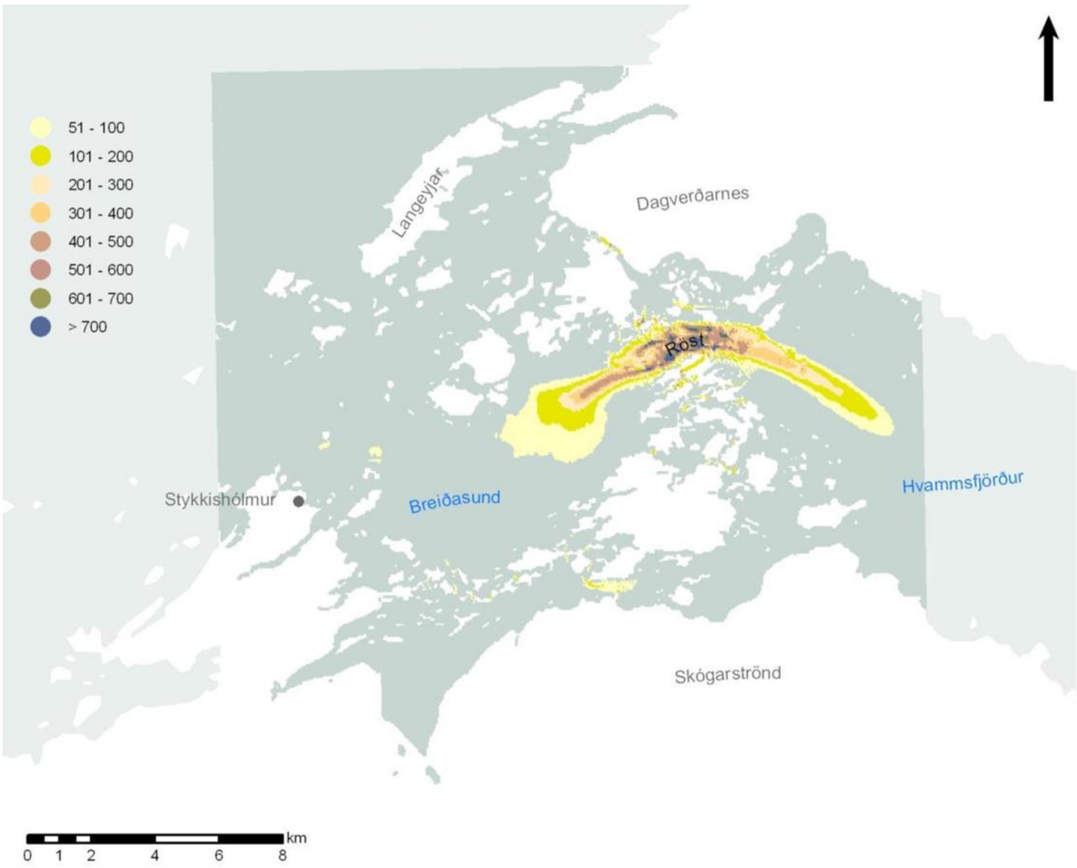


Figure 22. Showing the kinetic energy (MWh/m/year) in the Röst area without harnessing from the seabed up to 3 meter below average surface level.

Source: (Verkís, 2008)

3.1.2 What technology is suitable for Hvammsfjörður?

As seen on Figure 22 the amount of energy is greatest in the center of Röst. The reason is its natural funnel layout, meaning that in the center depth decreases and with that current speed is increased. However, the depth is also an issue for the technology used by the companies which are currently at the forefront of commercializing tidal current conversion. With the Lunar Energy RTT turbine's 15 meter duct diameter, the MTC's SeaGen's blade diameter of 16 meter and the Open Hydro's open center turbine's 16 meter diameter they all have in common the need for a depth of a minimum of about 25 meters of depth. This has to be the case since the turbines all lose considerable power if the blades or turbine wheel reaches above the surface. Security reasons related to possible boat traffic as well as accounting for the safety of the turbine are also reasons to allow for sufficient depth. If ice that quite commonly forms in Hvammsfjörður will travel out to Breiðafjörður, it will travel through Röst and might damage the turbines if depth is not sufficient.

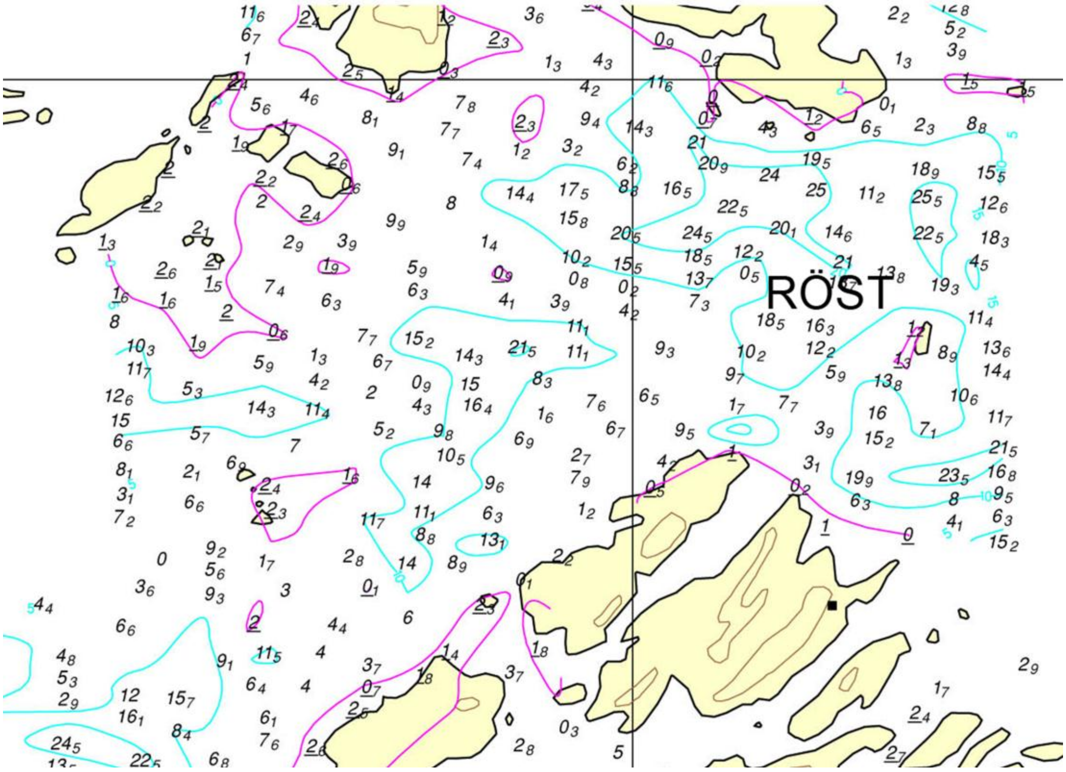


Figure 23. Seamap of Röst with depth numbers, created for Sjávarorka.
Source: Sigurjón Jónsson (Sjávarorka Ehf.), (personal interview and source, October 2010).

The fact about the depth needed for the turbines mentioned above more or less eliminates the turbines as a feasible option for Röst, at least in an economical manner since where few units can be placed in the Röst. In order to rationalize this statement and to provide an understanding of how the energy is distributed and decreased in relation with increased depth and distance from Röst, two maps, one of which is partly transparent, were put together and overlapped. The energy distribution map was placed over the sea map with depth numbers and is partly seen in Figure 24. This was necessary in order to get some idea of where turbines that require a depth of 25-30 meters could be located. As can be seen in Figure 24, the energy generated is only half of the amount of energy available in Röst itself, most likely less, at a depth of 30 meters. More measurements are however needed to make any bold statements on exact numbers. But the information at hand illustrates the general idea quite well, even if the maps are not exactly identical. The numbers placed on the map in Figure 24 note the particular depth numbers of corresponding areas in order to show how the energy decreases with increased depth.

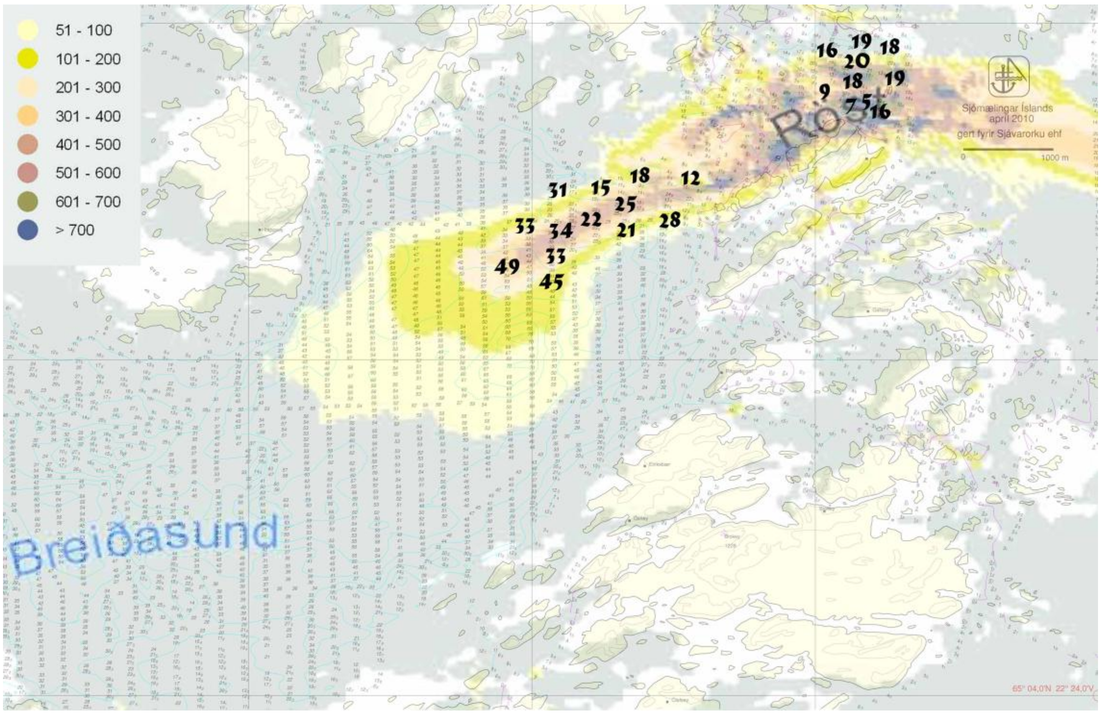


Figure 24. The sea map with depth numbers overlapping the energy distribution map. The numbers represent MWh/meter/year without any harnessing in the Röst area.

Source: (Verkís, 2008) & Sigurjón Jónsson (Sjávarorka Ehf.), (personal interview and source, October 2010).

After reading all available information printed in English on the experience gained on the orthogonal turbine in the Kislogubskaya tidal power plant, an idea was born. Would it be possible to merge together two known ways of harnessing ocean currents? The orthogonal turbine has been used to harness the ocean's potential energy that is created by the tides when a head of water is formed by barraging the Kislaya Bay and with that, utilizing its basin for the tidal plant. This is however a well-known and developed technology that both the Kislogubskaya TPP and the La Range TPP operated for over forty years. Barraging the Hvammsfjörður is not considered an option by Sjávarorka, and so came the idea of somehow merging that technique with a technique that does harness ocean current without any barrage. It is similar to when turbines are used to harness ocean currents underneath a bridge. Could the orthogonal turbine be used to create a turbine fence over Röst?

The idea is to simplify the power plant, whereby the turbines could be located in a building and be accessible on land or through the building and all the mechanisms pertaining to the rotors could be housed inside a building above sea level. As a result, the O&M cost could be greatly decreased and the utilization of the current's energy would be much greater due to the large area covered by turbines.

Using Google Translate to translate RusHydro's official webpage, contact information for one of the authors of the article: The new orthogonal turbine for tidal, wave and low-head hydropower plants (2009) was found, Mr.Viacheslav Yurievich Sobolev. At the end of the article, information about the authors is stated and Mr. Sobolev's information is following:

> *"Viacheslav Yurievich Sobolev graduated from Moscow State Technical University. He is a Senior Scientist at the Scientific-Technical Centre of Tidal Power and General Director at JSC NIIES, RusHydro. He has been working in the field of hydropower engineering for five years and has taken part in the design of new hydro and power units, as well as carrying out studies on the hydrodynamic of tidal power plants. He holds PhD, and has authored 10 scientific works."*

With the contact information available a short introduction letter was written and emailed to Mr. Sobolev, explaining the thesis work and a brief description of the idea about using the orthogonal turbine to harness the ocean current in Röst. After receiving a positive response about the idea, at least to take a closer look at the information available on the location, the next step was trying to visualize the idea with a drawing. An Icelandic artist, Páll Heimir Pálsson agreed to create drawings in order to get the idea delivered in as clear fashion as possible and shortly a draft was ready, detailed enough to send to Mr. Sobolev. Explanatory text was added in text as needed. The first draft can be seen in Figure 25.

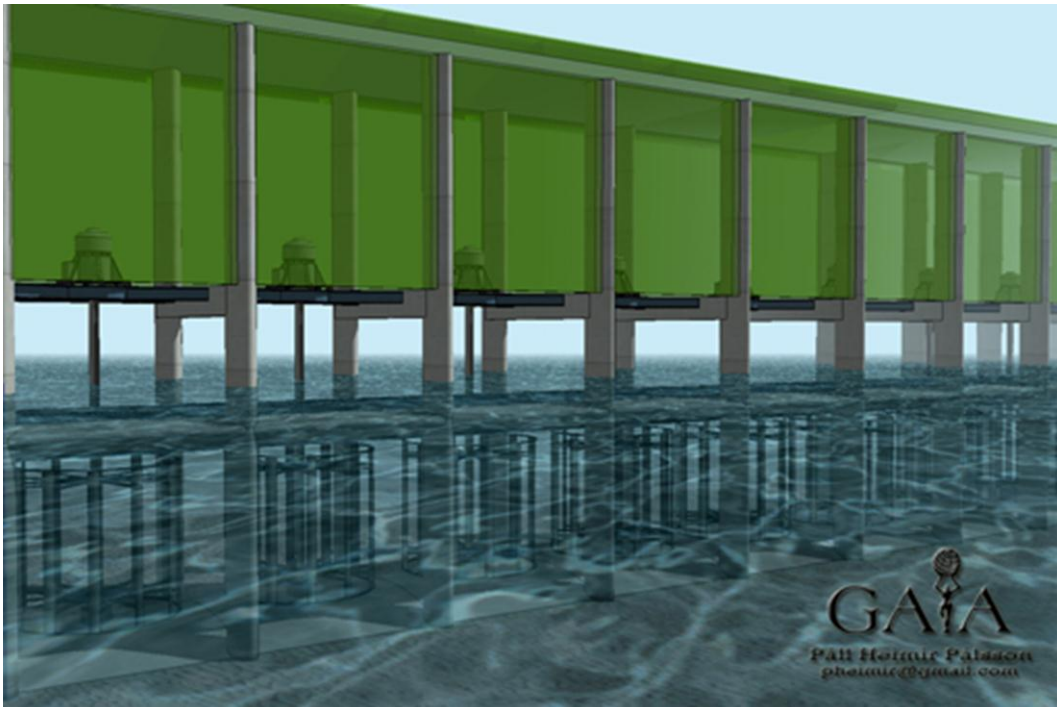


Figure 25. First drawing created by Páll Heimir Pálsson in order to visualize the author's idea for the orthogonal TPP.

Source: Páll Heimir Pálsson (personal interview and source, November 2010)

The information email to RusHydro's, Mr. Sobolev included the first drawing, along with sea map and a translation of a large part of the Verkis report (2008). The answer received did exceed expectations and is shown in full in appendix B. It did include two drawings, the first one idea for the plant's building (Figure 26), and the second one showing the location for RusHydro's idea for a TPP over Röst (Figure 27). That response and effort put in the RusHydro's answer gave positive signs on the idea for the TPP put forward by the author.

In short the answer was a short description on RusHydro's implementation on the idea for a TPP over Röst, results of their preliminary calculations for the plant power capacity of 130 MW and annual generation capacity of close to 400 GWh. It was emphasized that the idea was not to separate Hvammsfjörður from the sea so that was in tune with Sjávarorka's state of mind. The estimation of close to 400 GWh is however considerably higher than previously assumed that would be possible according to the Verkís report (2008), so further calculations and information sharing with RusHydro is advisable.

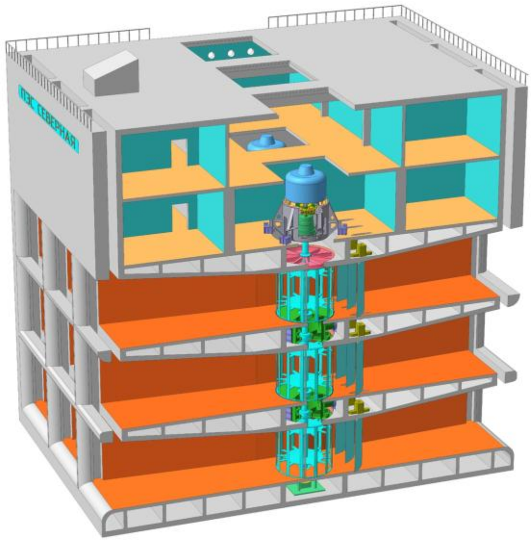


Figure 26. The idea for a tidal power plant as presented by Mr. Viacheslav Sobolev, senior scientist, Tidal Power Center, JSC NIIES, RusHydro

Source: Viacheslav Sobolev (appendix B, October 21st, 2010)

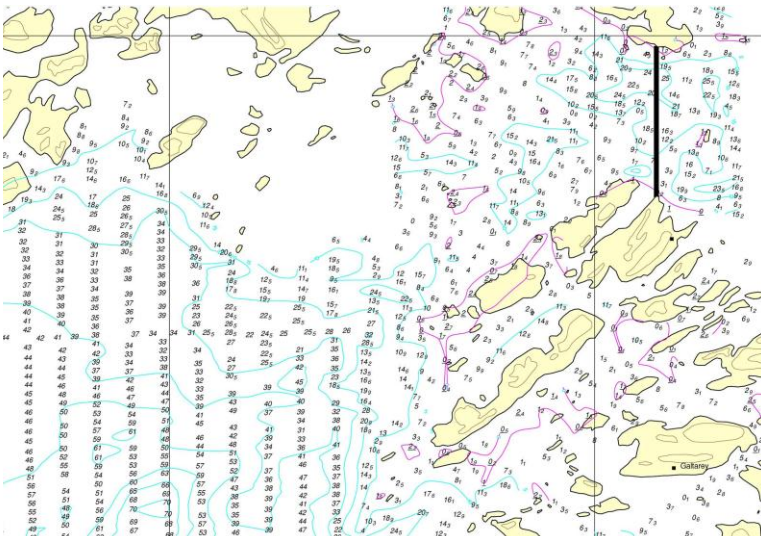


Figure 27. Map showing the suggested tidal plant by Mr. Sobolev, RusHydro

Source: Viacheslav Sobolev (appendix B, October 21st, 2010)

After reviewing the drawings and information from RusHydro, Páll Heimir Pálsson continued to work on the author's idea for the TPP with support from the author and the RusHydro drawing. The results can be seen in Figure 28.

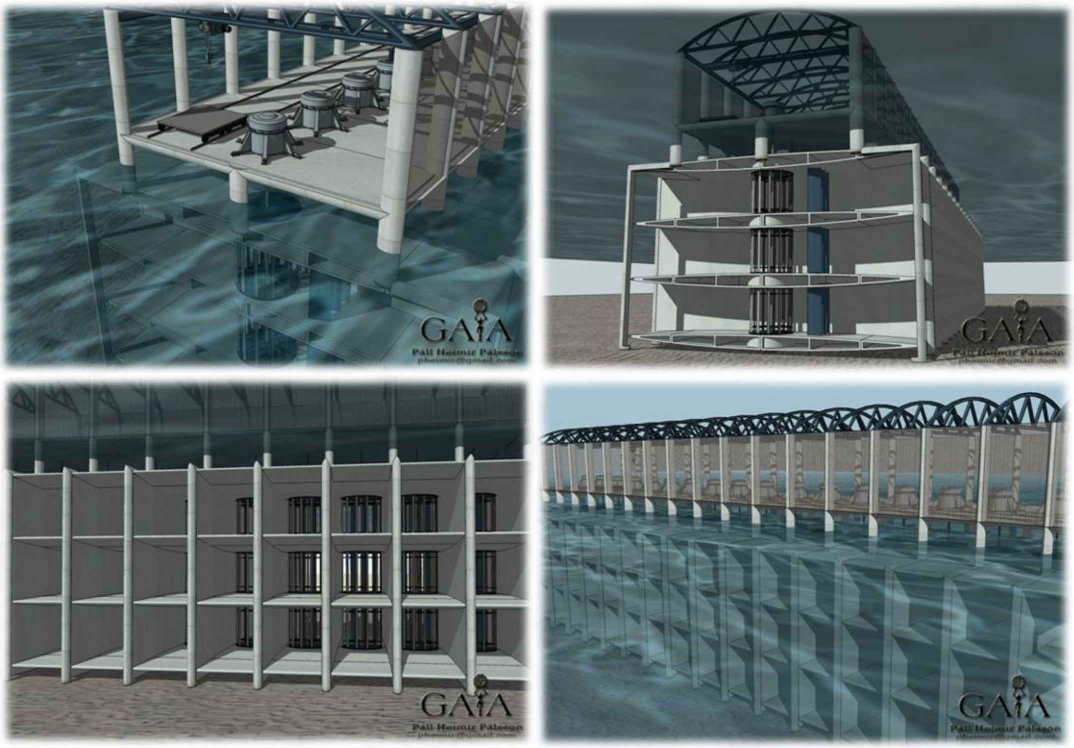


Figure 28. Second drawing of the orthogonal turbine power plant

Source: Páll Heimir Pálsson (personal interview and source, November 2010)

At this point in time the decision had been made to work with the information provided by RusHydro and using the Orthogonal turbine as the technology preferred for the Hvammsfjörður TPP.

4.0 PROFITABLITY MODEL

This chapter includes a description of the model used to create the project's outcome, why it is used and the main factors it involves. The commonly used method of Net Present Value (NPV) is used to see if the project of a tidal power plant at the mouth of Hvammsfjörður is profitable or not. In short, the method looks at the difference between the present value of cash inflow and the present value of cash outflow over a given period of time, taking into account return, interests and in some cases inflation. Often it is decided to do the calculations without factoring in inflation and use instead a steady exchange rate of the currency. If that method is used it is important that all numbers are calculated to the same currency as different time periods will most likely represent different values of the currency and would therefore create an unreliable outcome. NPV analysis is sensitive to the reliability of future cash inflows that an investment or project will yield so the input used should be as realistic as possible. If the return of an investment or project is agreed on and the NPV outcome is positive, then the project should be accepted, given the trustworthiness of the input. If however the outcome is negative, the project should be rejected since the cash flows will also be negative. In this case inflation will not be used but rather all numbers will reflect the Icelandic krona's (ISK) average currency rate against the US dollar (USD) in 2010.

4.1 Model methodology

Net Present Value (NPV) has been used for quite a long time in many investment planning problems by almost all researchers. It is commonly used in the oil and gas drilling and production industry as well as the petroleum exploration sector. Various conceptual development works also uses NPV as the profitability measure of choice.

NPV looks at all cash inflow and all cash outflow, determining the difference between the present value of both, associated with an investment project. By doing so, NPV can determine if an investment project would be an acceptable investment. But in order to do so, the investor must decide upon the interest rate required from the investment, often referred to as Minimum Attractive Rate of Return (MARR) and the time period of cash flows must be determined. In this this project 30 years of operation is used.

Net present value is defined as follows:

$$\text{NPV} = \sum_{n=0}^{N} \frac{A_n}{(1+i)^n} \qquad (4)$$

Where A_n is net cash flow at the end of period *n*, *i* is the MARR and N being the planned time horizon of the project. If the outcome is positive one should go ahead with the investment, if outcome should be 0, remain indifferent and further research might be advisable but if the outcome should prove to be negative the investment should not be realized. However, the NPV method is not without flaws, it does assume that all generated cash flow will be reinvested at the decided MARR, which might not be possible in reality (Björnsdóttir, 2010).

To evaluate engineering projects, variety of measures have been used in addition to NPV. Internal Rate of Return (IRR), Return Of Investment (ROI) and the payback period or payout time are among them. The measures all have one thing in common, in that they aim to simplify cash flow of defined periods of time in the future to a single number (Bagajewicz, 2008). IRR is covered in more detail but both ROI and Payback Period are not used in this assessment and do therefore not get any coverage here.

IRR is equal to the rate of return as given by the i* and the outcome is zero:

$$PV(i^*) = \sum_{n=0}^{N} \frac{A_n}{(1+i^*)^n} = 0 \qquad (5)$$

This can be considered the rate of return that makes the NPV equal to zero. In practical terms, IRR does have appeal due to its tendency to look at investments in terms of percentage return of the capital invested. A well-known downside is however that it does not take into account the time value of money. When it comes to decision making, IRR provides the following:

If $IRR > MARR$, accept the project

If $IRR = MARR$, remain indifferent

If $IRR < MARR$, reject the project
(Björnsdóttir, 2010)

Another downside of IRR is the fact that it assumes that cash flow will be reinvested at the MARR ratio which might not always be possible in reality. As an answer to that flaw Modified Internal Rate of Return (MIRR) was created. It is almost identical to the IRR method, except it assumes that cash flow will be reinvested at a different rate from the MARR. However, MIRR has not yet widely used for financial feasibility studies, compared to NPV or IRR (Björnsdóttir, 2010) and will not be used in this profitability assessment.

Both IRR and MIRR however include some known drawbacks, one being that they do not distinguish between lending and borrowing. This is an issue that does not affect investment planning models of all types (Bagajewicz, 2008), including the one put forward in this thesis, since lending is not likely to be a part of the operational model used for the Hvammsfjörður TPP. Another drawback is that the methods can have multiple solutions (Bagajewicz, 2008). In the MSc thesis Building and Using Assessment Models for Financial Feasibility Analysis of Investment Projects (Björnsdóttir, 2010), Fabozzi and Peterson (2003) are quoted on the steps involved in MIRR calculations:

1. Calculate the present value of all cash outflows, using a reinvestment rate as the discount rate;
2. Calculate the future value of all cash inflows reinvested at some rate;
3. Solve for rate, the MIRR, that causes future value of cash inflows to equal present value of outflows.

MIRR offers the following rule as a decision guide in regards to its outcome:

If $MIRR > Cost\ of\ Capital$, accept the project

If $MIRR = Cost\ of\ Capital$, remain indifferent

If $MIRR < Cost\ of\ Capital$, reject the project
(Björnsdóttir, 2010)

4.2 Model assumptions

As would be expected, many assumptions have to be made on such a large-scale project in a relatively small report as this thesis, and in this chapter the assumptions that need to be made are outlined and explained where needed. They are presented in three categories: Investment, Financing and Operation. The Investment assumptions are shown in Table 1.

Table 1. Investment assumptions

No.	Assumptions	Value	Unit
	Investment:		
1	Installed capacity of the TPP	130	MW
2	TPP equipment cost (per installed capacity)	1,500	USD/kW
3	TPP construction cost (per installed capacity)	1,500	USD/kW
4	Foundation construction work (total)	2,379	MISK
5	New power line and connection stations	2,000	MISK
6	Road constructions in land	70	MISK
7	Road constructions in sea	300	MISK

For assumptions 1-4, in regard to estimations done on TPP rated power and the construction cost along with equipment cost, estimations from RusHydro are used and can be seen in Appendix B. Like stated before, there are many uncertainties in terms of construction costs since a tidal power plant of this sort has never been built. The same characteristics that make the site feasible for harnessing the ocean's kinetic energy, such as the strong current, also make it a very challenging construction site. It was thought that the best way to construct the TPP was to build it in-land and float the building in sections to the site and sink them to a pre-prepared foundation. The idea was also supported by knowing that the same construction method was used by RusHydro when adding the new orthogonal turbine to the Kislogubskaya TPP in 2006 (Shpolyanskij et al., 2009). However, those two sites possess very different characteristics, the Kislaya Gulf being blocked with a barrage whereas it is estimated that the Hvammsfjörður TPP would harness the ocean's current in open sea, without any barrage. The result is a much more difficult foundation construction site at the Hvammsfjörður TPP since the Kislogubskaya TPP foundation could be constructed in still water, due to the barrage. Therefore a decision was made to add an extra 10% to the construction cost in addition to RusHydro's total construction estimations. With this project, the estimated total startup cost from RusHydro is about 367,000 ISK/kW (3,000 USD/kW, assumptions 2 and 3) of installed capacity (appendix B), using the average currency rate of 2010 (Central bank of Iceland, 2010), being the same as estimated for a small hydro power plant (International Energy Agency, 2010). The difference in generation capability is large, with this project's TPP holding efficiency about 34% and a conventional hydro power plant is in the area of 90%. The TPP results in close to 400 GWh/year, whereas a hydro plant of the same size with a 90% efficiency would generate about 1,025 GWh/year. On assumptions 5-7, the following applies: Transmission is needed for the produced electricity at the power plant and in order to estimate the cost related to construct new power lines from the station to the nearest connection building, Magni Þór Pálsson from Landsnet (appendix E, November, 2010), Iceland's electricity transmission company, provided the estimations. The best way would be to construct a new 40 km long 132 kV power line from the plant to the Glerárskógar grid connection station (Figure 29).

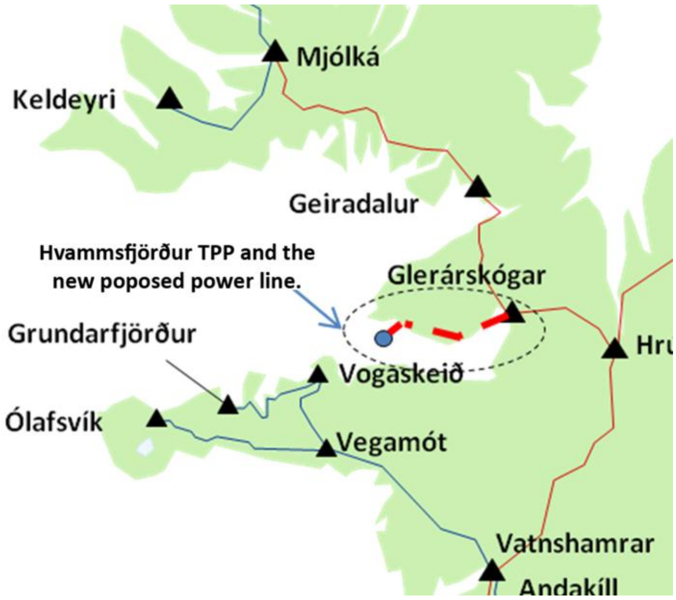


Figure 29. The new proposed power line from the TPP to Glerárskógar grid connection station.

Source: Magni Þór Pálsson (Landsnet), (appendix E, November 2010)

That solution will ensure that transmission capability from the suggested connection station will be sufficient when the TPP is at its maximum production. In addition to the new power line, an enlargement of the Glerárskógar connection station is needed as well as a new connection station at the power plant.

Information on road construction needed for the TPP was received from Rögnvaldur Gunnarsson (personal interview, November 2010) from the Icelandic Road

Administration. Separate rough estimations were done for the construction of the road on land and in the sea, between skerries, to the control building located on the skerry Barkarnautur. Total estimations for inland roads are 3,700 meters of 2-meter high roads, measuring 7 meters wide at the top with the gradient of the embankment of the road being 1:2, equaling a total of about 18,500 ISK per meter. Estimations for roads constructed in the sea are 770 meters and the assumptions used are an average depth of 8 meters, 7 meters wide at the top, rock-filling of 2 meters, filtering layer of 0.7 meters and the same gradient of 1:2 is used. In total, the cost is about 400,000 ISK per meter.

Table 2. Financial assumptions

No.	Assumptions	Value	Unit
	Financing:		
8	ISK (average currency ratio of USD at 2010)	122	ISK
9	Required Rate of Return from owners	8	%
10	Working Capital	1,200	MISK
11	Equity paid by shareholders	65	%
12	Loan	35	%
13	Loan Payments	30	Years
14	Loan Interest	5.0	%/year
15	Loan Management Fees	1.0	% (once)

Assumption 8 refers to the currency rate at which US dollars are changed to ISK. This was needed since estimations received from RusHydro are in USD. The decision was made to use average currency rate for the year 2010 as a reference point and do a sensitivity analysis on currency rate used. It however must be mentioned that Iceland, like most of the world has been going through strange and difficult financial time for over 2 years, during the ongoing depression. Iceland still has active restriction on the movement of currency moving in or out of the country, manually trying to control to some degree the value of the Icelandic krona against foreign currencies. When the average ISK/USD currency rate of 122 is compared to that of used when a renewed profitability assessment was created in January 2008 for Landsvirkjun' Kárahnjúkar power plant, only 3 years ago. In a paper issued by Landsvirkjun at that time the estimation for a balanced currency rate of 69 ISK/USD is used and is expected to do so in 3 years (Landsvirkjun Hf., 2008). Having the average rate of 2010 almost 77%

higher than 3 year old estimations is a very good indicator on the ongoing financial storm and the large uncertainty involved of the ISK “correct” currency rate. But a reference point is needed and the average ISK/USD rate of 2010 was decided upon.

Assumption 9 is the required rate of return for owners from the project. This assumption was decided upon with Sjávarorka Ehf., (Steinar Friðgeirsson, personal interview, October 2010) Assumption 10 is on the working capital needed in order to keep the cash account positive through the first years of operation. Assumptions 11-13 address how the ratio between the owners’ financial contribution to the project and therefore the loan amount along with its payback period. As stated before, the loan amount was adjusted so it could be fully paid in 30 years with available cash generated by the TPP. The rest was addressed as equity paid by owners. Assumptions 14 and 15, on loan interests and loan management fee, were decided upon with Sjávarorka.

In regards to financial assumptions, an 8% rate of return (MARR) is assumed as per the owners’ demand, 60% of the project is to be financed by owners and 40% financed by a loan with a 25-year payback period. The reasoning for 25 years is that a decision was made to use all available cash to pay back the loan received.

Table 3. Operation assumptions

No.	Assumptions	Value	Unit
	Operation:		
16	Average sales price (Iceland) (IKR/MWh)	3,91	ISK/kWh
17	Average power fee (IKR/MW)	8,268	MISK/MW
18	Annual rise in electricity price	4.5	%/year
19	Annual rise in power fee	3.0	%/year
20	Variable Cost (of operation)	0.5	%/year
21	Fixed cost (insurance, research etc.)	0.5	%/year
22	Annual cost increase	3.0	%/year
23	Maintenance	2.0	%/year
24	Depreciation time (average)	20	years

Assumptions 17-26 address the TPPs operation, both the revenue and cost side of the equation. Assumptions 17-20 address revenue and estimations for electricity price for industry in Iceland, over the years 2010-2030, come from Landsvirkjun, the state-owned power company (Landsvirkjun hf, 2010). A pricelist from Rarik (Helgi Óskar Óskarsson, personal interview, November 2010), the second biggest provider of electricity in Iceland, is used for comparison in order to get a clearer idea of a realistic price range. The same applies for the rate used for the power fee paid to the power plant. After consulting Sjávarorka, a decision was made to use a one-year contract wholesale price as a reference point and create a sensitivity analysis on how electricity price received would affect the project's NPV. When annual electricity price rise was decided upon, Lansdvirkjun estimations for electricity price for industry in Iceland to the year 2030 were also used. Landsvirkjun estimates that electricity price for industry will go from $27/MWh in 2010 to $65 in 2030, which accounts for an annual rise of 4.5%. In order to justify the electricity price received being related to industry the assumption was made that the Hvammsfjörður TPP would be owned by parties who also operate a conventional hydro power plant and use combined electricity generation to provide steady power to its clients. With that, the reservoir of the hydro station could be used to store energy.

Assumptions 21-25 address the cost of operation. A total cost ratio of 3% of total startup cost per year was decided upon after consulting with Rarik, on behalf of Sjávarorka. Normal estimations for hydro power plants assume 0.7-2% of total investment cost, depending on size. Since the Hvammsfjörður TPP is a new technology, and as such is without any operation history to reflect upon, a higher O&M cost is a logical way to go. One percent was divided between fixed- and variable cost of operation and 2% was alloted to maintenance of buildings and equipment. For assumption 26, a 20-year depreciation time of the TPP was decided upon.

After making the decision to work with the orthogonal turbine from RusHydro, the next step was to ask for collaboration and information sharing relevant to the usage of the turbine under the Hvammsfjörður conditions. The TPP size was calculated by RusHydro using numbers from the Verkís report, a sea map of the area and the experience gained on the orthogonal turbine. Same information source was used to calculate the annual electricity production.

Table 4. List of assumptions

No.	Assumptions	Value	Unit	Source
	Investment:			
1	Installed capacity of the TPP	130	MW	Appendix B
2	TPP equipment cost	1,500	USD/kW	Appendix B
3	TPP construction cost	1,500	USD/kW	Appendix B
4	Foundation construction work	2,389	MISK	Author's estim.
5	New powerline and connection stations	2,000	MISK	Appendix E
6	Road constructions in land	70	MISK	Gunnarsson, R. (2010)
7	Road constructions in sea	300	MISK	Gunnarsson, R. (2010)
	Financing:			
8	ISK (average currency ratio of USD at 2010)	122	ISK	(Central bank of Iceland, 2010)
9	Required Rate of Return from owners	8%		*Author's estim.
10	Working Capital	1,200	MISK	Author's estim.
11	Equity paid by shareholders	65	%	Author's estim.
12	Loan	35	%	Author's estim.
13	Loan Payments 1	30	Years	Author's estim.
14	Loan Interest	5.0	%/year	*Author's estim.
15	Loan Management Fees	1.0	% (once)	Author's estim.
	Operation:			
16	Wholesale price (IKR/MWh)	3,91	ISK/kWh	Appendix C
17	Power fee (IKR/MW)	8,268	MISK/MW	Appendix C
18	Annual rise in electricity price received	4.5	%/year	Appendix D
19	Annual rise in power fee received	3.0	%/year	Author's estim.
20	Variable Cost (of operation)	0.5	%/year	*Author's estim.
21	Fixed cost (insurance, research etc.)	0.5	%/year	*Author's estim.
22	Annual cost increase	3.0	%/year	*Author's estim.
23	Maintenance (buildings and equipments)	2.0	%/year	*Author's estim.
24	Depreciation time (average)	20	years	*Author's estim.

* Estimations done after consulting with Steinar Friðgeirsson, chairman of the board at Sjávarorka and CEO of Rarik Energy Development.

5.0 MODEL RESULTS

With the assumptions used, this is not a profitable project. When starting the thesis work, little to nothing was known about the profitability of a TPP operated under Iceland's electricity market conditions. It was known, however, that the startup cost of new technology is likely to be higher than for a well-developed technology, like hydro- or geothermal power plants. It was also a known fact that the electricity price in Iceland is considerable lower than that of its neighboring counties. Both facts indicate a low profitability outcome. However, this thesis holds large uncertainties about construction cost since a similar TPP has never been built. It is unlikely however, that with electricity price similar to that which currently exists in Iceland that this project will be a profitable method of generating electricity in the near future. In this chapter the findings of this thesis will be outlined and some light shed on which factors, if changed, might create a more profitable surroundings for this TPP.

5.1 Main results

Few key figures are presented in Table 5 as an overview of the project's outcome.

Table 5. Key figures for the first 30 years of operation

Number of year in operation *Year*	1 **2014**	10 **2023**	20 **2033**	30 **2043**
NPV of Total Cash Flow	-49.104	-43.751	-38.863	-34.992
IRR of Total Cash Flow	0,0%	0,0%	0,0%	0,7%
NPV of Net Cash Flow	-31.011	-31.011	-31.011	-29.152
IRR of Net Cash Flow	0,0%	0,0%	0,0%	0,0%
Total loan payments	820	1.383	2.396	0
Total revenue	2.128	3.090	4.690	7.138
Total cost	1.308	1.707	2.294	3.083
Operating Surplus (EBITDA)	820	1.383	2.396	4.055
Operation Outcome (gain/loss)	-1.535	-971	42	4.055
Accumulated Loss Transfer	-3.894	-25.023	-38.813	-8.275
Net Profit/Loss	-2.607	-2.068	-638	4.055
Total Assets	49.987	28.794	5.246	23.903
Total Debt	21.704	21.639	11.881	0

Source: Author

The NPV of total cash flow and capital is negative, about 34,992 million ISK and IRR is 0% using 8% required rate of return by owners and thirty years of operation time, excluding construction time. NPV of net cash flow is negative about 29,152 million ISK and IRR is 0% over the same time period. The loan received for 40% of investment cost and working capital, is paid over 25 years and the operation turns a profit in its 21st year of operation, 1,934 million ISK or 3.7% of the total investment cost. In the year 2043 the project is generating 4,055 million ISK in profit, then 7.75% of investment cost. As seen in Figure 30, the numbers are not very encouraging, with NPV of total cash flow negative close to 35,000 million ISK.

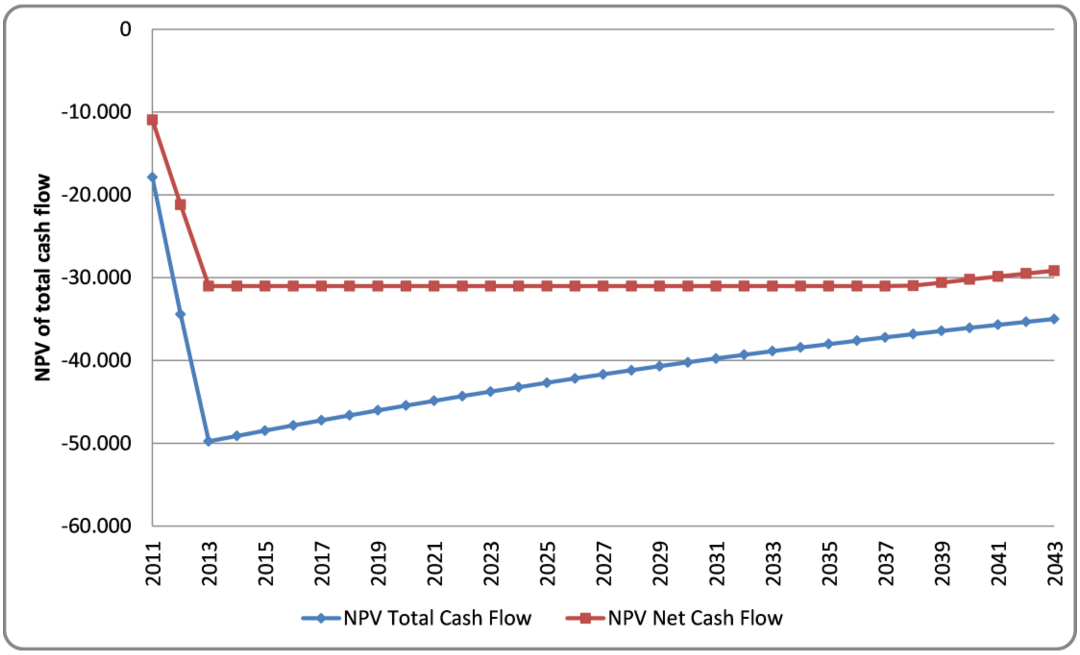


Figure 30. Accumulated net present value (NPV) over 3 year construction time and 30 years of operation.

In the first year of operation, electricity price received (0.00446 million ISK/MWh or 4.46 ISK/kWh) is 32.2% higher than cost of electricity generation (0.00338 million ISK/MWh or 3.38 ISK/kWh) (Figure 31).

With estimations for a more rapid growth in electricity price received than general cost of operation the working environment looks brighter in coming years, with difference close to double in year 15 (61.8%) and in year 30 the electricity price received is 101% higher than generation cost, this is shown in Figure 31.

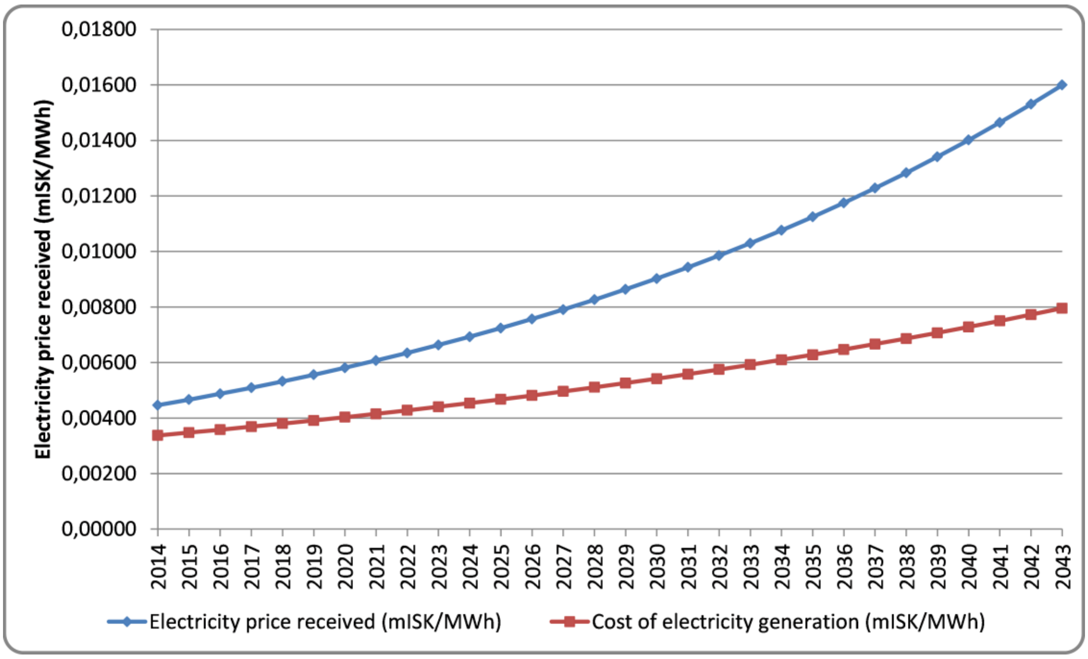


Figure 31. Electricity price received and cost of electricity generation

Source: Author

Figure 32 shows in a more visual manner, four of the same figures as are presented in Table 5, total revenue, operational- and financial cost along with the projects financial outcome, profit or loss. As covered in the assumption chapter, the annual rise in electricity price received was assumed higher than the annual rise in cost which is represented in a steeper upward slope for revenue opposed to the line representing operational cost. This is also mirrored in Figure 31 which shows development of cost of generation opposed to electricity price received previously mentioned. As stated before the TPP starts generating profit in year 21 of operation, which is the first year of operation after the 20 year depreciation period.

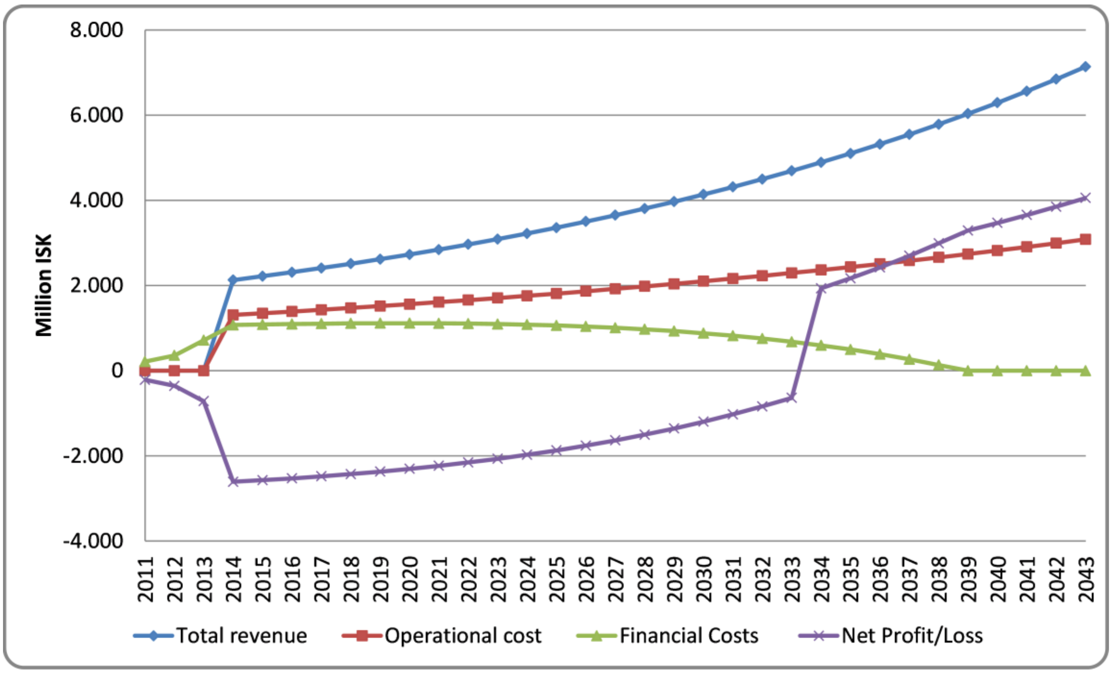


Figure 32. The development on total revenue, operational- and financial cost along with the final financial outcome, profit or loss.

Source: Author

5.2 Sensitivity analysis

In order to get a better idea of how different assumptions would affect the projects outcome, sensitivity analysis is necessary. All assumptions used in the model represent a reference point and the sensitivity analysis is done in regards to a drop of 50% (lower cost, less income) up to a 50% rise (higher cost, more income).

To start with, the effect a change in electricity price received would have on NPV of total cash flow is looked at, with prices dropping and rising 50% from the assumed reference point of 3.91 ISK/kWh. The same is done for the amount of electricity generated and price received per MW as a power fee, cost of generation, currency rated used, startup cost (construction) and maintenance, in terms of the same percentage change that is. Outcome is shown in Figure 33 and Table 6. As seen the effect of a change in either currency rate used or construction cost is almost identical and the second biggest factors affecting the projects outcome, after electricity priced received.

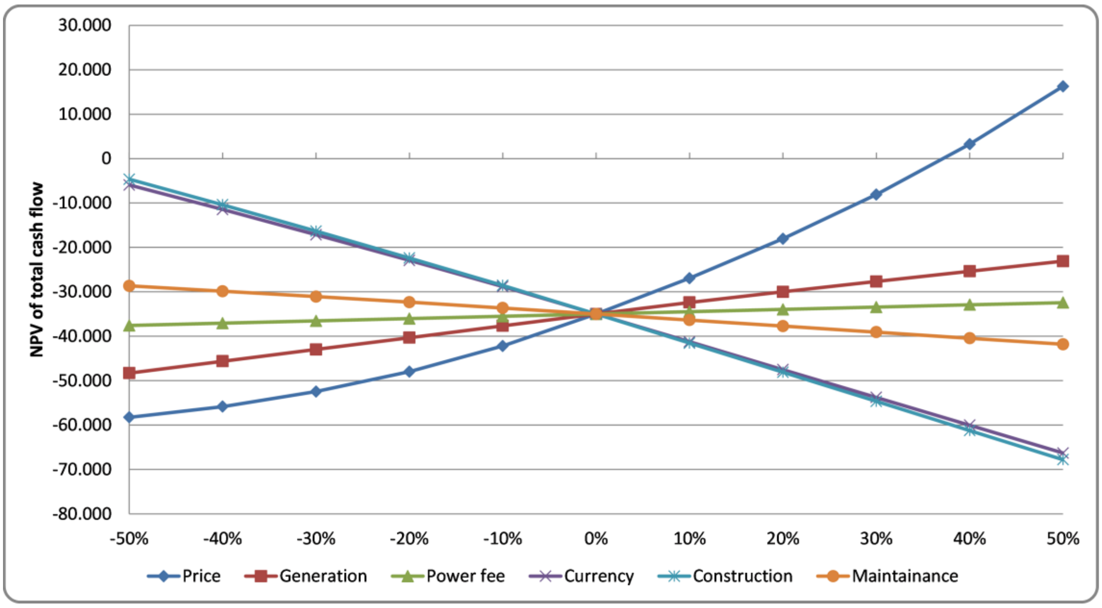


Figure 33. Sensitivity analysis on how electricity price received, generation, power fee revenue, currency rate used, construction cost and maintenance cost will affect NPV of total cash flow over 30 years, presented in a graph.

Table 6. Sensitivity analysis on how electricity price received, generation, power fee revenue, currency rate used, construction cost and maintenance cost will affect NPV of total cash flow over 30 years, presented in numbers.

	Price	Generation	Power fee	Construction	Maintenance	Currency
NPV	-34.992	-34.992	-34.992	-34.992	-34.992	-34.992
-50%	-58.256	-48.286	-37.590	-4.647	-28.661	-5.938
-40%	-55.837	-45.627	-37.070	-10.404	-29.863	-11.463
-30%	-52.460	-42.968	-36.551	-16.319	-31.081	-17.136
-20%	-47.967	-40.310	-36.031	-22.380	-32.315	-22.934
-10%	-42.197	-37.651	-35.512	-28.548	-33.630	-28.830
0%	-34.992	-34.992	-34.992	-34.992	-34.992	-34.992
10%	-26.942	-32.380	-34.473	-41.549	-36.354	-41.252
20%	-18.056	-29.991	-33.953	-48.106	-37.715	-47.512
30%	-8.093	-27.658	-33.433	-54.663	-39.077	-53.772
40%	3.252	-25.360	-32.914	-61.220	-40.439	-60.032
50%	16.274	-23.092	-32.430	-67.777	-41.800	-66.292

Source: Author

This clearly reveals that the biggest impact is made by the electricity price received, as mentioned before, with NPV moving from -34,992 MISK at the reference point used after 30 years of operation to a positive 16,274 MISK with same time period and a 50% rise in electricity price received. Meaning that the price received in 2014, the first year of operation, would need to go from 4.46 ISK/kWh to 6.69 ISK/kWh, still being a considerable lower price than that of a small sustainable power plant starting to operate in Norway today. Norway price of 72€/MWh (11,66 ISK/kWh), however, is including a 35€/MWh (5.67 ISK/kWh) feed in tariff which is valid for 15 years (Steinar Friðgeirsson, personal interview, October 2010), converted using ISK/Euro average currency rate of 2010 (Central bank of Iceland, 2010). This feed in tariff is currently not available to Icelandic energy companies. The effect of electricity generated, revenue from power fee and maintenance cost is less than the three factors mentioned before. If the factor of 50% rise is used, the result would be a 12,000 MISK higher NPV from generation, only about 1,500 MISK higher from power fee and a 50% drop in maintenance cost would result in about 7,000 MISK higher NPV.

6.0 CONCLUSION

In this thesis many assumptions have been made, some based on little information available and on others large amount of engineering work would be required to obtain an accurate image of the construction. In addition it is possible to speculate back and forth about how the Icelandic electricity market might change in coming years but the task of profitability assessment for a TPP at the mouth of Hvammsfjörður has been accomplished with quite good certainty. And now it is not, as clearly demonstrated in Figure 30 by the projects NPV.

In this chapter few viewpoints are covered along with shedding light on factors that might change the project outcome or are of importance to its realization. To construct the building blocks in-land may involve straight-forward engineering and construction work given the number of experienced individuals in Iceland but the project type is new which results in the need for assumptions. How to construct a buildings foundation, about 35 meters wide and 750 meters long on a seabed under the conditions where the ocean current can approach a speed of 9 meters per second (about 17 nautical miles per hour or 31 km per hour) is very challenging work, to say the least. As such, the assumptions made in this paper are questionable but it is the author's hope that they might give some insight as to how the reality of this project might appear.

If the plan to develop the project is realized, more research on the area will be needed. Placing a turbine fence over most of Röst, where about 75 percent of the sea travels in and out of Hvammsfjörður, will cause some delay in sea movement and a change in its traveling route. More research and calculations must be done in order to map that change and obtain more exact numbers for the profitability model. More research is also needed on the environmental issues. Experience gained and research done on the turbine by RusHydro can be utilized to some extent, for example if fish mortality as a result of passing through the turbine proves to be an issue for the fish inhabiting the area. An add-on site-specific research on other environmental aspects is also needed. For example, in the channels between Norðurey and Brokey and between Brokey and Skógarströnd combined, close to 20% of sea movement travels in and out of Hvammsfjörður. Would some kind of an invisible barrage, not visible above sea level that is, be possible in order to increase the energy available to the Hvammsfjörður TPP and increase its profitability, without applying negative environmental effects?

A further study of the technical solutions for the proposed TPP is of course required. More information is needed on the current speed away from Röst in order to exclude the stand-alone turbines from the companies mentioned in this paper, including Open Hydro, MTC and Lunar Energy. Can a similar amount of energy be harnessed with them if they are placed on both sides of Röst where the depth is sufficient and/or will O&M cost justify such a project? If the harnessing method proposed in this thesis is realized a small-scale test power plant would be the logical course of action. With Sjávarorka already holding a test plant license, that solution would be implemented into the plan, with a test plant running for 2-5 years to gain vast experience and allow for improvements of the efficiency of the technology. The same applies to the construction part of the project. With a small-scale prototype constructed in-land, a foundation created on site and the unit floated to location and sunk to settle at the foundation, important experience would be gained, making all plans for the full-size plant more accurate.

Landowners are another issue that has not been addressed in this thesis although it is obviously a very important issue to take into account for the project to be realized. The reason for not addressing the issue is the complex complication involved in the ownership of the land affected. Landowners also might, to some extent, affect the financial outcome due to payments made for land or rent paid for land usage, not only affecting the TPP itself but also the road constructed to it and the power line needed from it.

At the end of the day the assumptions used can be considered reasonably realistic, even if some of the assumptions are big and can in no way relate to a similar project for a reference point. The argument is that the total investment cost is similar or the same as considered for small-scale conventional hydro power plant, about 3,000 USD/kW of installed power capacity. Another argument is that with the sensitivity analysis construction cost is quite far off from being as influential on the project's outcome as the electricity price received is, meaning that 20% error in construction cost would have much less effect on the outcome compared to a 20% rise in electricity price. However today the electricity price is well-known but construction cost is not, so an error in construction cost is much more likely to occur than in the price department. But on the other hand, it was once said that it is very difficult to foretell anything, especially the future. If Iceland's electricity market is merged with another one, to the UK with a subsea cable for example, with EU entrance or without, the electricity price is very likely to rise. Feed-in tariffs for clean energy generation might also be introduced in Iceland. They are active in Sweden, in UK from 2010 and in Norway in January 2012. In Norway feed-in tariff is estimated to be around 35€/MWh for a small-scale hydro power plant (Steinar Friðgeirsson, personal interview, 29 December 2010). Using the euro's average 2010 currency rate (Central bank of Iceland, 2010) of 161.9 ISK that would translate to 5,666 ISK/MWh which would be valid over a 15-year period. The same feed-in tariff active in Iceland in 2020 would change the outcome a great deal. It would however not be enough to generate a positive NPV over a 30 year operation time if it is considered to be the same over the 15 years.

Another point of view that might be worth exploring is what other industries might gain from a TPP project like this one. The tourist industry is a good answer to provide and explore. Iceland is currently hos to about 500,000 tourists per year (Iceland Tourist Board, 2010), the Blue Lagoon being Iceland's most popular tourist attraction with about 400,000 visits per year (Blue Lagoon, 2010). With about 19.000 tourists visiting Landsvirkun's power plants last year (Anna María Sigurðardóttir, personal interview, 31. December 2010), about 100,000 visiting Reykjavík Energy's Hellisheiði power plant alone and 10-15,000 in the Nesjavellir power plant. Reykjavík Energy receives about 1,000,000 visits annually to all of its locations combined (Guðjón Magnússon, personal interview, 30 December 2010). Similar opportunity might apply to the Dalasýsla county if the Hvammsfjörður TPP is be designed with the tourist industry. To visualize the idea, Figure 35 was created by the artist Páll Heimir Pálsson (personal interview, November 2010). The options to create an attraction in addition to serving the plant's main purpose, the generation of electricity, can be large.

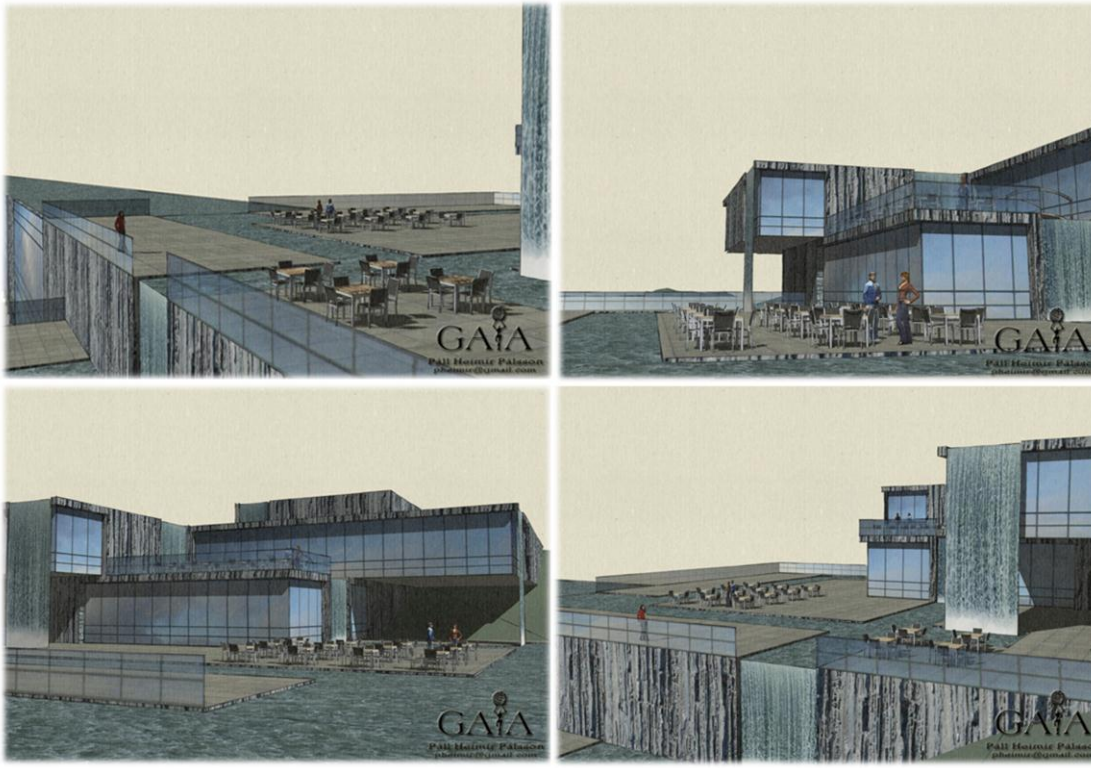


Figure 34. Showing the TPP control building as an idea on combining TPP and tourist attraction

Source: Páll Heimir Pálsson (personal interview and source, November 2010)

APPENDIX A

Revenue ratio of total investment cost					4,1%	4,2%	4,4%	4,6%	4,8%	5,0%	5,2%	5,4%	5,6%	5,9%	6,1%	6,4%	6,7%	6,9%	7,2%	7,6%	7,9%	8,2%	8,6%	8,9%	9,3%	9,7%	10,1%	10,6%	11,0%	11,5%	12,0%	12,5%	13,0%	13,6%
Payment as a ratio of total revenue		0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	39,8%	40,6%	41,3%	42,0%	42,7%	43,4%	44,1%	44,8%	45,5%	46,2%	46,8%
Cost / Revenue Ratio					75,5%	74,6%	73,8%	72,9%	72,0%	71,2%	70,3%	69,5%	68,7%	67,9%	67,1%	66,3%	65,5%	64,7%	63,9%	63,2%	62,4%	61,6%	60,9%	60,2%	59,4%	58,7%	58,0%	57,3%	56,6%	55,9%	55,2%	54,5%	53,8%	53,2%
Electricity price received (ISK/kWh)..	100%	0,00391	0,00409	0,00427	0,00446	0,00466	0,00487	0,00509	0,00532	0,00556	0,00581	0,00607	0,00635	0,00663	0,00693	0,00724	0,00757	0,00791	0,00826	0,00864	0,00902	0,00943	0,00985	0,01030	0,01076	0,01125	0,01175	0,01228	0,01283	0,01341	0,01401	0,01465	0,01530	0,01599
																								0,0070										0,0091
Power fee..	100%	8,27	8,52	8,77	9,03	9,31	9,58	9,87	10,17	10,47	10,79	11,11	11,44	11,79	12,14	12,51	12,88	13,27	13,67	14,08	14,50	14,93	15,38	15,84	16,32	16,81	17,31	17,83	18,37	18,92	19,48	20,07	20,67	21,29
Cost of electricity generation (ISK/kWh)..					0,00415	0,00427	0,00440	0,00453	0,00467	0,00481	0,00495	0,00510	0,00526	0,00541	0,00558	0,00574	0,00592	0,00610	0,00628	0,00647	0,00666	0,00686	0,00707	0,00728	0,00750	0,00773	0,00796	0,00820	0,00844	0,00870	0,00896	0,00923	0,00951	0,00979
Average:..																								0,00558										0,00658
Difference in mISK/MWh..					0,00032	0,00039	0,00047	0,00056	0,00065	0,00075	0,00086	0,00097	0,00109	0,00122	0,00135	0,00150	0,00165	0,00181	0,00198	0,00217	0,00236	0,00257	0,00279	0,00302	0,00326	0,00352	0,00379	0,00408	0,00439	0,00471	0,00505	0,00541	0,00580	0,00620
Difference in per cent..					7,6%	9,2%	10,7%	12,3%	14,0%	15,6%	17,3%	19,0%	20,7%	22,5%	24,3%	26,1%	27,9%	29,7%	31,6%	33,5%	35,5%	37,4%	39,4%	41,4%	43,5%	45,6%	47,7%	49,8%	52,0%	54,2%	56,4%	58,7%	61,0%	63,3%

Investment and Financing		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Investment:																																		
Total Investment in power plant..	100%	17.511	35.023	52.534	50.170	47.806	45.442	43.078	40.714	38.350	35.986	33.622	31.258	28.894	26.530	24.166	21.802	19.437	17.073	14.709	12.345	9.981	7.617	5.253	5.253	5.253	5.253	5.253	5.253	5.253	5.253	5.253	5.253	5.253
Booked Value		**17.511**	**35.023**	**52.534**	**50.170**	**47.806**	**45.442**	**43.078**	**40.714**	**38.350**	**35.986**	**33.622**	**31.258**	**28.894**	**26.530**	**24.166**	**21.802**	**19.437**	**17.073**	**14.709**	**12.345**	**9.981**	**7.617**	**5.253**	**5.253**	**5.253**	**5.253**	**5.253**	**5.253**	**5.253**	**5.253**	**5.253**	**5.253**	**5.253**
Depreciation:																																		
Depreciation (average)..		0	0	0	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	0	0	0	0	0	0	0	0	0	0
Total Depreciation		**0**	**0**	**0**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**2.364**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Financing:																																		
Equity..		11.642	11.642	11.642	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loans received..		6.269	6.269	6.269	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Principal of loans..		6.269	12.538	18.807	19.226	19.624	19.998	20.345	20.660	20.939	21.177	21.369	21.509	21.592	21.611	21.559	21.429	21.211	20.899	20.482	19.950	19.292	18.498	17.554	16.447	15.162	13.686	12.000	10.088	7.930	5.508	2.798	-222	-3.575
Payment of loans..		0	0	0	-419	-398	-374	-347	-315	-279	-238	-192	-140	-83	-19	52	131	217	313	417	532	657	795	944	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Interest of loans..		0	313	627	940	961	981	1.000	1.017	1.033	1.047	1.059	1.068	1.075	1.080	1.081	1.078	1.071	1.061	1.045	1.024	997	965	925	878	822	758	684	600	504	397	275	140	-11
Loan management fees..		188	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total payments:		**188**	**313**	**627**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1.869**	**1.985**	**2.107**	**2.235**	**2.370**	**2.512**	**2.662**	**2.819**	**2.985**	**3.159**	**3.343**

Operations Statement		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Revenue																																		
Annual production (average) (MWh)..	100%	0	0	0	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457	387.457
Revenue from elctricity sold..		0	0	0	1.729	1.807	1.888	1.973	2.062	2.155	2.252	2.353	2.459	2.569	2.685	2.806	2.932	3.064	3.202	3.346	3.497	3.654	3.818	3.990	4.170	4.357	4.553	4.758	4.972	5.196	5.430	5.674	5.930	6.197
Revenue from power fee..	100%	0	0	0	399	411	424	436	449	463	477	491	506	521	537	553	569	586	604	622	641	660	680	700	721	743	765	788	812	836	861	887	914	941
Undefiined revenure source..	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total revenue		**0**	**0**	**0**	**2.128**	**2.218**	**2.312**	**2.409**	**2.511**	**2.617**	**2.728**	**2.844**	**2.965**	**3.090**	**3.222**	**3.359**	**3.501**	**3.650**	**3.806**	**3.968**	**4.137**	**4.314**	**4.498**	**4.690**	**4.891**	**5.100**	**5.319**	**5.546**	**5.784**	**6.032**	**6.291**	**6.561**	**6.843**	**7.138**
Variable Cost																																		
Maintainance (average)..		0	0	0	1.576	1.623	1.672	1.722	1.774	1.827	1.882	1.938	1.996	2.056	2.118	2.182	2.247	2.314	2.384	2.455	2.529	2.605	2.683	2.764	2.846	2.932	3.020	3.110	3.204	3.300	3.399	3.501	3.606	3.714
Management & labor cost (total)..		0	0	0	11	11	12	12	13	13	14	14	15	15	16	17	17	18	19	19	20	21	22	23	24	25	26	27	28	29	30	31	32	34
Total variable cost		**0**	**0**	**0**	**1.587**	**1.635**	**1.684**	**1.734**	**1.786**	**1.840**	**1.896**	**1.953**	**2.011**	**2.072**	**2.134**	**2.198**	**2.264**	**2.332**	**2.403**	**2.475**	**2.549**	**2.626**	**2.705**	**2.786**	**2.870**	**2.956**	**3.045**	**3.137**	**3.231**	**3.329**	**3.429**	**3.532**	**3.638**	**3.748**
Net Profit Contribution..		0	0	0	541	584	628	675	725	777	833	891	953	1.019	1.088	1.160	1.237	1.318	1.403	1.493	1.588	1.688	1.793	1.904	2.021	2.144	2.273	2.409	2.553	2.704	2.862	3.029	3.205	3.390
Fixed Cost..		0,0	0,0	0,0	20,0	20,6	21,2	21,9	22,5	23,2	23,9	24,6	25,3	26,1	26,9	27,7	28,5	29,4	30,3	31,2	32,1	33,1	34,0	35,1	36,1	37,2	38,3	39,5	40,7	41,9	43,1	44,4	45,8	47,1
Total cost	**100%**	**0**	**0**	**0**	**1.607**	**1.655**	**1.705**	**1.756**	**1.809**	**1.863**	**1.919**	**1.977**	**2.037**	**2.098**	**2.161**	**2.226**	**2.293**	**2.362**	**2.433**	**2.506**	**2.581**	**2.659**	**2.739**	**2.821**	**2.906**	**2.994**	**3.084**	**3.176**	**3.272**	**3.370**	**3.472**	**3.576**	**3.684**	**3.795**
Operating Surplus (EBITDA)..		**0**	**0**	**0**	**521**	**563**	**607**	**653**	**702**	**754**	**809**	**867**	**928**	**993**	**1.061**	**1.133**	**1.209**	**1.289**	**1.373**	**1.462**	**1.556**	**1.655**	**1.759**	**1.869**	**1.985**	**2.107**	**2.235**	**2.370**	**2.512**	**2.662**	**2.819**	**2.985**	**3.159**	**3.343**
Depreciation..		0	0	0	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	0	0	0	0	0	0	0	0	0	0
Operating Gain/Loss..		**0**	**0**	**0**	**-1.843**	**-1.801**	**-1.757**	**-1.711**	**-1.662**	**-1.610**	**-1.555**	**-1.497**	**-1.436**	**-1.371**	**-1.303**	**-1.231**	**-1.155**	**-1.075**	**-991**	**-902**	**-808**	**-709**	**-605**	**-495**	**1.985**	**2.107**	**2.235**	**2.370**	**2.512**	**2.662**	**2.819**	**2.985**	**3.159**	**3.343**
Financial Costs (Interest & LMF)..		188	313	627	940	961	981	1.000	1.017	1.033	1.047	1.059	1.068	1.075	1.080	1.081	1.078	1.071	1.061	1.045	1.024	997	965	925	878	822	758	684	600	504	397	275	140	-11
Profit/Loss																																		
Profit before Tax..		-188	-313	-627	-2.783	-2.762	-2.738	-2.711	-2.679	-2.643	-2.602	-2.556	-2.504	-2.447	-2.383	-2.312	-2.233	-2.147	-2.051	-1.947	-1.832	-1.707	-1.569	-1.420	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Loss Transfer..		-188	-502	-1.128	-3.911	-6.674	-9.412	-12.123	-14.802	-17.445	-20.047	-22.603	-25.107	-27.554	-29.937	-32.249	-34.482	-36.629	-38.681	-40.627	-42.460	-44.166	-45.736	-47.156	-46.049	-44.764	-43.288	-41.602	-39.690	-37.532	-35.110	-32.400	-29.380	-26.027
Taxable Profit..		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Income Tax..		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Profit after Tax..		-188	-313	-627	-2.783	-2.762	-2.738	-2.711	-2.679	-2.643	-2.602	-2.556	-2.504	-2.447	-2.383	-2.312	-2.233	-2.147	-2.051	-1.947	-1.832	-1.707	-1.569	-1.420	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Dividend..		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Profit/Loss		**-188**	**-313**	**-627**	**-2.783**	**-2.762**	**-2.738**	**-2.711**	**-2.679**	**-2.643**	**-2.602**	**-2.556**	**-2.504**	**-2.447**	**-2.383**	**-2.312**	**-2.233**	**-2.147**	**-2.051**	**-1.947**	**-1.832**	**-1.707**	**-1.569**	**-1.420**	**1.107**	**1.284**	**1.477**	**1.686**	**1.912**	**2.157**	**2.423**	**2.710**	**3.020**	**3.354**

Cash Flow	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operating Surplus (EBITDA)........	0	0	0	521	563	607	653	702	754	809	867	928	993	1.061	1.133	1.209	1.289
Debtor Changes........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Creditor Changes........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash Flow before Tax........	0	0	0	521	563	607	653	702	754	809	867	928	993	1.061	1.133	1.209	1.289
Paid Taxes........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash Flow after Tax........	0	0	0	521	563	607	653	702	754	809	867	928	993	1.061	1.133	1.209	1.289
Financial Costs (Interest+LMF)........	188	313	627	940	961	981	1.000	1.017	1.033	1.047	1.059	1.068	1.075	1.080	1.081	1.078	1.071
Loan payments........	0	0	0	-419	-398	-374	-347	-315	-279	-238	-192	-140	-83	-19	52	131	217
Free Cash Flow........	-188	-313	-627	0	0	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	0	0	0	0	0
Financing - Expenditure (Wcap)........	400	400	400	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash Movement	212	87	-227	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Source of Funds																	
Profit before Tax........	-188	-313	-627	-2.783	-2.762	-2.738	-2.711	-2.679	-2.643	-2.602	-2.556	-2.504	-2.447	-2.383	-2.312	-2.233	-2.147
Depreciation........	0	0	0	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364
Funds from Operations........	-188	-313	-627	-419	-398	-374	-347	-315	-279	-238	-192	-140	-83	-19	52	131	217
Loan Drawdown........	6.269	6.269	6.269	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equity Drawdown........	11.642	11.642	11.642	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Funds for allocation	17.723	17.598	17.284	-419	-398	-374	-347	-315	-279	-238	-192	-140	-83	-19	52	131	217
Allocation of Funds																	
Investment........	17.511	17.511	17.511	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Repayment........	0	0	0	-419	-398	-374	-347	-315	-279	-238	-192	-140	-83	-19	52	131	217
Paid Taxes........	0	0	0	0	0	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	0	0	0	0	0
Total allocation	17.511	17.511	17.511	-419	-398	-374	-347	-315	-279	-238	-192	-140	-83	-19	52	131	217
Changes Net Curr. Assets	212	87	-227	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Analysis of Changes																	
Current Assets																	
Cash at start of year........	0	212	298	72	72	72	72	72	72	72	72	72	72	72	72	72	72
Cash at end of year........	212	298	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
Changes in Cash........	212	87	-227	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Debtor changes........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Changes in Current Assets	212	87	-227	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liabilities																	
Creditor changes........	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Changes Net Curr. Assets	212	87	-227	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Check line	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cash Flow	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Operating Surplus (EBITDA)........	1.373	1.462	1.556	1.655	1.759	1.869	1.985	2.107	2.235	2.370	2.512	2.662	2.819	2.985	3.159	3.343
Debtor Changes........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Creditor Changes........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash Flow before Tax........	1.373	1.462	1.556	1.655	1.759	1.869	1.985	2.107	2.235	2.370	2.512	2.662	2.819	2.985	3.159	3.343
Paid Taxes........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash Flow after Tax........	1.373	1.462	1.556	1.655	1.759	1.869	1.985	2.107	2.235	2.370	2.512	2.662	2.819	2.985	3.159	3.343
Financial Costs (Interest+LMF)........	1.061	1.045	1.024	997	965	925	878	822	758	684	600	504	397	275	140	-11
Loan payments........	313	417	532	657	795	944	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Free Cash Flow........	0	0	0	0	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	0	0	0	0
Financing - Expenditure (Wcap)........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash Movement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Source of Funds																
Profit before Tax........	-2.051	-1.947	-1.832	-1.707	-1.569	-1.420	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Depreciation........	2.364	2.364	2.364	2.364	2.364	2.364	0	0	0	0	0	0	0	0	0	0
Funds from Operations........	313	417	532	657	795	944	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Loan Drawdown........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equity Drawdown........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Funds for allocation	313	417	532	657	795	944	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Allocation of Funds																
Investment........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Repayment........	313	417	532	657	795	944	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Paid Taxes........	0	0	0	0	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	0	0	0	0
Total allocation	313	417	532	657	795	944	1.107	1.284	1.477	1.686	1.912	2.157	2.423	2.710	3.020	3.354
Changes Net Curr. Assets	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Analysis of Changes																
Current Assets																
Cash at start of year........	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
Cash at end of year........	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
Changes in Cash........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Debtor changes........	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Changes in Current Assets	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liabilities																
Creditor changes........	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Changes Net Curr. Assets	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Check line	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Balance Sheet		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Assets																																		
Cash Account	0	212	298	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
Debtors (Acc Rec)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Current Assets		212	298	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
Fixed Assets (Booked value)		17.511	35.023	52.534	50.170	47.806	45.442	43.078	40.714	38.350	35.986	33.622	31.258	28.894	26.530	24.166	21.802	19.437	17.073	14.709	12.345	9.981	7.617	5.253	5.253	5.253	5.253	5.253	5.253	5.253	5.253	5.253	5.253	5.253
Total Assets		17.723	35.321	52.605	50.241	47.877	45.513	43.149	40.785	38.421	36.057	33.693	31.329	28.965	26.601	24.237	21.873	19.509	17.145	14.781	12.417	10.053	7.689	5.325	5.325	5.325	5.325	5.325	5.325	5.325	5.325	5.325	5.325	5.325
Debts																																		
Dividend Payable		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Taxes Payable		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Creditors (Acc Pay)		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Next Year Repayment		0,0	0	-419	-398	-374	-347	-315	-279	-238	-192	-140	-83	-19	52	131	217	313	417	532	657	0	0	0	0	0	0	0	0	0	0	0	0	0
Current Liabilities		0	0	-419	-398	-374	-347	-315	-279	-238	-192	-140	-83	-19	52	131	217	313	417	532	657	0	0	0	0	0	0	0	0	0	0	0	0	0
Long Term Loans		6.269	12.538	19.226	19.624	19.998	20.345	20.660	20.939	21.177	21.369	21.509	21.592	21.611	21.559	21.429	21.211	20.899	20.482	19.950	19.292	19.292	18.498	17.554	16.447	15.162	13.686	12.000	10.088	7.930	5.508	2.798	-222	-3.575
Total Debt		6.269	12.538	18.807	19.226	19.624	19.998	20.345	20.660	20.939	21.177	21.369	21.509	21.592	21.611	21.559	21.429	21.211	20.899	20.482	19.950	19.292	18.498	17.554	16.447	15.162	13.686	12.000	10.088	7.930	5.508	2.798	-222	-3.575
Equity	0	11.642	23.285	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927	34.927
Profit & Loss Balance		-188	-502	-1.128	-3.911	-6.674	-9.412	-12.123	-14.802	-17.445	-20.047	-22.603	-25.107	-27.554	-29.937	-32.249	-34.482	-36.629	-38.681	-40.627	-42.460	-44.166	-45.736	-47.156	-46.049	-44.764	-43.288	-41.602	-39.690	-37.532	-35.110	-32.400	-29.380	-26.027
Total Capital		11.454	22.783	33.799	31.016	28.253	25.515	22.804	20.125	17.482	14.880	12.324	9.820	7.373	4.990	2.678	445	-1.702	-3.754	-5.701	-7.533	-9.239	-10.809	-12.229	-11.122	-9.837	-8.361	-6.675	-4.763	-2.605	-183	2.527	5.546	8.900
Debts and Capital		17.723	35.321	52.605	50.241	47.877	45.513	43.149	40.785	38.421	36.057	33.693	31.329	28.965	26.601	24.237	21.873	19.509	17.145	14.781	12.417	10.053	7.689	5.325	5.325	5.325	5.325	5.325	5.325	5.325	5.325	5.325	5.325	5.325
Check Line		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Profitability Measurements	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
NPV and IRR of Total Cash Flow																																	
Cash Flow after Taxes	0	0	0	521	563	607	653	702	754	809	867	928	993	1.061	1.133	1.209	1.289	1.373	1.462	1.556	1.655	1.759	1.869	1.985	2.107	2.235	2.370	2.512	2.662	2.819	2.985	3.159	3.343
Loans received	-6.269	-6.269	-6.269	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equity received	-11.642	-11.642	-11.642	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Cash Flow & Capital	-17.911	-17.911	-17.911	521	563	607	653	702	754	809	867	928	993	1.061	1.133	1.209	1.289	1.373	1.462	1.556	1.655	1.759	1.869	1.985	2.107	2.235	2.370	2.512	2.662	2.819	2.985	3.159	3.343
NPV Total Cash Flow	-17.911	-34.496	-49.852	-49.438	-49.024	-48.611	-48.199	-47.790	-47.382	-46.978	-46.576	-46.178	-45.784	-45.394	-45.008	-44.627	-44.251	-43.880	-43.514	-43.154	-42.798	-42.449	-42.105	-41.767	-41.435	-41.109	-40.788	-40.474	-40.165	-39.863	-39.566	-39.275	-38.990
IRR Total Cash Flow	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
NPV and IRR of Net Cash Flow																																	
Free Cash Flow	-188	-313	-627	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equity	-11.642	-11.642	-11.642	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow & Equity	-11.830	-11.956	-12.269	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPV Net Cash Flow	-11.830	-22.901	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419	-33.419
IRR Net Cash Flow	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Financial Ratios																																	
ROI Profit+Interest/Debt+Capital		0,0%	0,0%	-3,5%	-3,6%	-3,7%	-3,8%	-3,9%	-3,9%	-4,0%	-4,2%	-4,3%	-4,4%	-4,5%	-4,6%	-4,8%	-4,9%	-5,1%	-5,3%	-5,5%	-5,7%	-6,0%	-6,4%	37,3%	39,6%	42,0%	44,5%	47,2%	50,0%	52,9%	56,1%	59,3%	62,8%
ROE (Profit/Shareh. Capital)		-2,7%	-2,8%	-8,2%	-8,9%	-9,7%	-10,6%	-11,7%	-13,1%	-14,9%	-17,2%	-20,3%	-24,9%	-32,3%	-46,3%	-83,4%	-482,9%	120,5%	51,9%	32,1%	22,7%	17,0%	13,1%	-9,1%	-11,5%	-15,0%	-20,2%	-28,6%	-45,3%	-93,0%	-1483,2%	119,5%	60,5%
TR (turn over ratio) Revenue/Debt+Capital		0,0%	0,0%	4,0%	4,4%	4,8%	5,3%	5,8%	6,4%	7,1%	7,9%	8,8%	9,9%	11,1%	12,6%	14,4%	16,7%	19,5%	23,1%	28,0%	34,7%	44,7%	61,0%	91,8%	95,8%	99,9%	104,2%	108,6%	113,3%	118,1%	123,2%	128,5%	134,0%
Capital/Debt+Capital		64,5%	64,2%	61,7%	59,0%	56,1%	52,8%	49,3%	45,5%	41,3%	36,6%	31,3%	25,5%	18,8%	11,0%	2,0%	-8,7%	-21,9%	-38,6%	-60,7%	-91,9%	-140,6%	-229,6%	-208,9%	-184,7%	-157,0%	-125,4%	-89,4%	-48,9%	-3,4%	47,5%	104,2%	167,1%
Net Current Ratio (should be greater than 2)		0,0	-0,2	-0,2	-0,2	-0,2	-0,2	-0,3	-0,3	-0,4	-0,5	-0,9	-3,8	1,4	0,5	0,3	0,2	0,2	0,1	0,1													
Market value of shares (Total Capital/Equity)		1,0	1,0	0,9	0,8	0,7	0,7	0,6	0,5	0,4	0,4	0,3	0,2	0,1	0,1	0,0	0,0	-0,1	-0,2	-0,2	-0,3	-0,3	-0,4	-0,3	-0,3	-0,2	-0,2	-0,1	-0,1	0,0	0,1	0,2	0,3
Debt Service Coverage		0,0	0,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0
Acceptable minimum																																	
Loan life cover ratio																																	
Future cash flow	7.053	7.618	8.227	8.885	9.033	9.147	9.224	9.256	9.238	9.163	9.022	8.808	8.510	8.119	7.623	7.010	6.265	5.375	4.322	3.088	1.655	3.284	4.886	6.462	8.010	9.531	11.024	12.490	13.928	15.339	16.721	18.076	19.404
Principal of loans	6.269	12.538	18.807	19.226	19.624	19.998	20.345	20.660	20.939	21.177	21.369	21.509	21.592	21.611	21.559	21.429	21.211	20.899	20.482	19.950	19.292	18.498	17.554	16.447	15.162	13.686	12.000	10.088	7.930	5.508	2.798	-222	-3.575
Loan life current ratio (should be higher than 1,5)	1,1	0,6	0,4	0,5	0,5	0,5	0,5	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Loan repayments as a ratio of revenue:				24,5%	25,4%	26,2%	27,1%	28,0%	28,8%	29,7%	30,5%	31,3%	32,1%	32,9%	33,7%	34,5%	35,3%	36,1%	36,8%	37,6%	38,4%	39,1%	39,8%	40,6%	41,3%	42,0%	42,7%	43,4%	44,1%	44,8%	45,5%	46,2%	46,8%

APPENDIX B

frá **Вячеслав Соболев** <jscniies@gmail.com> fela nánari upplýsingar 21.10.2010

til Niels Sveinsson <nielssveins@gmail.com>

dagsetning 21. október 2010 10:55

titill Re: would Orthogonal turbine fit for Iceland's tidal power plant?

sent af gmail.com

undirritað af gmail.com

Dear Mr. Sveinsson,

We have analyzed the information, which you sent us.

Keeping in mind that these results are strictly preliminary I can state the following:

1. We propose to place concrete caissons housing orthogonal turbines of various heights (one-, two- and three-staged) as it is shown at Fig. 1. The design of such caisson is shown at Fig. 2. Using almost all the width of Rőst channel we can build a tidal power plant with installed capacity of 130 MW, which would produce almost $0.4x10^9$ kWh per year.
2. I want to emphasize that we do not plan to separate Hvammsfjőrdur from the sea. Closure of Rőst would just lead to the redistribution of water flows in the area thus allowing us to keep the natural tidal range in the area and hopefully to avoid any measures of ecological protection of the fjord.
3. Aforementioned redistribution should be carefully calculated in order to obtain actual water head on orthogonal turbine and to calculate their actual characteristics. If you or your colleagues who made the report on ocean current which you have sent me are going to made such calculations yourselves, we would be happy to provide you with any necessary information. We are also able to conduct such studies, but that would require official collaboration between RusHydro and any Icelandic company which is interested in such research. RusHydro is the main producer of electrical energy in Russia and possesses all necessary resources for any research or design work. Also it must be mentioned that RusHydro is very interested in expansion of international contacts.

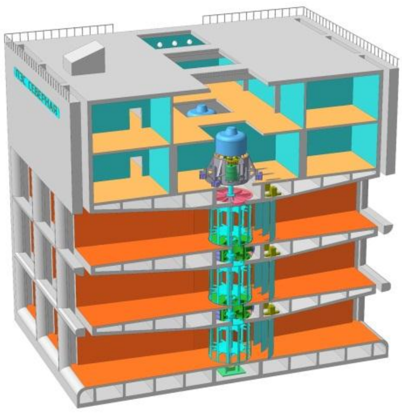
If you have any questions please feel free to ask me, I would be happy to help.

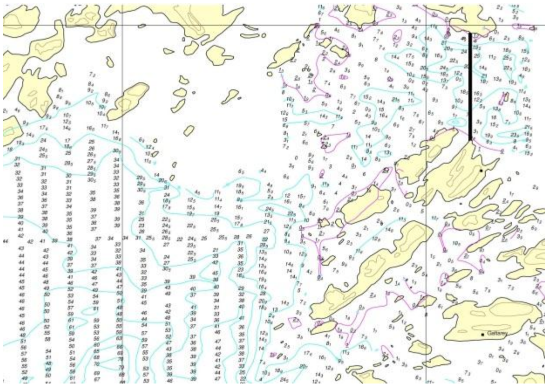
Best regards,

Viacheslav Sobolev,

Senior scientist, Tidal Power Center, JSC NIIES, RusHydro

2 viðhengi — Hlaða niður öllum viðhengjum   Birta allar myndir





frá **Вячеслав Соболев** <jscniies@gmail.com>   fela nánari upplýsingar 10:10 (Fyrir 20 mínútum síðan)
til Niels Sveinsson <nielssveins@gmail.com>

dagsetning 16. de ember 20 0 10:10
titill Re: More information sharing on the Ort ogonal turbine before Thesis Deadline...
sent af gmail.com
undirritað af gmail.com

Dear Mr. Sveinsson,

about the cost breakdown I can say the following:

First of all, I think I gave you rather high estimation of the cost of hydro power unit. Usually when we say 3000$/kW we mean the total cost of tidal power plant construction. So I think at this moment it would be safe to estimate the cost of hydro power unit as 1500$/kW. This price consists of the cost of generator, step-up gear, turbine runners and all additional expenses such as installation etc. It is rather difficult to obtain exact prices on generators, step-up gears and so on as they depend on the amount of produced equipment, are these machines made in series or not, where are they made and so on. So I think for you it will be enough just to mention the total estimated price of the whole hydro power unit.

Secondly, I can give you an estimation of the cost of reinforced concrete which was given to us by Skanska Norge, a Norwegian contractor firm. If floating caissons of tidal power plant

would be built in Norway (and I don't really know what the difference in prices is between Norway and Iceland, I expect they are not very different) they would cost around 1200-1500 $/m3. This price includes the cost of materials, labor, dock preparation and so on.
Thirdly, I don't remember if I sent you the work of British engineers on Severn project. If I did there is a lot of information on tidal power plant construction and there is a whole chapter of the project on the estimation of tidal power plant construction cost. I think at this stage you can use their information, if not the actual numbers than which part (in per sents) of the total construction cost different items (such as for example the cost of foundation preparation) take.

As for your additional questions:
1. 5 m is recommended diameter of orthogonal turbine for calculated water head from 1.5 to 4 meters and for depths up to 40 meters. for higher depths it would be advisable to use turbines of larger diameter, but that would lead to some problems with their cost, production, structure loads and so on. So usually we advise to use runners of 5 m diameter. The height of blades can be different. For example, at Kislogubskaya plant we use runner with the height of blades of 4 m. Power output of turbine (with the same diameter) change proportionally to the blades' height.

2. Rated power of three-staged 5 m turbine is 4 MW. It is rated for the water head on turbine of 2.5 m. Actual power depends on water head.

3/4. Our estimation of annual tidal power plant production, as I said, at this stage is really a wild guess. Usually we consider that in average turbine produce its rated power output 3000-5000 hour per year thus producing 12000000-15000000 kWh per year. But still each project must be considered separately, especially such project as this.

Hope this will help.

frá **Вячеслав Соболев** <jscniies@gmail.com> fela nánari
til Niels Sveinsson <nielssveins@gmail.com> upplýsingar 16.12.2010

dagsetning 16. desember 2010 10:10
titill Re: More information sharing on the Orthogonal turbine be ore Thesis Deadline...
sent af gmail.com
undirritað af gmail.c m

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about the cost breakdown I can say the following:

First of all, I think I gave you rather high estimation of the cost of hydro power unit. Usually when we say 3000$/kW we mean the total cost of tidal power plant construction. So I think at this moment it would be safe to estimate the cost of hydro power unit as 1500$/kW. This price consists of the cost of generator, step-up gear, turbine runners and all additional expenses such as installation etc. It is rather difficult to obtain exact prices on generators, step-up gears and so on as they depend on the amount of produced equipment, are these machines made in series or not, where are they made and so on. So I think for you it will be enough just to mention the total estimated price of the whole hydro power unit.
Secondly, I can give you an estimation of the cost of reinforced concrete which was given to us by Skanska Norge, a Norwegian contractor firm. If floating caissons of tidal power plant would be built in Norway (and I don't really know what the difference in prices is between Norway and Iceland, I expect they are not very different) they would cost around 1200-1500 $/m3. This price includes the cost of materials, labor, dock preparation and so on.
Thirdly, I don't remember if I sent you the work of British engineers on Severn project. If I did there is a lot of information on tidal power plant construction and there is a whole chapter of

the project on the estimation of tidal power plant construction cost. I think at this stage you can use their information, if not the actual numbers than which part (in per sents) of the total construction cost different items (such as for example the cost of foundation preparation) take.

As for your additional questions:
1. 5 m is recommended diameter of orthogonal turbine for calculated water head from 1.5 to 4 meters and for depths up to 40 meters. for higher depths it would be advisable to use turbines of larger diameter, but that would lead to some problems with their cost, production, structure loads and so on. So usually we advise to use runners of 5 m diameter. The height of blades can be different. For example, at Kislogubskaya plant we use runner with the height of blades of 4 m. Power output of turbine (with the same diameter) change proportionally to the blades' height.
2. Rated power of three-staged 5 m turbine is 4 MW. It is rated for the water head on turbine of 2.5 m. Actual power depends on water head.
3/4. Our estimation of annual tidal power plant production, as I said, at this stage is really a wild guess. Usually we consider that in average turbine produce its rated power output 3000-5000 hour per year thus producing 12.000.000-15.000.000 kWh per year. But still each project must be considered separately, especially such project as this.

Hope this will help.

frá **Вячеслав Соболев** <jscniies@gmail.com> fela nánari upplýsingar 4.12.2010
til Niels Sveinsson <nielssveins@gmail.com>

dagsetning 4. desember 2010 21:42
titill Re: More information sharing on the Orthogonal turbine before Thesis Deadline...
sent af gmail.com
undirritað af gmail.com

Dear Mr. Sveinsson,

I am very sorry for the delay but I am on the long business trip to Latin America and will be at the office only on the 10th of December. I will try to do my best to help you but before that date I am out of the reach of the necessary information.

Still, I am able to provide you with some data. First of all, the cost of 2500 - 3000 USD per kW is the estimation of a total cost of a three-storied power unit, including generator and step-up gear. Secondly, our analysis of tidal power plant potential was based mainly on guesswork and experience. For such an unusual scheme as Röst serious hydraulic analysis is absolutely required. As for the characteristics of our turbine, such as efficiency and so on, you can find some information in Marine Energy Supplement. The rest of the data I will send you later, as soon as I will get to the office.

APPENDIX C

LANDSVIRKJUN — Heildsölusamningar 2010

Heildsölusamningar 1. janúar 2010

Einingaverð 3 ára heildsölusamnings 2010

3 ára samningur	2010	2011	2012
Janúar	4,469	4,692	4,809
Febrúar	4,469	4,692	4,809
Mars	4,469	4,692	4,809
Apríl	4,469	4,692	4,809
Maí	3,351	3,519	3,607
Júní	2,235	2,347	2,405
Júlí	2,235	2,347	2,405
Ágúst	2,235	2,347	2,405
September	3,351	3,519	3,607
Október	4,469	4,692	4,809
Nóvember	4,469	4,692	4,809
Desember	4,469	4,692	4,809
Aflgjald (kr/kW)	7.875	8.268	8.475

Einingaverð 1 árs heildsölusamnings 2010

1 árs samningur	2011
Janúar	4,871
Febrúar	4,871
Mars	4,871
Apríl	4,871
Maí	3,654
Júní	2,435
Júlí	2,435
Ágúst	2,435
September	3,654
Október	4,871
Nóvember	4,871
Desember	4,871
Aflgjald (kr/kW)	8.591

Verð er gefið upp án VSK.

APPENDIX D

frá **thorolfur@lv.is** fela nánari upplýsingar 9.12.2010
til nielssveins@gmail.com

dagsetning 9. desember 2010 16:54
titill Fw: spá um raforkuverð á Íslandi, fyrirspurn
sent af lv.is

Sæll Niels

Á glærunni "Möguleg þróun raforkuverðs á Íslandi" úr haustfundarerindi Harðar má sjá aðraforkuverð á Íslandi er sett fram í tveimur liðum. Annars vegar raforkuverð til almenningsveitna og hins vegar til orkufreks iðnaðar. Athugaðu að grafið er á föstu verðlagi og sýnir því hækkun á raforkuverði umfram almennt verðlag í landinu.

Á grafinu er gert ráð fyrir að raforkuverð til almenningsveitna muni halda í við verðlag og þannig vera óbreytt á föstu verðlagi um $30/MWh.

Hins vegar sýnir grafið hækkun á raforkuverði til orkufreks iðnaðar sem er einhvern veginn svona, 2010: $27/MWh, 2015: $33/MWh, 2020: $40/MWh, 2025: $48/MWh, 2030: $65/MWh.

Í dag er Landsvirkjun að selja um 80% af allri raforku sinni til orkufreks iðnaðar og varla útlit fyrir að það hlutfall muni minnka. Með það í farteskinu ættirðu að geta áætlað eitthvert eitt meðalverð Landsvirkjunar út frá þessum tölum fram til 2030.

Vona að þetta hjálpi þér. Annars hikaðu ekki að hafa samband aftur.

Kv,
Þórólfur

APPENDIX E

frá **magnip@landsnet.is** [fela nánari upplýsingar](#) 10.12.2010

til nielssveins@gmail.com

afrit arnije@landsnet.is

dagsetning 10. desember 2010 12:46

titill Tenging Hvammsfjarðarvirkjunar

Sæll Níels,

Takk fyrir fundinn áðan. Það var mjög áhugavert að kynnast þessum pælingum. Ég sendi þér í viðhengi með þessum pósti gróft kostnaðarmat á tengingu virkjunarinnar við kerfið okkar, ásamt korti sem sýnir hvar hún myndi tengjast (Glerárskógar). Eins og við bentum þér á miðast kostnaðurinn við háspennuhlið (132 kV) vélaspennis og gerir í raun aðeins ráð fyrir einum vélaspenni fyrir allar vélarnar (þ.e. framleiðslan frá öllum vélunum er tekin í gegnum einn spenni upp á 132 kV). Ef eitthvað er óljóst þá er þér velkomið að hafa samband við mig.

Gangi þér vel á lokasprettinum.

Kveðja,
Magni

Kostnaðarmat tengingar.pptx
279K Birta Sækja

Below are information from the attachments (Kostnaðarmat tengingar.pptx) that where used in the thesis.

Gróft kostnaðarmat tengingar sjávarfallavirkjunar í Hvammsfirði við flutningskerfi Landsnets í Glerárskógum

Verkþáttur	**Kostnaður**
Loftlína, 40 km	1.600 mkr
Tengivirki Glerárskógar (stækkun)	100 mkr
Tengivirki við virkjun (nýtt)	300 mkr
Alls	**2.000 mkr**


Mjólká
Keldeyri
Geiradalur
Sjávarfallavirkjun
Glerárskógar
Grundarfjörður
Vogaskeið
Ólafsvík
Vegamót
Vatnshamrar
Andakíll

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