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Renewable Electrification for Chiloé Islands

Master Degree Program, Innovative Sustainable Energy Engineering

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ABSTRACT

Small scale renewable electricity is technically feasible but not massively available yet. Many different initiatives are taking place around the world taking solar based systems to un-electrified villages[1]. These types of systems could be enhanced by including other renewable resources available in the vicinity. In fact areas with low solar radiation have no appropriate solution yet.

To address this problem this thesis proposes a robust, user-friendly, renewable generator system appropriate for isolated housing, based on the study case of the islands of Chiloé, southern Chile. This system would address the demand of a single dwelling and aim to be movable and cost effective. The system includes complementary generator sources to offer a more stable supply and be suitable for the conditions of the islands of Chiloé. It is interesting to evaluate the possibilities of combining:

- Wind energy·
- Wave energy
- Micro-hydro energy

KEY WORDS: Small scale electric generation, wave energy, isolated housing.

[1] Grameen Shakthi http://www.gshakti.org/

CONTENTS

Acknowledgment

The master thesis is the final part of my studies in Innovative Sustainable Energy engineering programme at Chalmers University of Technology.

I would like to express my gratitude to all those who assisted me in the process of writing this paper. I would like to thank Isabel Ordonez my colleague, with whom I worked this Master thesis.

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Introduction

The technology to generate electricity from renewable sources, causing a minimum impact on the environment is available. There are several examples of successful implementation of small scale renewable technology around the world. The Freiburg energy plus houses[2] and Michael Reynolds´s earthships[3] are good cases.

It is expected that the demand for electricity grows with the increase in population, as there is an increase in the use of domestic appliances. With such a burden on the existing resources, it becomes necessary to undertake norms to reduce impact on the environment. Steps are being taken in this direction all around the globe, for example, investments on research and implementation of massive wind and solar power plants. Although the massive production of electricity is changing to cleaner forms, the small- scale production must also be addressed, to respond to the demand. In order to obtain a carbon free electricity system we will have to convert the existing grid to a smart one, where the end users are not only consumers, but also producers of energy.

As of 2009, 1.4 billion people had no access to electricity (20% of the world population), of which 85% were located in rural areas[4]. This demand for electricity exists where there is no existing infrastructure for supply. This happens in two types of situations:

- In developing countries with heavily increasing population numbers (for e.g. India).
- In remote areas, where geographic and climate conditions do not permit a reliable energy supply from the grid renders (e.g. southern Chile)[5].

In the first type of situation, usually the amount of people with no access to electricity is significantly higher. For example India has 580 million people with no electricity connection. Although their current network is technically within the reach of 90% of their population, only 43% are connected because many people cannot afford the cost of this service. Added to this, households that may afford the connection are discouraged to do so because of the poor quality of service[6]. Approaches to mitigate this situation will tend to meet the electricity needs of the urban poor before the needs of the rural poor. This is because the urban solution has a much lower cost per capita, in spite the fact that four of every five people lacking electricity live in rural areas. In the second type of situations, distance and geographical conditions make connection of different communities to the national or regional grids expensive. For example in Chile there are a little over 300,000 households with no electrical connection, spread out over the national territory[7]. Many of the unconnected dwellings opt for using diesel generator engines. This would also include travel to purchase the fuel for their electricity, adding the transport costs to their running fuel costs.

Use of diesel engines would cause carbon dioxide emissions. If [8]one would consider all unconnected dwellings in Chile to use this system, the total emissions of CO_2 would amount to 5.5 mega-tons per year[9].

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[2] http://live.pege.org/2005-plus-energy-village/solar-ship, retrieved 2010-12-01
[3] http://earthship.com/, retrieved 2010-12-01
[4] World Energy Outlook http://www.worldenergyoutlook.com/electricity.asp
[5] World bank report :http://rru.worldbank.org/documents/publicpolicyjournal/214jadresic-710.pdf
[6] International energy agency (IEA), 2002. World Energy Outlook 2002
[7]Instituto Nacional de Estadística (INE), 2002. Síntesis de Resultados, Censo 2002

The needs and the requirement of people from developing countries are not the same as industrial countries. The analysis of the problem of developing countries are carried out from the actual situation and the point of view of the industrial countries, and not with the understanding that some of the problems that developing countries have today are of similar nature to those that of industrial countries once had when they were at the same level of economy, technical and organizational development[10]

Aim Of The Work And Methodology:

The aim of the thesis is to design and develop a simple technology to suit single house energy demand. As a case the Island of Chiloe was considered. This thesis also addresses hurdles that one has to overcome to create carbon free self sustained homes.

The metodology used in this study has been: literature review, consulting books, journals, official publications, internet sites, etc. The main topics reviewed were rural electrification, domestic electricity use, renewable electric generation technologies, social and environmental data for the study site in Chiloé, basic electric theory and market availability of specific technologies and materials

During the research process different people in Chile and Chiloé have been contacted. The most interesting have been:

- Video interview held with Julio Albarrán, CEO of the Chilean renewable energy company EcoPower.
- A series of e-mails with Solange Duhart, ex director of the Rural Electrification Area for the National Commission of Energy (CNE).

EcoPower is a Chilean company that sells different types of renewable technology systems in Chile. Some of which are the plug and play systems that aim for the same installation simplicity we target. Currently they have a big ongoing project for a wind park in north-west Chiloé, and have tried setting up wind-diesel systems on smaller islands in Chiloé.

Mr.Solange Duhart was in charge of the rural electrification program when the Isla Tac pilot project was formulated, implemented and later discarded. She has important insight of the existing problems affronted when dealing with rural electrification for Chiloé.

In the design process there were simple experiments conducted to confirm theoretical behavior. The parametric 3-D modeling program Top solid was used for the plans. The CES Edupack software, from Granta was used to help in the material selection process.

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[9] Calculation done only for estimation purposes, using data from the Sustainable Energy Futures course compendium. Assumptions made: annual use per household to be half of the annual primal energy use per capita in a OECD country, oil conversion efficiency of 40%, carbon content of oil 20gC/MJ.

[10] Dillard, Dudley, Economic Development for North Atalntic Community. Historical Introduction to Mordern Ecnomics, Prentice hall Inc. Englewood cliffs, New Jersey USA 1967

1. Chiloe, Chile

Chiloé is an archipelago located in the Los Lagos region, in southern Chile. It is midway-from Santiago to the southern-most point of continental Chile, Tierra del Fuego. The archipelago lies after the Chacao channel, just south of Puerto Montt, the region's administrative capital. This channel is 25.9 kms long, varies between 1.8 to 4.6 kms broad, presenting heavy currents (from 3 to 9 knots) and marks the beginning of Chile's broken coast line.

Chiloe islands is located between 41 ^{0} 47'S to 43^{0} 26'S latitude. The islands are wet with a yearly average temperature of 10^{o}C (varying between an average of 15°C in summer and 5°C in winter). Rains are frequent ranging between 2200 to 3000 mm per year, with no less than 80mm per month[11].

The archipelago is composed by Chiloé's main island, Isla rande (big island), a group of 23 relevant islands (that lie to the east of the main island) and several smaller islets, almost all inhabited, that duplicate the number of islands.[12]

The land is hilly, but not mountainous, and is covered by one great forest, except where a few green patches have been cleared round the thatched cottages. From a distance the view resembles Tierra del Fuego. In winter the climate is detestable, and in summer it is only a little better. The winds are very boisterous, and the sky almost always clouded.

These areas have impressive rain-fall, abundant wind and frequent divisions by canals of sea. It seems as if the natural forces promote isolation and self-provision.

“Having evolved for centuries isolated from mainland Chile, the "Chilotes" developed a strong, self-reliant culture, rich in folklore, mythology and tradition. This very identity is what constitutes the island's major attraction for domestic and international tourism. Tourism to Chiloé is very strongly based on the island's cultural heritage, predominantly consisting of crafts markets, appreciation of cultural landscapes, museum exhibitions, seafood cuisine and architectural heritage[13].”

1.1. Demography

The whole province of Chiloé has 154,800 inhabitants in the year 2002, of which 44% are in rural locations[14]. The population is concentrated in the oriental coast, where the conditions are more favorable. There is less wind and rain than in the western shore, since the coastal mountain range (Cordillera de la Costa) protects the innermost shore of Chiloé from the climatic influences of the Pacific Ocean. There is also availability of ideal agriculture lands, since the ground is very moist and fertile.

The three main cities of the big island are Castro, capital of the province (29,148 inhabitants), Ancud, in the northern area of the island (27,292 inhabitants) and Quellón in the south (13,656 inhabitants). The rest of the towns on the island have less than 5,000 inhabitants.[33]

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[11] http://www.educarchile.cl/Portal.Base, retrieved 2011-03-04.
[12] Dir. de Asuntos Culturales del Min. de Relaciones Exteriores de Chile
[13] Patry, Marc. ”M useums: a link between living cultural heritage and the tourism industry” Museums and Sustainable Communities Canadian Perspectives, ICOM, UNESCO.
[14] INE, Chile, Censo Nacional 2002

1.2. History and Culture

"Chilote" culture differs significantly from the rest of Chile, partly because of its isolation to the mainland. There was a significant cultural mixture between the indigenous people and the Spaniards when they arrived, higher than in the rest of the country.

The archipelago was initially populated by Chonos (a nomadic indigenous group) and later on by Huilliches (part of the Mapuche, indigenous from the mainland) that practiced agriculture and fishing in the eastern shore. The islands where already inhabited when the Spaniards came to conquer in 1567. Given the isolation factor, after the cultural encounter, the population continued with the Huilliche's practices pretty much untouched. Until today the main activities in the archipelago are agriculture and fishing.

Other thing that distinguishes the islands culture is their mythology. A mixture of the ancient Huilliche beliefs and the Spaniards superstitions, "Chilote" mythology counts with numerous magical creatures. These range from ghost ships and witch craft to satiric forest creatures that impregnate the local maidens (Trauco)[15]. This mythology is still seriously believed in by the islanders, shaping their worldview and distinguishing generations of Chilotes from the rest of the Chilean population. In 1843 a significant number of Chilotes where shipped further south, to lay the Chilean claim on Magallanes. The later development in sheep and wool farming in Magallanes is mainly due to Chilote labor. Their influence is still felt in the far south regions[16].

Rural Chiloé has historically depended on fishing and doing subsistence agriculture as means of their sustent. Since the arable land is limited the main logic in their agriculture is self consumption. Some may produce to sell it in local markets, but this endeavor does not generate enough income to be profitable by its self in the long run. They have always accompanied this agriculture with fishing and collecting of mussels, depending on the fertility of the sea as much as they do on the land[17].

Because of this much islanders traveled further south, to Aisen or Magellan's and even to southern Argentina looking for jobs. This means that they were able to save significant money working in coal mines or skinning sheep. Some of them even returned to their original Chiloé, venturing into commercial projects in their towns.[18]

1.3. Architecture

a) Churches

Chiloé is famous for its colonial churches built in wood. There are more than 400 churches scattered around the archipelago, of which16 where accepted into the UNESCO World Heritage List.

Their criteria for acceptance is stated as: "The churches of Chiloé are outstanding examples of the successful fusion of European and indigenous cultural traditions to produce a unique form of wooden architecture. The mestizo culture resulting from Jesuit missionary ac-

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[15] García Barría, N. "El trauco", Tesoro mitológico del archipiélago de Chiloé, Santiago, Editorial Andrés Bello, 1989, pp.120-125

[16] Lonely Planet, Chile, 2008.

[17] Salieres, M; Le Grix, M; Vera, W; Billaz, R. 2005. La agricultura chilota en perspectiva. Economia, Historia y Territorio. Universidad de Los Lagos.

[18]Barrientos, Edison. Video interview, 2008. Historiade un Comerciante. This interview is part of the "Memorias del Siglo XX" initiative from the DIBAM, Chile.

tivities in the 17th and 18th centuries has survived intact in the Chiloé archipelago, and achieves its highest expression in the outstanding wooden churches.[19]"

The story of these constructions starts in the XVII century with the Jesuit missionaries that where in charge of evangelizing Chiloé. Since they needed more priests to fulfill this mission, they asked for permission of bringing Jesuit priests from other parts of Europe, not only Spain.

This was accepted, so they brought foreign priests, mainly from Bavaria, Hungry and Transylvania. It was these foreign priests that impulse the church construction during the XVIII century. These constructions were durable than initial missionary shelters and were inspired in the design of the churches from their home countries. These priests would work with local Chilote carpenters, who provided both materials and labor. Chilote carpenters followed some of the priest's construction advice, but also incorporated their own techniques, inspired on boat construction. Resulting in a rich characteristic form of architecture, that prevailed even after the Jesuits where expelled from the archipelago, in 1767, and the Franciscans took their place[20].

Some of these constructions have fallen or been demolished, but some still remain standing after more than 300 years, making them some of the oldest remaining wooden constructions on Earth. The need to preserve them drove the "Friends of the Churches of Chiloé"[21] to apply them into the World Heritage List.

b) Minga de Tiradura de Casa

Minga in Chiloé means a gathering of neighbors to help in a defined task or work. It is a get together where the person asking for help, provides abundant food and drink for the community that comes to help him. It is a way of obtaining labor with no contract of money exchange. Mingas work under the assumption that the people that come to help to a minga, will eventually need help themselves, so it is a way of the local community to help itself. Mingas can be made for building a house, plowing, harvesting, or "Pulling a House" (Tiradura de Casa)

The tradition of "Pulling a House" is common in Chiloé and the XI region's channels. It consists of literally pulling a house from its location, using oxes and boats to transport it to a new place, where the family desires to live. Houses are pulled by oxes to areas that get flooded in the high tides, and once the house is in the water, it is tied to one or several boats to be dragged through the channels to its new location. Styrofoam and other plastic devices (like buoys) are fixed inside the house to help it float. The structure of the house is also reinforced to help it withstand the different strains the travel will submit it to[22].

This costume is relevant for this project, since it highlights the idea of household mobility that Chilotes have had traditionally. Hence it is necessary to have mobile electricity supply. There is no necessity for the system to be extremely light and portable (Eg: mobile generators for camping sites).

[19] World Heritage Convention, UNESCO , retrieved 2011-02-23.
[20] Guarda, Gabriel. 1995. La tradición de la madera. Santiago de Chile: Pontificia Universidad Católica de Chile.
[21] Fundación Amigos de las Iglesias de Chiloé, retrieved 2011-02-23
[22] Interview with Isadora Ruz, who witnessed a house pulling in Quemchi, 2010.

It should be movable, but not necessarily portable. Ideally it could be dismantled and mounted into a small boat or pickup truck. This approach would avoid investing into fixed infrastructure that will be abandoned if the inhabitants decide to move to a different area.

Figure 1:Minga Tiradura de casa[23] **.**

2. The Power System in Chile

Good economic policies, maintained consistently have contributed to steady growth in Chile. The country had a GDP growth of 5% in 2010[24], and it is predicted to have a GDP of 3.98% between the years 2011-2014. Power consumption of Chile would increase from an estimated 54.8TWh (2009) to 65.4TWh for a forecast period of four years (2014)[25].

Chilean electricity sector was one of the earliest country in the world to privatize the generation of electricity (1986-88), forcing companies to compete between themselves. Which made the sector fairly efficient and sophisticated, according to international standards[26]. None the less, given some recent energy crisis's (Argentina's constraints on gas supply since the late 90s, low levels of water in the dams due to droughts), the cost of electricity in Chile has climbed to be the most expensive in Latin America, having domestic customers pay over 0.22 $/kWh[27].

Though Chile is gifted with abundant natural resources such as hydro and solar power, the majority of energy comes from fossil fuels (63.5%). Being highly dependent on the importation of these fuels. The renewable energies contributes 36.5%, mainly due to hydro electric power (table 1).

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23 http://library.thinkquest.org/25816/tradiciones.htm
24 CIA, World Fact Book, retrieved 2011-02-25
25 Chile Power Report Q3. Buissness Monitor International, July 2010, Pages 56.
26 CNE, Diseño de una estrategia energética para Chile. 2009.
27 nostroza, R. 2010. La Maldición de la Electricidad en Chile, retrieved 2011-03-01

The total installed capacity is 15.94 MW divided into four separate electrical systems: Interconnected System, Central Interconnected System, Aysen Electric System and the Magellan Electric System. The first two systems contribute to 99% of the total installed capacity[28].

Type	%	General Type
diesel	14.67	Fossil Fuel
Carbon	14.37	Fossil Fuel
Natural Gas	34.43	Fossil Fuel
Bio Mass	0.21	Renewable
Hydro	35.77	Renewable
Eolic	0.56	Renewable
Total	100	

Table 1: Installed Capacity by Source Type, (CNE, 2010)

Fossil Fuel 63.47% , Renewable Energy 36.53%

2.1. Potential of Renewable energy in Chile

Chile is placed in strategic location (relative to sea lanes) bordering the South Pacific Ocean between Argentina and Peru. The coastline runs 4,270km; the country has 12,290 sq km of running fresh water and the Atacama Desert occupying 181300 sq km[42]. These varied landscapes make Chile rich with natural resources.

Chile depends heavily on fossil fuels to drive its economy and most of the fuel is imported which makes the country highly vulnerable to the global market[29].This problem can be easily overcome by utilizing natural resources, which would make the country energy independent. Even though hydro power contributes 35.7% of total energy production (table 1), recent droughts and energy crisis have made Chilean authorities think about mixed power generation. A recent study made by Chilean Ministry of mines estimates 16,000 MW of geothermal potential that could be tapped, exceeding the entire current national installed capacity[30].

Solar power in the North of Chile is viable and constant, since the Atacama desert has hardly any rainfall (less than 1mm/year[31]). Solar intensity has been mapped throughout Chile, by Rodrigo Escobar (director of the Master's in Energy and engineering at Universidad Catolica).

Wind energy potential in Chile is higher in the southern compared to northern Chile. Numerous companies have started investing in Chile to harness wind energy. Some of the important investments are from Sea wind 100 MW wind farm, SN power 46MW Canela 18.15MW[32] .

28 http://centralenergia.cl/centrales/, retrieved 2011-02-20
29 CNE, *Diseño de una estrategia energética para Chile*. 2009.
30 http://thinkgeoenergy.com/archives/1840
31 http://www.extremescience.com/zoom/driest-desert, retrieved 2011-03-01
32 http://www.finalternatives.com/node/10911

Wave Energy Chile with a long coast line of 4270 Km has been estimated (Baird & Associates Santiago and Canada) to be the country with highest wave energy potential in the world[33]. The installation of underwater turbines would make it possible to harness 3800 MW of energy which is 26% of the country's total requirement as of 2007[34].

Potential of Renewable in Chiloe Islands: A study conducted in 2004, prepared by the e7 Fund in collaboration with CNE (Chile´s National Energy Commission) and UNDP (United Nations Development Program), presented the pre-feasibility report of powering 36 Islands of the Chiloe Archipelago with Renewable and / or Hybrid Energy Systems within the Chilean Government's Rural Electrification Program. This study investigated in detail the installation of wind-diesel hybrid generation systems coupled to local distribution grids for 32 Islands, involving approximately 3,700 customers[35].

The recommendations obtained from this report are:

- The technical and financial studies have indicated that installation of wind diesel hybrid system is viable, sustainable and the cost effective solution to the project.
- The Chilean REP program provides strong institutional and financial support for the electrification of the Chiloé islands

2.2. Rural Electrification Programs

In early 1990's 240,000 rural households were not electrified even though Chile's energy sector was growing at 7%[36] since 1992. To address this problem, the rural electrification program was launched in 1994. It was an initiative designed by the central government to reach disperse and un-dense population. Even though the Rural Electrification Program (REP) was a grand success and is an example for other growing countries to follow, it has not been 100% successful. The ideal goal of REP was to provide service at the standard offered by the distribution grid. The standard is to supply 220 volts effective monophasic alternative voltage and 50 Hertz frequency with twenty four hours availability, which is not been fully achieved yet[37].

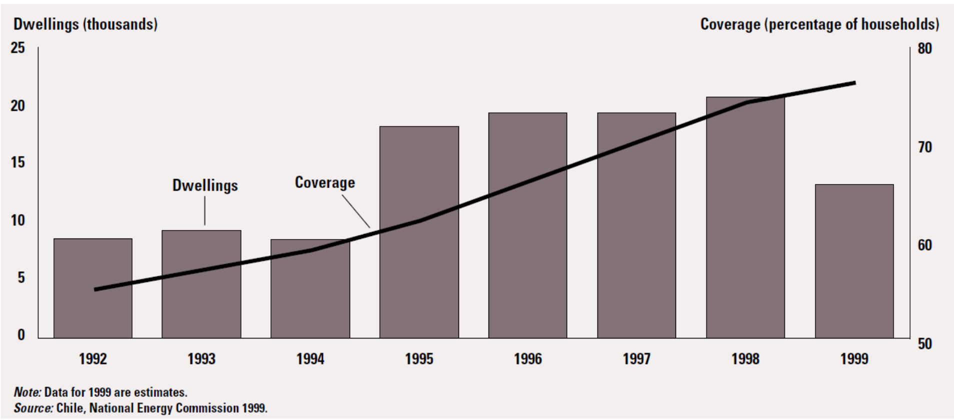

Figure 2:Rural dwellings with electricity between 1992-1999

[33] Monardez, Acuña, Scott *Evaluation of the Potential of Wave Energy in Chile*. 2008.
[34] option=com_content&do_pdf=1&id=131
[35] Chiloé Project, Pre-Feasability Report, December 2004.
[36] http://www.geni.org/globalenergy/national_energy_grid/chile, retrieved 2011-02-25
[37] Jadresic, A. *A case study on subsidising rural electrification in Chile*, World Bank Energy Report, 2000.

a) REP in Chiloé

In 1999 there was a pilot project implemented in Isla Tac, bringing a wind-diesel hybrid generation system to the island with 82 households. An abstract from that report states: "Rural electrification in Chiloe islands have always been a daunting task. The Chiloé archipelago consists of more than 40 islands, of which 32 are too far from the coast to be connected to the mainland grid. These island's have no access to electricity or utilizes intermittent power source like diesel generators. The island's ranges in size from 12 to 450 homes, with projected load requirement ranging from 17 to 1004 kWh/day[38]

This project was intended as a test implementation and data collection to be able to replicate the system for the rest of the islands. It ran under a 10 year contract between the Municipality of Quemchi and SAESA (the electric utility company responsible for the area). SAESA hired a regional company that works with renewable energies, Wireless Energy, to develop and install the system. The whole project started as a cooperative agreement between the United States Department of Energy (DOE) and Chilean National Energy Commission (CNE) under the direction of the Chilean Rural Electrification Program (REP), where the project obtained it's funding[39] .

System was installed the system between May and September 2000, and had it running for few years. Unfortunately, after few years of success, project lost its symbolic importance. There was no further funding for maintenance and a broken helix brought the wind mills to a halt[40].

The local community had invested heavily in domestic appliances to improve their life style. Had no means of financing the long term maintenance of the system. The scale of the system (one central system that feeds 82 households) calls for replacement parts manufactured and expertise is found far from the island). It is important to point out that to reach the Tac Island, one must take a four hour boat ride, from the nearest town on the main island of Chiloé that is already a four hours drive and a 45 minute ferry trip away from continental Chile. One of the most interesting observations done in the report of Isla Tac, is that the villagers are willing to adapt their use of electricity so that the system can work better. "The community has organized to limit peak loading conditions during critical hours buy manually displacing non-critical loads such as freezers to operate at off peak hours. [41]

Besides this project of the REP in Chiloé, there was the E7 study (mentioned in section 5.1.1) conducted in 2004, obtained positive results. Despite pre assessment study and pilot case implementation no progress had been made in implementing hybrid or renewable systems for rural electricity. In 2009 the REP decided to proceed with the electrification of 22 of the internal island of the archipelago using diesel generators[42].Because of the higher cost of the electricity production using diesel, the families benefited from this program, will also be subsidized for a period of 10 years starting from 2010[43].

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[38] Data for the implementation of Isla Tac hybrid project, 1999, retrieved 2011-02-25.
[39] Stevens, N. Wireless Energy Chile Ltda. Isla Tac Power System: First Year Status Report. 2001
[40] Interview with Julio Albarrán, CEO from EcoPower.
[41] Stevens, N. Wireless Energy Chile Ltda. Isla Tac Power System: First Year Status Report. 2001.
[42] News from Radio Bio Bio, Electrification beguins in 22 islands, 2009-11-22
[43] SUBDERE, Precedence of the Plan Chiloé, retrieved 2011-02-10

This solution is not environmentally friendly and is not viable economically, signifying to the government 3 million USD in subsidy per year. The project installed different generators around these islands, each one feeding a group of houses, providing limited hours of electricity supply. For example, the 30kVa generator installed in the island Cheniao, at the locality of El Callao, feeds 23 families between 7 p.m to 11:30 pm[44] REP program was executed between 2009 and 2010. About 223 households and the schools, medical and social centers on these 22 islands (Figure 7). The Department of Regional Development (SUBDERE) states that this is the first phase of this program, but does not specify what the continuing steps would be.

Figure 3: Islands of Chiloe

2.3. Problems with previous REP experiences

During a skype meeting with Julio Albarrán, CEO of Ecopower Chile spoke about Isla Tac project, to understand the scenario in the island. He said "A wind mill was set up, but in short course of time it stopped operating because of lack of maintenance in the Island ". The islander's would require good knowledge of the system, and also some experience to work with these systems.

Huge infrastructure, high front end cost, operation and maintenance cost make these installations impractical. Many ongoing projects have come to stand still due to lack of funds[45]. It is impractical to use diesel generators alone, as the fuel would make them dependent and the cost would increase with time. Taking into consideration the environment surrounding this, it would incur in more money than the renewable system.

[44] News on the Municipality of Quemchi's web page, retrieved 2011-02-15.
[45] A similar hybrid wind-diesel system was being planned by EcoPower for the island of Melinka, in the Palena province, just south of Chiloé. It counted with local support, but there where no means of financing the project.

Figure 4: Newly installed electricity grid on the island of Cheniao, Municipality of Quemchi. The system was inaugurated the 7th of December of 2010.

Conclusion:

In a report from CNE, it is stated that: ”One of the biggest challenges still is to speed up the design and execution of renewable energy projects, sweep away the strong burocratic barriers and improve the technical capacity of the different regional and national actors[46].”

It is seen through this chapter wind generators are advisable for Chiloe islands. Abundant rains suggest a micro-hydro system and small wave generator could be interesting to research.

[46] Duhart, Solange. CNE. ”Difficultades Observadas en la Ejecuccion del Programa de Electrificación Rural en Chile”. Report for the GEF-CNE-PNUD project, 2008.

3. Introduction To Technology:

3.1. Wind energy

Wind is caused by uneven heating of the atmosphere by the sun, irregularities in the earth's surface and rotation of the earth. The kinetic energy from the wind is transformed to electric energy or mechanical energy. Wind turbines can be basically classified into two they are horizontal axis and vertical axis turbines.

For an understanding of wind turbine power equation considered first power extraction by means of a device, which is easily understood. A circular disc of area A is mounted on a trolley (as shown in fig 5). It blows with velocity v and the trolley runs in with average speed u in the wind direction. The trolley is braked with the force F, Fig. 5.The disc relative velocity is v-u. The force that the wind exerts on the disc, is calculated by the equation[47].

$$F = Cd \cdot 0.5 \cdot (v^2 - u^2) \cdot A$$

Where

C_d = air resistance
A = circular disc area
u = initial velocity
v = final velocity

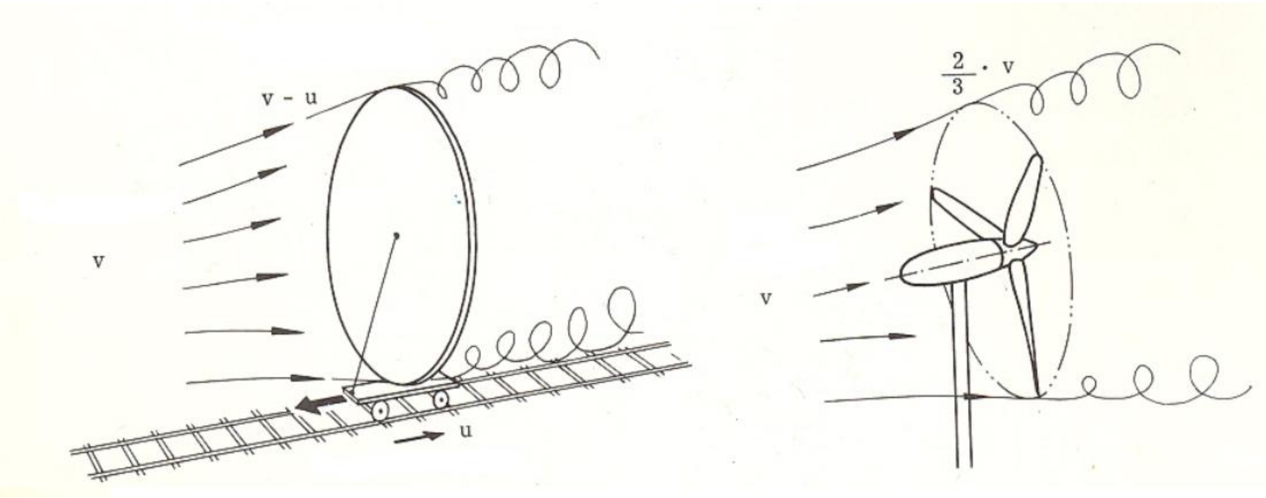

Figure 5 :Principles of Wind

The coefficient of air resistance C_D is 1.12 for a round disc, while considering the air density (1.25kg/m^3).The trolley is also slowed down with a force equal to the air pressure force on the disc. According to mechanics is power is defined as a prodct of force and speed. In this case, the power is F and the velocity u. The trolley slowed thus with power P = F • u. This is the effect that can be utilized, if the braking is done with an electric generator. The equation can also be written as follow

47 Vindkraftboken,Bengt Södergård

$$P = F \cdot u = Cd \cdot 0.5 \cdot \rho \cdot (v^2 - u^2) \cdot u \cdot A$$

By differentiating the expression [1 - (u/v^2)]. (u / v) will be greatest when u/v = 1/V^3. It has the value 0.385. A higher speed and thus less braking power produce less power exchange. Equal thing will happen if the speed is reduced and braking force larger than the best optimal case. Then one gets the maximum effect, which can be extracted with the device

$$P = Cd \cdot 0.5 \cdot \rho \cdot V^3 \cdot [1 - \frac{u}{v}]^2 \cdot u/v$$

Wind turbines propeller brakes the free wind speed v to a lower speed, when the air passes the propeller field. The propeller blades are formed as parts of the screw surface and the slipping away from the wind because of the rotation. With a speed equal to speed of the trolley u. But generator (trolley) tower brakes propeller shaft rotation. It is the equivalent of trolley braking in the first described device, Figure 5.

$$Pi = 0.432 \cdot 0.5 \cdot \rho \cdot A \cdot V^3$$

The effect reaches this maximum, when the velocity through the propeller field is 2 • v/3 and a distance behind the propeller v/3.The real wind turbine propeller has friction losses; relatively exact can be calculated. It also uses measurements in the wind tunnel on carefully conducted propellers in model scale. In calculations and wind tunnel measures, the result is a power coefficient cp, which is lower than the theoretical maximum coefficient of 0.592. Wind turbine real power is:

$$P = 0.592 \cdot \frac{\rho}{2} \cdot A \cdot v^3$$

As a measure of wind turbine capacity to exploit the available wind energy it is common to use the propeller efficiency coefficient

$$\eta_p = \frac{c_p}{0{,}592}$$

Propeller efficiency up to 90% can be achieved, but the practical design wind turbine propeller has an average efficiency of about 70% for different wind speeds. In comparison to other devices for the extraction of wind energy has the propeller an unprecedented high efficiency.

3.2. Solar energy

Solar energy can be harnessed using different technologies some of them are solar cells, photovoltaic cells, solar fibers, solar ponds, solar upward design and energy tower.

But the application of photo voltaic is much easier in homes and it is modular.

Principle of Photo voltaic cells:

PV cells work with the same principle of PN junction. PV cells are made up of two layers positive and negative layer with a barrier between them. When photons (obtained from the sun‘s radiation) falls on the solar cells would create a free electron, hence would result in potential difference.

Each PV cell produce very less energy , hence a number of cell combine together to form a PV module and several modules combine together to form PV.

a) Estimation

Photovoltaic peak power produced is determined by the type and number of panels used:

$$P(Peak\ Panel) = N \cdot P(Panel) = P \cdot T$$

Where

N	= No of panels
P(Panel)	= per panel Energy
T	= Hours of sunshin
P(peak Panel)	= E_{used} / T_{sun}
P	= Power
T	= Time

3.3.Pizo Electric effect

Whenever a mechanical stress is applied an electric charge is produced. This effect is formed in the crystals that have no center of symmetry. Each molecule that makes up the crystal has a polarization one end is positive and the other end is negatively charged and is called as dipole.

In order to produce piezoelectric effect the polycrystalline is heated under the application of strong electric field. The heat allows the molecules to move more freely and the electric field forces all of the dipoles in the crystal to ine up the face in nearly the same direction[48]. Piezoelectric crystal bends in different ways in different frequencies. This bending is called as vibration mode.

Application of piezoelectric: It is used in Cigarette lighter, used in light gas grills or stoves. Attempts to install piezoelectric generators in soldier's boots are researched in United States. East Japan Railway Company powers Tokyo station's ticket gates and display units using piezoelectric energy[49]

3.4.Ocean Energy

Density of water is 832 times more than that of air. For example an 8 Knots tidal current has more energy than 380km/per hour wind[50]. Ocean energy has great potential for future energy requirement.

Different forms of ocean energy that can be harnessed are wave, tidal and ocean thermal energy. Tidal energy and ocean thermal energy would require massive infrastructure and investment. Hence these technologies are not in scope of this report.

[48] http://www.aurelienr.com/electronique/piezo/piezo.pdf
[49] Inhabitat "Design will save the world" Tokyo-subway-get-piezoelectric-floors
[50] tidal Energy PVT

3.5. Wave Energy

Wave are caused by blowing winds, there is tremendous amount of kinetic energy stored in them. Wave energy has a potential between 140-750 TWh / wave per year[51], globally that can be captured economically from existing technologies.

a)Power Estimation

Wave power can be estimated by using:

$$P = \frac{\rho \cdot (g^2) \cdot T \cdot H}{32 \cdot \Pi} E = P \cdot hr = H \cdot g \cdot \boldsymbol{\eta} \cdot Q$$

Where

P = wave power (W/m)
g = acceleration due to gravity (9.86 m/s)
T = period of waves (s)
P= density of sea water (1025 kg/m^3)
H= wave height (m)

b) Present Technologies used in wave energy

There are many technologies today to capture wind energy these technologies are in different phases they are oscillating water column, Attenuators, Mac cube wave pump, Pelamis wave energy , Aqua Buoy point absorbers.

Pelamis Wave energy :

Pelamis is world's first commercial wave energy project delivering 2.25 MW at Agucadoura (coast in Portugal) which has a potential to displace 60,000 carbon emission[52].

Principle of Pelamis:

The system consists of semi submerged cylindrical sections linked by joints. The wave causes relative motion which is resisted by hydraulic cylinders. This would cause high pressure oil through hydraulic motors. The hydraulic motors in turn would drive electrical generators to produce electricity.

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[51] Technology White, Wave energy potential on the U.S. outer Continental Shelf
[52] Power Technology.com http://www.power-technology.com/projects/pelamis/

4. ENERGY USE - ELECTRICITY USE

Electricity is one of the most common energy carriers in the world makes people sometimes turn to electricity to power their kitchen stoves or radiators. When in an area where electricity is unavailable, it is wise to clearly define what energy needs can be satisfied by other means than electricity.

The energy need in rural communities may be divided into the following categories[53]:

1. Heat
2. Water
3. Lighting
4. Cooking
5. Electricity (to operate specific equipment, like water pump
6. Refrigeration of food
7. Communications
8. Transportation
9. And some agriculture equipments

Transportation and agriculture are beyond the scope of this study, since aim is to provide electricity to households. The rest of the categories will be analyzed in this chapter.

It is important to say that the energy used for agriculture or other small scale commercial activities have a direct influence in the islanders productivity, hence to their economic potentiality and life quality. None the less this report aims to solve problems oriented with domestic electrification.

4.1. Cooking and Heating

In Chiloé, as in many other parts of the world the means of heating and cooking is through firewood. These islands have the advantage that wood is an abundant and locally available fuel. There have been initiatives to promote sustainable firewood production and usage[54], regulating forestry, so to protect endemic species and bio-diversity. Many Chilote farmers live of selling firewood, so getting them to certify themselves as sustainable firewood producers is a challenging ongoing process.

It is greatly embedded into the Chilote culture [55] to have a cast-steel central heart, which is used for cooking, drying clothes and family gathering around the warmth. It is considered as soul of the home.

If a firewood heart is implemented with adequate ventilation, good thermal isolation of the housing and a proper filtering system for the fumes, it becomes an effective and sustainable means of heating[56]. Unfortunately, all these conditions are not normally fulfilled in Chilote households. To start implementing these measures in Chiloé, would be more efficient and sustainable way of satisfying the need of heating and cooking with firewood. None the less, this lies beyond the reach of this study. We will consider that the need for heat and cooking fuel is satisfied by this mean, so no electricity will be used for that matter in the proposed system.

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[53] Bassam, Maegaard. 2004. Integrated Renewable Energy for Rural Communities

[54] Sistema Nacional de Certificación de Leña (National System of Firewood Certification) did téchnical talks in Expobosque 2011, in Chiloé this past February.

[55] Venegas, Schweikart, Paredes. 2007. Chiloé: una reserva de Patrimonio Cultural.

[56] Gulland, J. 2010. Sustainable Firewood: Recycling Atmospheric Carbon.

4.2. Lighting

Energy efficient bulbs are recommended, as it would consume 80% less energy compared to normal bulb. Simple spiral fluorescent lamp has a life span of 10,000 hours[57]. Requirement of illumination varies with need of the user, the system design considers 5 spiral fluorescent lamp.

4.3. Water

The houses on the inner islands of Chiloé do not count with communal piping systems. Their inhabitants rely on rain or nearby streams to provide them of water. Fortunately the environment where they live in is rather clean, so locally available water is considered drinkable. Even so, some people prefer to buy their drinking water in the bigger islands, or boil water before consumption. The average yearly rainfall in Chiloé[58] is sufficient to feed a rain water collecting system that could provide household water, if no nearby well or creek is available. The fact that they rely on these sources for water tells us that they need to be able to power water pumps and gives room for the possibility of using micro-water electric generators. This will be further evaluated when designing the generator system.

4.4. Refrigeration of Food

General electric company produces small refrigeration units. The model considered in analysis was SMR0DAS[59], with a storage capacity of $0.121m^3$. It is a compact refrigeration unit, since it is considered only for food that will go bad if not kept in cold storage. Its overall dimensions are approx 530 x 520x $830mm^3$. This would be ideal for the islander's usage, since it has such a low energy consumption.

4.5. Communications

The most common equipment on the islands once they get electricity is the TV (table 3, next page). None the less, it is a very passive communication element that doesn't allow user interaction, so the system design will give preference to computers instead. Personal computers or laptops can provide the same function as a TV and much more, for similar cost. Though laptops are not very prevalent among the islander's, System design considers usage of laptops for future consideration. A normal laptop would consume 60 - 190W[60].

The most elemental communication equipment is the radio. Families in these islands normally have one running on batteries, may it be only to listen to, or also as a two way reception devise. But, the introduction of mobile phones is growing widely. The system considers mobile with AC-5 charger which would require 0.3W

4.6. Electric Appliances

Here we consider all the rest of the appliances that serve an important use to the islanders 82 end users at Isla Tac.

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[57] Commercial lamps Online, retrieved on 29/03/2011

[58] Los Lagos meteorological data, Educar Chile web site.

[59] General Electric Appliances: SMR04DAS retrieved on 29/03/2011.

[60] Penn computing,retrieved on 29/03/2011.

Equipment	Nº
Television	85
Radio	70
Washing Machine	40
Electric Iron	30
Refrigerator	18
Dryer (Cloth Spinner)	16
Battery Charges	15
Electric Drills	12
Electric Saws	4
Freezer	3
Computer	1

Table 2: Equipment distributed between the 82 end users of Isla Tac

As a referents, the following chart shows the distribution of domestic equipment in the Isla Tac community[61], after the first year of the pilot project's implementation (presented in section 3).

Of the equipment that is not present in the other sections of this chapter, the most relevant are the washing machines. This reflects the substantial work alleviation that these units present[62].

Moist climate makes it tough for clothes to dry; hence the usage of centrifuge is very prevalent among islanders. System design considers washing machine indesit PWE 8148 model, which has an A energy rating[63], and an included cloth spinner mode. Since the consumption of water from a well or nearby creek is a daily routine, the system design considers a small scale water pump. QY65-7-2.2 is chosen, a centrifugal pump that requires 2.2KW.

Conclusion:

Energy consumption is vital for the system design. The analysis of the energy needs, or expectations during a period of time, the economic activities and financial resources of the users, are some fundamental parameter needed for the selection of the appropriate energy system. In fact, the function of the energy system, its size and power needs (including power reserves) should be calculated from the user needs and their financial resources, and available and energy resources.

[61] Stevens, N. Wireless Energy Chile Ltda. Isla Tac Power System: First Year Status Report. 2001.
[62] Rosling, Hans. 2011. The magic washing machine. Ted talks.
[63] Indesit Washer Machine, retrieved on 29/03/2011

House hold electrical appliances used by the islander’s were identified with references to other projects and by personal questionnaires (detailed in section 6.1). Islanders use electrical appliances such as refrigerator, small water pump, lights, washing machine and it is anticipated in near future laptop and mobile phones will be more predominant. It is recommended to use energy efficient appliances. Thus, the following chart summarizes the suggested use of equipment.

	Nº Use Hours	Nº Hours per year	kW	kWh/day
Light	20	7300	5 x 0.011	1.1
Refrigeration	24	8760	0.039384	0.945205
Laptop	2	730	0.061	0.122
Mobile Phone	2	730	0.0005	0.001
Washing Machine	0.5	182.5	0.17	0.085
Water pumps	1	365	2.2	2.2
Total				4.4532

Table 3: Suggested load

5. PROPOSED SYSTEM

Now by recollecting the information that was presented earlier, the idea of the system is proposed.

5.1. Requirement of Electricity

To define the electric consumption required we will take several approaches:

a) Have a rough estimation based on available data of Chile's energy consumption per capita, the portion of energy used in households and the amount of people per household.

b) Use the data collected by previous rural electrification programs done in the area as reference for this project.

c) Propose an ideal consumption model, defining the different uses electricity will have in the islander´s case.

d) Interview islanders about their current electric use and supply situation.

a) Rough Estimation

Each person in Chile has an average consumption of 3326 kWh per year[64]. But, only 16% of that energy is used in residential areas[65], leaving us with a residential consumption per capita of 532 kWh/year. Considering also that there is an average of 4 people per household in the province of Chiloé[66], a final estimation of 2129 kWh/year per household. This is equal to 5.8 kWh/day, or 0.24kW of power. As a comparison an average home in the US would need 1.02kW[67].

b) Data from previous REPs

From the first year status report, of the Isla Tac power system (presented in the section 5.2.1) we know that in the first year of operation, the system produced 54 kWh/day. This was divided between 82 users, resulting in an average of 0.66 kWh/day per household[68].

The same report clarifies that the system's use is not equally distributed. Four costumers have the grid installed but do not use it. The minimum use is of 1.65 kWh/day (57 customers, the vast majority), followed by 3.3 kWh/day (13 users) and with a maximum of 9.9 kWh/day (a single user). This high usage is suggested to be due to productive activities realized with electricity.

The REP implemented in Chiloé 2010 (described in section 5.2.1) had several different sized solutions. Since it has been extremely difficult to obtain information on all the 22 systems installed, only a few examples are presented.

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[64] International Energy Agency, Key World Energy Statistics, 2009. Obtained using data from page 52.
[65] CONICYT, Chilean Government. The Energy Sector in Chile, 2007. Page 2.
[66] Obtained from the database of the 2002 Chilean National Census, INE.
[67] Electrical Energy." The New Book of Popular Science. 2000 edition. Grolier Incorporated, 1998.
[68] Stevens, N. Wireless Energy Chile Ltda. Isla Tac Power System: First Year Status Report. 2001.

Yr. Operation	Generation KWh/day	Generacion KVA/day	Generation KWh/yr	Diesel Fuel Liters	Diesel Operation Hours	Maximum Demand KW	End Users
YR1	47	55.3	17000	3128	818	7.5	59
YR10	85	100	31000	9505	2394	15	78
YR1 Actual	54	89.4	19710	5300	2820	7.4	82

Data recollected in the Isla Tac project. YR1 and YR10 are yearly estimations developed with the studies' models. YR1 Actual is what actually happened the first year of implementation

In the locality of Metahué there is a 150 kW generator that supplies energy from 9 to 12 pm. These results in 450kWh shared between 90 households, which would mean an average of 5 kWh/day per household.

In the island of Cheinao they have two 30 kW generators. One feeding 18 families in the locality of Capilla and the other supplying energy for 21 families in the area of El Callao. Both function for 4.5 hours between 7pm and 11:30pm. Families in Capilla obtain 7.5 KWh/day and the ones in EI callao 6.4KWh/day.

It is important to say that these estimations are based on data given on journal's coverage about this news, and we are not considering any losses produced in distribution or 0therwise. It serves only as illustrative examples, to know what size of systems the REP in Chiloé considered.

c) Ideal Usage Load

As justified and detailed in chapter 5, it will be considered 4.4 kWh/day as ideal usage of load.

d) Interview with Islanders

A survey was sent to the people living in the municipality of Quemchi to understand the life style and the energy required per household.

The questions in the survey were:

1. Where do you obtain the electricity used in your home?
2. How much money do you spend on electricity monthly?
3. Do you consider this expensive?
4. What do you use electricity for?
5. Do you have electric machinery?
6. Do you have electric supply constantly or is it interrupted?
7. If you could use more electricity, what would you use it for?
8. Have you heard of renewable energy generators?

Table 4 shows the different answers obtain from this survey. For comparison purposes the second column shows the results from someone living in a town on the big island of Chiloé, where they are connected to the central interconnected grid system.

Place	Quemchi Town	Caucahue land
Q.1	Saeza Mainland	Diesel Generator
Q.2	17000$	25000$
Q.3	No	Yes
Q.4	Washing Machine, Refrigerator, Computer, Lights	Refrigerator, Centrifugal
Q.5	No	Water Pump
Q.6	Constantly	It is turned off in the
Q.7	Nothing	Nothing
Q.8	Yes, but I don't know	No

Table 4: Survey results.

5.2. System Description

Houses in Chiloe Island's can satisfy their energy requirements by capturing available natural resources. (Potential natural resources in Chiloe reviewed in section 3.1). Requirement of energy in these islands' (assessed in the previous section) will be defined for 4.4 kWh/day. Hence to make natural resource available to the islander's, an Electric Generation Gadgets (EGG) system is introduced. The EGG system contains different small scale energy generation units. These units will be summed up to satisfy energy requirements of one house. It will be designed to acquire energy from wind, wave and rains, which is found to be abundant in the region.

Proposed system

Micro Wind Turbine
Micro Water Turbine
Small Scale Wave Buoy

With controller

Battery
Charge Controller
Inverter

To user requirements, such as

Lighting

a) Components

The system can be classified into three parts: generation, BICC and supplying it to the end user. Generation: Electricity is generated by using micro wind mill, small scale wave unit and harness rain from micro turbines/ piezoelectric unit.

BICC: Stands for Battery, Inverter and Charge Controller. This is the second phase of the system. It consists of a charge controller, a device to regulate the electric current flowing to the battery. Battery is used to store the generated electricity. And finally an inverter which changes direct current to alternating current.

Supply: Once the required AC is obtained it can be transmitted through cables to the end users.

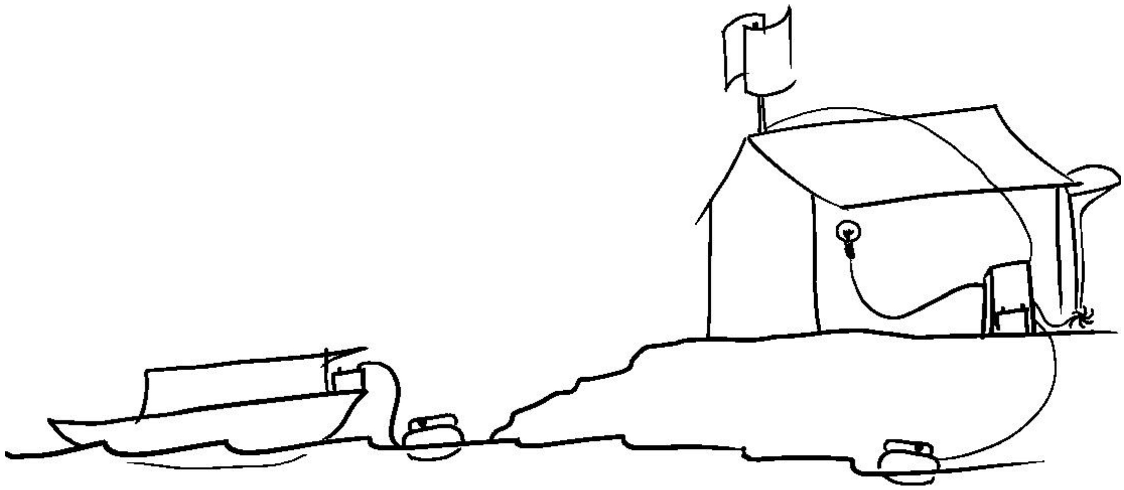

Figure 6: Schematic representation of the different system elements.

Developing the Proposal

Most of the components in the proposed system are common equipment that is readily available in the market today.

From the proposed EGG units, Micro-Wind turbines are very well developed and Micro-Hydro systems have several old solutions. Here the challenge will be to simplify the process of tailoring these solutions to the specific housings, aiming to incorporate the final users into the decision making of where to install these equipments, avoiding costly expert site analysis. This report will also do a comparison between the available products and propose the best considered option. However, in the case of Small Wave Generators, there are no appropriate available products in the market. Hence this research will do design proposals for small scale wave EGG. The BICC is an adding of existing equipment, it can be even bought assembled into one integrated unit. All the user loads can be also bought directly. For this section the report will present a comparative market research and determine the more adequate components.

6. ELECTRIC BASIC CONCEPTS

Generators normally have coils and magnets. They produce electricity by varying the movement between these two elements. The main ideas used in the EGG system to generate electricity are

- Using rotational movement to drive a generator (wind, hydro).
- Using wave movement to change a magnetic field.

Copper windings: Copper is a good conductor of heat and electricity. It is highly corrosive resistant material. Copper has a thermal conductivity of 59.6 x 10^6 S/m making it second among metals. Slow drift in copper is due to the fact that it has a charge density of 13.6 x 10^9 C/m^3. These reasons make copper an obvious choice.

Magnets: Permanent magnets are metallic pieces (normally iron, nickel or cobal) that generate a consistent magnetic field. This field is invisible but affects other ferromagnetic or conducting elements that come into its range of influence. The movement of a magnet inside a copper coil produces an electric current in the coil, which can be stored for later use.

7.1. Faradays law

Electro Magnetic Field (EMF) is induced in a conductor (i.e in a coil) when the magnetic field around it changes. The magnitude of the EMF is proportional to the rate of change of the field or rate of cutting flux, while its direction depends on the direction of the rate of change.

$$EMF \propto \frac{d\Phi}{dt}$$

The constant of proptionally is equal to N the number of turns in the coil cutting the flux, so

$$EMF = -N \text{ X } \frac{d\Phi}{dt}$$

To be able to calculate the magnetic field rate of change in the case of a permanent magnet moving inside a coil, the force of the magnet should be known and the frequency at which it completes a period of variation.

6.2. Ohm's Law

Ohms Law states that current through a conductor between two points is directly proportional to the potential difference across the two points and inversely proportional to the resistance between them. This produces the well known electrical equation that relates Cur rent

$$I = \frac{V}{R}$$

Where,

I= Current
V=Voltage
R=Resistance

6.3. Analog Multimeter

Analog multimeter is a device to measure electrical resistance, voltage, current and frequency[69]. It consists of multiple scales, moving needle and many manual setting on the function switch. It consists of battery, overload compensation and mirrored scale.

It is important to consider operating temperature of the instrument before the experiment is made[70].

Figure 7: Analog multimeter used in our experiment.

6.4. Experiment

To be able to further relate the coil characteristics to the electricity production, a copper coil was winded with approx 220 turns, and a 1Tesla magnet was used to vary the EMF around it. The current produced was measured with an analog multimeter. The results obtained are shown table 5. With these results, we could compare our experiment with an experience recorded by Jonathan Hare and Ellen McCallie[71], in England, when they were experimenting with wave induced coil generation (table 6).

Procedure

1 .Multimeter was checked for zero error. The device was found to have no zero error.

2. The function switch was fixed to mA to measure the respective reading

3. Black (+) and Red (-) terminal wires were connected to the coil windings. The terminals were placed securely with the device to avoid influence of human disturbances.

4. The magnet was passed through the coil with a frequency of one second per cycle to produce EMF.

5. Reading in the multimeter was noted down.

6. The experiment was repeated for five time to avoid parallax error.

[69] How to use multimeter, retrieved on 8/4/2011.
[70] The electricity Forum, analog multimeters , retrieved on 8/4/2011.
[71] Hare, J. McCallie, E. June 2005, *Starting to experiment with wave power* . 2005 Phys. Educ. 40 574-578

N°	Zero Error	volt	mA	volt
1	No	25	1	50
2	No	23	1	48
3	No	25	1	50
4	No	24	1	49
5	No	25	1	50

Table 5: Measurement data

Observation of the Reading:

> No zero error was found in the instrument.
> Number of windings: 220.
> Material: Copper, 0.9mm wire diameter.
> Strength of Magnet: 1 Tesla.
> Scales: 0-250DC V, 0-50 mA, 0-1 k ohms.

The scales have a correction factor from the readings given as: 0.01 for the volts, and 0.001 for the amperes. This is used when passed the results to table 6.

	Coil Diameter (m)	Cross Section Coil m^2	N° of windings	Freq	Tesla	Magnetic Flux	Amp	Volts	Watts (V x A)
Exp 2009	0.980	0.0050	1000	1.0	1	1.00	0.02	5.00	0.10000
Exp 2009 w/wave	0.080	0.0050	1000	7.5	1	0.13	0.02	0.67	0.013333
Exp 2011	0.027	0.0005	220	1.0	1	1.00	0.0002	0.13	0.000025
Exp 2011 w/wave	0.039	0.0012	1000	7.5	1	0.13	0.0002	0.15	0.000032

Table 6: Experiment results

	Wave Period	Seconds Period	Period/Hour	Period/Day	W/day/unit	N° Units	Power Wh/day
Exp 2011	1	8	450	10800	0.34	30	10
Exp 2005	1	8	450	10800	144	8	1152

Table 7: Expected Daily Power Output

Considering a wave period of 8 seconds per waves[72], we can estimate the amount of energy production per day (table 7).

[72] Ross, D. 1995. Power from the Waves. Oxford University Press 1995. Page 199

7. SMALL WAVE GENERATION

Even though wave generation technologies are experiencing a new development given their interesting potentials, there is little research done on micro scale generation. It is precisely this small scale that would be interesting for the isolated households of Chiloé.

In general, the different issues that affect wave generation are:

- The way the gadget is supposed to harvest energy.
- How it is moored or anchored.
- How it is moved by the wave.
- How it floats (its buoyancy).

Buoyancy is a key concept to consider. It means that whatever body submerged (or partially submerged) in a liquid, experiences an upward push that is equal to the weight of the volume of fluid displaced by the body. If the object is less dense that the liquid it is immersed in, then it will stay afloat. This parameter must be considered in the wave generators that can be developed.

7.1. Different Concepts for Wave Generation

Wave energy has great potential in Chiloé islands, as discussed earlier in chapter 3. To harness energy from wave's different concepts were developed. The main criterion during development of these concepts was to make the generator mobile and simple.

Concepts	
1	Vertical Buoy
2	Bottle arrays
3	Snake
4	Blade buoy
5	Dock Buoy
6	Blade Dock

Table 8: Different developed concepts

a)Vertical Buoy

Description: The system consists of a buoy suspended in water. A cable is attached to the buoy leading to a movable magnet which is concealed inside an air tight cylindrical box. Inner circumference of the box has copper windings wounded around. A counter weight is attached to the cylindrical casing to avoid drift, making the system more stable.

Working: The waves would cause linear movement in the buoy. This movement will be transmitted to the magnet causing to generate electromagnetic force when it cuts the copper windings. Spring is used to amplify the movement obeying Hooke's law (F = -K x x) where F is restoring force exerted by the material, x is displacement of the spring end from its equilibrium position and K is spring constant.

Advantages: System is scalable; it's easy to increase number of units to satisfy required power. Several buoys can be connected to the same cable leading to a single battery.

Disadvantages: Connecting to the battery would be challenging. System would require regular maintenance.

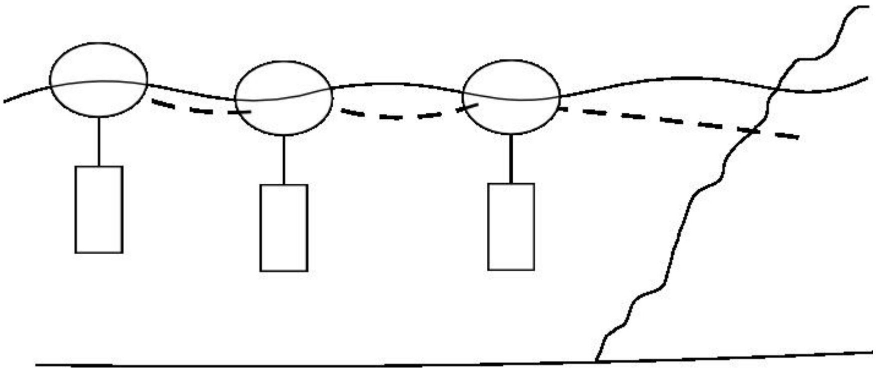

Figure 8: Several vertical buoys connected together.

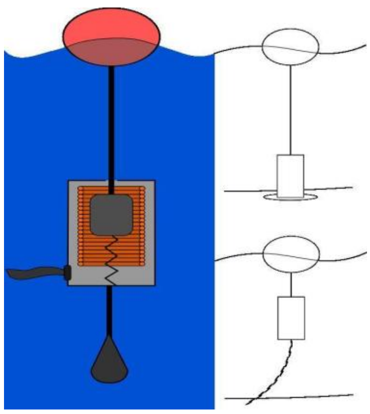

Figure 9: Vertical Buoy Diagram. To the right (different anchoring possibilities)

b) Bottle array

Description: Bottle array is designed to use PET bottles. This consists of copper windings and magnet in it. The system utilizes cable to connect bottles with the battery bank. Bottle can be connected in an array to generate energy.

Working of the system: The bottle would float in water due to buoyancy, when bottle moves along the wave direction this would cause magnets to cut the coil and generate EMF. Generated EMF is stored in the battery through a cable. Increasing the number of units would generate more energy.

Advantage: PET bottle that are discarded can be made productive using bottle array method.

Disadvantage: Bottle array system would be resource intensive; generating sufficient energy would be more expensive than other conceptual designs. Due to the requirement of copper wire and magnets are high.

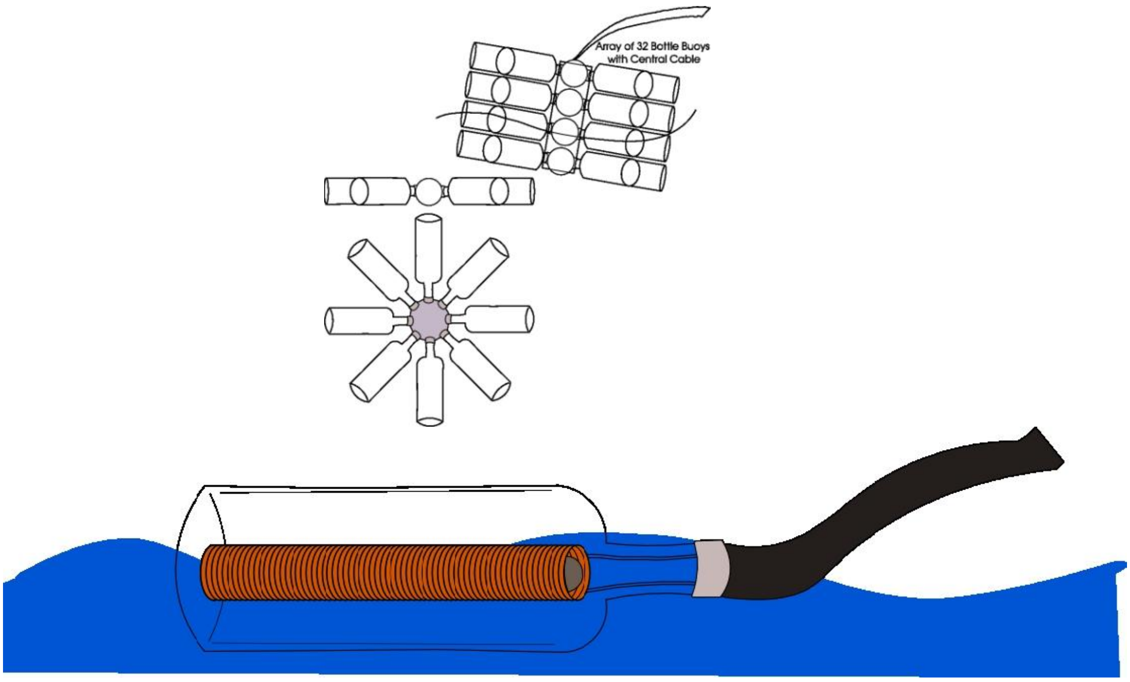

Figure 10: PET Bottle diagram. To the top-right array representations

c) Snake

Description: This system consists of a many cylindrical casing connected to each other via cable. Each casing consists of a coil and a magnet. The number of casing can be increased or decreased based on the requirement.

Working of the system: The snake will experience linear, translation and angular motion causing the magnet to cut the coil hence producing EMF. The system is modular, connected to the battery by a cable running throughout the system.

Advantage: The system is both modular and scalable. It can be used at the boat, to charge the boat's battery. It could also serve as fishing net borders.

Disadvantage: Snake system is resource intensive. The movement it has is very irregular, not allowing for a required frequency in the movement of the generators.

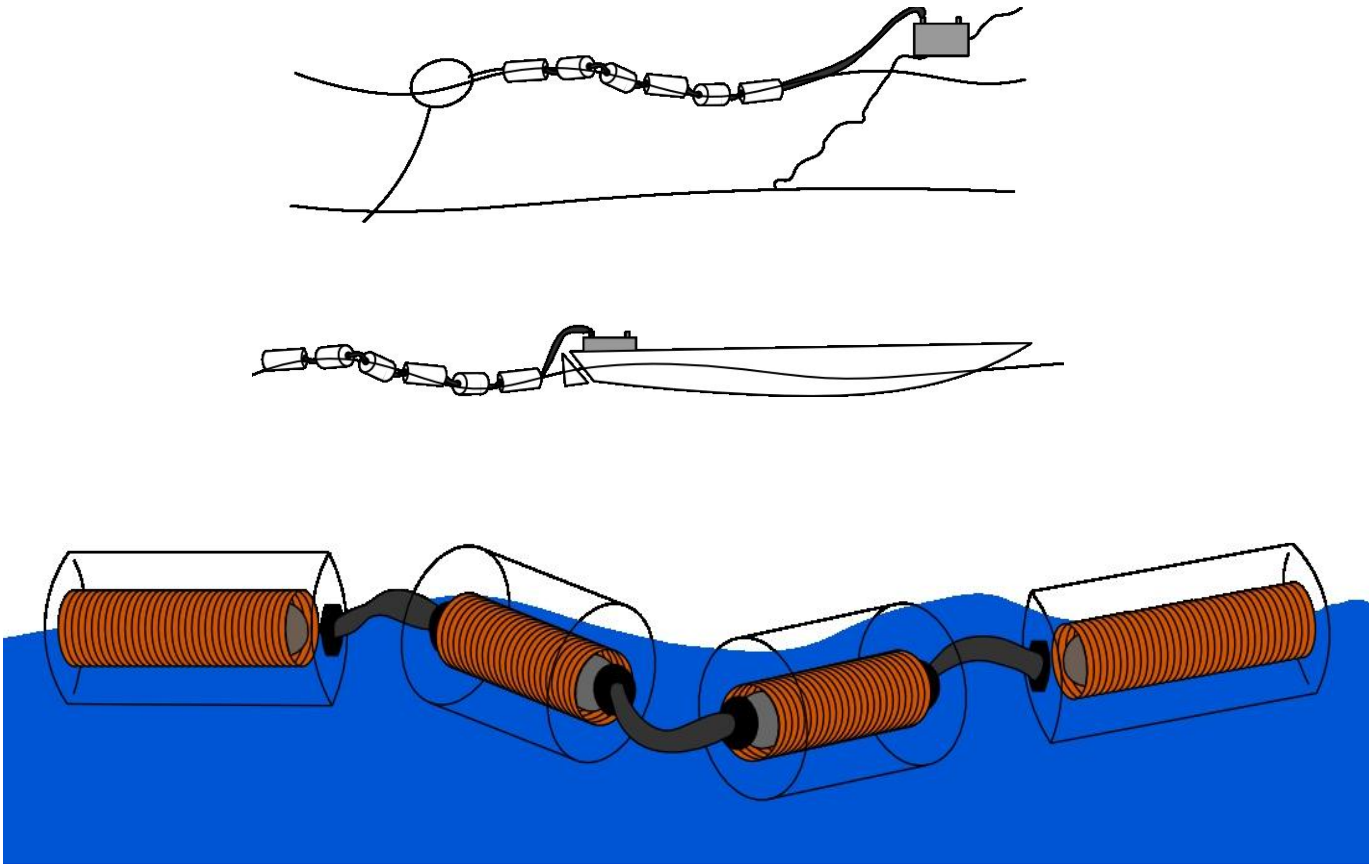

Figure 11: Snake diagram. Upper right shows two possible connections to battery.

d) Blade Buoy

Description: There are two buoys making possible to float. The floating system is a cylindrical pipe connected to fins the interior of the cylindrical pipe consists of magnets which will act as rotor and the coil would act as the stator. Connecting cable is used to connect the system with battery.

Working of the system: The waves would cause the fins to rotate, which in turn would make the system to revolve. This will cause the magnets cut the coil producing EMF. This energy can be transmitted to the battery through the cable. To the battery through the cable.

Advantages: System is scalable and can also be fixed to the existing dock.

Disadvantage: The system can be complex to design and manufacture. The system consists of more components than the other systems

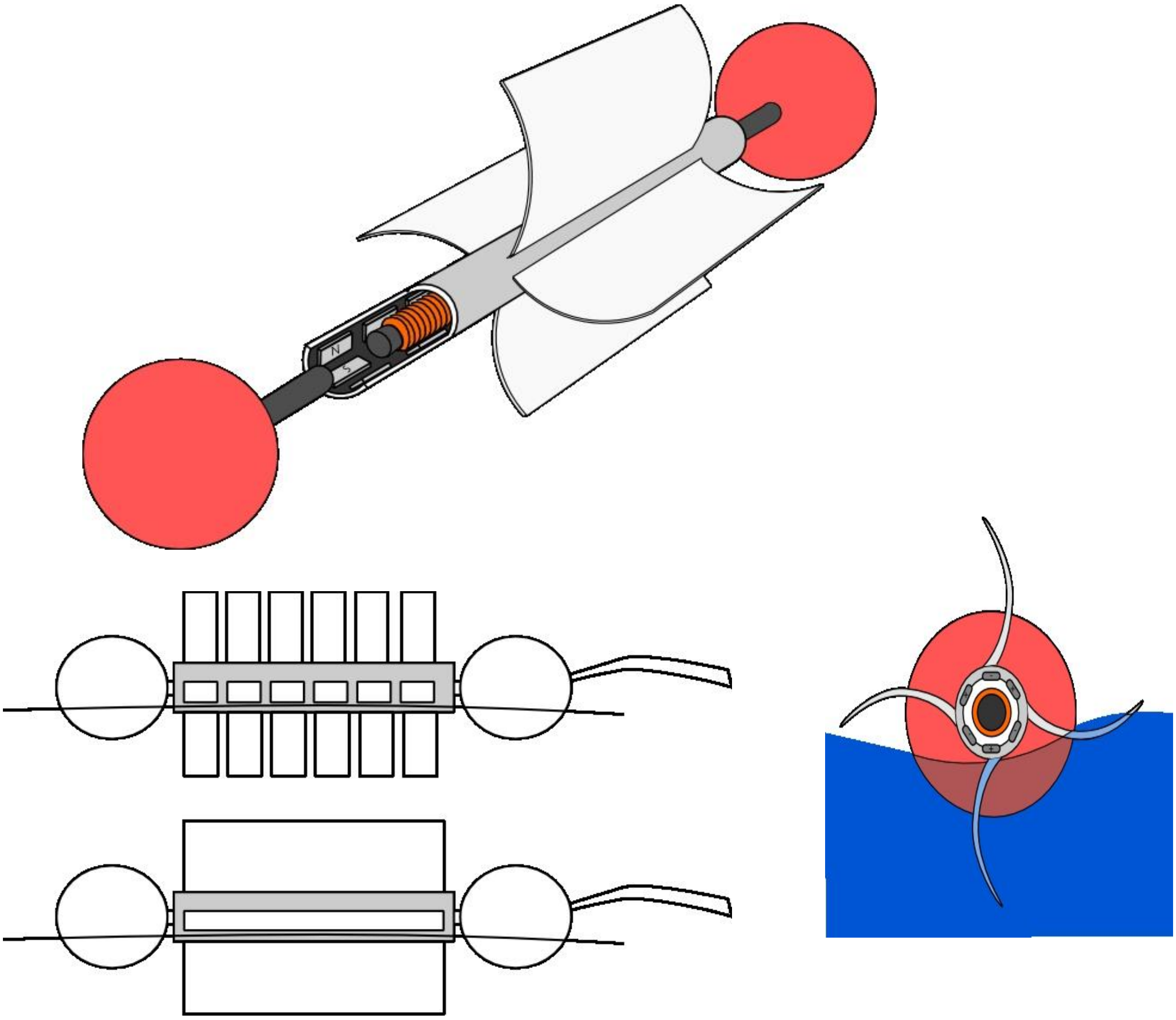

Figure 12: Blade Buoy diagram. From left to right: cross-section, axonometric view with detail, blade type option.

e) Dock buoy

Description: the system consists of a buoy which is placed close to the dock Dock contains lion share of the system such as the fixed coil. Coil and the buoy are connected through a movable shaft.

Working of the Unit: The working principle of the system is simple; when the buoy moves with the waves which translate the motion to the shaft connected to the magnet, hence causing production of EMF. The produced EMF would be translated to the battery through a cable.

Advantages: Simple principle easy to maintain and control.

Disadvantage: Would need a fixed dock, making it case specific.

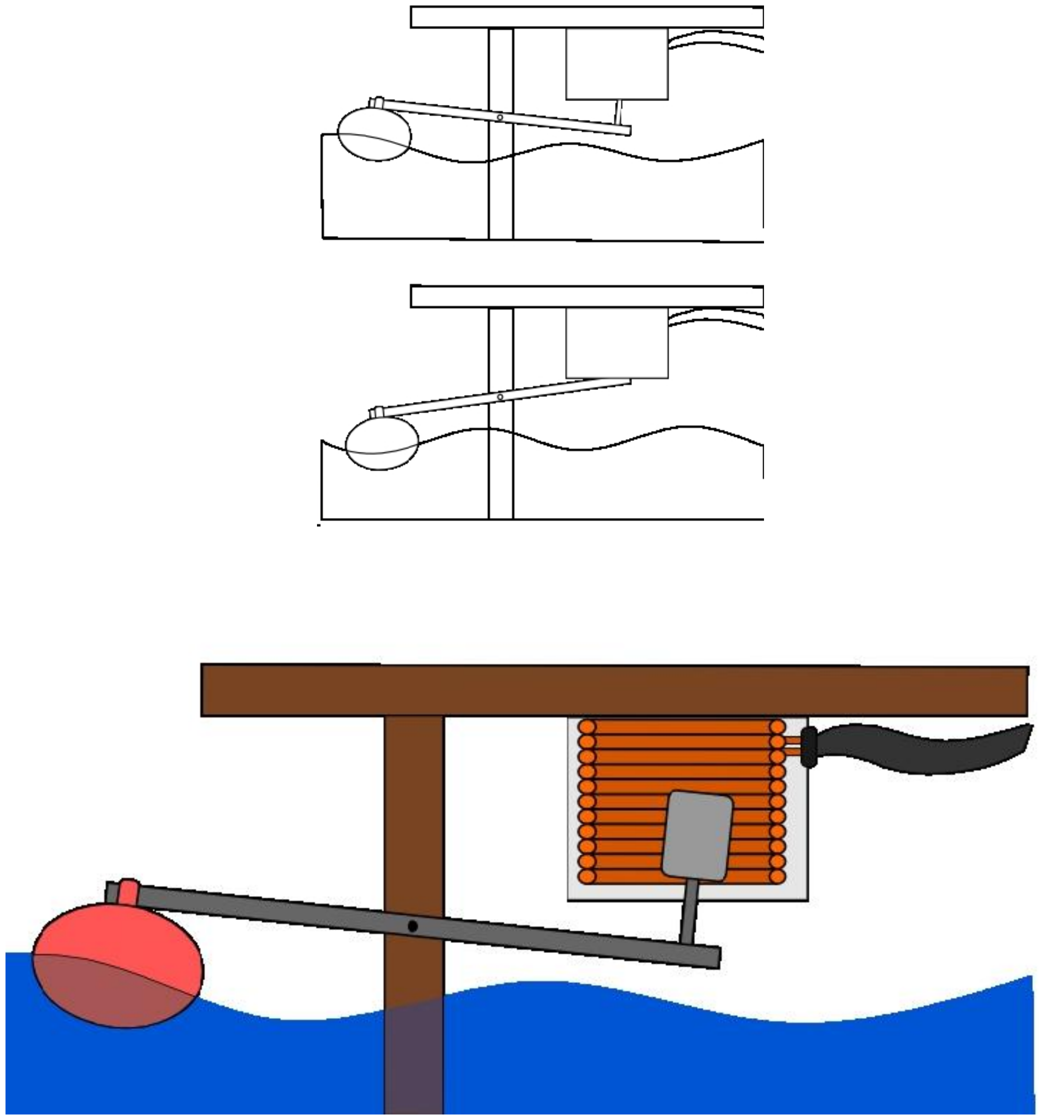

figure 13: Dock buoy diagram. Top-right: Extreme movements in the buoy system

f)Dock Blade

Description: The system consists of a cylindrical pipe attached to a fixed dock. There are four fins attached to the cylinder pipe. And a transmission cable connecting generator and the pipe.

Working of the unit: The wave causes the fins to rotate. This rotation is transferred to the generator via transmission cable. This transmission cable allows for different radius connections, so the low frequency wave movement can generate a more frequent rotational movement that would power the generator

Advantage: This system is simple to build and the generator is on the shore and could be readily bought .It also increases the frequency of the rotation of the generator.

Disadvantage: The system needs a dock and would become case specific.

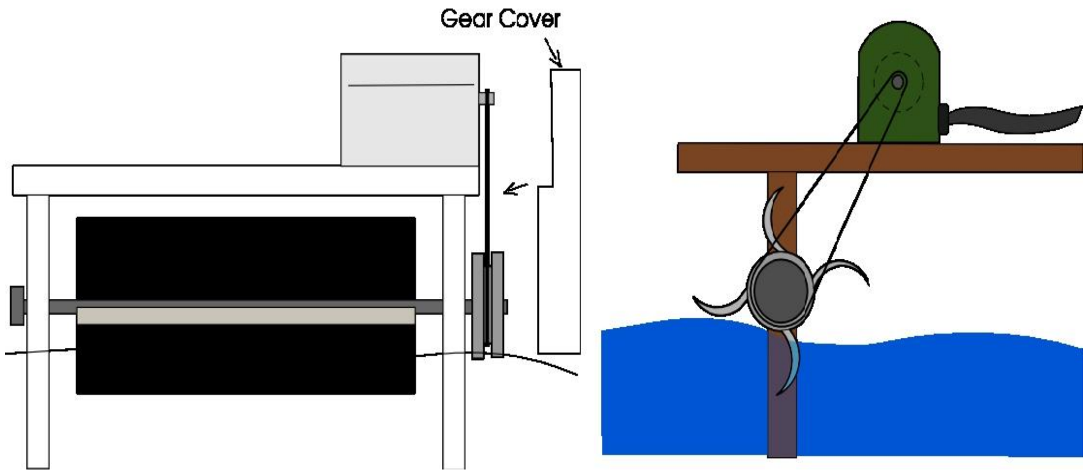

Figure 14: Dock Blade diagram. Top: Frontal view. Bottom: Side view

7.2. Comparison between different concepts

The different conceptual designs just reviewed are compared to further develop the best concept. The fish bone method[95] was adopted to understand the pros and cons of the systems. The basic comparison of systems was based on number of components, moving parts, scalability, multiple units, multi-functionality and production complexity. These factors are compared in table 9 given below.

Continuing, a brief description of the criteria used to compare:

- Number of Components: System with lesser components would be easier to manufacture. Every component of the system was listed to compare them.
- Moving Parts: More number of moving parts would cause wear and tear due to friction. Wear and tear would reduce life span of the component. Hence all the moving parts of different system were compared.
- Scalability: This ability to scale the unit of the system would make it easier during design process. The possibility to scale was considered and compared.
- Multiple Units: Increasing more units to the system would give room for further development of the system. The possibility to have multiple units is compared in the table.
- Multi functionality: Having more uses than one would give an upper hand to the system. The snake concept is considered multifunctional as it can also be used along fishing nets. If the systems were associated to a dock this was also considered an extra functionality.
- Production Complexity: The complexity of manufacturing was also considered during comparison process. It appears as a simple ranking, from 1 (most complex) to 3 (least complex).
- Estimated Power Production: These values were obtained based on the experimental measurements described in the section 7.4. The difference relates more to the assumption that snake buoys would have a slightly higher frequency than that of a vertical buoy, since they would be on the surface instead of submerged. The blade-buoy design considers three different pairs of magnets, making the frequency of magnetic flux variation 6 times per wave instead of one.

[73]The three best concepts were chosen based on less moving parts, less components, ability to scale, ability to add new units and its multi-functionality. The chosen system after initial scrutiny was vertical buoy, blade buoy and snake. Due to production complexity involved in the blade buoy system it will not be considered to be developed further.

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[73] Problem Solving tool www.frahme.com/fishbone.htm retrieved on 30/3/2011

	Vertical Buoy	Blade Buoy	Blade Dock	Bottle	Snake	Dock Buoy
Magnet	1	6	6	n	n	1
Coil	1	1	1	n	n	1
Spring	1				n	1
Box	1	1	2	1		
Weight	1				n	1
Transmission	1		1			
Buoy	1	2				1
Fins	1	4	4			1
Fixed Dock		1				
Floating Dock			1			1
PET bottle				n		
Connection Cable	1	1	1	1	n	1
Total N^{o} Components	8	16	17	2+3	4 x n	7
Magnet	1			1	1	1
Spring	1					
Transmission	1		1			1
Fin+Box+Magnet		1				
Fin+Box			1			
Magnet +Coil Box			1			
Connection Cable Buoy						1
Total N^{0} of Moving Parts	3	1	3	1	1	3
Scalablity/Unit	y	Y	y		y	y
Multiple unils	y			y	y	
Multi Functionality			y		y	y
1st filter			No	No		
Production complexity(RANK)	2	1				3
Estimated Power Production (W)	0.4	1.2				0.5
2nd Filter		No	No	No		No

Table 9: Comparison between different Wave EGG concepts.

7.3. Snake Wave EGG

The snake wave EGG was detailed up to its composing pieces. To be able to define the size each one of these units must have, movement equations for them where calculated. These movement equations considered a wave height of 0.5 meters and a wave period of 8 waves per minute. This gave a very small inclination angle, hence a very short distance to be covered by the rolling magnet, resulting in a very small expected electricity production. Because of this the decision of developing this type of generator was reconsidered.

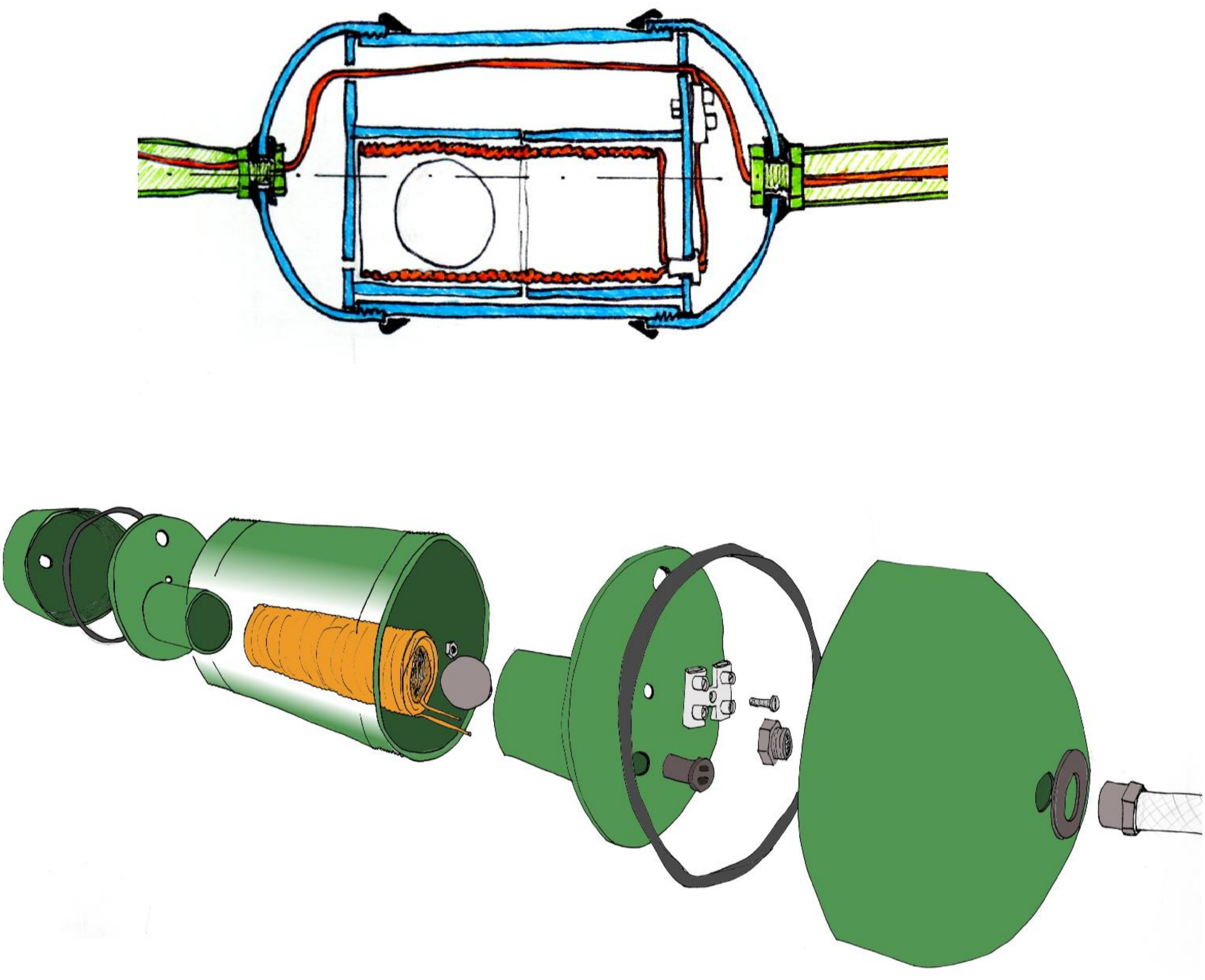
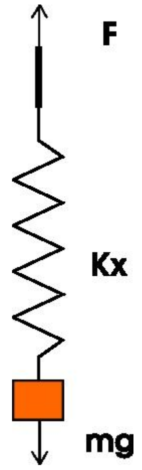


Figure 15: Exploded view of a snake buoy unit. Top right: Section view of the assembly.

7.4. Vertical Buoy EGG

a)Free body diagram

The designed system consists of a transmission cable connecting the spring and the buoy. Extension spring is hooked to a magnet. A free body diagram is as shown to the right.



This leads us to the following equation F=- Kx+mg, where F is force, x is the distance displaced, K is the spring constant, m is the mass, g is the gravity.

Kinetic energy obtained from the waves played a very important role in the design phase of the vertical buoy. Initial calculations revealed the force generated on the buoy by the waves was 0.38 N (considering velocity of 0.2m/s, vertical displacement of 0.5 m, in a time of 2.5 s and acceleration 0.04 m/s^2)[74].

b) Spring Design

The spring is a vital component for the vertical buoy design. The distance travelled by the spring would decide the possible energy that can be produced from the system. The design procedure of spring is as following[75]

Hooke's law states that "The extension of spring is directly proportional to the load applied to it" in other words it can be simply defined as strain is directly proportional to stress. Mathematically Hooke's law can be stated as F = - Kx.

Where K is the spring constant which is dependent on spring geometry, spring material's shear modulus G and the number of active coils, na. K can be defined as

$$k = \frac{Gd^4}{8D^3na}$$

G is shear modulus can be found from the materials elastic modulus E Poisson ratio v

$$G = \frac{E}{2(1+v)}$$

D is the mean diameter of the spring

$$D = Douter - d$$

Distance between adjacent spring coils can be obtained by dividing the spring length by the number of active coils

$$Coil\ pitch = \frac{Lfree}{na}$$

The rise angle of the spring coil is obtained from the arctangent of the coil pitch divided by the spring circumference,

$$\theta = \text{atan}\left(\frac{Coil\ pitch}{\pi D}\right)$$

[74] Ross, D. 1995. Power fro the Waves. Oxford University Press 1995. Page 199.
[75] Efunda, http://www.efunda.com/designstandards/springs,retrieved on 17/04/2011

The solid height of the spring is found by asumming the width of all spring coils and including 2 coils at the spring end.

$$Lsolid = na + 2$$

The length of the wire needed to make the spring is found from

$$Lwire = \pi D\left(\frac{na}{cos\theta} + 2\right)$$

Spring Force and Stress

Maximum force the spring can take when spring deforms all the way to its solid height

$$Fmax = K(Lfree - Lsolid)$$

Maximum shear stress in the spring is associated with the maximum force given

$$\tau_{max} = \frac{8WD}{\pi d^3}F_{max}$$

WW is the Wahl correction factor and is C is the spring index:

$$W = \frac{4C-1}{4C-4} + \frac{0.615}{C}$$

$$C = \frac{D}{d}$$

Spring Resonance

The lowest resonant frequency of the spring is found from the simple equation

$$f_{res} = \frac{1}{2}\sqrt{\frac{K}{M}}$$

M is the mass of the spring which is obtained by the equation given below

$$M = \rho * Vol = \rho(Lwire\frac{\pi}{4}d^2)$$

The design of the spring revealed the distance moved by the spring which is hooked to a magnet of 16.8g. Based on the movement of the spring the placement of the coil and the length of the coil was decided. The spring is designed to have the following characteristics as shown in table . The estimated energy produced from the vertical buoy is 0.6W per wave.

Wire material	Chrome SiliconA401
Spring Constant K	0.451 N/mm
Shear modulus G	79.244 GPa
Mean Diameter of the spring	28 mm
N° active coils	16
Diameter of the spring	2.00 mm
Free length of the spring	70 mm
Maximum Displacement	150 mm
Maximum possible Load	76.72N
Length of the wire to make the spring	1528.00 mm

Table 10: Spring characteristics

C) Object Design:

A three dimensional model was developed for the vertical buoy EGG. It consists of four main body parts (referred to as designed parts, being the items a through d in table k) and uses 10 elements of hardware, to be bought as input (e through n in table k)

The designed parts fulfill different functions:

• Lid (a): Connects the buoy to the generator, through four polypropylene cables. It also allows for the electrical connection, through a water tight rubber fitting.

• Internal lid (b): Serves as union between the Lid and Body. Supports the electrical connection between the cables coming from the coil with the cables going to the exterior storage unit. It also holds the eye bolt from which the spring and magnet will hang.

• Body (c): Encases the generator in a water tight environment. It holds the copper coil in place.

• Bottom (d): Can be removed to vary the amount of weights that the generator needs to counter balance the sea current.

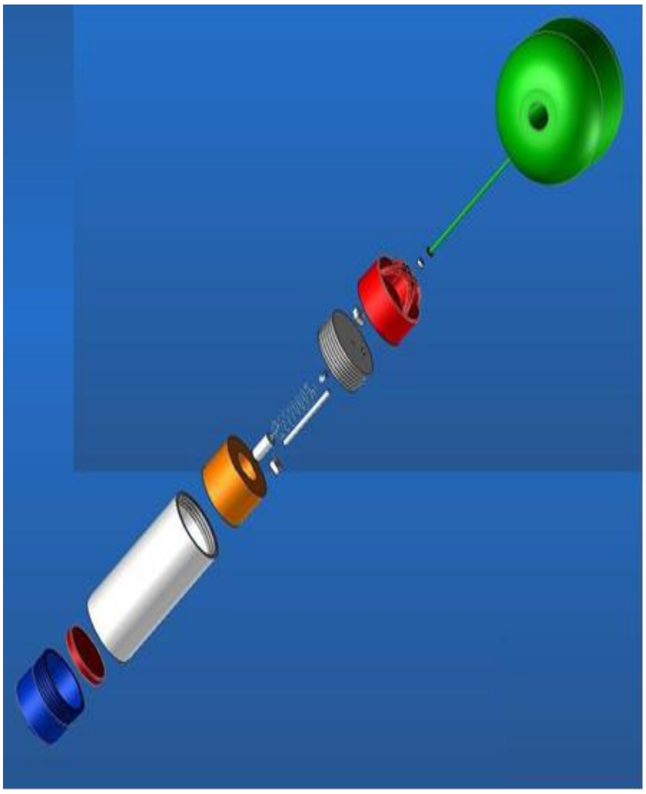


Figure 16: Exploded view of the Vertical Buoy

Figure 16 is a screen shot of the 3d model developed using TopSolid. It serves as a reference for the design, even though the cable that connects the generator to the buoy is missing. Further detailing of the design of the vertical buoy will be given through the tech nical drawings in the appendix.

ID	Part Name	Supplier	Cost (Euro)
a	Lid	-	4.42
b	Inner Lid	-	4.41
c	Body(extruded tube)	-	0.80
c	Body (molded inner bottom)	-	4.41
d	Bottom	-	4.41
e	Electric Connectors, 2ps	Cass Royal	0.50
f	Rubber plug	DVP	0.11
g	Weights Cast iron 4kg	Maquitmetal	8.00
h	Electric Cable, Rubber insulated 10m	Donggang	9.35
i	Magnet FTN- 10 and 4 x S-20-10N	Supermagnet	12.18
j	Copper coil 0.2mm wire 3300 windings	Maquimetal	100.00
k	Spring (detailed above)	Zhuoyue	0.17
l	Buoy G11, 7 kg	vinycon	33.00
m	Cable PP 4mm, 5m	Sodimac	1.34
n	Eye bolt, wire 3/16	Bolt depot	1.20
		Total Cost	184.30

Table 11: Vertical Buoy Component Cost

The costs for the included hardware (components listed in table 11 from e-n), where obtained from available market prices on April 2011. Were possible Chilean suppliers were preferred.

To choose the material used for the vertical buoy's designed parts; the material selection software CED Edu Pack 2010 was used. Six different selection criteria's were used

- Modulus v/s Compressive strength.
- Corrosion resistance: Excellent salt water durability, Good UV radiation resistance.
- Water proof: Water absorption at saturation of less than 1%.
- Production possibilities: The material must be able to be injection molded.
- Environmental impact: Recyclable and able to have a fraction of recycled material of up to 100% in the current supply. Limits were also considered for CO2 emissions in the processing stages of molding (1.8kg/kg) and machining (1kg/kg).
- Cost: Materials that passed the above requirements were ranked by cost, to choose the cheapest.

Using all these criteria's in the mentioned software, the material that comes up as the best option is Polyethylene Naphthalate (PEN).

The costs for the designed components (listed in table 12 from a-d) were estimated using the following equation for the total production cost per unit of output[76].

$$C = \left[\frac{mCm}{1-f}\right] + \left[\frac{\sum Ct}{n}\right] + \left[\frac{1}{x}\right]\left[\sum X\left(\frac{Cc}{Lt\ two}\right) + Coh\right]$$

Where

m: mass of the component
Cm : material cost
f: scrap fraction
Ct : tooling cost
n: batch size
x: production rate
Cc : capital cost
L: load factor
T two : write-off time
Coh : overhead rate

The volume was obtained from the 3d model done in TopSolid. Some of the data needed was obtained from the CED EduPack 2010 software; specifically:

Material density: 1390 kg/m3
Material cost: 3 euro/kg
Injection Molding:
Capital cost (average): 345500 euros
Material utilization (average) [1-f] : 75%
Tooling Cost (average) : 38208 euros
Production rate (average) : 1530 units/hr

Extrusion:
Capital cost (average): 330200 euros
Material utilization (average) [1-f]: 94.5% (Tooling)
Cost (average): 2204 euros
Production rate (average): 1530 units/hr

The rest of the data needed was assumed as:

•	Batch size:	10000 units
•	Capital right off time	5 years
•	Load Factor:	80%
•	Labor Cost	34 Euros/hr

This was obtained by adding the following assumptions:

[76] Ashby, M.; Cebon, D. 2007. Cost Modeling in CES. Part of the handed out material for the course Material Selection by Design.

Time (labor) clp/hr:	5000
Energy cost clp/hr:	3000
Space, administration clp/hr:	10000
Information, R&D, licenses clp/hr:	5000

These assumptions and data used, give as a result the prices are as above. It is important to notice, that even though these prices were calculated with data from reliable sources. These are merely estimative approaches to what a vertical buoy generator could cost when produced industrially. An initial working prototype is bound to be more expensive.

Being the production cost nearly 200 Euros; a reasonable commercial price would be around 250 Euros. This will be considered in the economical evaluation section.

8. MICRO-HYDRO GENERATOR

Chiloe islands receive heavy rainfall all the year. The bar diagram given below shows number of rainy days:

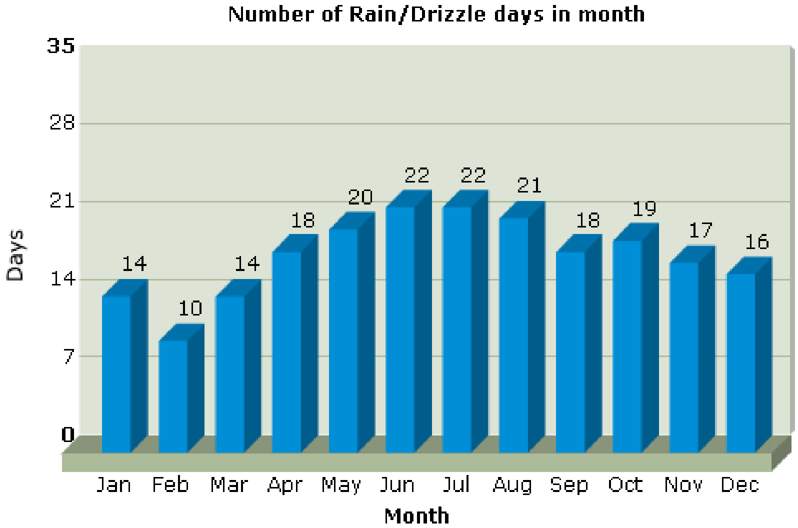


Figure 17: Bar diagram [77]

Micro-hydro generation is normally associated to using the force of natural running water, as in rivers or streams. Micro-Hydro power is rarely associated with rain water collection systems, due to the fact that collector systems normally occur where rain fall is not very abundant.

[77] http://www.myweather2.com/City-Town/Chile/Isla-Grande-De-Chiloe/climate-profile.aspx

Here there is the possibility to challenge these preconceptions. The idea is to have a rain water collector tank, that can be discharged into a small water turbine that can generate electricity. The height from which the water falls (called head) defines its potential energy to be transferred to the turbine. Considering that the system would collect the rainwater fall from the roof of a house, the following assumptions are done based on Chiloe :

Roof surface for a small house = 40 m^2
Floor to ceiling height in the house = 2.5m
Minimum monthly rainfall = 65 mm[78]

This means in a month the system would collect a minimum 2600 liters of rainwater. The idea would be to have a water collection tower next to the house, just under the roof water outlet, as seen on illustration 35. The water there collected is fed to a small turbine generator that can charge a battery. The system is worth putting up if there is at least 2 meters of head for the falling water, considered from the bottom of the collector tank.

When deciding if using a micro-hydro system, users should evaluate the possibility of using a nearby stream for these purposes. Running water may provide a higher flow rate than that achieved with a two meter head. In that case, the only elements needed are the turbine, the generator and cabling to connect that to the battery bank. If there is no available stream to tap into, the proposed rain water storage system developed here is an option.

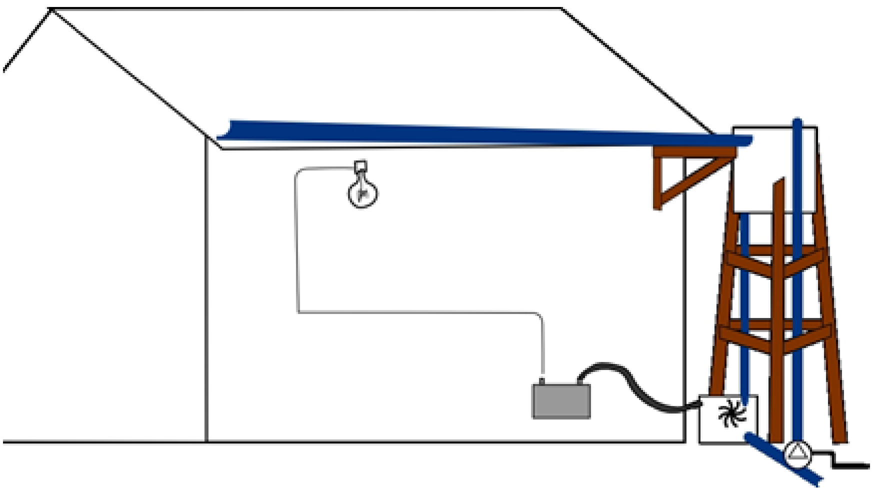


Figure 18: Rain water storage for micro-hydro generation

8.1. Power estimation of micro hydro system

Ideal power that can be produced from 2 m high head with a flow rate of 0.34 l/s is estimated 6.6 KW. Total energy potential from 2600 liters per month (discussed earlier, rain data available in section 5.3) tank system is estimated to 14.14 KWh/month. Potential energy estimation was calculated without considering friction losses in penstock and efficiency of turbine.

When friction losses in the penstock and efficiency of turbine are considered then energy produced would range 11.32KWh/month. Energy production is estimated using the formula as shown below.

[78] Los Lagos meteorological data, Educar Chile web site. Also shown in section 5.3.

$$E = P \cdot hr = H \cdot g \cdot \eta \cdot Q$$

Where

E = Energy potential KWh.
P= Power produced KW.
hr= number of hours.
H = head m
g= gravity m/s^2 .
η =Efficiency %.
Q = flow rate l/s.
= density of water kg/m^3

8.2. Pump and Motor

Pump and motor can be used as a turbine and generator set. Using pump as turbine is easier to maintain, shorter delivery time, better knowledge among local suppliers and they are available in different sizes.

Friction losses are completely eliminated when transferring energy from turbine to the generator by utilizing an integrated motor.

a) Selected Pump with Integrated Motor

The pump selected for the turbine operation is based on Sharma's recommended equations they are as given below[79]:

$$Q = \frac{Q_{bep}}{\eta_{max}^{0.8}} \qquad H = \frac{H_{bep}}{\eta_{max}^{1.2}}$$

Where

Qbep- Flow rate (Best efficiency Performance) (m^3/hr)

Q- Flow rate (m^3/hr)

H- Head (m)

Hbep- Head (Best efficiency performance) (m)

The recommended equation helps to choose the pump based on the turbine requirement. The best suited pump for Chiloe house conditions has the following characteristics:

Head - 167 m with a flow rate of 1.29 m^3/hr.

Under these conditions with a tank capacity of 1200 liters the maximum power that can be generated would range 5.2KWh per tank. The model is a centrifugal pump, HS code 84131900[80]

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[79] Scribd http://www.scribd.com/doc/40700251/Pumps-as-Turbinesim-for-Low-Cost-Micro-Hydro-Power retrieved on 22/04/2011

[80] Made in China.com http://shtpypump.en.made-in-china.com/product/PbaJeNpvfCcX/China-Centrifugal-Pump-End-Suction-Type.html ,retrieved on 22/04 /2011

Pump Specification:	
Flow	3.1-400 m^3/h
Head	2.6-300 m
Speed	1450/2900
Power	0.55- 160 KW
Working Temp	$\leq 80^0$ C

Table 12: Technical Specifications for Centrifugal Pump

8.3. Putting the system together

Pipes	ID	Units	Price (clp)	Price (euro)	Total
Channel 4m	a	2.50	3900	5.8	14.49
Channel end	b	2	550	0.82	1.63
Drop tube 3m	c	1	2700	4.01	4.01
Fixation hook	d	20	400	0.59	11.89
Decent roof border (m)		10		Total	32.03

Table 13: Designed pipes of the stem

Having chosen the main equipment for the system, the rest of the components have to be detailed. In order to evaluate the final cost of this system users must see if they already have a rain water drainage system and if it is possible to use that one to guide .

Just as well they could see if they can provide the structure to support the water tank.If the supported structure must be purchased, it will be produced with local certified wood and constructed with a local carpenter team. Estimative cost charts for these structures have been developed based on current Chilean market values for the materials required (table 14). The same is done for the piping, but here the final cost will depend on the roof edge meters for each case, so this information must be provided by the final user, into the outlined cell of table 13. Depending on this the chart will calculate the final cost for the materials.

Wooden Structure	Id	Size	Length (mm)	units	Price (Clp)	Price (euro)	Total
Pillar	e	Dia 4”	2440	4	2400	3.57	14.27
Sold format	f	2”x6”	4000	1	7000	10.40	-
H.Board	g	2”x6”	1000	8	1750	2.60	20.81
V.Board	h	2”x6”	1500	16	2625	3.90	62.42
						Total	97.49

Table 14: Wooden structure cost chart. Based on a simple structure design.Identification tags refer to Figure 17

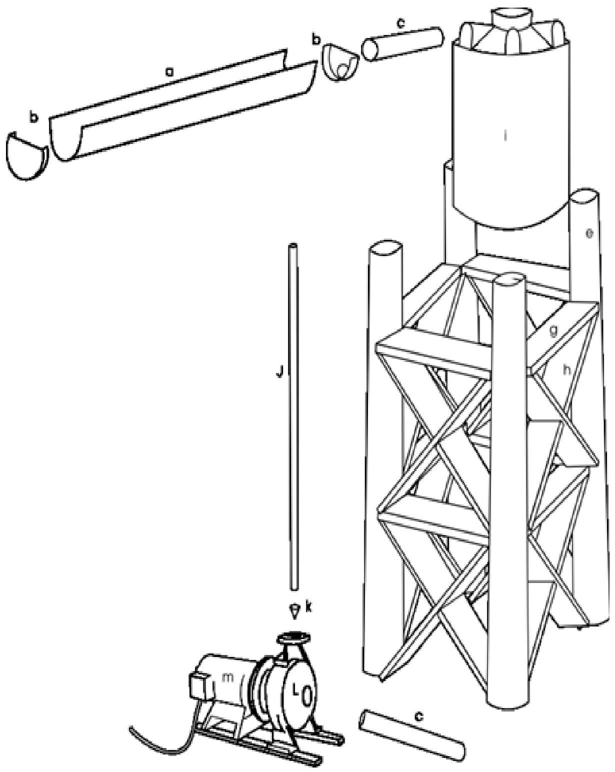


Figure 19: Exploded view of elements needed for Micro-Hydro generator, using a rain water collector tower

Element	Id	Provider	Amount	Cost(euro)
Water Tank 1200lt	I	infraplast	1	150
Pipes	-	Vinlit	Pipe table	32
Wood	-	Arauco	Wood structure	146
Drop Pipe	J	Vinlit	1	7
Nozzle	K	Relab	1	2
Pump and Motor	L	Pacific pump	1	573
			Total	910

Table 15: Total Cost Chart for the Micro Hydro System.

The water tank selected was chosen from the Chilean manufacturer company Infraplast, in the spirit of choosing components from local suppliers. With this information a total cost chart was developed, adding a 50% of the materials cost to pay for the manual labor needed for its assembly.

19. MICRO-WIND GENERATOR

Chiloe has an average wind speed of 7-8 m/s at 30 meters above sea level (e7 report). This is complemented with 2010 wind data[81].

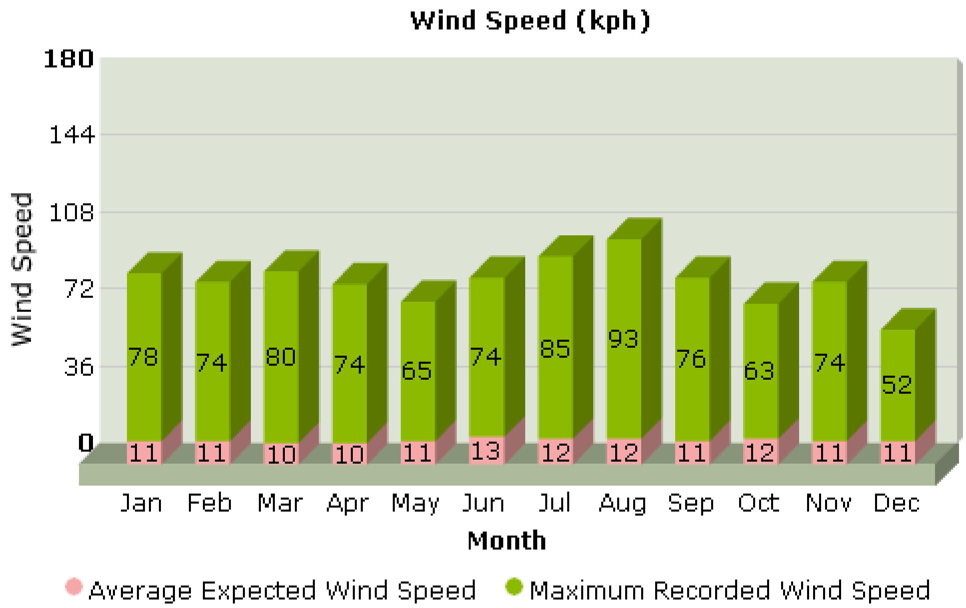


Figure 20 : Wind speed

81 Weather 2 ,http://www.myweather2.com/City-Town/Chile/Isla-Grande-De-Chiloe/climate-profile.aspx, retrieved on 20/04/2011

9.1. Comparison

The choice of wind mill was made based on Chiloe's wind condition. After screening through several wind mill suppliers, three models were compared: CXF1KW, S594 and FD-3.6 2000-E. Table 16 shows a comparative chart between these three models[82].

	CXF 1 KW	S594	FD 3.6 2000E
Cut in Wind Speed	3m/s	5m/s	2m/s
Cost (Euro)	1884	11775	160
Power produced	1KW	4.5KW	2KW

Table 16: Wind Mill comparative chart

The optimum wind turbine for Chiloe house is FD-3.6 2000-E model because it has better cut in wind speed and lower price compared to the other system.

9.2. Estimated Power

The estimated power from model FD-3.6 2000-E wind turbine is 2 KW (peak). Average power production for Chiloe houses is calculated using the formula given below

$$P = 0.592 \cdot \frac{\rho}{2} \cdot A \cdot v^3$$

Where,
ρ = Density of air kg/m^3
A= Swept area m^2
v = wind speed m/s

Estimated power production is 20 KWh/day assuming the following conditions:

- Wind speed at 7 m/s
- Swept area of FD-3.6 2000-E model is 4.26 m^2
- Density of air is 1.288 Kg/m^3

[82] http://www.alibaba.com/product-gs/213545102/wind_mill.html

	FD 3.6 2000E
Rated power (W)	2000W
Rated voltage (V)	120
Rotor diameter (m)	3.3
Start- up wind speed(m/s)	2
Cut in wind speed (m/s)	3
Rated wind speed (m/s)	9
Furling type	Electronic
Rated rotating rate (r/m)	300
Generator work way	Magnetic saturation
Blade material	Fiber glass
Guy cable tower height(m)	9
Free stand tower height (m)	8
Suggested battery capacity	12V200Ah 10 pcs
Matched inverter type	Sine wave

Table 17: Specification of FD-3.6 2000-E

10. BATTERY, INVERTER, CHARGE CONTROLLER

10.1. Battery

Batteries are used as storage bank to level the mismatch between production and consumption. Batteries are classified based on energy density and its recovery rate. Energy density can be defined as the amount of energy that can be stored. Recovery rate is defined as efficiency at which the energy can be recovered. Possible generic storage systems are electrochemical, mechanical, electrical, chemical and thermal.

Method	KWh/kg
Gasoline	14
Lead acid battery	0.04
Hydro storage	0.3 /m^3
Flywheel fused Silica	0.9
Hydrogen	38
Compressed Air	2/m^3

Table 18:Energy Density Comparison

Important factors to be considered during selecting the battery are life time, overall cycle efficiency, and depth of discharge per cycle and cost of unit of power. Properties of few batteries are given in table 19.

Properties	Wh/kg	Wh/m^3	Voltage	Cycle life
Lead acid	35	0.08	2	400
Nickel cadmium	35	0.08	1.2	>1000
Nickel Hydrogen	55	0.06	1.2	>10000
Lithium	150	300	>3.6	>2000

Table 19:Different Battery Materials

Different methods can be adopted to store energy; the selection purely depends on user's requirement. Some of the important characteristics while choosing batteries are discharge time, cost of the system, energy density and energy recovery. Table 20 compares different storage type based on estimated cost[83]

Storage Type	US $/KW	US$/KWh
Pumped Hydro	800	12
Li-ion	300	200
Flywheels	350	500
CAES	750	12
SMES	650	1500
Ultra capacitors	300	3600

Table 20: Estimated Cost per Battery Type

Recommended battery: Lead acid batteries are suitable for slow discharge; the major classifications are flooded batteries, gel and AGM[84].

Battery	Cost(Euro)	Average per Cycle Cost (Euro)	Life Cyle	Total Cost
DC AGM	152	0.99	500	2766
DC Flooded	182	0.46	500	496
DC Gel	302	0.54	600	325

Table 21: Comparison of single 6 volt @ 350 Ah

[83] Energy and Sustainability center: Florida State University 1857, Lecture Energy Storage.
[84] Discover http://www.discover-energy.com/faqs/cycle_life_cost_comparisons retrieved on 31/03/2011

DC gel battery is recommended because it is less toxic compared to flooded battery and gel battery is more acid starved than AGM giving it an upper hand. (Cost as per 2011)

Total Power Required	4000	Wh/day	4000Wh/day
N^0 back up days	0.414(10h)	days	1656Wh
Depth of discharge	50	%	3312 Wh
Battery temperature	10^0	C	3941.28
Battery bank capacity	24	V	164.22Ah

Table 22: Battery Sizing for deep cycle batteries.

The required storage of the battery was calculated to be 165Ah.The assumptions made to estimate the Ampere hours:

- Energy requirement of the house per day was considered as 4 kWh/day , estimation is as shown in the chapter 5.
- Required storage was considered for ten hours.
- Depth of discharge (DOD) of the battery is assumed to 40%.
- And there is a loss factor due to temperature. The loss factor varies with temperature as shown in table 16.
- Capacity of the battery was decided to be 24 V.
- Hence arriving to battery requirement of 165 Ah.

T^0 (F)	T^0 (C)	Factor
80	27	1
70	21	1.04
60	16	1.11
50	10	1.19
40	4	1.3
30	-1	1.4
20	-7	1.59

Table 23: Loss factor according to temperature

Battery Connection

Depending on how they are connected a battery bank produces different outcomes. This is shown in illustration 34[85].

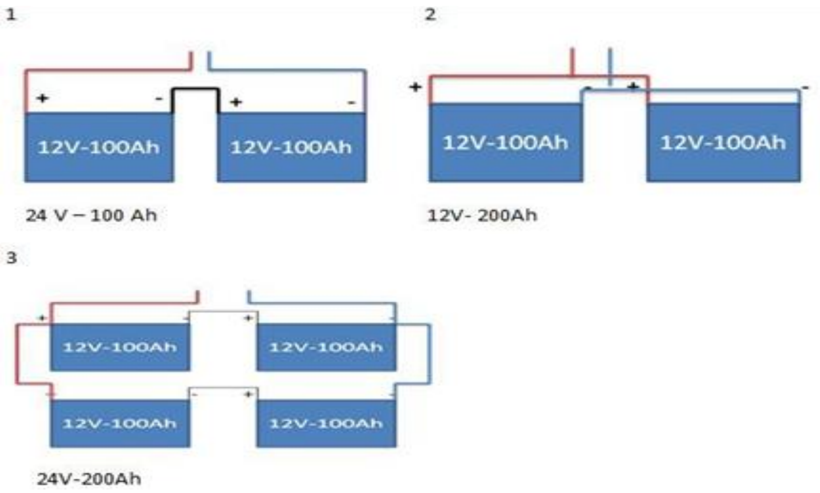


Figure 21: Battery connections

Battery choice

The selected battery is the Gel Haze 150Ah - 12 V. Model HZY-MR 12-150. The proposed system would require two batteries connected as the connection type 2, from illustration 34. Hence supplying 12V-300Ah[86].

- Battery Cost: 419 Euro/each
- Dimension: 482 x 170 x 242 mm
- Weight: 45.5 kg.

10.2. Inverter

An inverter is a device that produces high voltage alternating current from a low voltage direct current. They can be broadly classified as modified sine wave inverters and pure sine wave inverter.

Looking for an inverter that can supply the required energy and can be charged from the batteries defined above, the choice is a sine wave inverter 12V-220V-1500W cotek[87]

- Cost: 599 Euro.
- Dimension: 415 x 191 x 88 mm.
- Weight: 4.8 kg.

[85] Battery marinates Gel Haze, retrieved 2011-04-10.
[86] Battery marinates Gel Haze, retrieved 2011-04-10
[87] Watteo nomad energy,Sine wave inverter, retrieved on 2011-04-10.

10.3. Charge Controller

A charge controller is a device that prevents batteries from overcharging and blocks reverse current (battery discharging) which is vital for renewable energy sources. SCC3-12V with 0-20 Amps continuous is chosen as it can support battery range between 0.5 to 400Amp Hour. It is suitable for lead acid gel type battery. The SCC3 kit would cost 32 euros[88].

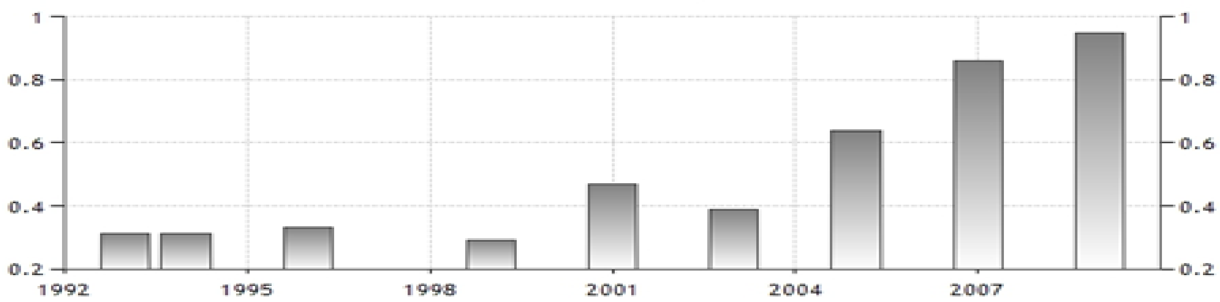
11. ECONOMICAL AND FINANCIAL EVALUATION

Payback time is a frequently used economic tool which helps to compare different economical options. It can be defined as annual savings over total investment cost.

The proposed system has an investment cost of 2850 euros. The annual savings are considered as the savings in the diesel fuel that would otherwise be used to power a generators to the supply of the eight hour a day and a proposed EGG system supply of 24 hours. The payback time is 3.2 years.

Components	Cost (Euro)	Cost %	Power Produced (KWh per day)	Production %
Battery	838	29	-	-
Inverter	599	21	-	-
Charge Controller	32	1	-	-
Vertical Buoy	250	9	6.8	27.016
Wind turbine	222	8	18	71.51
Micro Hydro	910	32	0.37	1.47
Total	2851		25.17	
Fuel Used	890.6			
Payback Time	3.2			

Table 24:EGG System Cost Analysis at Peak Load condition



[88] Cirkits , http://www.cirkits.com/scc3/ , retrieved on 2011-04-10

The cost of diesel has had a linear growth in Chile since 2003 as can be seen in the chart , as shown above[89]. This makes the system more promising to invest in longer hours of fuel supplied (diesel generator) would increase the fuel saved per annum making the EGG system a better choice. The graph shown in the figure 23 shows the hours of fuel supplied in x- axis and payback time for the proposed EGG system in the year y-axis.

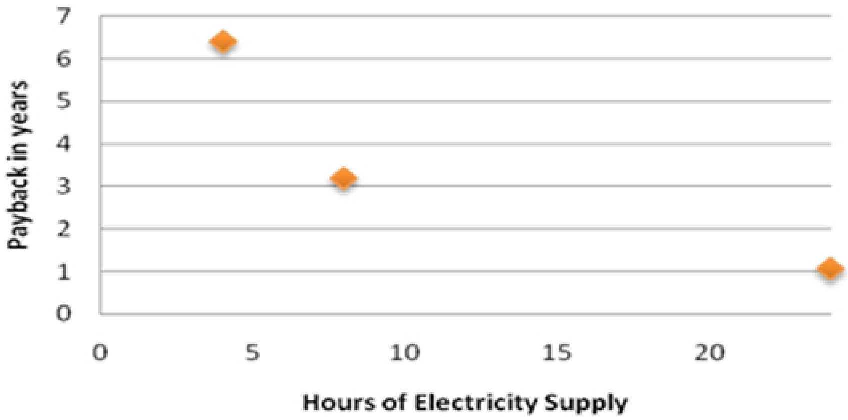


Figure 23: Payback time v/s Hours of saved Fuel

The pie diagram shown in figure 24, explains the distribution of the total investment cost, from table 24. The most expensive elements are the battery, inverter and charge controller contributing to 51% of the total cost. None the less, these elements cannot be avoided. On the other hand from the generator systems the micro hydro EGG is roughly 3 times the cost of the other systems, but contributes with only 1% of the electricity supply. If it was eliminated leaving behind a wind and wave system then the payback time is reduced from 3.2 to 2.1 years, reducing the energy production with only 0.37 kWh per day.

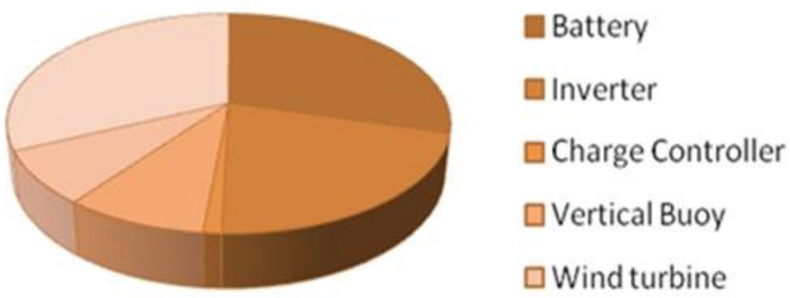


Figure 24: Investment Cost Distribution

[89] Trading Economies http://www.tradingeconomics.com/chile/pump-price-for-diesel-fuel-us-dollar-per-liter-wb-data.html , retrieved on 2/04/2011

12. Some Projects as Examples

When looking into electrification of remote areas using renewable energies several initiatives came up. Some of these projects are discussed below.

12.1. Solar Electric Light Fund

The Solar Electric Light Fund (SELF) has been working in the field of renewable energy, household energy and decentralized rural electrification since 1990[90]. They have developed projects in 22 countries around Africa, Asia, South and North America.

They work with governmental institutions, World Bank projects, NGOs, companies and particular fund raising organizations, not only to provide solar electrification to a number of housings but to establish a mechanism that can be self-sustaining over the long term, and that will eventually pave the way for commercialization of solar household electrification in the developing world[91].

Figure 25: Image from one of SELF implementation projects

SELF has established an integrated development model that relies on the fact that the villagers that live in un-electrified houses are those who define the need and the scope of the system. Villagers pay the equipments through micro-credit, so the project funds can be used for the operation and maintenance of the system. Finally local men and women are trained to fix, maintain and even replicate these solar systems.

There is great care in the system design and equipment selection, to ensure these are simple and reliable. Currently SELF is dedicated to more complex projects, called Whole Village Projects. They do not only solely indulge in Solar Home Systems (SHS), but also in solar electrification of schools, medical centers, water wells, irrigation systems, etc.

12.2. Grameen Shakti (GS)

Is a non- profit company that has been dedicated to provide affordable, clean, modern and sustainable energy technologies to the rural people of Bangladesh since 1996[92].

[90] http://www.self.org/whatwedo1.shtml, retrieved 2011-02-12
[91] http://www.self.org/history.shtml, retrieved 2011-02-13
[92] http://www.gshakti.org/, retrieved 2011-01-15

Established by Muhammad Yunus, a Nobel laureate, the Grameen Bank initiative follows the same spirit as the “Bank of the Poor”.

They developed financial packages based on installment payments which reduced costs and helped reach economy of scale. Under this initiative, the SHS reached an installation figure of 366,000 units, in a short duration of 12 years.

Grameen Shakti (GS) started with simple standalone solar systems and continued with the development of Biogas, an organic fertilizer and improved cooking stove programs, which they have currently running. As of now they continue to further their research in Wind and Bio Diesel projects. Their project emphasizes to educate local communities about the technological possibilities of renewable energies by presenting the system to local people and then earn their trust by providing an excellent after sales service. To face the need of qualified personnel this means, they train local women as technicians for these systems. GS engineers pay monthly visits to the households while the installment payment is being fulfilled and continue to do so if the user wishes to purchase an annual maintenance agreement[93]

On the GS website they declare their keys to success as:

- No Direct Subsidies
- Innovative Use of Micro-credit to reduce costs and reach economy of scale
- Vast Rural Network with 904 branch offices all over Bangladesh
- Trained & Motivated Staff who are also known as Social Engineers
- Motivation & Community Involvement
- Local Technician Training
- Linking technology with income generation
- Local manufacturing of SHS accessories

The commercial and social model this company has developed is a cornerstone of their success. Also the fact that they are responding to a huge market need, as about 70% of the population of Bangladesh had no access to electricity in 2002[94], this is a great example of the commercial and technical feasibility of rural electrification systems based on renewable energies.

Their SHS can be found for urban areas or off the grid applications. The following chart shows the specifications of the smallest and largest off-grid systems offered by GS.

[93] http://www.gshakti.org/, retrieved 2011-01-15
[94] The World Bank, Bangladesh projects, www.worldbank.org.bd

System	Load	Includes	Price(Euro)
Min off- Grid	1 5Watt CFL Lamp or 2 LED Lamps	110Wp Solar module 118 Ah Industrial Battery 15Amp or 10 Amp Charge controller 1 structure 15 Watts CFL or 2 LED lamps Switch, switch board, Installation Other Accessories	100
Max. off Grid	11 7Watt Lamps and 17” to 20” B/W TV point	1130 Wp Solar Module 2100 Ah industrial Battery 115 Amp charge Controller 1 structure 117 Watts lamps Switch, switch board installations Other accessories	680

Table 25: Grameen Shakthi SHS

12.3. Village Project

The Village Projects Website is an endeavor of the Global Energy Network Institute (GENI) that seeks to show projects that are currently working in rural electrification, poverty alleviation and social entrepreneurship, with emphasis on energy efficiency and clean electricity.

It serves as an exposition for good example of ways to alleviate poverty, with the intention of spreading the knowledge so people in similar condition can replicate the solution.” We see the website and marketing campaigns as the fastest ways to broadcast and accelerate the exchange of information on thousands of projects operating successfully in countries around the world. Ultimately, the goal is to accelerate the rate of success in village thereby pulling themselves out of poverty.[95]”Since similar initiatives are so numerous a website like this helps pursuers to adapt themselves by organizing news chronologically and thematically, maintaining their information well referenced and up to date.

[95] http://www.villageprojects.org/ , retrieved 2011-02-07

12.4. Solar Gem

“Solar-Gem aims to "light-up the world" by providing affordable off-grid energy based on clean solar technologies.[96]“ This Australian based company designs and produces a total of five products for their use in a modular system. The products include two types of solar panels, two types of solar charge controllers and one LED lighting module. The idea is that with these 5 products the clients can build up a tailored system that responds to the needs in each case, being able to have several lights, or a single light with an electrical output able to charge a laptop and mobile phones.

Their aim is to provide a product for all the governmental, corporative and NGO aid initiatives that are aiming to bring electrification to un-electrified homes around the globe. They are not a charity group, but do help raise funds for smaller aid organizations that do not necessarily provide funding for the entire project. Currently they have shipped products to Botswana, Congo and India, besides the projects installed in Australia.

One of their charge controllers, the SGC-2 is a “modular solar charge controller with integrated battery and tariffing support.”[97] They have integrated several components of the system in this product, counting with batteries, regulators, circuit breakers, information display and a USB host interface that allows pre/ postpaid tariffing systems. They packed all this into a modular unit that can be staked for a larger storage capacity. The casing for this product has designed integrated handles, concentrates all the connections in the rear part (a bit like a desktop computer) and can also be used as a seat or stool.

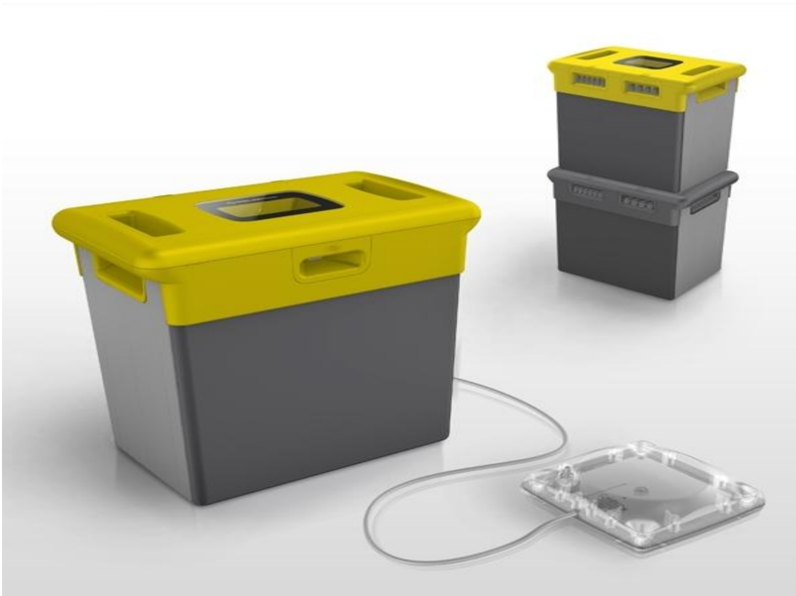


Figure 26: Rendering or SolarGem's SGC-2, showing two units mounted in the back, where the connection dock can be seen, and a light unit in front.

[96] http://www.solar-gem.asia/, retrieved 2011-02-12
[97] http://www.solar-gem.asia/solargem retrieved 2011-02-12

12.5. Barefoot Power

This Australian social entrepreneurial business designs and produces appliances aimed poor people to help them reduce their poverty situation. Their first step was to develop a range of solar based lighting products, that aim to replace the use of kerosene lamps around the world.

Their products have two categories, the Fireflies and the PowaPacks. In general these products use from 5 to 12 LED lights and incorporate the solar panel including frame and wiring (4 meter per lamp). Depending on the product selected one may obtain a single lamp or several, even incorporating 6 Watt tube lights. They sell batteries and replacement LED separately.[98]

Their Firefly products (image) won the Best Value award, in the Lighting Africa Program's contest. Lighting Africa is a World Bank Group program that helps to develop off-grid lighting markets in Sub-Saharan Africa, as part of the Group’s wider efforts to improve access to energy.[99]

12.6. Wave Power Project - Lysekil

This research project from Uppsala University aims to test a new concept of wave generators, under real sea conditions and over a longer period of time. Their aim is to develop technology that can serve in the near future to generate big amounts of electricity using only wave energy that has been proven to be environmentally sound. So, besides testing and measuring the performance of their equipment, they will perform marine life studies surrounding these installations[100].

The schematic sketch to the right shows a linear generator for the extraction of energy from wave power. [Fig 6] About 20 percent of the incoming energy can be absorbed and turned into electrical power. The buoy's motions are transferred through a rope or cable to the generator's moveable part, which in this case consists of a piston. The piston is equipped with very strong (Nd-Fe-B) magnets and induces currents in the stator’s windings. In addition the piston is connected to a spring system, which gives the generator additional power also when the buoy is moving down

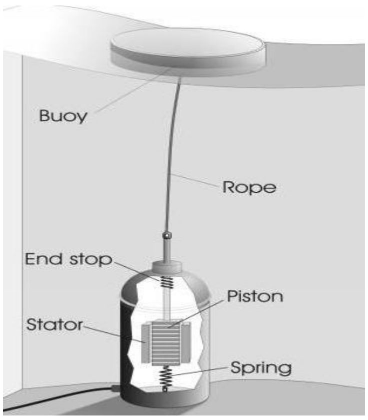


Figure 27: Lysekil Project

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[98] http://www.barefootpower.com , retrieved 2011-02-09
[99] http://www.lightingafrica.org/, retrieved 2011-02-12
[100] Wave Power Proyect web page, retrieved 2011-02-18

12.7. Do It Yourself (DIY) line:

These are very interesting cases to be looked at. One of the first ones is pedal power. Enthusiasts like David Butcher[101]do their own pedal machines, including big flywheels to help them even off the irregularities of human pedaling power. Butcher actually has daily workout sessions to be able to power his laundry machine and several other house appliances. There are also commercially available Power-A- and pedal away to power a generator. This can be Watt stands, where you put your normal bicycle, connected directly to an artifact to be used, or to a storage unit. On average a normal adult can produce from 100 to 320 watts, depending on their strength[102]. Equipment's cost around $400 USD. Other DIY significant achievement is William KamkWamba's handmade wind mill. His alawian boy had to drop-out of school because his family could not afford it. He ended up using his spare time to lend books from the library. With the help and inspiration of one of the books he loaned, he constructed a wind mill that generated electricity for his house.

This brought up much attention to William's project: first local newspapers and bloggers. Then Emeka Okafor(program director for TED global) invited him to speak at a TED conference, where William's presentation led him to donors and mentors willing to support his education and village programs[103].

[101] Pedal power generator - Electricity from excersice, retrieved 2011-03-20.
[102] Pedal-a-watt, stationary bike, retrieved 2011-04-12.
[103] http://movingwindmills.org/story, retrieved 2011-04-12

Conclusion:

From the different projects reviewed, the three important factors to be reviewed are:

- Simplicity.
- Micro-credit.
- Community involvement.

Perhaps William KamkWamba's[104] story is the best example of how simple electric systems can be. Comparing William's handmade mill to other available commercial wind generator systems, where the costs seem overwhelming, one is left to wonder: What is it they are charging for? Of course there is the electricity quality and quantity to consider. Just as an example, domestic size wind generators available on the market start from around 100W[105]. But how much electricity do you need in rural areas anyway? This is where community involvement is relevant. It should be the community that defines their overall need for electricity, like it is done in the SELF programs (section 3.1)

Using micro-credit loans to allow the people from rural communities to buy their own generator system is a viable way of financing the project in the long term. It also helps so that the people will feel that the equipment is their property and will tend to take better care of it since they know the value invested into it.

There is a marked tendency of using photovoltaic panels for rural energy systems. It seems to work well, but maintenance is a relevant question. The project that takes PVs to an isolated community should consider teaching the locals to maintain and repair their equipment, so they don't depend on external help in the future. The problem still remains are that these communities may not have access to the material needed to replace some photovoltaic cells, for example. So we return to the simplicity issue. How complex the technology is in these types of projects should be considered carefully.

104 http://williamkamkWamba.typepad.com , retrieved 2011-03-06.
105 http://www.allsmallwindturbines.com , retrived 2011-03-15.

13. ORGANIZATIONAL ISSUES

13.1. Background

In Chile there are no limitations to incorporate renewable energy generators into the electrical grid sources. It was just in 2004 that there appeared governmental incentives to do so. These incentives allow renewable energy projects to sell energy to the central grids, and latter laws even set the goal of having 17.5% of Chilean energy production from renewable sources by 2025[106].

In the case of renewable energies that are independent from central supply grids, the CNE impulse a series of 45 regulations that serve as a legal frame for the implementation of this type of systems (specifically photovoltaic, hydro, wind and hybrid systems). They also promoted the development of 92 renewable energy projects for rural areas. Of those projects only 18 have been developed[107].

The CNE claims that the main problems with fulfilling the rest of the projects is the lack of technical expertise in these areas and the refusal from the electric distribution providers to participate in the implementation and maintenance of these systems.

After what happened with the Isla Tac project, SAESA, electric distribution company designated for the entire Los Lagos Region, refused to continue collaborating in renewable energy projects, due to the difficulties they had in the administration and maintenance of that pilot project. SAESA considers small scale wind technology not mature enough, with a small share in the international market and high maintenance costs[108].

As a result the Chiloé islands are now electrified with diesel generators that run only 4 hours per day, with a subsidized tariff which makes the government spend 3 million USD per year. The plans to electrify these islands using underwater cables from the big island continue, but this may take still several years, since they must obtain the water permits to pass the cables. The intention is that when that happens, the diesel generators will remain only as a backup system.

13.2. Leagal Permit Requirement

Current Chilean legislation does not demand any special permit for installing electrical generation units or their annex infrastructure. If it is a generation central, it is submitted to the same norms that regulate any industrial installation. There are technical requirements for connecting centrals to the grid system that ensure the supply quality and safety precautions[109]. Since there is no existing grid on these islands to connect and the EGG system does not qualify as a generation central, there is no permit required.

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[106] Tirapegui, J. ENDESAeco. "Introducción a las Energías Renovables No Convencionales", 2006

[107] Duhart, Solange. CNE. "Difficultades Observadas en la Ejecuccion del Programa de Electrificación Rural en Chile". Report for the GEF-CNE-PNUD project, 2008.

[108] Duhart, Solange. CNE. "Los Proyectos de Electrificación de Islas con Energías Renovables". Report 2009

[109] CNE. "Política Energética: Nuevos Lineamientos", 2008

Sea regulations in Chile demand that any fixed buoy placed at sea must apply for a permit that allows port or route signaling to help navigation. This also applies for docking stations and small sea ports. The application is free, must be done by the interested company or user up to 45 days after the installation of the device and must be addressed to the local port authority (Capitanías de Puerto)[110]. Every commune in Chiloé has a local port authority. Depending on each case they will require site specifications and authorizations if necessary. However, if the buoys are not fixed to a defined location and do not affect navigation there is no need to obtain a permit. None the less, it is wise to consult with the local port authority before using these EGG buoys, since it is a new element in the sea to consider.

13.3. Management Possibilities

Since the company SAESA, in charge for the electrical supply in the region, does not want to get involved with projects with renewable energy, there is the need to put up another company that will implement these types of projects. None the less, authorization for this new company to operate must be obtained, either through the government or directly from SAESA.

This may seem problematic, but the fact is that for SAESA the electrification projects for the inner Chiloé islands are not commercially interesting. The cost of producing electricity with diesel generators is higher than the price these users should pay, according to Chilean law. Since there has been talk about electrifying these islands with renewable since 2000, the population got their hopes up and have been very disappointed to see that the pilot project did not work out. Given that situation, they have pressed local authorities to fulfill their electrification promises by any means, resulting in the subsidized diesel generator systems they have today.

Given this background, the company to develop these projects should develop a user participation program, to clear out the doubts and uncertainties the islanders may have regarding renewable technologies. This is also very important, since the proposed system requires important user participation in the system definition, installation and maintenance. In this sense the proposed system is closer to bringing appropriate technologies[111] to rural communities in order to empower them, than to a normal commercial project. The trick is to manage the project in a way that it can finance itself in the long term.

To do that there are different possibilities should be evaluated. A few ideas are presented below, but to properly compare them is beyond the reach of this research. The diagram in illustration 35 shows the involved actors.

1. Traditional approach: Company owns the systems and charges for the electricity use.

2. Company sells the system to the islanders for a long term loan that includes the maintenance cost for a period of time.

3. Company associates buyers with the bank for a long term loan, while it is responsible for the maintenance.

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[110] Government of Chile. Guide to State Services, "Permiso para instalar señalizaciones de ruta o de puerto", retrieved 2011-04-01

[111] Hazeltine, B.; Bull, C. (1999). Appropriate Technology: Tools, Choices, and Implications. New York: Academic Press

4. Company sells the equipment (with a long term payment system) to a cooperative made by the islanders. During the payment time the company trains people from the cooperative to take over the maintenance.

Perhaps this last option is the preferred one. It could be postulated for international development funds[112] to be able to finance its start up. The development of the project should pay back its initial expenses.

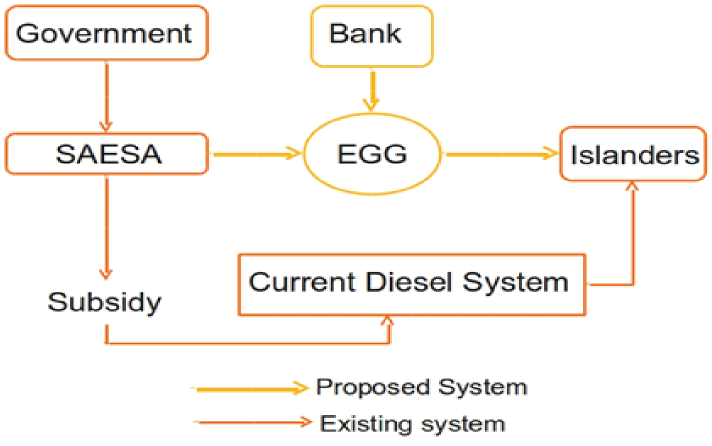

Figure 28: Diagram of the relevant actors in the managing of electric systems.

[112] Like the ones operating for the Isla Tac pilot project, from GEF, E7, PNUD and BID. That specific project required a locally based company to be able to operate.

Discussion and Conclusion

a. General

This thesis looked into incorporating small scale simple technologies to electrify isolated rural communities. The motivation behind this was to be able to produce and fix the generators locally to empower the community socially and economically. The risk with this (just like any bare foot engineering) is that the technology may appear to be old fashioned and unsophisticated for the users. None the less, this would supply their required energy.

The scope of the thesis is broad as it deals with many components. This limited the detailed studies on the topics approached, but covered a wide range of possible solutions to tackle the problem. While looking into these possibilities it is evident that small scale wave generation is a promising field to develop further.

A problem encountered during coil design was to make an accurate estimation of the electricity production the coil would have. Even though the estimation of losses, EMF and coil conductivity was based on theoretical formulae they will deviate in practice. Thus more experimentation is required and developing a working prototype is highly recommended.

b. Micro Hydro

The proposed system for a single house usage proves to be material intensive for one family. If it was developed for a community with one centralized water tower it would be more cost effective. If there is a running water source available in the vicinity it would be preferable to use this than the proposed rain water collector, since this would require fewer infrastructures.

c. Buoy systems

The main difficulty encountered when developing different buoy generators is the complexity of describing wave movements. To attempt to describe wave movements the average wave height and frequency were used, disregarding the variations in the sea (Ross, D. 1995. Power from the Waves. Oxford University Press 1995, Page199). The consideration for frequency was not site specific, but the wave height was. Development of different Buoy systems: The simplified movement equations used showed that the angular movement was too small to harvest energy as expected with the snake buoy. Since only single wave movements were considered, disregarding overlapping and resonant waves. This would require more investigation which might prove the development of the snake buoy interesting.

d. Wind

Wind technology is very developed and has proved itself over the years. This boils down to market availability of readymade solutions for different prices and sizes. This allowed for the selection of a wind turbine that fitted the requirements of Chiloe’s context.

The question that rises is: Why is there no wind turbines produced in Chile? The technology is simple, thus could be manufactured locally. This would generate value and employment in the local economy.

e. Power Production

The amount of power produced by the wind turbine as shown in the graph is 20 KWh/day which is assuming wind speed of 7m/s. This will vary with the wind conditions; hence it would produce more or less energy than represented in the graph.

Similarly the vertical buoy power production is considering constant wave speed and direction. There is possibility of change in wave direction and movement which would vary the total power produced by waves.

Storing energy of the Buoy is very challenging, as this thesis has not considered amplitude and frequency variation which would cause practical problems while storing. And from data of wave power project in Uppsala had shown only 30% of energy was recoverable.

Further in-depth analysis would be required to quantify the production of buoy project.

However the amount of estimated power produced (25 kWh per day) is way over the proposed consumption (4 KWh per day). This guarantees the minimum power requirement independent of the variation in production mentioned. It is good to oversize these systems as they tend to be highly variable. Since the overhead in production is big it gives the user a choice to use only one EGG, be it the most prominent energy (wind or wave) available in the site.

Conclusion:

Through this study it is made clear that small scale renewable electricity could be technically feasible. It can complement or replace existing diesel generators (commonly used in isolated areas), reducing the CO_2 emissions they produce.

The islands in Chiloé have a huge wave energy potential, that has not been exploited yet (2011). This could complement wind generators that have already been proved viable. Considering the size of the population and how disperse it is, it would be wise to invest in small wave energy generators.

To be able to completely electrify the Chiloé islands using renewable energy sources, further studies are required to test our proposed technologies. It would be recommended to develop prototypes and to carry out measurement on a case study house located on the islands. This can only be done if it is possible to attract investors to this project.

However from the literature review and conversations with Germán Malddonado with experience in rural electrification in developing countries the most important limitations for rural electrification seems to be related to the availability of money to finance the projects, the lack of appropriate and cheaper user components and small industries, for the users. Only if this would happen electrification programs will contribute to the economic development. Until now many of these projects build as a social rights, has been in many cases an expensive experience if not for the users, for the countries.

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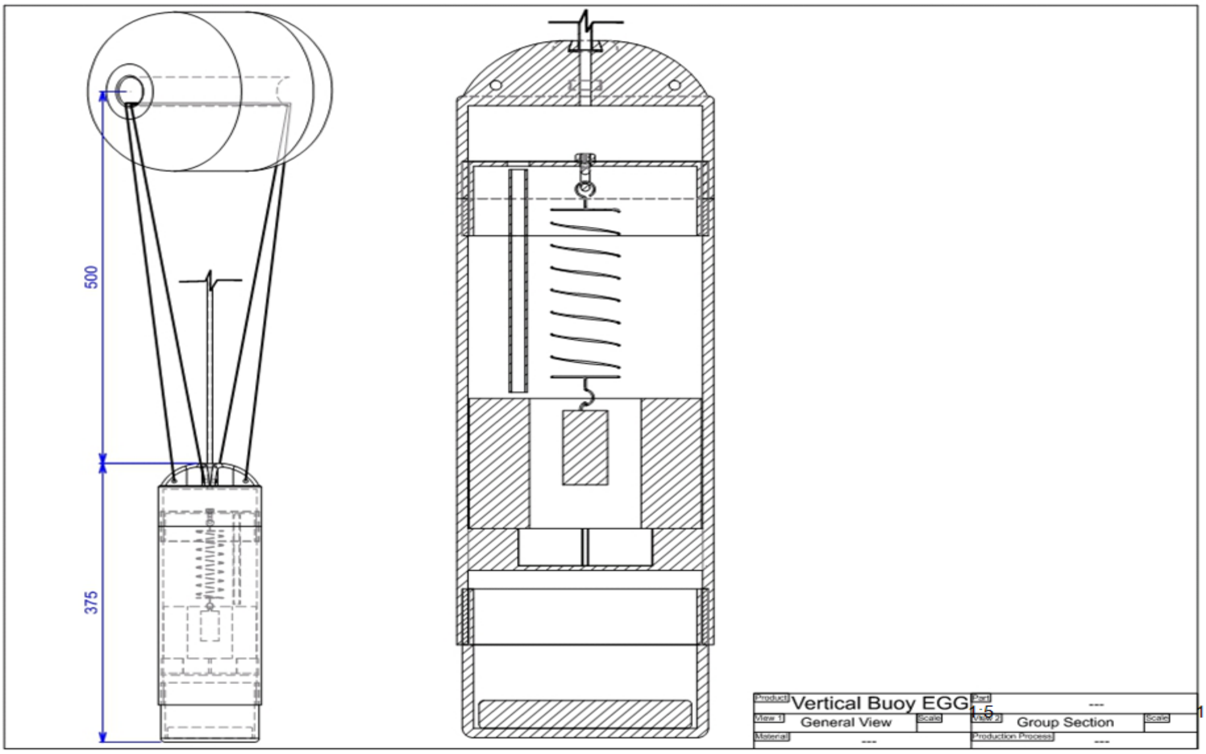
List of Tables

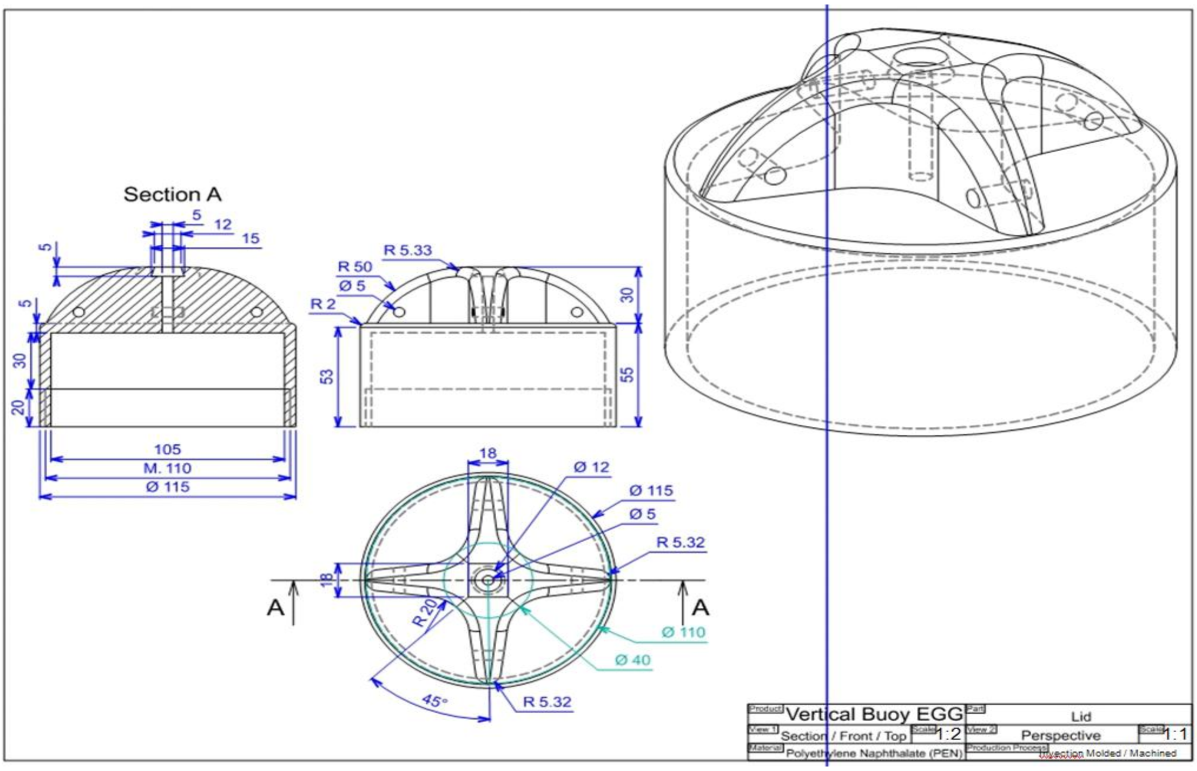
Appendix 1:



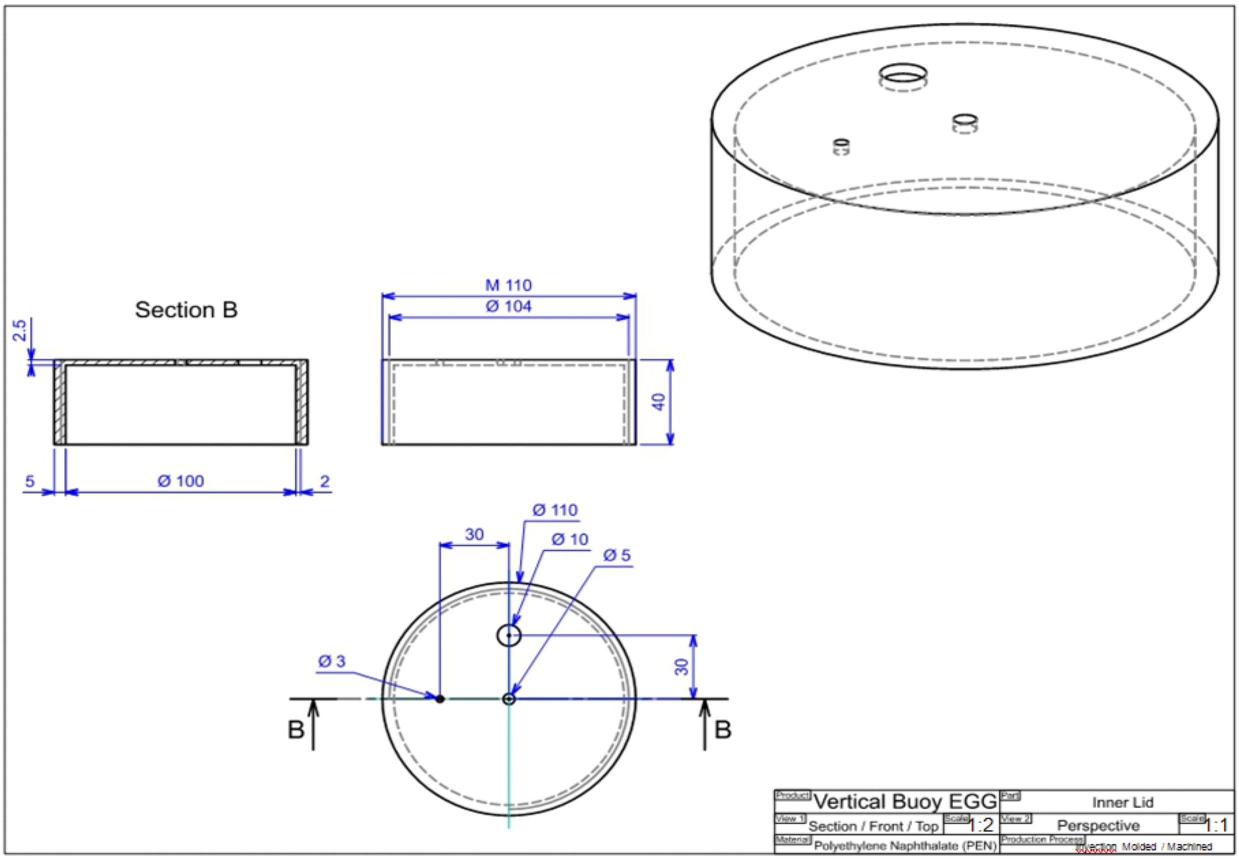
500
375
Product
Vertical Buoy EGG
View 1
General View
Scale
1:5
Part

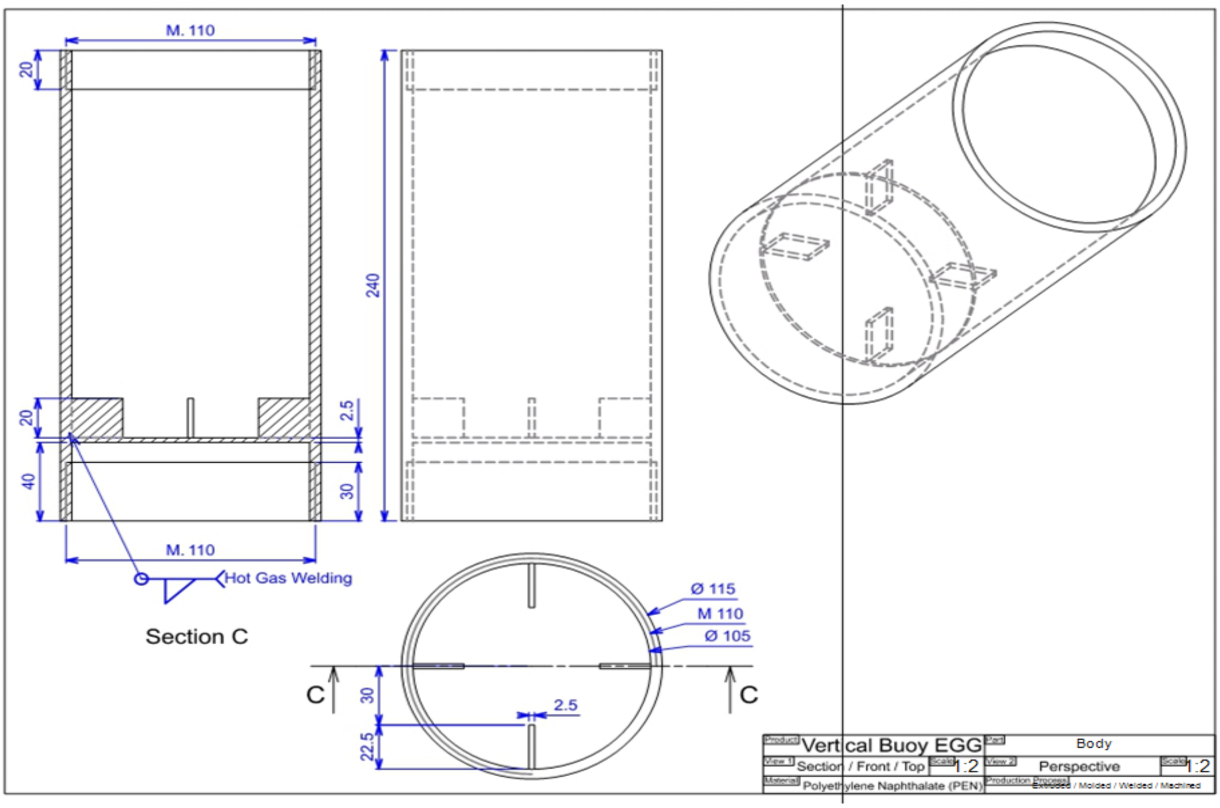
View 2
Group Section
Scale
1:2
Material

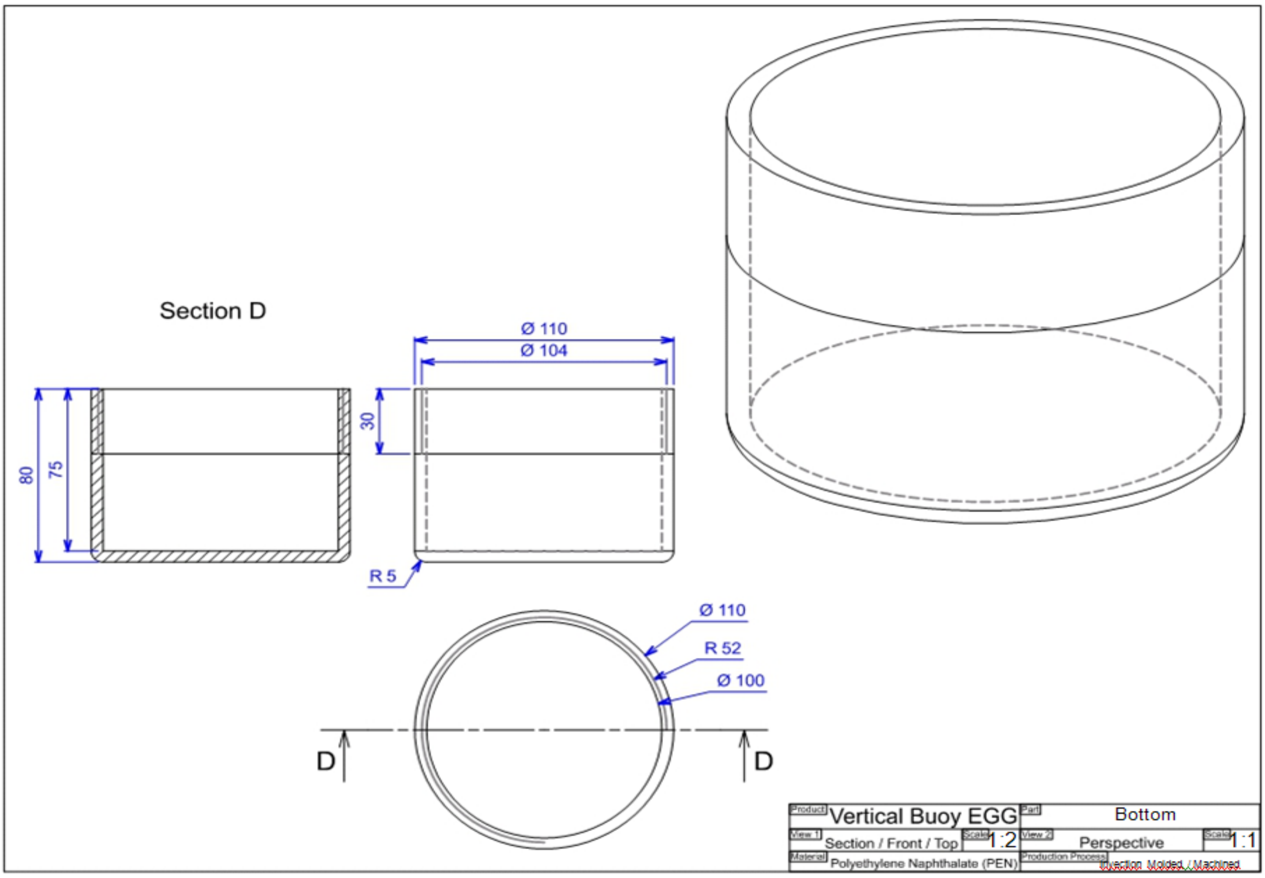
Production Process



Section A
5
12
15
5
5
30
20
105
M. 110
Ø 115
R 5.33
R 50
Ø 5
R 2
30
53
55
18
Ø 12
Ø 115
Ø 5
R 5.32
18
A
A
R 20
Ø 110
Ø 40
45°
R 5.32
Product
Vertical Buoy EGG
View 1
Section / Front / Top
Scale
1:2
Part
Lid
View 2
Perspective
Scale
1:1
Material
Polyethylene Naphthalate (PEN)
Production Process
Injection Molded / Machined


Section B
2.5
5
Ø 100
2
M 110
Ø 104
40
Ø 110
30
Ø 10
Ø 5
Ø 3
30
B
B
Product
Vertical Buoy EGG
Part
Inner Lid
View 1
Section / Front / Top
Scale
1:2
View 2
Perspective
Scale
1:1
Material
Polyethylene Naphthalate (PEN)
Production Process
Injection Molded / Machined


M. 110
20
20
40
2.5
30
240
M. 110
Hot Gas Welding
Section C
Ø 115
M 110
Ø 105
C
C
30
2.5
22.5
Product
Vertical Buoy EGG
Part
Body
View 1
Section / Front / Top
Scale
1:2
View 2
Perspective
Scale
1:2
Material
Polyethylene Naphthalate (PEN)
Production Process
Extruded / Molded / Welded / Machined


Section D
Ø 110
Ø 104
30
80
75
R 5
Ø 110
R 52
Ø 100
D
D
Product
Vertical Buoy EGG
Part
Bottom
View 1
Section / Front / Top
Scale
1:2
View 2
Perspective
Scale
1:1
Material
Polyethylene Naphthalate (PEN)
Production Process
Injection Molded / Machined

Appendix 1.2

Chile: Indigenous Communities Of Chiloe Island Make Demands To The Chilean State For Injuries To Ancestral Land

Translated from Spanish,

During the past week Wiliche communities in the territory of Ancud on the island of Chiloé in the tenth region of southern Chile, made public presentations to state authorities to respect the territorial rights, because in this area inhabited by indigenous communities would be installed a wind farm bycompany EcoPower with Chilean and Swedish investors.

Indigenous communities denounce this serious abuse of which are being want to install a project of this magnitude, although they were not consulted by state agencies in an environmental impact study, on the other side is violating regulations existing laws that promote development and safeguard the rights of indigenous peoples in Chile and the International Convention ILO 169, indigenous law 19.253 among other legal requirements. That state institutions so far are missing, as if this were not enough aware of the existence of indigenous peoples in the area.

The wind farm would be located in an area of 1,400 hectares, where 56 turbines would be installed 128 meters above sea level in rural areas of Guapilacui and Mar Brava in the town of Ancud, northern Chiloé province. Project is in its second stage is to get all the legal permits to be approved the third phase would be construction.

In none of these steps the authorities and state institutions have considered the views of indigenous communities in no time, have asserted Aboriginal rights has Williche people of this territory, shall not be considered heritage and sacred places that have community members and that for years the community has been calling for them to be protected. As serious threat mind the life and worldview of the communities Willich.

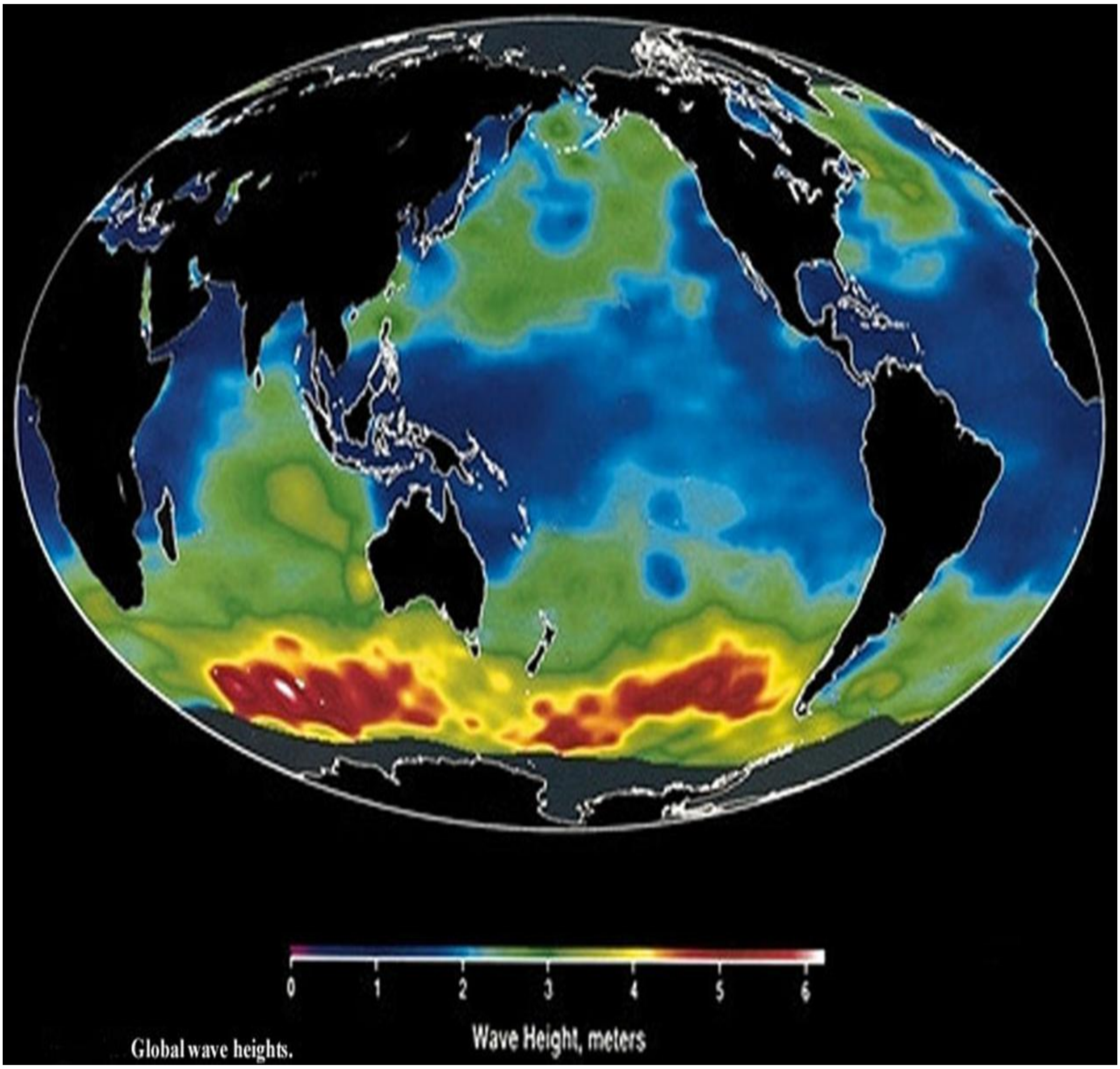
That's why traditional indigenous authorities of the territory sent documents to all Chilean state authorities to demand respect for the territorial rights and demanding enforce laws that excited for the indigenous peoples of Chilean territory. That draw on all levels so as not to trample the fundamental rights of indigenous communities, which are now being subjected.

Source:

http://indigenouspeoplesissues.com/index.php?option=com_content&view=article&id=10004:chile-indigenous-communities-of-chiloe-island-make-demands-to-the-chilean-state-for-injuries-to-ancestral-land&catid=53:south-america-indigenous-peoples&Itemid=75

Appendix 1.3

World Wave Map:



The graph given below explains capital cost per unit power Vs Capital cost per unit energy and the other graph describes system power rating Vs Discharge time at rated power. One of the major factors that influences system performance in batteries

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