



Dissertation

Master in Energy and Environment Engineering

**Identification of electric power generation techniques taking
advantage of sea energy for its integration in the energy matrix of
Ecuador**

Juan Sebastián Guamán Herrera

Leiria, Outubro de 2017

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Juan Sebastián Guamán Herrera

Dissertation developed under the supervision of Doctor Eliseu Manuel Artilherio Ribeiro, professor at the School of Technology and Management of the Polytechnic Institute of Leiria and co-supervision of Doctor Juan Leonardo Espinoza Abad, professor and researched at the Faculty of Engineering of the University of Cuenca.

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Acknowledgements

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Resumo

Esta investigação tem por objetivo identificar as diferentes formas de energia do mar e descrever aquela que está disponível para ser utilizada no Equador, através de tecnologias de vanguarda. Demonstra-se a possibilidade, de acordo com a matriz energética do país, da utilização das correntes marinhas, através de uma central de produção com 20 MW de potência. Seleciona-se esta tecnologia em base nas características técnicas adequadas para a realidade nacional, para depois efetuar-se o estudo económico-financeiro da proposta. Demonstrou-se o potencial de um projeto, deste tipo, a partir da corrente de Cromwell, e a análise do impacto na matriz energética do Equador.

Palavras-chave: Energias renováveis não convencional, Energia do mar, Corrente marinha de Cromwell, Matriz de energia do Equador, IEEE

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Abstract

This research aims to identify the different forms of energy of the sea and describe which one is available to be used in Ecuador, using cutting-edge technologies. The possibility of including in the energy matrix of the country the contribution of energy from the marine currents, through an electricity generating plant of 20 MW of power is shown. This technology is selected based on the technical characteristics appropriate to the national reality in order to develop the economic-financial analysis of the proposal. It is concluded that a project of this type is feasible, based on the Cromwell current, and the project impact on the energy matrix of Ecuador is analysed.

Keywords: Non-conventional renewable energies, Energy from the sea, Cromwell marine current, Energy matrix of Ecuador, IEEE

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List of acronyms

CONELEC – Consejo Nacional de Electricidad

MEER – Ministerio de Electricidad y Energías Renovables

USA – United States of America

OWC – Oscillating Water Column

OTEC – Ocean Thermal Energy Conversion

UK – United Kingdom

EDF – Electricité de France

INOCAR – Instituto Oceanográfico de la Armada

V – Voltage

KHPS – Kinetic Hydropower System

SEAI – Sustainable Energy Authority of Ireland

RTT – Rotech Tidal Turbine

NPV – Net Present Value

IRR – Internal Rate of Return

NIS – National Interconnected System

MAE – Ministerio del Ambiente del Ecuador

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List of symbols

TWh – Terawatt per Hour

MW – Megawatt

CO₂ – Carbon Dioxide

GWh – Gigawatt per Hour

kW – Kilowatt

kWh – Kilowatt per Hour

kW/m² – Kilowatt per Square Meter

km – Kilometer

km² - Square Kilometer

kV – Kilovolt

kW/m – Kilowatt per Meter

m/s – Meter per Second

mph – Mile per Hour

km/h – Kilometer per Hour

kts – Kilo Knots

cm – Centimeter

m³ – Cubic Meter

cm/s – Centimeter per Second

m – Meter

rpm – Revolution per Minute

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1. INTRODUCTION

Ecuador is a developing country that during the last decade it has been promoting the change of its energy matrix through the generation of electricity from alternative or renewable sources, particularly hydroelectricity. This change of Ecuadorian energy sector looks at eliminating or reducing consumption of fossil fuels.

This research seeks to provide knowledge of the energy potential that Ecuador has on its coast in order to exploit the energy from the sea in its various forms. This type of energy doesn't have greater application in developing countries, however the geographical features of Ecuador show that this energy could be used.

The growth of energy demand on the one hand and the climate change and pollution, which go hand in hand, are issues of concern to the whole world, hence the importance of constantly investigating in untreated fields and seeking more efficient technologies that allow supply energy for development and care for nature, in order to engage with the "sumak kawsay" or plan of good living raised in the country.

1.1 Background

As a background of this study, no detailed research has been found at the Ecuadorian national level on the subject; however access to local and global information is feasible because of the facilities provided by digital tools such as the internet.

In the development of the dissertation, there is a recount of the technologies available to exploit the energy of the oceans. The study also shows the main projects of electric power generation from the sea at world level, which are currently implemented in countries with greater technological and economic development. These experiences will then be applied to the particular situation of Ecuador, in order to obtain a preliminary proposal for energy exploitation from the sea.

1.2 Objectives

This research seeks to meet four specific objectives in a sequential manner, all of them presented under the main objective: to demonstrate that there is potential energy in the sea to transform it into electricity and that it can be integrated into the energy matrix of Ecuador.

1.2.1 Specific objectives

1. Characterization of the techniques of power generation through the energy of the sea
2. Identification of location and potential solutions, for an optimal use of the energy of the sea in Ecuador
3. Cost evaluation (construction and operation) of the proposed system
4. Evaluation of the impact of the proposed project on the energy matrix of Ecuador

1.3 Justification

This research justifies its elaboration since it is adjusted to the constant research for new sources of energy, with the conviction to avoid pollution and to obtain power generation technologies with greater efficiency, which goes hand in hand with the energy policies implemented by the Ecuadorian State to investigate a new technology that brings benefits to Ecuador's energy matrix.

1.4 Scope

This research proposes a project of electric power generation, at pre-feasibility level, taking as primary energy source the energy of the sea along the coasts of Ecuador. The feasibility of implementing a power plant to exploit marine resources will be tested and sufficient information will be provided for its construction, however it does not address any implementation.

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2. CHARACTERIZATION OF THE GENERATION TECHNIQUES OF ELECTRICITY THROUGH ENERGY OF THE SEA

Before characterizing the different uses for the energy from the sea, it is considered necessary to briefly discuss the description of renewable energies and some characteristics of them.

2.1 Non-Conventional Renewable Energy

There are several types of renewable energy around the world, some more efficient than others, but all under the same peculiarity of being less pollutant with respect to the conventional energies based on fuels, which are closer to disappear.

In addition to being environmentally friendly energies, many of these sources are inexhaustible energies such as wind and solar energy.

With the exceptions of nuclear, geothermal and tidal energy, all forms of energy used in earth that originates from the solar energy , this being the result of a process of nuclear fusion that takes place inside.[1]

Following it is presented the main types of unconventional renewable energies:

2.1.1 Solar Energy

The term unconventional does not necessarily mean that it is a new type of energy recently discovered. For example, the energy that comes from the sun has been known for a long time. It has taken time for this energy to take advantage due to the constant delay of the technologies.

The main applications that are given to solar energy are two, the first and most common worldwide is to take advantage of radiation to heat equipment or water reservoirs and the second, which is more attached to this research are panels or photovoltaic cells that use the photoelectric effect to produce electricity.

2.1.2 Wind Energy

Despite being a type of energy derived from the impacts generated by the sun on our planet, wind is considered within the world of electric energy as an important renewable source, its applications in the oceans are several as will be studied in the third chapter.

From the energy of the sun that reaches the planet, 2% becomes wind. This originates from the displacement of large masses of air from the high pressure zones to the low ones and from the rotation of Earth. Of all the winds that generate, only a very small fraction can be harnessed since conditions of intensity and regularity are required.[1]

2.1.3 Biomass Energy

Broadly speaking the term biomass refers to any type of organic matter that has had its immediate origin in a biological process and it is ultimately, solar energy transformed by photosynthesis. Wood, agricultural wastes and animal manure fall into this category. Its use is old-fashioned; firewood was the first and only energy source used by man to meet his domestic needs and is still an important source in many developing countries.[2]

There are two processes of energy conversion from biomass: it can be by biochemical production or by thermochemical production.

The types of biomass are three: natural, like forests or scrubland. Residual, consisting of residues that come from agricultural, livestock or forestry activities. And the third type deals with the biomass of energy plantations, the same ones that have been a reality for more than a decade in countries like Brazil or the United States that are looking for ethanol through the production of sugarcane or corn, respectively.

2.1.4 Geothermal Energy

It is the heat contained within earth that generates geological phenomena. This type of energy is used for electricity generation in many countries, the main generation equipment being conventional steam turbines and binary cycle plants.

The estimated energy potential with this technology, according to data from the International Geothermal Association is 22400 TWh / year.[3].

2.2 Renewable Energies in Ecuador

Almost all of the renewable energy sources described in the previous section have already been implemented in Ecuador; the country's energy matrix has undergone important changes with respect to these new technologies. Since 2006, projects, laws and regulations have been implemented to promote clean energies, which is why it is important to develop a research that encourages these energy sources and take advantage of the innumerable resources available in the country.

Within the energy matrix of Ecuador, two are the main sources of electricity generation in the country, fossil fuels (non-renewable) and hydropower. Renewable energy from water sources has become the main source of generation; it is not considered a new source, since it is a conventional use in the country.

This study takes as reference three main renewable sources of unconventional renewable technology, which have been implemented in Ecuador, before addressing the energy proposed from the sea. These technologies are:

Biomass. Ecuador has some projects, mainly plants installed in sugar mills such as the following: "Ingenio Azucarero del Norte", that generates 3 MW through biomass; "Sociedad Agrícola and Industrial San Carlos S.A"., which reaches a generation of 35 MW, almost a similar generation is obtained from Company Azucarera Valdez, as it delivers 36.5 MW to the grid.[4]

Also in the southern region of the country, specifically in the city of Cuenca, a gas-fired power plant came into operation, coming from the city's landfill; its first stage generation reaches 1 MW and in full stage reaches 2 MW. These biomass projects become energy suppliers from organic waste, and avoid significant amounts of CO₂ emissions into the environment.

Wind energy stands out as another important non-conventional renewable source, as these plants are not only found in the continental geography of the country, but also in the island region or Galapagos Islands.

In the province of Loja, it's the Villonaco project, which has 11 wind turbines and contributes 16.5 MW to the national grid. In the Insular region, specifically in the Baltra and San Cristóbal Islands, there are two wind farms, one with a generating capacity of 2.25 MW and the second generating 2.4 MW, respectively. It is assumed that these projects with clean energy serve 150 thousand ecuadorians. [5]

Finally, the third form of energy that is considered important because it has been implemented in recent years in Ecuador is photovoltaic solar energy. Currently this type of energy contributes approximately 40 GWh annually to the national network.[6]

2.3 Marine Energy Forms

In the ocean there are enormous amounts of energy, without a doubt the main reference of energy in seas are the hydrocarbons, but it is necessary to reach greater depths to extract oils, under the ocean.[7]

Coal mines also exist in countries such as Scotland, Taiwan, or Japan, but with the constant struggle to reduce greenhouse gases, futuristic thoughts arise, suggesting the sophisticated extraction of hydrogen, deuterium, Tritium, while these ideas may be technically feasible, costs remain high, which is why there is no possibility. The same situation happens with non-renewable geothermal submarine energy.[7]

However in the ocean there are other sources of energy that should be considered for implementation, given their potential and low environmental impact. Unfortunately, implementation is still costly. Some of these sources have the possibility of being exploited in the short and medium terms such as tides, waves or sea winds, others will remain conditioned to the development of engineering such as marine currents or salinity gradients, but the technology progresses and because of this its use becomes more and more feasible.

For the present research, it is important to differentiate and describe the ways in which this energy can be found and thus to attach each of the energy benefits of the sea to the reality of what happens in the ecuadorian coasts. The following sections describe the energy forms that are or have been studied in depth in the oceans, each with its characteristics as well as its advantages or disadvantages:

2.3.1 Tidal Power

Anyone who has the opportunity to observe the tides in the different coasts of the planet can testify the force of them. The phenomenon has already been observed, of course, in classical times, this power was put to work in rivers such as the river Tiber in Rome, the common estuary of the rivers Tigris and Euphrates even long before. The tidal mills on the

Danube may be from later periods. Mechanical energy was sought to grind the grain, for sawmills, to lift heavy loads. These tidal mills are not different from the river mills, except that they include a flood basin where the water brought by the tide rise is stored, when the tide goes down, the water is released but has to pass through a channel in which the mill wheel is fixed. The decline of tidal mills in the industrial sector of man was slow, but their numbers declined rapidly and abruptly as new technologies developed.[7]

This type of tidal mill can be considered the precursor of tidal power plant that generates electricity. The geographic location may initially limit coasts with large tidal ranges; the development of "very small head" turbines allows the implementation of tidal power plants in many more places. "The development of the tidal power plant was accompanied or at least driven by the bulb turbine (France, Russia) and later the Straflo turbine (Canada).[7]

This type of electricity generation begins to be feasible to apply to countries with scarce economic resources, using modern versions with technologies that together with its development are reducing the required budget. In addition, according to research at the end of the previous century, the kilowatt installed in tidal power plants, has a similar cost of one kilowatt in conventional plants, or even in a nuclear plant. The useful life of a tidal plant is between two and three times greater than that of a conventional plant.[7]

In addition, tidal power plants have added benefits because "artificial currents can interact with tidal currents to divert, redirect, and modify sediment transport. To the displeasure of dredgers, this would reduce the maintenance costs of the navigation channel and control the formation of sandbanks that would hinder ship traffic"[7]

2.3.2 Sea Winds

Of all the energies to be addressed, sea winds are the type of energy that has developed the most in recent decades. These winds are used by wind turbines that do not require more investment than those installed on the continental shelves. A number of such

plants have been installed along the north of Europe (off-shore); however, it remains a major challenge for engineering to avoid the noise generated by them.

Its operation is similar to that of onshore generation plants, but it has not been able to overcome the environmental barrier generated by the visual impact and the noise produced, in addition it is assumed that it can create hecatombs of Poultry.[7] If these problems are overcome, the designs are ready, and there is no greater novelty in the construction of these plants.

For example, in Utgrunden within the Baltic, one of the first wind power plants of this type was inaugurated in 2005[8], then some northern european countries continued, and even the United States is looking for feasible places where these could operate generating plants within their seas. Also the combinations of wind energy parks with coastal defense are additional benefits of the installation of these wind farms. Its thinking of capturing the energy of the sea winds through wind turbines placed along an artificial reef implanted as a recreational device of protection against the waves in the beaches.[9]

Some researches claim that the wind resources in seas are even greater than those of earth. In european zones, as the depth of seawater increases, it favors the installation of turbines. In short, these plants are less costly to install on land than at sea which, the generator at sea, would be profitable only if there are several megawatts, so the bigger the turbine the better, there are wind turbines with 70 meters in diameter, in the northern seas it delivers five to six million kilowatts per hour each year, as there isn't people who reject the noise from the windmills in these areas, "wind farms" are growing at a rate of 10-20% greater than those installed onshore.[8]

Table 2.1 Main turbines in offshore wind projects

Turbines used in offshore projects				
Creators	Name	Origin	Power	Contribution to the EU network
Siemens	SWT	Germany	2.3 – 8 MW	67.8%
MHI Vestas	V-164	Wales, UK	9.5 MW	16.4%
Senvion	6.2M126	Germany	2 – 6.2 MW	6.2%
Adwen	AD 5-135	Germany	5 MW	5.2%
BARD	5M BARD	Germany	5 MW	3.2%

Source: Created by the author, based on official data of the industries

Table 2.2 The largest offshore wind farms

Wind projects at sea, the largest in the world			
Name	Location	Power	Generation since
London Array	United Kingdom	600 MW	2013
Gwynt y Mor	United Kingdom	576 MW	2015
Greater Gabbard	United Kingdom	504 MW	2012
Anholt	Denmark	400 MW	2013
BARD	Germany	400 MW	2013

Source: Created by the author, based on The European offshore wind industry

At world level the installed capacity by marine wind plants is of 13,894.1 MW; the European continent has 90% of this energy.[10]

2.3.3 Energy of the Waves

Waves are a concentrated form of wind energy. The very nature of wind waves requires a large number of small devices for their energy extraction. Waves have the distinction of generating more available energy as energy is extracted because of the

inefficiency in which energy is transferred from wind to sea in highly developed marine states.[7]

The number of patents taken on wave-activated machines are impressive and they date back more than two hundred years. Probably the first was by Girard, father and son in 1799 who proposed to draw mechanical energy using a raft. In the 20th century. Buoys and headlights used electricity generated by the waves. In the United States, several attempts were made in California (San Francisco, Capitola, Pacifica). Power is provided by the attack of a rupture wave, which can be captured in a reservoir, accessible by means of a converging ramp, and connected to a return channel at the outlet of a low pressure turbine. Energy can also be generated by means of devices placed directly in motion by the wave itself. Although diffused, the available energy is impressive: there is more power represented in the potential energy of a booming vessel present in the thrust of its engines. The total available energy of the oceanic wind waves amounts to 2.7×10^{12} watts. It is conceivable to use similar waves of landlocked seas or even lakes; the power of such waves is 2.5% less than that of sea-water waves.[11]

It remains a challenge for engineers and staff who are responsible for designing the use of this type of energy, controlling the enormous force of the waves that destroy everything in its path, so to develop research requires plants and expensive construction. In this sense, the search for appropriate methods for obtaining correct energy continues.

Systems that seek to take advantage of the energy of the waves use both the vertical ascent and the fall of successive waves, in order to increase the pressure of the water or the air to activate the turbines, in the same way it can be used of the movements of swinging of the waves through pallets or chambers that spin turbines. Another method used is the concentration of incoming waves in a convergent channel that allows the accumulation of a head of water, which then makes it possible to operate a turbine.

Some 38 systems have been described that fit four points with wide interpretation to obtain energy: the variations of the surface profile of the deep water waves that move, then we find the sub-surface pressure variations, the movement of sub-surface particles and the

unidirectional movement induced naturally or artificially of the particles of fluid in the breakage of a wave.[11]

Mechanical concepts such as motors operated by the rise and fall of a float, by the back and forth movement of the waves, or the convergent wave channels, which provide a basin that forms the front dome for a power station, providing a high yield, its economic viability has been questioned.

One feature that greatly outstands this type of energy, is that waves are commonly available and could be exploited at many sites rather than tides.

The systems involve a moving body, a swinging column or a diaphragm. They are pollution-free generators, widely available, and their operation is low-cost, more efficient systems than conventional fossil fuel plants, another advantage would be that their production is not affected by weather or time.

Table 2.3 Main Technologies for the use of wave energy

Main technologies for the use of wave energy			
Name	Origin	Power	Installed in
Pelamis	Scotland	750 kW	Portugal
Oyster	Scotland	800 kW	Scotland
Waveoller	Wales, UK	330 kW	Projected for Mexico
Ceto 5	Australia	240 kW	Australia
Seabased AB	Sweden	1 MW	Sweden

Source: Created by the author, based on official data of the industries

Wave energy has recently been used in sophisticated plants, especially in Sweden and Norway. A large British study yielded many proposals, but the question has; by all practicality, been put to rest. Japan has a very active research program; ongoing for decades, that has led to some large-scale efforts. The "Big Whale", a floating power device with air turbine conversion to electricity or compressed air, or the previous Kaimei, a barge equipped with compressed air chambers. Air turbine buoys are used in Japan, as in the USA and the United Kingdom, as well as air turbine generators (Osaka).[12]

In India research is also underway and the Indian Institute of Technology has considered combining a wave energy converter with a harbor breakwater, thus making double use of concrete works. Its Indian researchers also developed an electrical system that uses the piezoelectric effect: plastic sheeting should be suspended from floating rafts and secured to the bottom of the ocean. As the waves raise the rafts, the leaves bend and generate electricity in the process.[13]

A device named Pelamis belongs to the group of semi-submerged articulated structures, from which other types have been tested and proposed in the past. Pelamis, currently installed in Portugal, is directly towards the incoming wave and contains three power conversion modules of 250 kW each using an independent generator. The hydraulic arms resist the undulatory movement that pumps an intermediate fluid through the motors. A single dynamic umbilical duct is connected to the machine transformer located in the nose that conducts the energy to the seafloor. It is "sustainable", not site specific, it has good energy capture efficiency, deployable at depths of up to 100 m, it has a competitive price with an offshore wind energy system.[13]

A wave convergence field was placed at a site about 7 kilometers off the coast of northern Portugal, near Póvoa de Varzim in 2006. The Archimedes wave oscillation generator designed and developed by a Scottish company completed successful tests in Portuguese waters. The system is tied to the ocean bed and invisible from the surface. Electricity is generated when the waves move an upper housing filled with air against a lower fixed cylinder. The technology is of Dutch origin.[13]

The 2.5 MW project is expected to respond to electricity demand for more than 15,000 portuguese households, while more than 60,000 tons per year of carbon dioxide emissions from conventional generation plants will be displaced. On October 1st 2006, wave-driven electricity for 1,500 families in Portugal was provided by a floating power plant located about eight kilometers offshore from Aguçadoura.



Figure 2.1 Equipment "Pelamis" power converter

Source: www.wikienergia.pt

The Ocean Power / Enersis System comprises 3.5 m of diameter 142 m long tubes, three generators and a set of high pressure hydraulic pumps. The electricity generated is conveyed to the continent via submarine cable. The refining of meteorological equipment and methods allows to predict the strength and height of the waves until six to seven days before. The costs are similar to those of a wind system, but optimistic forecasts by the designers state that the exploitation of "the wave farm" will be three times greater than the wind farm.[13]

In Mexico experiments were carried out on a wave-driven pumping system to clean the stagnant water in the coastal lagoons. Ireland concentrated on oscillating water column systems. The European Union contributed to the financing of an oscillating water column plant to replace energy from Pico (Azores) waves by diesel. Of all the devices proposed and investigated in the United Kingdom, only two were retained for further studies: an oscillating water column (OWC) and the "Sea Clam" circular. The OWC was deployed on the island of Islay (Scotland) using a natural rock ravine, thus saving construction costs and facilitating access to maintenance. Another project funded by the European Union is a two-chamber OWC located near the coast in Scotland.[13]

In Toftehallen, Norway, the world's largest oscillating water column system had a capacity of between 500 and 1,000 kW. It worked properly, but was unfortunately wrecked in 1998 during a particularly intense storm.[13]

2.3.4 Ocean Thermal Energy Conversion

This type of energy known as OTEC uses the prevailing temperature difference between the different layers of ocean waters to produce electrical energy. In the waters between the tropics the amount of heat stored daily by the superficial layers of water in a square kilometer is equivalent to the burning of 2,700 barrels of oil.[13]

The pilot projects of Arsène d'Arsonval and Georges Claude have been described clearly and repeatedly. They date back to the first half of the last century. After the oil crisis of 1973, interest in OTEC increased and the "Mini-OTEC" and "OTEC-1" projects were launched in the United States of America in 1979 and 1980, respectively. In 1981, Japanese researchers built a closed-circuit power plant in Nauru that delivered 31.5 kWh; it placed cold water pipes in the ocean floor at a depth of 580 m. It was a result that far exceeded the most optimistic expectations.[13]

Several technical improvements have been made to the plans of the proposed schemes, and energy conversion has achieved a fairly high efficiency of 97%, water exchange equipment is no longer made out of titanium, it may be aluminum which is less expensive, corrosion and bio fouling have been significantly reduced. The 1993 closed-circuit prototype established at Keahole Point (Hawaii) delivered 50 kWh net.

These very small plants, unfortunately, produced electricity at a high cost. Research is being carried out on a modest scale, and no full-scale OTEC power station has been built or commissioned.[7]

2.3.5 Marine Biomass

A few developments have been reported in the area of conversion of marine biomass, although increasing algal biomass has caused great concern to coastal regions. This runs counter to the considerable progress made in using biomass for purposes no other than electricity production.

Experts argue that the conversion of marine biomass is promising, it has a future, but it can be predicted that its development will be rather regional, and on a modest scale.[7]

2.3.6 Marine Currents

Ocean currents represent enormous energy potential. To take advantage of it, there are many proposals. Some projects include turbines that are fixed to the seafloor; others put them in the current itself, allowing several turbines to be connected at different depths to a single cable. Given that the distances to the consumer could be too large, it is proposed to place the industrial complexes in the middle of the ocean and the product manufactured then would be brought by the ship to the mainland.

A Canadian company, after testing six prototypes, decided to build a 2,200 MW ocean power conversion plant in the Philippines using a Davis hydro turbine. The scheme provides for a dam in which a number of vertical rotors of slow rotation are to be housed.

However, these projects conflict with concerns about safety of navigation, climate modification, the danger to ocean life, and the cleaning of floats if they were used. It is known that the Italians are considering a central marine current in the Strait of Messina.[7]

2.3.7 Tidal Currents

Although it can be considered part of the tidal power, the use of tidal current has recently received more attention, it has even been a supplier of mechanical energy in earlier times. Considering tidal currents, rather than the tides themselves, poses new problems both from the environmental and energy production points of view.

Professors Bryden, Grinsted and Melville of the University of Robert Gordon (UK) have directed efforts since the beginning of the new millennium to make possible a way to extract energy from the tidal current. In a recent paper (Journal of Applied Physics), they developed a simple model to evaluate the influence that energy extraction might have on hydraulic flow. The extraction of ten percent crude energy would result in changes in flow characteristics, and could be used as an approximate guide to know the resource potential of a tidal energy extraction site.[7]

In the model of the Robert Gordon University, the calculations are based on an extraction of 10% to 2 km of the entrance of the channel. Obviously, the energy extraction has a negative (reducing) effect on the flow velocity.

From a practical point of view, it is not possible to predict energy production based only on the natural flow of the river. The authors' note that in more complex systems, two, even three dimensional flow analyzes would be appropriate.[7]

Despite being subject to weather changes, tidal currents, such as tides, are an essentially predictable, sustainable and renewable source of energy. If in Scotland spring tides can provide a kinetic energy flow of 175 kW/m^2 ; there are many regions around the world where the flow is about 14 kW/m^2 , which is sufficient for energy production. Unlike atmospheric currents, tidal current flows are limited between the seabed and the surface of the sea, and may even be more limited in one channel.[14]

2.3.8 Salinity Gradients

It is a natural process that does not cause thermal contamination, does not produce carbon dioxide or generate any other pollutant emission due to combustion. This concept consists of the production of electricity directly from the difference in salt concentration between sea and river water. For this use a membrane is used whose function (or principle) is reverse electro dialysis, alternating fresh and salt water cells.

Membrane problems, particularly their cost, remain a major obstacle to progress in harnessing that type of ocean energy. A recent proposal led to the development of a prototype scheme in which the ocean surface plays the role of membrane. Fresh water can be stored in a nearby area. Based on the principle of osmosis, it is mitigated in the direction of the sea salt water mass, passing through a turbine and mixed with sea water on the other side. A disadvantage is the size of the turbines required.[7]

The salinity gradient has been used for the production of electricity through batteries. Flowing sea water assumes the role of electrolyte.

From an environmental point of view, there may be a problem with the animals that can be sucked into the ducts also the salt residues should be disposed of properly and sufficient fresh water would be available.[7]

2.4 Main Power Generation Plants from the Sea Energy

Around the world there are several power generating plants that are harnessing the energy of the oceans to serve thousands of homes. In virtue of this, each one of these installed plants has its particularity, which must be described to take as a reference for a future energy undertaking in Ecuador. Below it is briefly described the main generating

plants in the world, using three of the most developed technologies for marine energy use: tidal, wave and wind offshore.

2.4.1 Tidal Power Plant La Rance, France

This plant in Rance River (Brittany) has successfully supplied electricity since 1966, is the oldest of its kind in the world.

The power of this renewable energy plant is 240 MW, currently being operated by *Electricité de France* (EDF), has an annual generation capacity of 540 GWh.



Figure 2.2 "La Rance" Tidal power plant

Source: fierasdelaingenieria.com

Its work was carried out between 1961 and 1966, it consisted in the construction of a dam of 145.1 m of length with six gates of fixed wheels and a dam of 163.6 m of length, being the area of the basin covered by the plant of 22.2 km². The location of the facility has an average 8.2 m tidal range, the highest in France, allowing the production of energy through 24 Kaplan reversible bulb turbines with a nominal power of 10 MW each. The

electricity produced is sent to the national transmission network of 225 kV, covering the needs of approximately 130,000 households each year. [15]

2.4.2 Tidal Power Plant Sihwa Lake, South Korea

This tidal power plant is located on Lake Sihwa approximately 4 km from the city of Siheung, in Gyeonggi Province in South Korea. Its inauguration took place in august of 2011, with a 12.5-kilometer boardwalk built in 1994 to prevent flooding and to fulfill agricultural purposes. The project was built between 2003 and 2010 with a budget of 256.8 million euros; Daewoo Engineering & Construction Company was responsible for engineering, supply and construction.



Figure 2.3 Sihwa Lake tidal power plant

Source: fierasdelaingenieria.com

With an electrical production capacity of 254 MW, it becomes the largest tidal power plant in the world. This project belongs to the Korean Water Resources Corporation.

Energy production is provided by 10 submerged bulb turbines, each with a generating capacity of 25.4 MW, which take advantage of tidal revenues in the 30 km² basin. To

remove water from the dam it is necessary to have 8 sluice gates. At present, the annual capacity of the facilities is 552.7 GWh.[16]

2.4.3 “Tidal Lagoon” Tidal Power Plant, United Kingdom

This is a breakwater project in the form of "U", is built from the coast that has a bank of hydraulic turbines. Due to the incredible tides on the west coast of Great Britain, "by keeping the turbine doors closed for only three hours, there is already a difference of 14 feet (4.26 m) in the water between the interior and the outside lagoon. The plant will be constructing a wall-type breakwater of 6 miles (9.6 km) in length to create a lagoon cordoning 11.5 km² of sea." [17]

The water fills and empties the artificial lagoon as the tides rise and fall. Electricity is generated in the incoming and outgoing tides, four times a day, every day. The plant will use 16 reversible bulb hydraulic turbines to generate energy. Energy is generated as water rushes through 200-foot long draft tubes, rotating turbines 23 feet in diameter.



Figure 2.4 Project in Swansea Bay, UK

Source: www.tidallagoonpower.com/projects/swansea-bay/

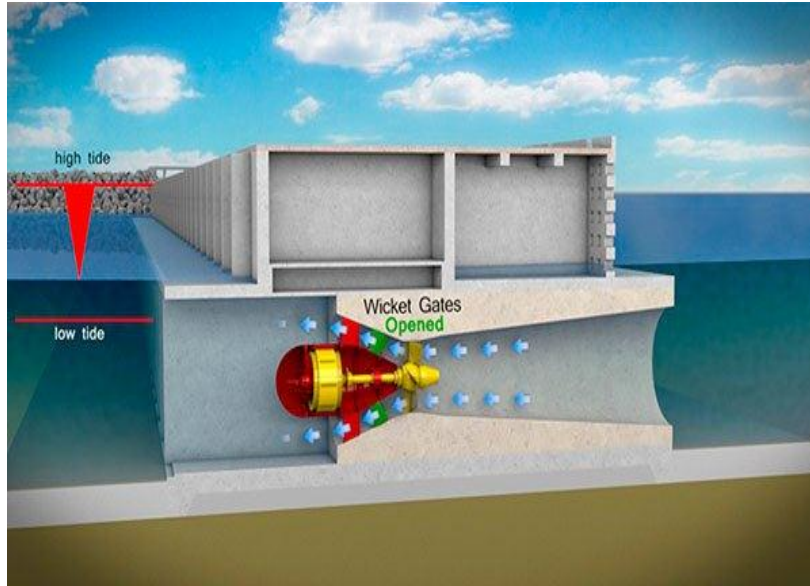


Figure 2.5 Turbines Tidal Lagoon plant

Source: fierasdelaingenieria.com

This 240 MW generation plant is part of a pioneering project involving 320 MW and some lagoons are involved in the Swansea Bay sector in the United Kingdom. Its construction was approved in march 2013 and has a budget of 850 million pounds sterling (1,011 million euros). The innovative tidal power project has been built since 2015 and is expected to be completed and put into operation in 2018.

The plant, with an estimated power generation capacity of 400 GWh per year, will provide power to more than 155,000 households over a 120-year period. Its main partners include Atkins, General Electric, Andritz Hydro, Laing O'Rourke and Alun Griffiths Ltd.[17]

2.4.4 Annapolis Royal Tidal Power Project, Canada

This plant was built in 1980 and came into operation in 1984, its dam already existed in order to control the tides, the electrical generation system is built with an investigative purpose of the use of this type of marine energy. Annapolis Royal is located in the Annapolis Basin in the Bay of Fundy in Canada. The installed capacity of this generator is

20 MW and delivers about 50 GWh of electricity per year covering the energy needs of some 4,000 homes.

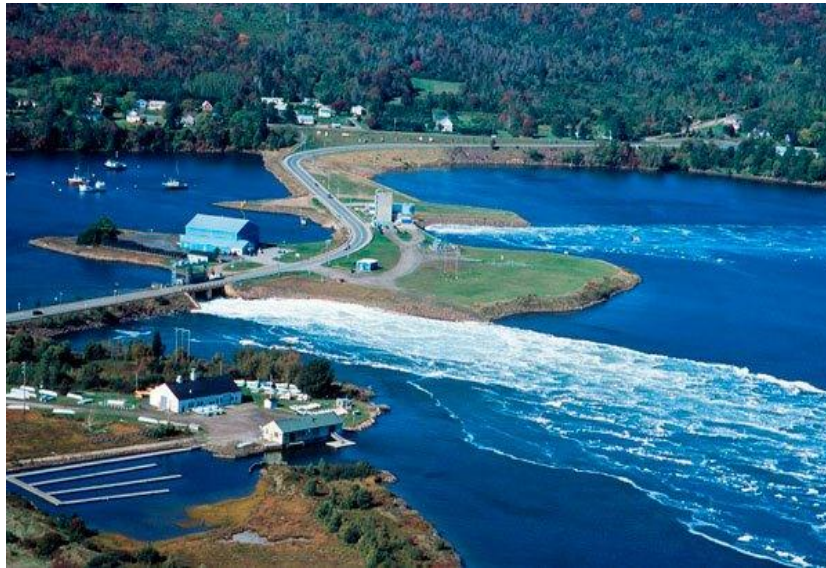


Figure 2.6 Bay of Fundy, Canada

Source: fierasdelaingenieria.com

This plant is being operated by Nova Scotia Power and consists of four-bladed turbines and sluice gates, which remain closed with incoming tides to create a pond in the lower Annapolis River. When the floodgates are opened, the water moves to the sea, pushing the turbine to generate energy, provided that the difference in height is 1.6 m or more between the pond and the sea with the descent of the tide.[18]

2.4.5 Wave Power Plant Limited, Scotland

It is the largest wave power plant on the planet. It is named "Lewis Wave Power Limited" because it is the subsidiary of "Aquamarine Power" in Scotland, which was approved by the Scottish government. The company's engineering group considers it feasible to install the Oyster wave power equipment in the entire area planned for the generation plant along the Lag na Greine coast near Fivepenny Borve.[19]

When the network infrastructure is implemented, 40 to 50 Oyster equipment will be implemented, with a capacity of 40 MW installed, which is considered sufficient to provide electricity to more than 38,000 homes near the region. With this contribution, Scotland in the year 2020 will have 100% of electricity generation from renewable resources. In addition, in 2012, the Comhairle nan Eilean Siar (Western Isles Council) approved the planning of an onshore hydroelectric plant, which will be connected to the future wave energy park.[19]

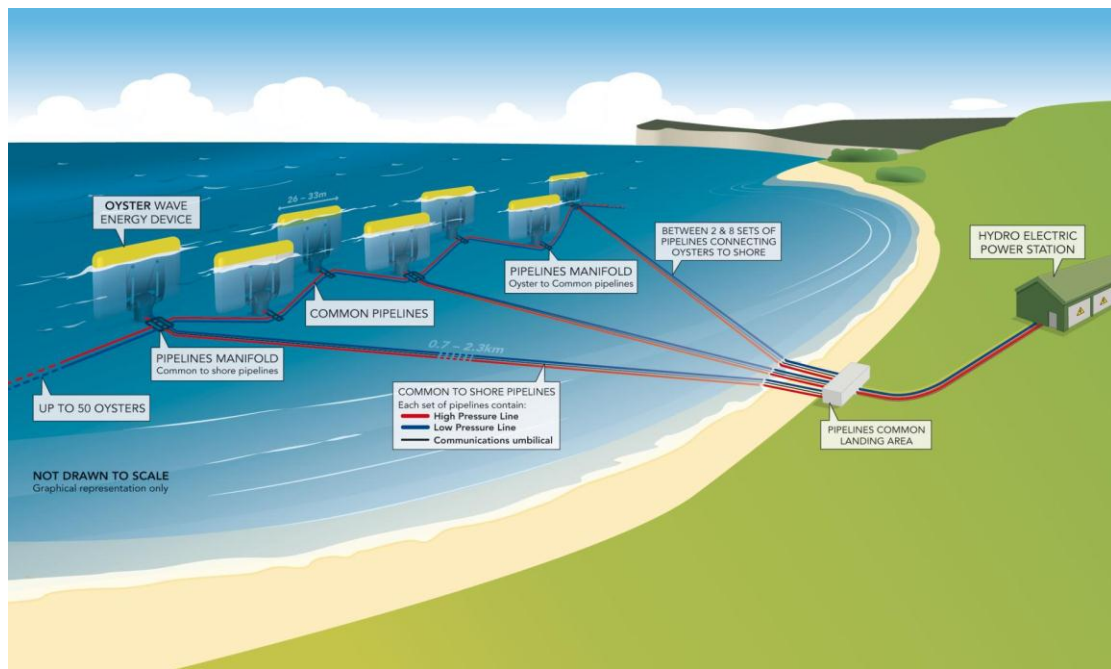


Figure 2.7 Network of worm units to be installed

Source: 40MW Oyster Wave Array North West Coast, Isle of Lewis Environmental Statement; Volume 1: Non-Technical Summary; March 2012

In 2013, Aquamarine Power engineers tested the full-scale Oyster 800 system at the European Center for Marine Energy in Orkney, seeking to complete new wave generation technology and increase equipment efficiency and resilience.

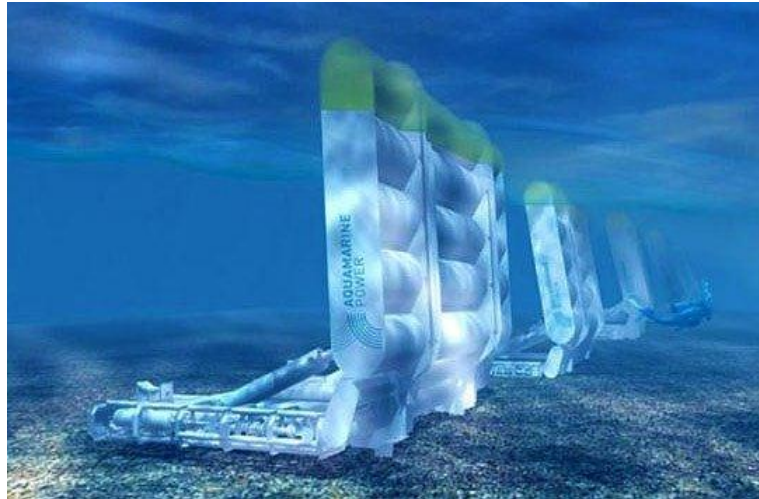


Figure 2.8 Oyster equipment installed

Source: fierasdelaingenieria.com

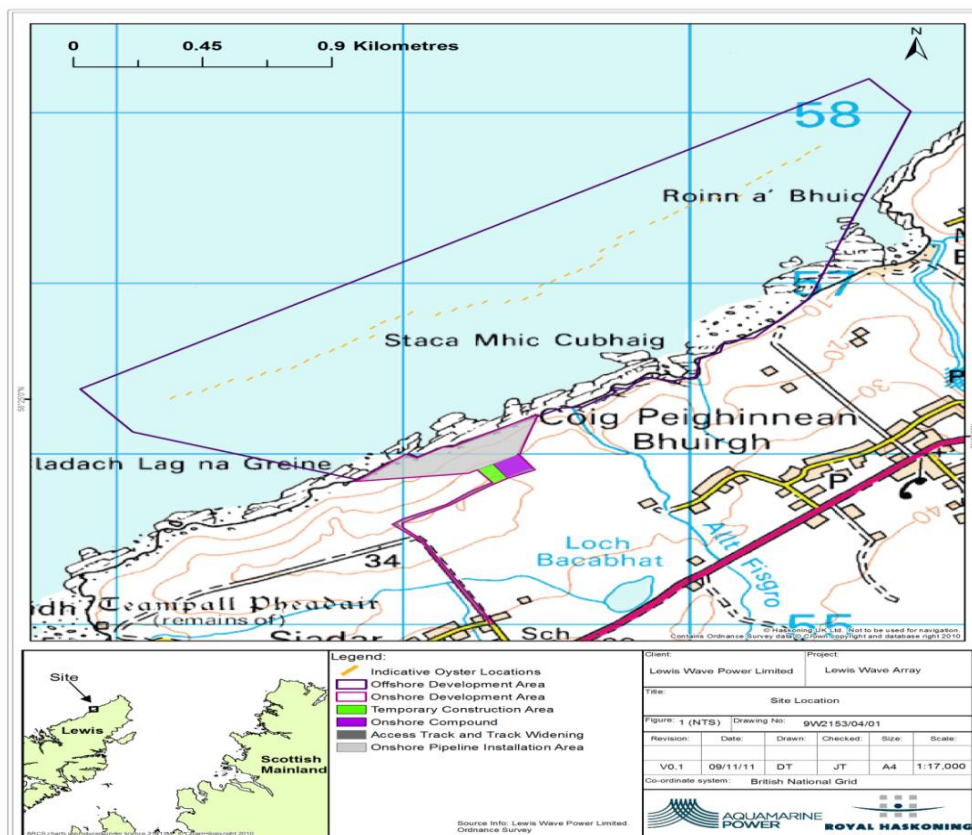


Figure 2.9 Geography encompassing the wave project in Scotland

Source: 40MW Oyster Wave Array North West Coast, Isle of Lewis Environmental Statement; Volume 1: Non-Technical Summary; March 2012

2.4.6 London Array Marine Wind Farm, United Kingdom

It is the most important marine wind park in the world and the largest generation. In 2012 the first wind turbine was placed and it took one year to place the last one, it was inaugurated in July 2013 and is located on the outer perimeter of the Thames estuary, about 20 kilometers off the coast of Essex. It has an area of approximately 100 km² in which more than 450 km of submarine cables have been deployed.

It was built by a consortium made up of three large energy companies such as: Masdar, EON and DONG Energy.[20]



Figure 2.10 *London Array marine wind farm*

Source: www.londonarray.com/the-project-3/

It has a generating capacity of 630 MW through 175 wind turbines of 6.3 MW each supplied by the German Siemens, one substation on the ground and two substations on the high seas. It is estimated that the London Array avoids the emission of 925,000 tons of carbon dioxide per year at its current capacity.[20]

The project has a second phase which aims to reach 1 GW of capacity, increasing 370 MW, but there are environmental impediments, as it is considered that the first phase is disturbing the flight of the birds of the region, So it was decided to monitor the current plant in operation and with the results, in 2017 make the decision regarding the feasibility of the second stage.[20]

2.4.7 Wind Generation Plant, The Netherlands

Westermeerwind is a wind farm that generates 144 MW in the shallow water of IJsselmeer, the largest lake in the Netherlands. This wind energy project is part of the country's largest wind farm, Noordoostpolder, located along the dikes of the IJsselmeer. Westermeerwind caters to around 160,000 households.[21]

The Westermeerwind wind farm was officially inaugurated in June 2016. The wind project is owned by Westermeerwind, a special purpose company founded in 1996 by two farmers from Creil, Pieter Meulendijks and Tjitte de Groot, to build an offshore wind farm at along the dikes of Westermeer and Noordermeer in IJsselmeer.



Figure 2.11 Westermeerwind wind farm, Netherlands

Source: <http://www.power-technology.com/projects/westermeerwind-wind-farm/>

The Westermeerwind wind farm project reached its nominal capacity in March 2016, by means of 48 wind turbines of 3 MW each.

After reviewing some important references within the electricity generating plants using marine resources, an essential starting point is to identify the available resources and technologies that could be used in Ecuador. These aspects are discussed in the next chapter.

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3. IDENTIFICATION AND LOCATION OF POTENTIAL SOLUTIONS FOR THE USE OF SEA ENERGY IN ECUADOR

After the description provided in the previous chapter, the forms of energy available on the country's coast are looked for, as well as the necessary geographical conditions and the appropriate technologies to propose an electric power plant, taking as main energy a renewable source of energy, the sea.

3.1 Form of Marine Power Available in Ecuador

Section 2.4 describes some of the most important plants of the planet each with a different technology and under different conditions to present an optimal operation and adequate efficiency. Based on this information, a list of resources that could be exploited in the sea that bathes the ecuadorian coasts is elaborated.

3.1.1 Tidal power in Ecuador

The tidal power has some conditions to be exploited; it is carefully reviewed if the section of the ocean that belongs to Ecuador fully fulfills each of these conditions to proceed to test the feasibility and cost-effectiveness of generating electricity through this resource.

The three main conditions for considering the feasibility of a generating plant of this type are the following[22]:

Tidal range: Refers to the difference in height between high tide and low tide. Nowadays the technology provides the facility to take advantage of tidal difference greater than 5 meters, otherwise projects with very low efficiencies would be involved.

Number of turbines: This is a condition that depends directly on the design and the area available for construction of the plant.

Reservoir area: When constructing a water catchment reservoir at high tides, the area is an important factor, as shown by the projects in operation such as "La Rance" in France or "Royal Anapolis" in Canada, which generates 240 and 20 MW respectively, with areas of 17 km² the first and 6km² the second, that is a tidal project should address values similar to these.



Figure 3.1 Ecuadorian coastal map

Source: Oceanographic Institute of the Ecuadorian Navy

According to these conditions, specific points are located on the map of Ecuador and the values of tides according to official data of the Oceanographic Institute of the Ecuadorian Navy (INOCAR) are described below.

The red dots on the map describe places in Ecuador where you can get accurate tide data, according to this map a survey of each of the points is made in search of the highest tide differences that allow to fulfill the first and main condition to give feasibility a tidal project.

From the data provided by INOCAR, the largest difference between tides is concentrated in the Guayas River (Guayaquil-Río, according to the illustration) in which up to 4.5 meters of tidal amplitude that can be obtained.

However, as discussed in the main conditions for thinking of a tidal-type plant, this tidal difference turns out to be very low as well as being with unstable values.

The figures from 3.2 to 3.4 show some measurements of tide levels reported in daily, monthly and annual charts.

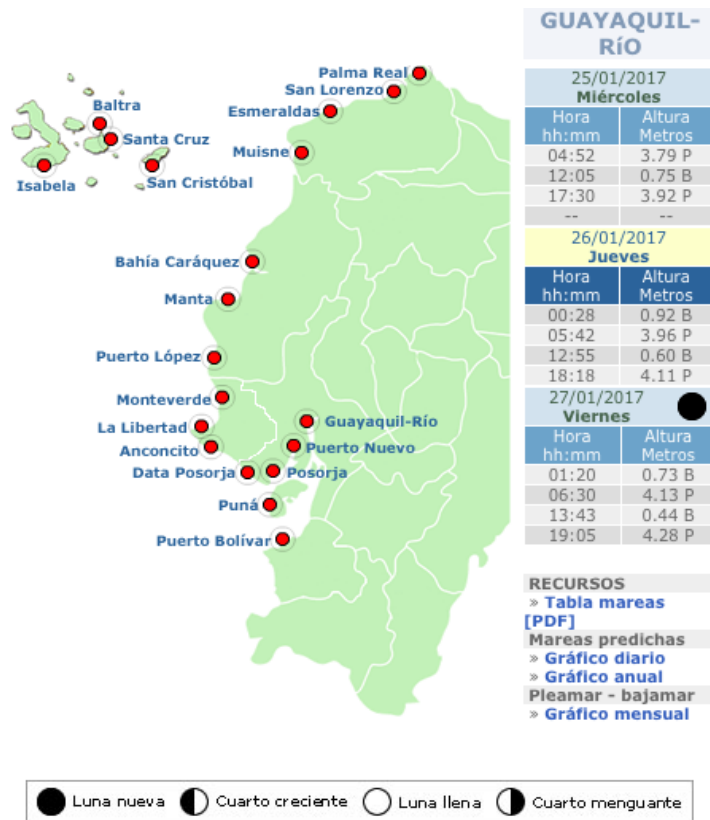


Figure 3.2 Daily data of Guayaquil-Rio tide in real time

Source: Oceanographic Institute of the Ecuadorian Navy

It should be emphasized that under "New Moon or Full Moon" tides are predicted to be larger, even under this characteristic, the tides of the Guayas River do not reach the value of 5 meters considered as the minimum for feasibility of a tidal project (Figure 3.2).

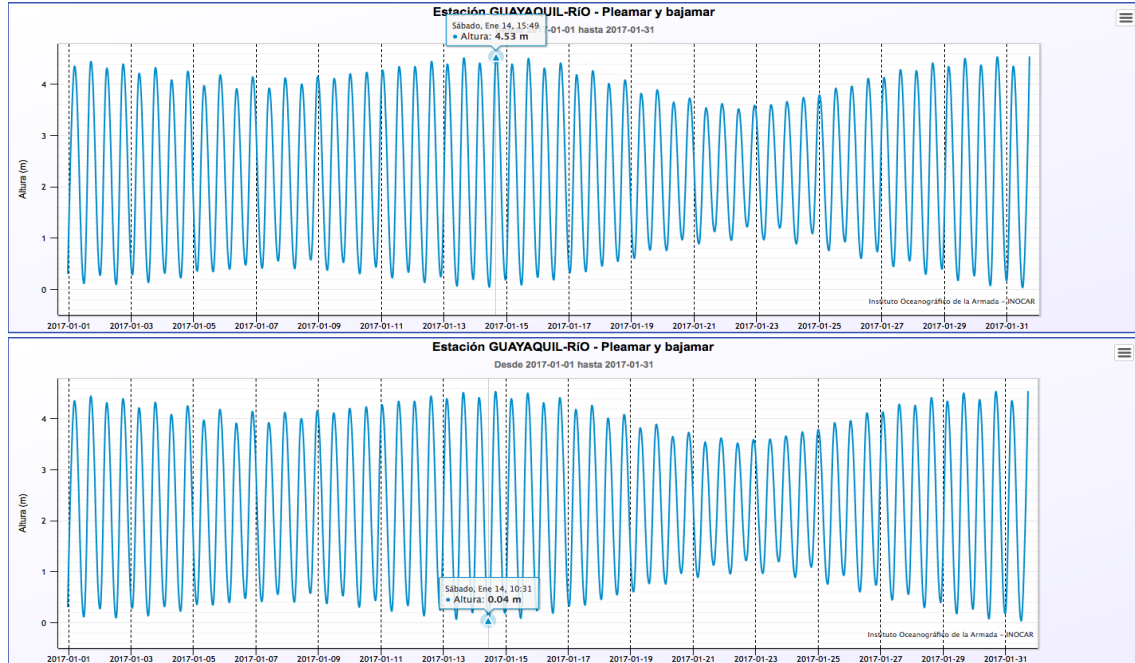


Figure 3.3 Daily tidal data taken in real time

Source: Oceanographic Institute of the Ecuadorian Navy

According to the data collected in January 2017, as shown in figure 3.3, the maximum tide level reaches 4.53 meters and the minimum reaches 0.04 meters, within this period a tide difference of 4.49 meters and is the largest amplitude of the month presented.

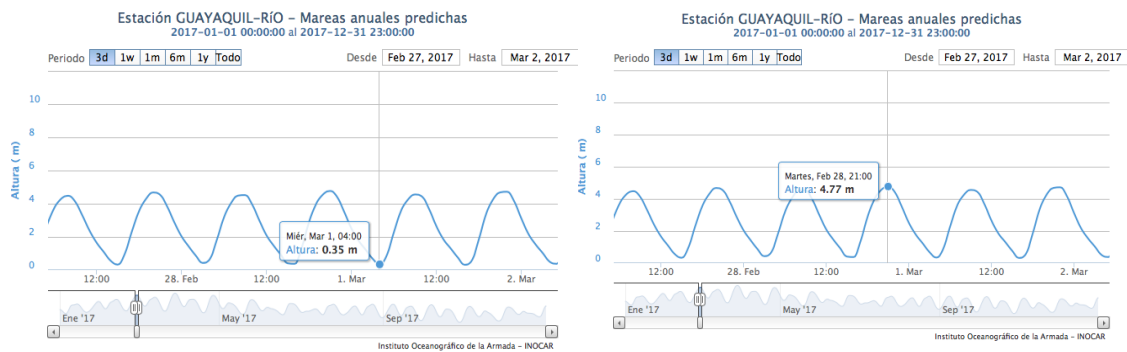


Figure 3.4 Annual tide data taken in projection

Source: Oceanographic Institute of the Navy

Under the review of tide levels of 2017, maximum and minimum points are shown in order to have the biggest difference, an exposition of this case is presented in figure 3.4 in which is taken as an example the date of february 28 and march 1st in which a difference of 4.42 meters is achieved.

With these antecedents presented, any possibility of generating electricity is lost from the energy of the existing tides in Ecuador.

3.1.2 Wave power in Ecuador

In this section of the study, the possibility of obtaining electrical energy from the waves that exist in the Ecuadorian sea is evaluated.

The European Directorate for Renewable Energies in the year 1991 drew up a world map which, according to the author, describes the available energy of the sea waves, expressed in kilowatts per meter of sea front.[23]

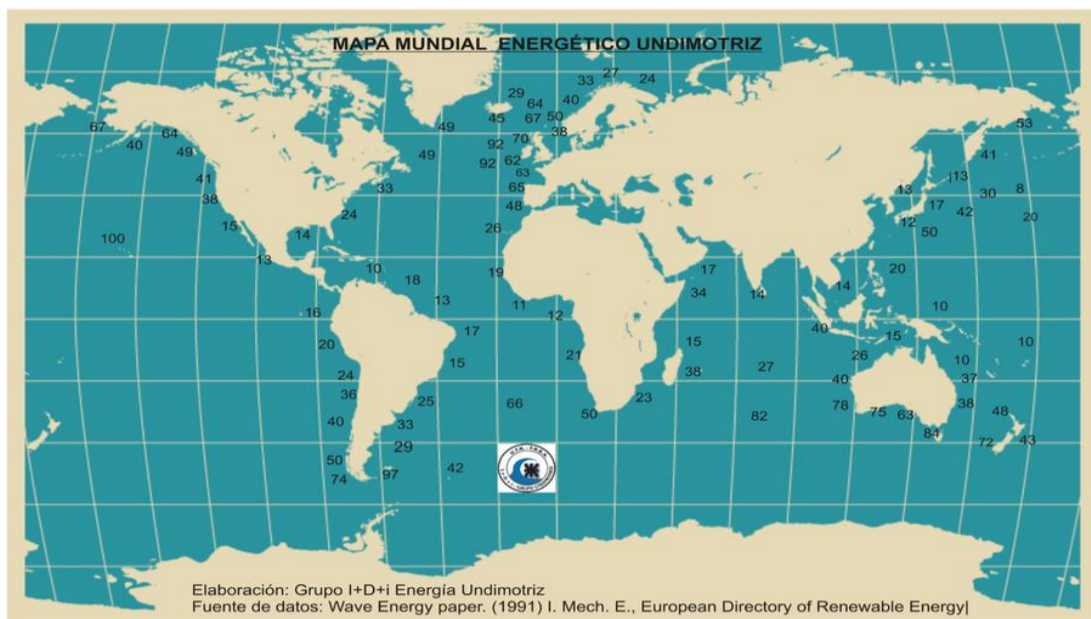


Figure 3.5 World wave energy map (kW/m)

Source: I. Mech. E., European Directory of Renewable Energy. Wave Energy paper. (1991)

According to figure 3.5, Ecuador has an energy average of 16 kW/m, which is the initial data to be considered for the feasibility of implementing this type of technology in the country.

After knowing that there is energy in the waves of the sea, a main condition is to know and select the best technology option that takes advantage of the swinging of the waves and that its characteristics adhere to the available data of the ocean in Ecuador. For this reason, in spite of a great diversity of equipment that can generate electricity through this resource, in this study it is necessary to filter and find which of them is coupled to the benefits of the sea in Ecuador, mainly in terms of efficiency, both energetic as economic, since the national reality does not allow the moment to spend resources in technologies of low efficiency or reduced benefit.

Based on the information presented in the previous chapter (section 2.3.3), within the types of equipment and ways of absorbing the energy of the waves, more than a dozen can be counted, according to their proven efficiency and study developed in each one of these technologies can be classified the three main as follows[24]:

- 1. Attenuators:** Floating features and placed parallel to the waves.
- 2. Floating point:** It has a buoy that floats on the surface of the ocean, and the structure of this machine is fixed in the depth
- 3. Oscillating Converter:** It is submerged in the sea at relatively short distances of the coast, has hinges that move its oscillating structure with the water of the waves.

Other forms of use such as oscillating water column (OWC), pumping waves, pressure differentials, etc. are not considered. This is because, despite having passed certain tests and generating electricity in several parts of the world, its research and technological development is not considered optimal or sufficiently developed for the purpose of this research that seeks electricity generators with broader studies and that reach considerable powers to commercialize electricity and insert it into the energy matrix of Ecuador.

According to a study carried out from the Polytechnic School of the Coast in 2010, the following data can be presented concerning the wavelength and its period; these data were collected in the Gulf of Guayaquil, the most favorable point according to samples to take advantage of this type of energy. These magnitudes are necessary to test the feasibility of any project using the energy source under study:

Table 3.1 Height and period of the waves in the coasts of Ecuador

Month	Hs Surf Break (m)	Hs Swell Deep water	Ts Swell (s)	Dir Swell (degrees)
January	1.59	1.58	13.85	215
February	1.62	1.60	13.94	215
March	1.85	1.85	13.70	215
April	1.73	1.77	13.67	210
May	1.77	1.78	13.58	205
June	2.11	2.04	14.19	2015
July	1.97	1.93	13.27	210
August	2.12	2.11	13.69	205
September	1.95	2.03	13.39	210
October	1.91	1.91	13.85	210
November	1.90	1.87	13.37	210
December	1.63	1.70	13.53	210

Source: Secretary of Risk Management - ESPOL, CADS (2010)

Currently there are many technologies available and considerable development for the use of wave energy, however two of the main ones that will show if feasible and profitable is an ocean wave characteristic project in Ecuador:

Waveoller:

It is a device in the process of development that during 2012 already had its first tests in the sea of Peniche in Portugal, because they installed 3 devices of 100 kW each, in this

project the functional and efficiency part was monitored of the equipment as well as the environmental part, delivering positive results in this last aspect.[25]

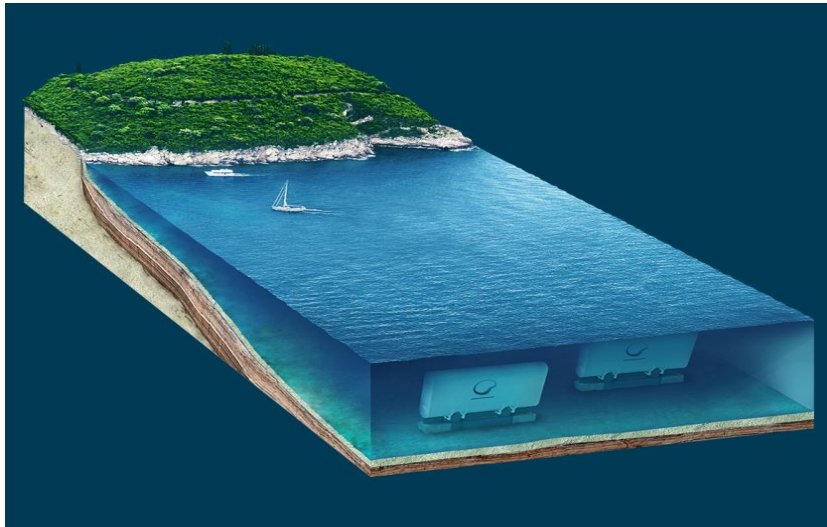


Figure 3.6 Waveoller Submerged

Source: <http://aw-energy.com/en/>

The general characteristics of this generator are summarized as follows:

- The prototypes presented so far can generate 100 W, but we are looking to build machines that generate between 500 and 1000 W, this will depend on the size of the equipment and the performance of the waves in the ocean that is looked forward to implement.
- Waveoller is expected to operate near the coast in a range of 300 meters to 2 kilometers maximum; this makes it advantageous equipment since it facilitates the operation and maintenance and above all the costs of energy transportation is reduced compared to other technologies.
- The depth at which it is installed varies from 8 to 23 meters.
- The costs of the equipment according to the company that makes it are very high with respect to other technologies of generation of electricity unconventional, however is worked at the moment in which these are reduced.

The manufacturers of the machine, AW-Energy Ltd. of Finnish origin, present the following energetic map of the use of world-wide wave energy:



Figure 3.7 Wave energy according to AW Energy

Source: <http://aw-energy.com/en/>

As can be seen in figure 3.7, the continental section of Ecuador is not suitable for applying this type of technology, there is also a great potential near the island region of Galapagos, but it is not necessary the distance to which we would find the potential it also takes into consideration that Galapagos is a biodiversity zone unique in the world so it would be very difficult from the environmental point of view or to some extent for it to notfit to implement an energy project with this technology.

Added to these criteria, another important point is the commercial information of the equipment, not yet available for calculations or real appreciations of the economic resources that are required to think about a possible implementation.

These aspects do the Waveoller an interesting project but beyond the scope of the study that is carried out.

Pelamis:



Figure 3.8 Pelamis machine on the sea

Source: <http://ctp.lns.mit.edu/energy/files/pelamisbrochure.pdf>

Pelamis is undoubtedly the most developed and proven machine of all those related to the energy of the waves, it has the characteristic of being put into operation commercially and after several experiences and information collected, it is possible to show its main properties[26]:

- It is named P-750, because it's 750 W the generation capacity of the "snake"
- It's weight is around 700 tons
- It has a diameter of 3.5 meters
- It's total length is approximately 150 meters, consisting of four sections
- The installation of the equipment is foreseen to a depth between 50 and 100 meters
- Its design is adapted to install between 5 and 10 km of the coast
- It has a "loose" anchor because it uses the movements of the waves in every way

The first experiences with the Pelamis was in Portugal, installing 3 equipment that produced 2.25 MW, the tests were rated as positive, so to dream of implementing a 30 MW generator for which an area of 1 km². [26]

Regarding the efficiency and power of utilization of the machine, the following information is presented by the figure 3.9:

		Power period (T_{pow} , s)																
		5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
Significant wave height ($H_{s,95}$, m)	0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
	1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
	1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
	2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
	2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
	3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
	3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
	4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
	4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
	5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
	5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
	6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
	6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
	7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
	7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
	8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

Figure 3.9 Power (kW) regarding amplitude and wave period

Source: <http://ctp.lns.mit.edu/energy/files/pelamisbrochure.pdf>

The main parameters that govern the efficiency and the energy utilization of the machine are the significant height or amplitude of the wave and it’s period, in the figure 3.9 presented to obtain a considerably high efficiency or that encourages the expenditure of resources, would be It is necessary to concatenate a significant wave height of at least 4.5 meters and a period of less than 10 seconds which shows in the red zone of the figure. With this information it can be concluded that there are no such benefits in Ecuador, since according to table 3.1 above, in the best case the height of the waves in the sea reaches 2 meters and the period of repetition of one wave has an average of 13.67 seconds. With this data the power that could be used is between 30 and 60 kW, which is insignificant with respect to the efficiency that the machine has.

Figure 3.10 shows the power curve for the energy utilization of Pelamis.

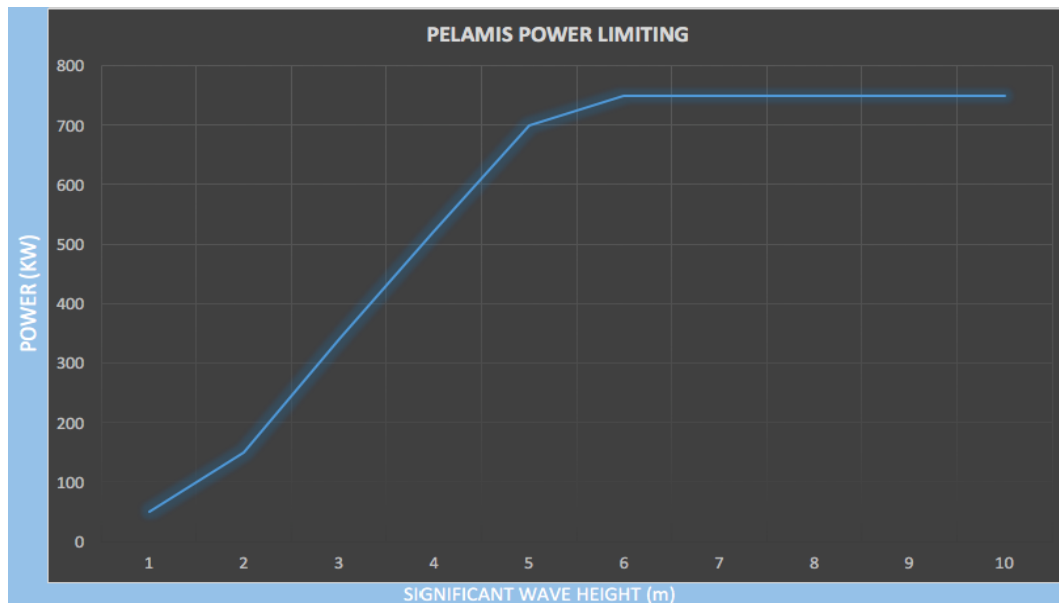


Figure 3.10 Pelamis Power as a function of the wave height

Source: Prepared by the author from the powers presented in figure 3.9

In economic terms, the University of Chile made an approximation of what it would cost to install this machinery in two possibilities:

The first one analyzes a generation plant of 3 MW and its average cost is 20 million dollars, in the second scenario it is analyzed for a generation center of 30 MW and the approximate cost is 99 million dollars[27], that is in the first case 1 MW installed would cost 6.5 million dollars and in the second study would pay 3.3 million for the installation of 1 MW. That is, in the case of this technology, applies the economy of scale.

All the information presented regarding the Pelamis machine, suppresses for the moment the possibility of having this technology in the sea of Ecuador, mainly by the power of the waves of both height and period, parameters that do not meet a minimum requirement.

3.1.3 Wind power in the Ecuadorian sea

In different oceans and coasts close to several countries there is an interesting wind potential to be harnessed by turbines and generate electricity. In the previous chapter a reference was made to the turbine farm on the Dutch coast called Westermeerwind and the United Kingdom sea wind generator, London Array.

The basic characteristic to undertake a wind energy project on the coasts of any part of the world is wind speed, based on this it can be mentioned that the turbines generating the relevant projects require a wind speed of at least 3 m/s (7 mph - 11.2 km/h) to start operation and reach a generation with maximum efficiency when the resource reaches 13 m/s (29 mph - 46.4 km/h)[20].

That is to say that in order to develop a wind power project in Ecuador in search of high efficiency, wind would need more than 37 km/h, representing 80% of the wind resources in the projects taken as referents.

In Ecuador, four coastal sites are considered for check their wind speed, and these points are selected because they have the best wind energy conditions in the country, the sectors are: Esmeraldas, Bahía de Caráquez, Manta and Santa Elena and their results are presented from Figure 3.11 to 3.14:

Mes del año	ene	feb	mar	abr	may	jun	jul	ago	sep	oct	nov	dic	Año
	01	02	03	04	05	06	07	08	09	10	11	12	1-12
Dirección del viento dominante	↖	↖	↖	↖	↖	↖	↖	↖	↖	↖	↖	↖	↖
Probabilidad de viento >= 4 Beaufort (%)	6	3	4	4	4	9	11	13	14	14	13	14	9
Velocidad media del viento (kts)	6	6	6	6	6	7	7	8	7	7	8	8	6

Figure 3.11 Wind velocities on Esmeraldas coast

Source: www.windfinder.com

This first image describes the wind behavior in Esmeraldas; the annual average is 6.8 kts (kts is the unit of wind speed called knots and corresponding to one nautical mile per hour, is the most common unit of measurement within marine studies) or 12.3 km/h.

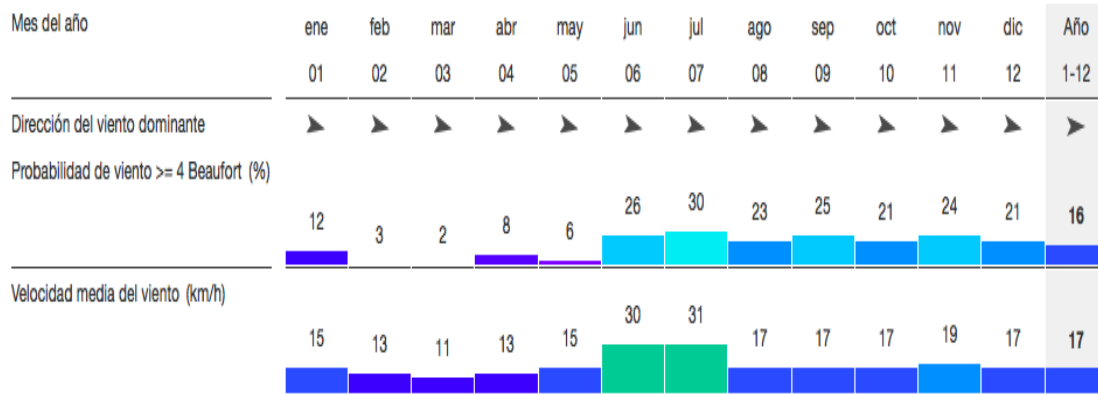


Figure 3.12 Wind speeds on the coast of Bahía de Caráquez

Source: www.windfinder.com

On the coast of Bahía de Caráquez, the average wind speed per year is 17 km/h and there are peaks in the months of June and July, where an average speed of 31 km/h is reached.

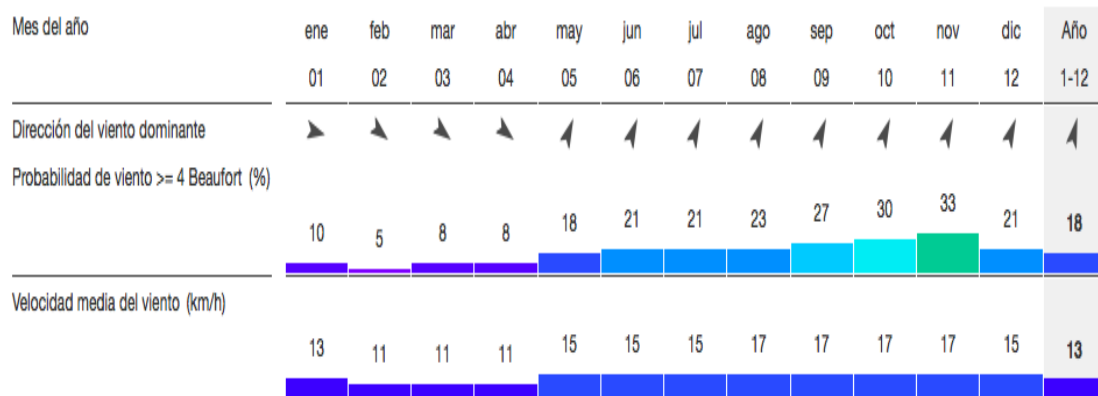


Figure 3.13 Wind speeds on the coast of Manta

Source: www.windfinder.com

In Manta the average speed according to the samples of the last years is 13 km/h.

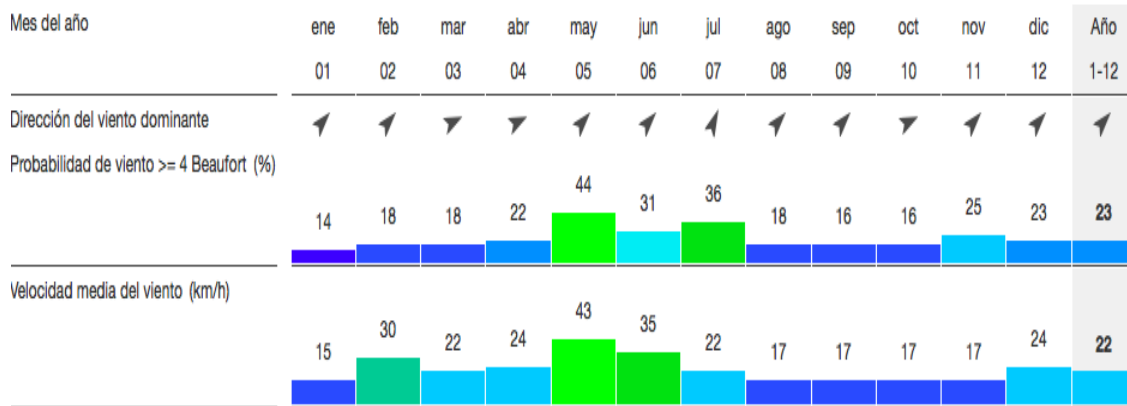


Figure 3.14 Winds speeds on the coasts of Santa Elena

Source: www.windfinder.com

The Santa Elena peninsula has the best wind conditions on the coast of Ecuador, its annual average is 22 km/h and in May and June it has the highest values with 43 and 35 km/h, respectively.

In real time samples of wind speeds are taken in the sectors of importance for a more effective comparison. For this the “windfinder” platform was used.[28]

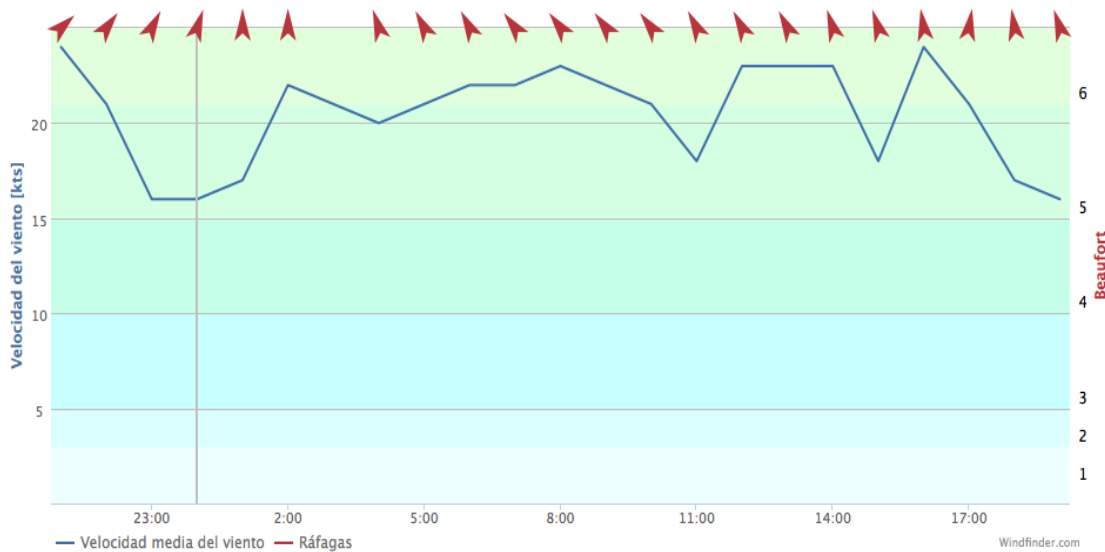


Figure 3.15 Real-time wind speed sector London Aray, UK

Source: www.windfinder.com

Observaciones del viento actuales

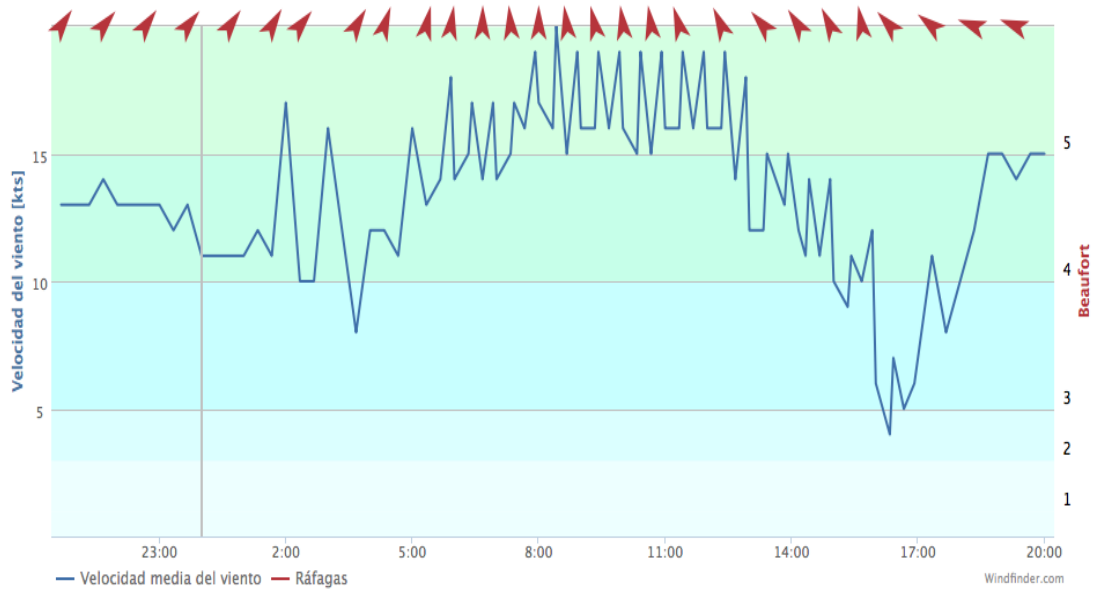


Figure 3.16 Wind speed in real time sector Westermeerwind, Netherlands

Source: www.windfinder.com

Observaciones del viento actuales

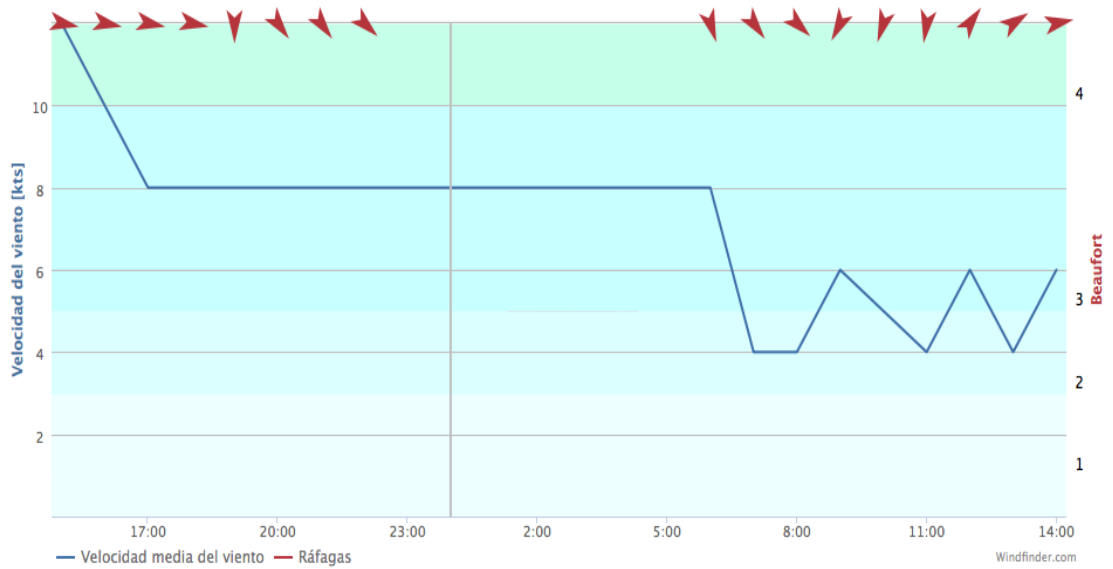


Figure 3.17 Real-time wind speed Peninsula Santa Elena, Ecuador

Source: www.windfinder.com

The wind velocity on march 22, 2017, results in the London Array project having an average of 20 kts (Figure 3.15), while similar data are being sought for the Westermeerwind ocean sector in (Figure 3.16) and it's average is 14 kts (25.2 km/h), finally the Figure 3.17 shows for Santa Elena in Ecuador an average of 8 kts (14.8 km/h).

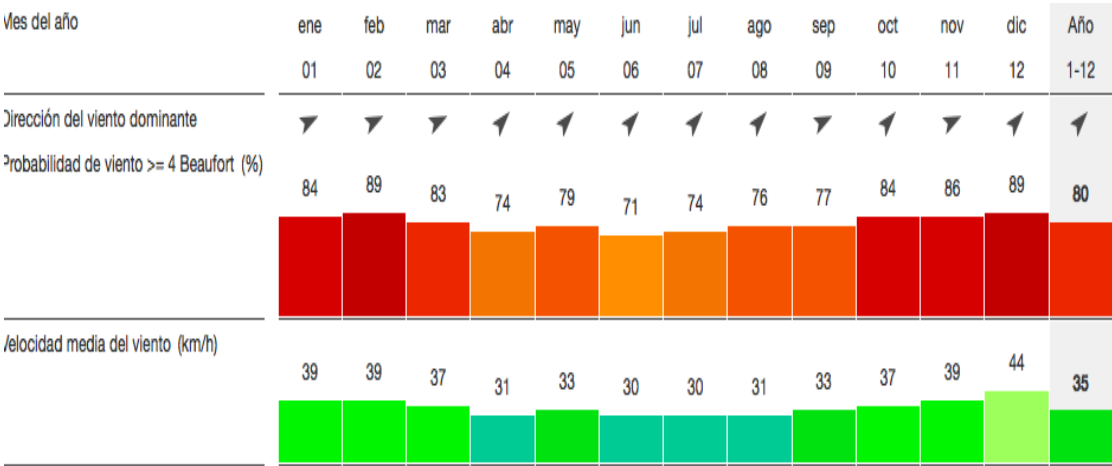


Figure 3.18 Annual wind speed sample on the Dutch coast

Source: www.windfinder.com

In conclusion regarding the wind energy in the different coasts studied, it is possible to mention that the resource in this country is scarce and does not reach the minimum levels to undertake a project of electric generation by this type of energy.

At the beginning of this section it is proposed to have high efficiencies of the order of 80% for which it is necessary wind speeds of 37 km/h and in Santa Elena as place with better conditions of the resource only 22 km/h of average, in addition this speed is not constant and in most of the time of the year is usually less.

Figures 3.15 and 3.18 show the characteristics of the winds in the United Kingdom and the Netherlands, which fully justify the reason why a project of this type was built at such sites, where their annual average speed is greater than 35 km/h, in the middle of the number of months of the year tends to be higher.

3.1.4 Energy from marine currents in Ecuador

Around the world in the oceans that wrap the continents there are several masses of water in movement. This movement can be due to different reasons like the wind, the tides or the difference of temperature and salinity of the water. Figure 3.19 shows the main circulations of these bodies of water called marine currents:

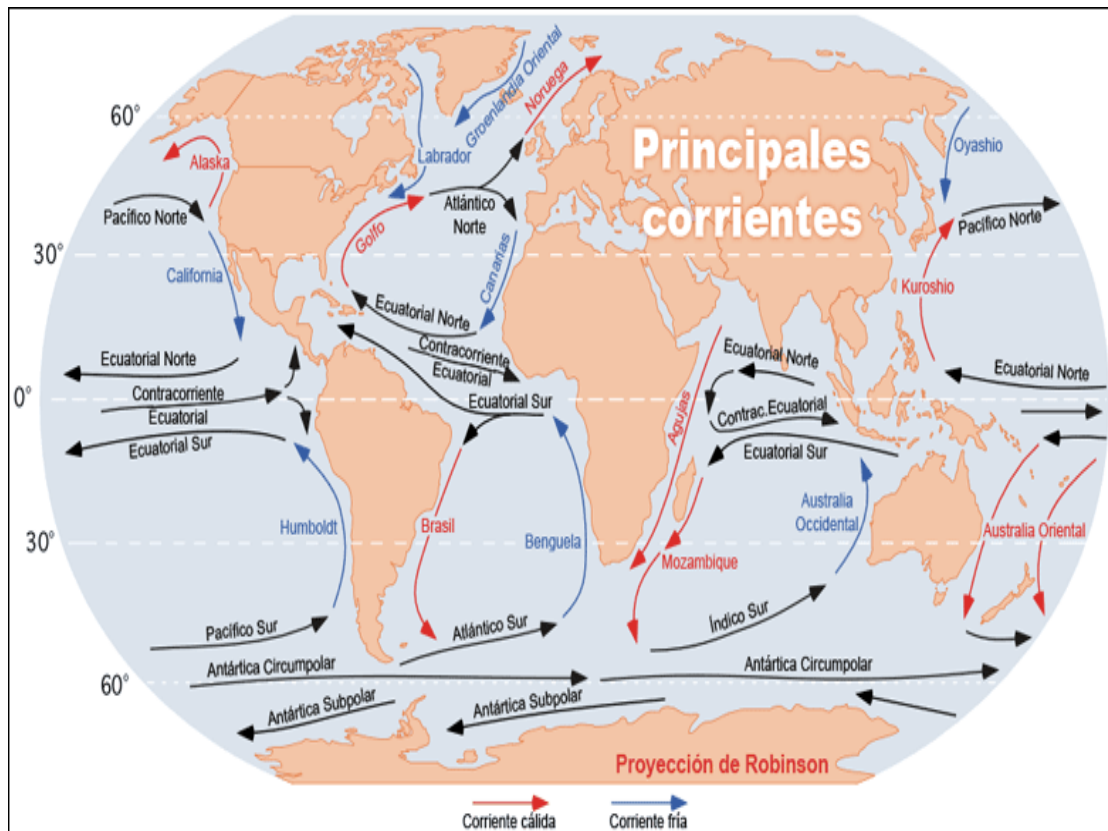


Figure 3.19 World map of ocean currents

Fuente: <http://www.auladehistoria.org/2015/09/mapa-de-corrientes-marinas-practicas-de.html>

On the coasts of Ecuador, the energy of the sea currents has several suppliers because the ocean section that belongs to the country come from the sea currents both north-south and south-north, there is also a marine counter current known as current of Cromwell, and that has a very interesting energy potential, Figure 3.20 can be better appreciated this resource on the coasts of Ecuador.



Figure 3.20 Ecuadorian continental shelf and marine current system

Source: Current System / Echinoderm Research and Diversity in Latin America. January 2012

The energy of the marine currents have more power with respect to the wind energy since the variable to be considered of each resource is the speed at which the masses of water move and the speed of the wind, respectively. With the great difference that the density of water in the ocean where the resource is usually about 800 times the density of the wind.[29]

Most of the marine currents in the equatorial strip of the Pacific Ocean are directed towards the west, the handling of the winds predominates in its characteristics, in the Northern Hemisphere is the Northern Equatorial Current and in the Southern Hemisphere the South Equatorial Current , the latter very close to the sector where hotter surface water bodies are found, in addition the components of the South Equatorial Current are driven by the presence of the Humboldt Current that comes from Peru, also exists or is generated the presence of the Equatorial Flow to the west, which is slightly north of the geographical Equator and traces the northern fringe of the South Equatorial Current.

In the ocean that corresponds to the Equator exists a current that is below the equatorial current, below the surface of the sea, flows in direction opposite to the superficial current, to which it is called Equatorial Countercurrent, usually obtains velocities greater than 1 meter per second at a depth of 100 meters.[29]

As shown in Figure 3.20, the currents that have a presence in the ecuadorian sea are:

Northern Equatorial Current and the Southern Equatorial Current:

They are characteristically similar and are the main systems in the ecuadorian Pacific Ocean. These two streams flow east-west, approximately 600 miles (965 km) wide separated by a counter-current traveling east. They usually flow to depths of less than 1,650 feet (500 m), equatorial currents travel at speeds of 10 to 40 inches (25 to 100 cm) per second. The Northern Equatorial Current is slightly influenced by the Panama Current, unlike the Southern Equatorial Current which is highly driven by the Peruvian Current and together contribute to generate the Equatorial Current.[29]

Humboldt Current or Peru Current

This current has a presence in the seas of Chile, Peru and Ecuador. It is a cold temperature (4 °C) and the most important in the South Pacific, between 5°S and 20°S. With an extension of 4000 km, it is composed of two branches, the coastal and oceanic branch at depths of 300 and 400 meters, respectively. It has an average speed of 0.32 m/s and in winter times reaches 0.5 m/s.[30]

Subsurface Countercurrent or Cromwell's Current

This countercurrent was discovered in 1951, it is a subsurface stream whose natural objective is to replace the masses of water that are moved by the effect of the equatorial currents of the north and the south and extends throughout the length of the equatorial line in the Pacific Ocean.

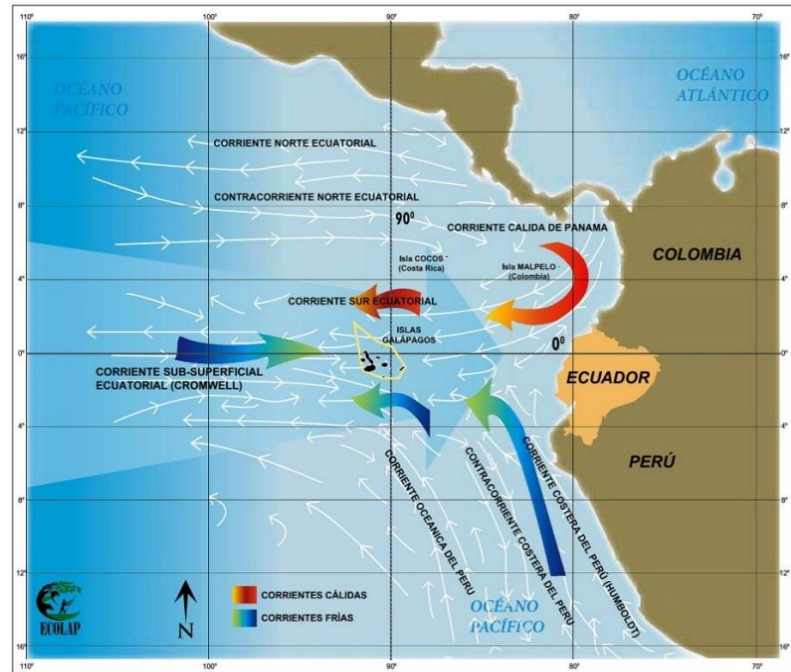


Figure 3.21 Latitude and longitude of currents in Ecuador Sea

Source: www.cuyabenolodge.com/national-parks/galapagos-islands-ecuador/

The Cromwell Current is a narrow and fast stream, centered at the equator and extending in width from latitude 2°N to 2°S. It's main feature is that it has an advantageous velocity of approximately 1.5 m/s for energy use[31]; [32]. This current is centered in the equatorial line, carries 40 million m³ of water per second, has a width of about 400 km and the depth varies between 50 and 500 meters but the main and characteristic axis of the current is close to 100 meters deep.[33]

The first study carried out on this subsurface current in order to obtain the information of the physical characteristics of the same was made in the Pacific Ocean from 140° to 90° of length to the West, this section of ocean was several times studied, arriving always to the conclusion that the equator is the main characteristic axis, since it is the axis in which the best energy performances of the Cromwell Current are presented.[34]

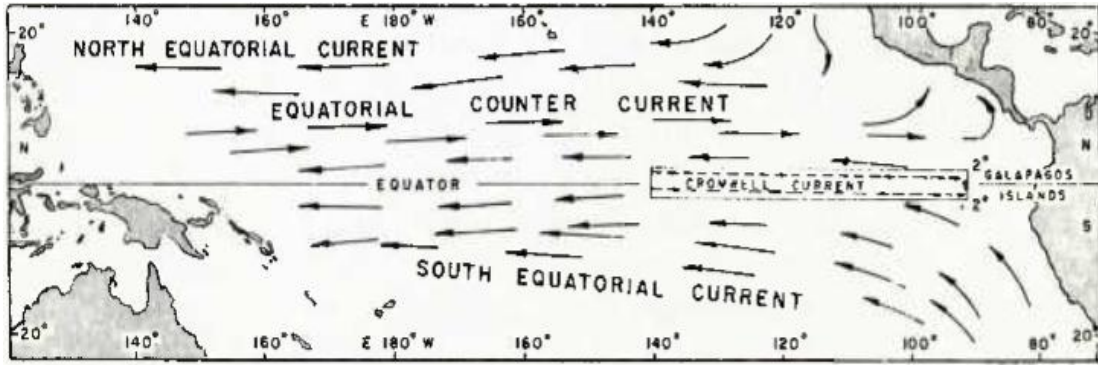


Figure 3.22 Currents of Equatorial Pacific

Source: "The Cromwell Current". U.S. Navy Weather Research Facility. 1961

3.2 Energy Potential in the Ecuadorian Sea

According to the forms of energy reviewed in section 3.1 and the summary presented in Table 3.2 follows that the country's greatest marine energy potential is found in marine currents, specifically in Cromwell's current or equatorial countercurrent which has relatively high marine current velocities for energy use.

Table 3.2 Characteristics of marine energy form

Energy form	Required minimum parameters	Parameters in Ecuador
Tidal power	<i>Difference between high and low tide</i>	
	5 meters	4.27 meters
Wave power	<i>Significant wave height (m) – Repetition period (s)</i>	
	5 meters - 8 seconds	2.14 meters - 13 seconds
Sea winds	<i>Wind speed</i>	
	25 km/h	13 km/h
Marine currents	<i>Marine current velocity</i>	
	1 m/s	1.5 m/s

Source: Created by the author, based on section 3.1 information

The literature review shows the graphs that deduce the physical characteristics of the current in which there are the best energy performances.

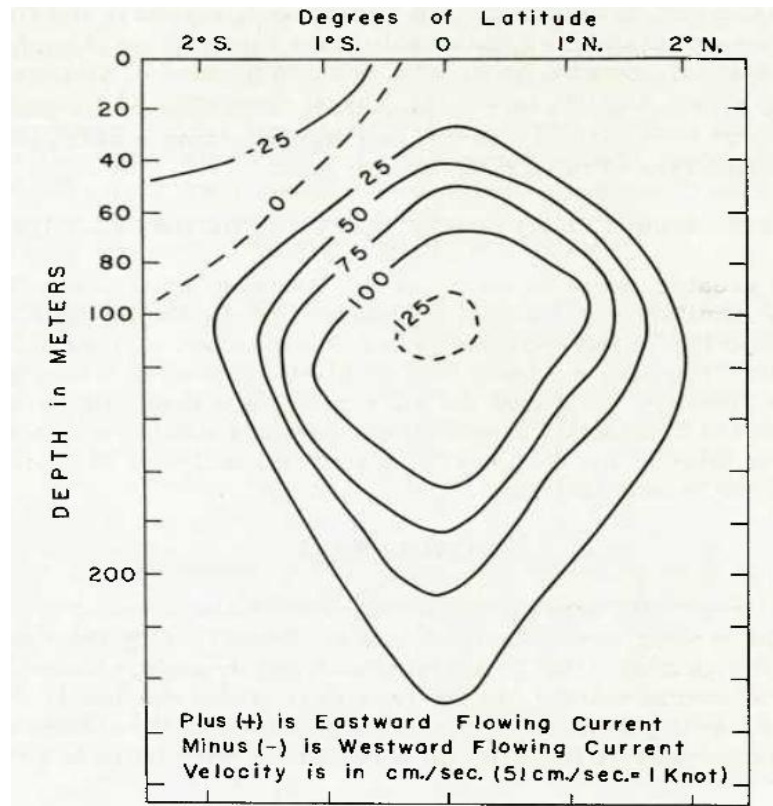


Figure 3. 23 Cromwell current cross section

Source: The Cromwell Current. U.S. Navy Weather Research Facility. R-48 Naval air station. Norfolk, Virginia. 1961

According to Figure 3.23, the first bibliographical reference in this section indicates that at latitude 0, at a depth between 100 and 120 meters can be counted with speeds up to 125 cm/s[35], this data is considered coherent since the core of the current is at said depth.

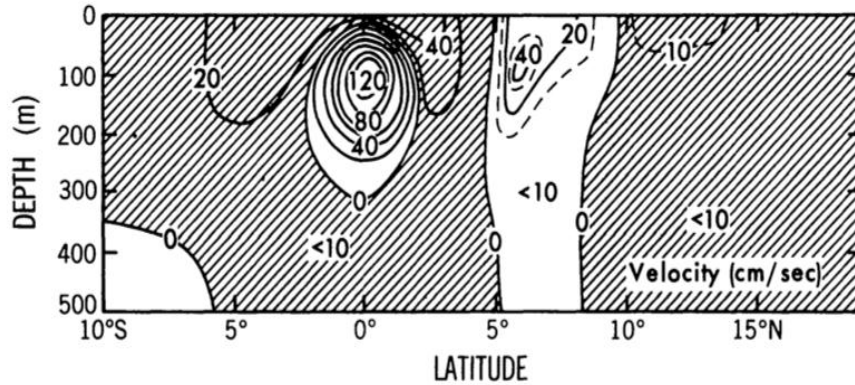


Figure 3.24 Current velocity in the equatorial cross section

Source: The equatorial undercurrent revised. S. G. H. Philander. Geophysical fluid laboratory / NOAA. Princeton University. Princeton, New Jersey

Figure 3.24 corroborates the information presented in the previous image and at latitude 0, approximates a speed of 120 cm/s, also at a depth of 100 meters.[36]

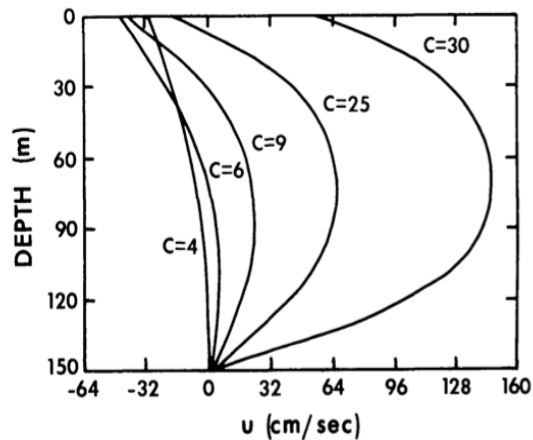


Figure 3.25 Cromwell current velocity with respect to depth

Source: The equatorial undercurrent revised. S. G. H. Philander. Geophysical fluid laboratory / NOAA. Princeton University. Princeton, New Jersey

Figure 3.25 shows that at a depth of 80 meters the marine current velocity reaches 150 cm/s.

Within the reference investigation, a parameter "c" is also approximated, which has as a mathematical formula:

$$c = \left(H^5 \tau \beta / \nu^3 \right)^{1/3}$$

Where:

Table 3.3 Variables for the graph of marine current velocity from the parameter "c"

<i>H</i>	depth where you want to take measurements
<i>τ</i>	wind intensity in the area
<i>β</i>	latitudinal derivative of the vertical component of the rotation vector of the earth
<i>ν</i>	coefficient of the vertical diffusion of the moment

Source: The equatorial undercurrent revised. S. G. H. Philander. Geophysical fluid laboratory / NOAA. Princeton University. Princeton, New Jersey

In a third study of the Cromwell Current, the most recent, conducted in 2016 by the Geophysical Institute of the University of Tokyo, has a hypothesis of current speeds in the core between 100 and 500 cm/s [33], which would result highly advantageous for the energy plans of this research.

3.3 Technologies Available for the Harnessing of the Energy of the Marine Currents

The energy of the sea currents has enormous potential and advantageous because in several parts of the world can be predicted characteristics of the same as described in section 3.1. This energy potential and the technology to extract it is still under investigation because it is a resource that is sought to exploit in recent years and is new for some types of renewable energy in the sea such as tidal or wave.

Devices used for the purpose of extracting energy from marine currents come in four common forms: it may have horizontal axis turbines, vertical axis turbines, oscillating hydroplane devices, and submerged devices with reference to the surface. Although each shape has distinct advantages over the others, horizontal axis turbines are generally better developed.[37]

Below are the most relevant types of devices in order to have a technological reference of energy use and evaluate the possibility of implementing it in Ecuador.

3.3.1 Turbines for Marine Currents “SeaGen”

The Siemens business unit created the Marine Current Turbines Company, which developed the machine called "SeaGen-S", seeking to commercialize it for electricity generation by sea currents. The site for the study was the waters of Strangford Lough in Northern Ireland.[38]

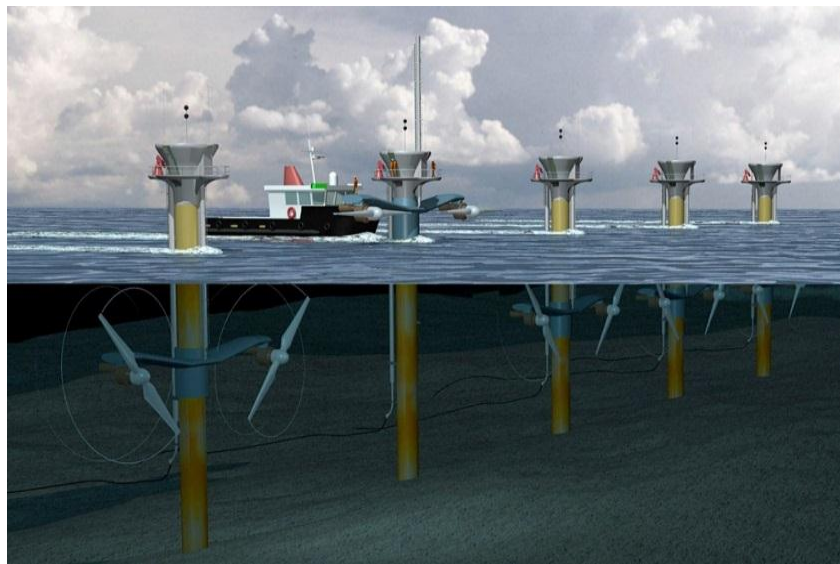


Figure 3.26 Marine Current Turbines, Generators in Wales

Source: www.marineturbines.com/3/news/article/44

The characteristics of this technology that is the pioneer in applying this exploitation are the following[38]:

- Each rotor has a diameter of 20 meters, and rotates at a speed of 4 to 11.5 rpm

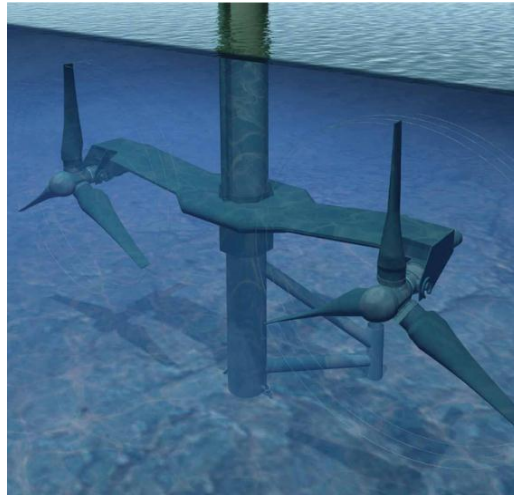


Figure 3.27 SeaGen-S Generators, blades and Casting

Source: Marine Current Turbines. Article

- The generator is asynchronous with a nominal power of 1 MW and generates at a voltage level of 690 V

Power Curve for SeaGen -S 2MW

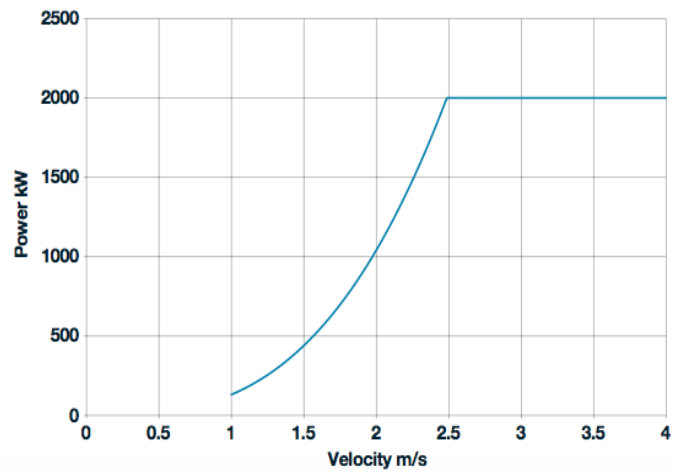


Figure 3.28 SeaGen-S Power curve

Source: Marine Current Turbines. Article

- The water velocity of the minimum marine current for generation is 1 m/s and the machine reaches its nominal power in 2.5 m/s

- In the first generation farm this equipment were installed to a depth of 38 meters
- The estimated cost for the installation of a plant of this type is around 3.8 million dollars per MW installed.[39]

Figure 3.28 shows the power curve of the SeaGen-S, in which it can be observed that the nominal power of the machine is 2 MW as two turbines (1 MW per turbine), despite reaching this power with 2.5 m/s of marine current speed, the machine can generate from speeds of 1 m/s and the minimum power that would deliver in this case would be 250 kW.

3.3.2 Verdant Power Flow, Kinetic Hydropower System

The company of North American origin (Canada – U.S.A.), Verdant Power, developed an electricity generating machine by the water currents independently if it is in the sea or in a river. The first designs have the requirement that the water stream must have a minimum velocity of 1 m/s, and this is how you get to the fourth generation equipment that has the following characteristics.[40]



Figure 3.29 Gen 4 KHPS

Source: verdantpower.com/media

- The horizontal axis turbine has 3 blades, rotate in a diameter of 5 meters
- The generator located in the main body of the equipment is induction
- For the fourth generation equipment the nominal power is 175 kW
- The voltage level generates 480 V, however this value is flexible because there are prototypes of tests with higher voltages.[40]

In December 2006, the first turbine of this type of technology was connected to the grid in the Roosevelt Island Tidal Energy demonstration project, located on the East River Channel in New York, and then in 2007, 5 more generators were installed, obtaining 1.05 MW as installed power. The project worked more than 7000 hours and energy was delivered to companies in the sector.



Figure 3. 30 Roosevelt Island - Project demonstration area

Source: verdantpower.com

- In the fifth generation of the machine that has been working since 2016 looking to improve all the characteristics of its predecessor, the speed of rotation of the blades are of 40 rpm, a relatively low speed with respect to generators of this type

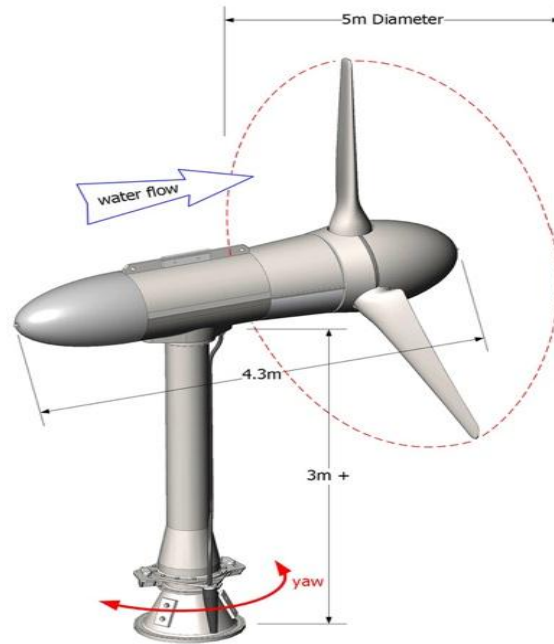


Figure 3.31 Dimensions of Gen 5 KHPS

Source: verdantpower.com

- In addition, the turbine support can rotate up to 170° to take advantage of different flow directions.

In 2016, Verdant Power Ltd. and Ireland's Belleville Duggan Renewable Ltd. decided to form a partnership called Verdant Isles Ltd. in order to develop large-scale commercial projects to take advantage of sea currents in Ireland and various parts of the UK.

The first economic calculations of this new society carried out by the Sustainable Energy Authority of Ireland (SEAI) indicate that in order to implement an electricity generation project of 900 GWh per year, which is the viable capacity according to this institution, it is necessary about 385 millions of dollars. For that reason, it results 3.77 million dollars per megawatt installed by implementing this technology.[37]

3.3.3 Lunar Energy's Rotech Tidal Turbine (RTT)

This is a relatively small machine developed by Britain's Lunar Energy since 2006, the initial design has the following characteristics[41]:

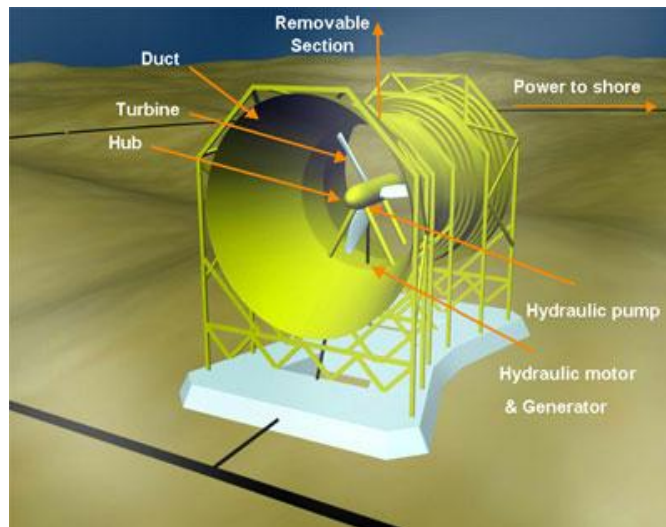


Figure 3.32 Rotech Tidal Turbine

Source: <http://www.reuk.co.uk/wordpress/tidal/lunar-energy-tidal-power/>

- The hydraulic generator is connected to a horizontal axis turbine that can rotate in a bidirectional flow direction.
- The nominal generation power is one MW when the marine current velocity is 2.6 m/s.
- The initial model is 1 MW, but since 2012 the idea of doubling power and obtaining a generation of 2 MW has been studied, which would give it a more commercial advantage.
- The section of the machine that makes it advantageous is its Venturi type duct design, which acts as a flow accelerator which produces an increase in energy

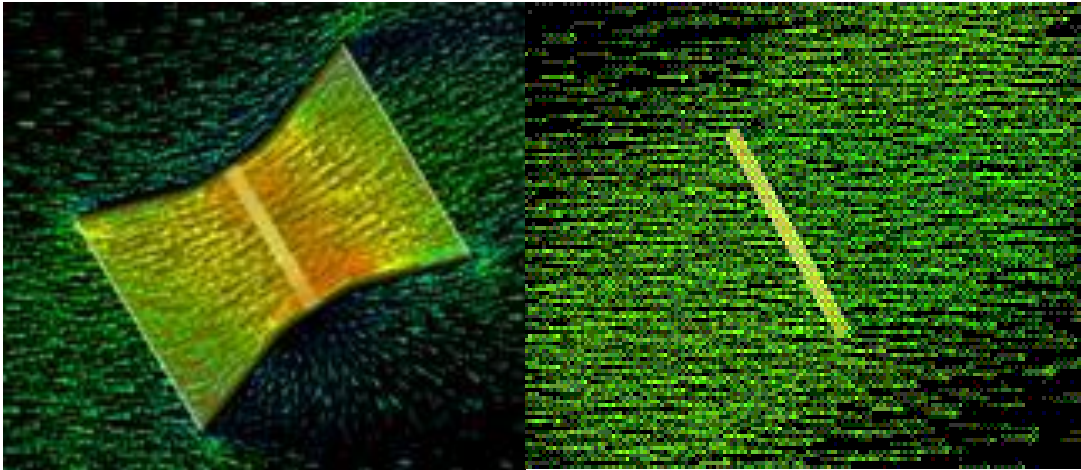


Figure 3.33 Flow ratio: "Venturi" Design vs. Perpendicular Design

Source: www.lunarenergy.co.uk

- According to laboratory tests, the energy output through the compressed center duct is practically double with respect to the perpendicular design
- Manufacturers recommend installing it at depths greater than 40 meters which allows the environmental impact to be lower
- In Korea, Hyundai Samho Heavy Industries and Korean Midland Power are working on developing such turbines to implement them on the Korean coasts, on the Wando Hoenggan Canal
- According to the study of these Korean companies, 300 generating units of 1 MW would cost 642 million dollars
- This economic analysis shows that for each installed megawatt is necessary 2.14 million dollars

3.3.4 Atlantis Resources

This company founded in Edinburgh, develops the power generator using energy from the sea currents called "AR1500 Tidal Turbine".

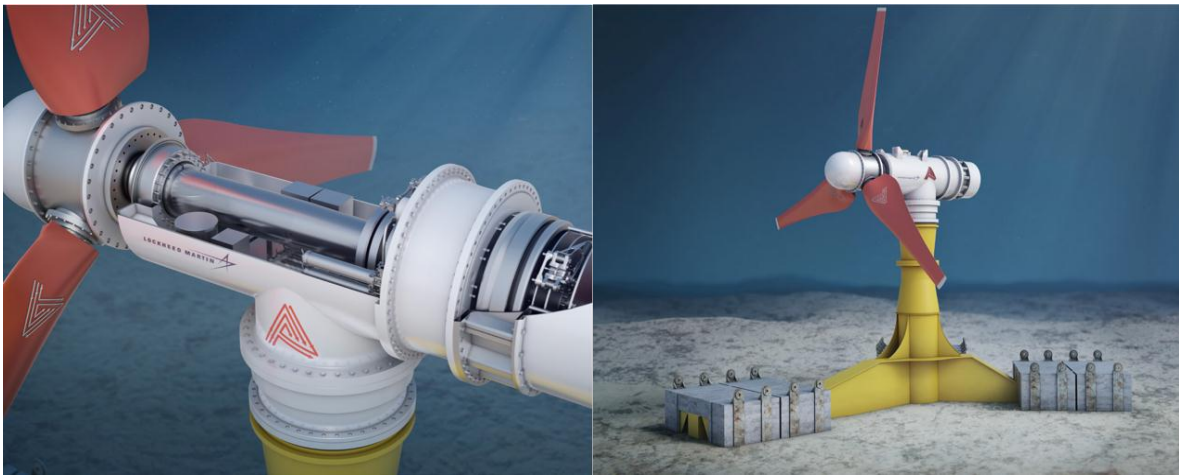


Figure 3.34 AR1500 Tidal Turbine

Source: www.atlantisresourcesltd.com

The characteristics of this machine are shown below[42]:

- Designed for a 25 year life time
- Its weight is approximately 150 tons
- It is necessary that the equipment is submerged at least 30 meters to cover the whole machine
- The length of the turbine is 12 meters
- The turning diameter of the blades is 18 meters
- The nominal power is 1.5 MW

- The generator reaches its nominal power when the marine current is 3 m/s, but the machine can operate with a maximum speed of 5 m/s
- It has an efficiency of 97%

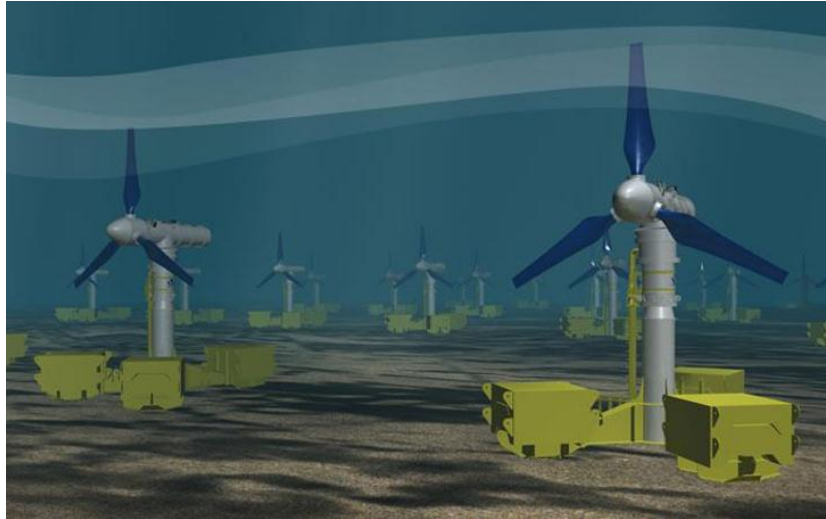


Figure 3.35 MeyGen marine current power project

Source: www.meygen.com

The most ambitious project with this technology is called "MeyGen", located north of Scotland and is being built since 2016 and consists of 3 stages

- This project seeks to generate 398 MW
- Within the third stage consists of the installation of 49 turbines to generate 73.5 MW and this stage has a cost of 540 million dollars
- Therefore, the installation of a megawatt has an approximate cost of 7.35 million dollars[43]

With the description of the technologies, a table can be elaborated that presents the main characteristics of each one, which allows to know and select the one that is the most adequate according to the benefits or potential energy of the country.

Table 3.4 Summary of characteristics of the proposed technologies

TECHNOLOGY	Nominal Power (MW)	Minimum Speed (m/s)	Nominal Speed (m/s)	Cost (MM\$/MW)	Shelf life (years)
SeaGen	1	1	2.5	3.8	---
Gen 4 KHPS	0.175	1	2	3.77	20
Rotech TT	1	---	2.6	2.14	---
AR1500 TT	1.5	---	3	7.35	25

Source: Prepared by the author

Through Table 3.4 it can be understood that the generation equipment that conforms to the qualities of this study is the "Gen 4 KHPS" machine built by the Verdant Power Company of origin and studies USA. along with Canadian resources.

The criteria for the selection of this equipment are as follows:

- The starting point and initial criterion is to check the marine current velocities at which each generator requires both minimum and nominal, Gen 4 KHPS, has the most suitable range to ecuadorian resources, a nominal velocity of 2 m/s, and the closest to the speed of the Cromwell current.
- Rotech Tidal Turbine despite having the lowest unit cost of those exposed, it does not generate at speeds lower than nominal, so in terms of cost compared to others, Gen 4 KHPS technology has the lowest price per megawatt installed
- It has a minimum useful life of 20 years which is an average period of time for the equipment that works submerged in sea waters, although AR1500 TT has a longer life time, 25 years, comparing the cost of these two technologies, this last one costs double of the selected one, in spite of having 5 years more of useful life which does not represent the great difference of prices.
- The nominal power of each machine is not that important in this analysis because the costs are estimated for each megawatt, not by the number of equipment that needs to be installed.

- An additional bonus to select this technology is that an Irish company is developing the Gen 5 KHPS and according to the first studies done since 2016 has samples of higher power at lower rated speed, longer life time and despite improving these features its cost has not increased.

3.4 Available Location for Implementation of Marine Energy Projects in Ecuador

Based on the physical characteristics of the most favorable current in the ecuadorian coasts we proceed to show the location.

The Ecuador extends from 1.45° north latitude to -3.4° south latitude, and in terms of length, the coastal waters that can be used range from 80° west which is the point of contact of the sea with the estuary of Guayaquil, from this point 200 nautical miles (370 kilometers) are counted as waters of ecuadorian membership, just as in the Galapagos archipelago Ecuador has 200 nautical miles in the round (Figure 3.37).

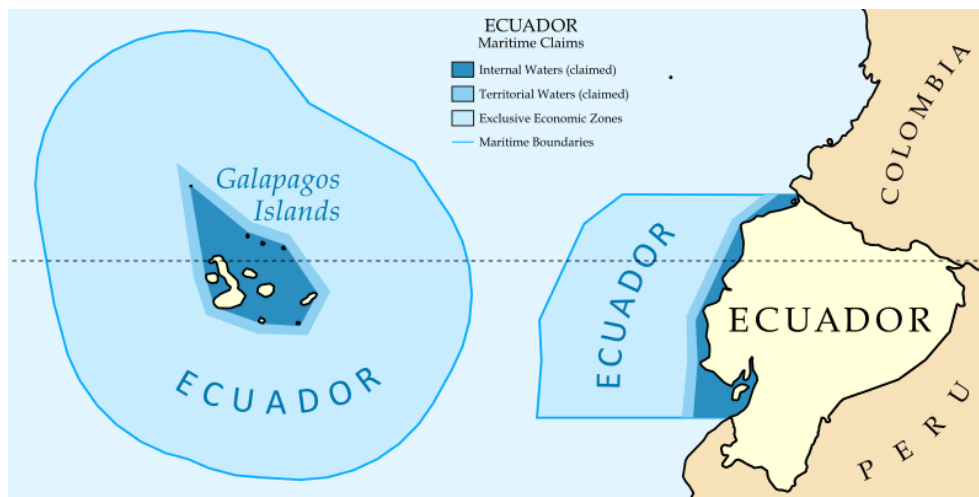


Figure 3.36 Ecuadorian Maritime Terretory

Source: commons.wikimedia.org/wiki/File:Maritime_Claims_of_Ecuador.svg

After analyzing studies of the current, first in terms of latitude it is indisputable that the best conditions are in latitude 0, characteristic point of our country. Now regarding with

the length points, the most convenient for implementing such energy projects is to look for locations that have high rates of electricity consumption and water reaching the required depth closest to the coasts of Ecuador, since one of the fundamental purposes for the implementation of any power generating plant is to place it as close as possible to the places of consumption to save resources in terms of energy transmission.

In this way, the physical characteristics of the Cromwell current that are mentioned in the studies proposed in point 3.2, now with presence in the equatorial line, in the north coastal zone of the continental Ecuador, with margins of 1° both north and the south. This zone corresponds to the coastal provinces of Manabí and Esmeraldas.

At the same time, this study proposes to replace the fossil fuel energy generators that are currently serving their regions, fulfilling the common objective of having an energy matrix in the country with less environmental impact and giving rise to unconventional renewable energies. In this sense, two scenarios are presented.

3.4.1 Coastal Sector Province of Manabí

Within the province of Manabí in its different cantons, it requires an installed capacity capable of supplying 220 MW, in thermoelectric plants displaced around the entire province an installed capacity of 204.4 MW[44] is achieved, 93% of the demand. From this point of view, it is considered that the province doesn't have sufficient self-sufficiency of energy, since the missing power to serve Manabí comes from the hydroelectric plants installed in eastern Ecuador; this becomes a motivation and a reason to seek energy from sea.

Therefore, in search of providing more energy to Manabí or to replace these thermoelectric power plants; in this province are analyzed the 3 plants closest to the coast:

1. Thermoelectric Power Plant Jaramijó, Jaramijó, Manabí

It is the most powerful powered station in the province, 140 MW, its operation is based on fuel oil # 6 (bunker), to this plant is transported by sea from Esmeraldas refinery

one million forty thousand gallons of fuel every day, the cost of transporting each gallon is \$ 0.06.[45]

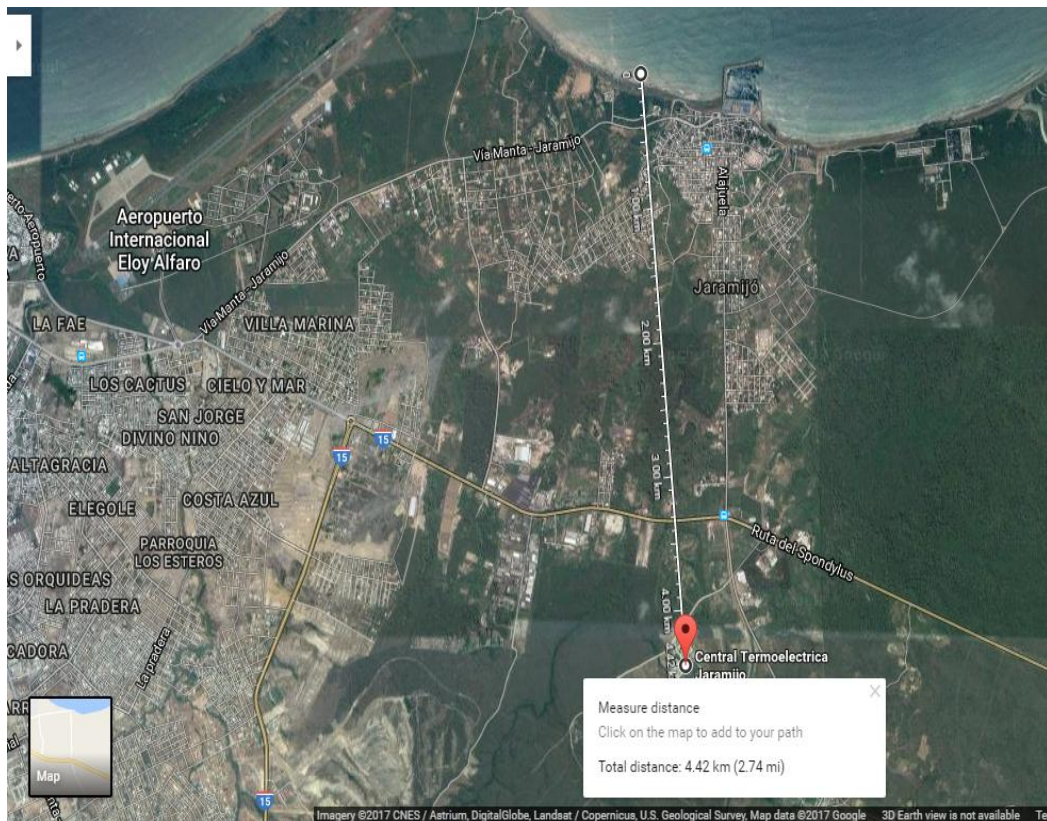


Figure 3.37 Satellite outlet, location of the Jaramijó Thermoelectric

Source: Prepared by the author / [google.com.ec / maps](https://www.google.com.ec/maps)

As shown in Figure 3.37, the distance from the central to the site where an electric substation is sought to where the energy from the sea is dispatched is located approximately 4.5 kilometers; the image also shows that the site of consumption is close the generation.

From the reference point on the coast, it is calculated to which distance marine can be counted with 100 meters of depth that is the location where it is assumed to have the best characteristics of the marine current. For this, an approximation is made with the data provided by the Oceanographic Institute of the Navy of Ecuador (INOCAR).

Table 3. 5 Distance and depth date Jaramijó

Distance from coast x (km)	Depth of the sea y (m)
0.48	5
2.41	10
4.02	20
14	100

Source: INOCAR

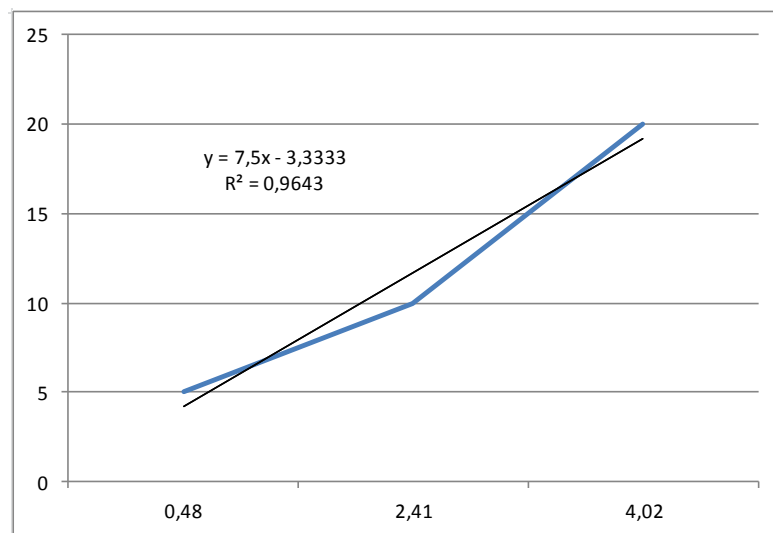


Figure 3.38 Calculation of depth in the sea of Jaramijó

Source: Prepared by the author

Using the computer tools, a linear regression is applied to calculate the equation that models the behavior of the depth of the sea:

$$y = 7.5 x - 3.3333$$

$$R^2 = 0.9643$$

Means of the same, where "y" is the calculated depth and "x" is the distance of the coast. It's found that 100 meters of depth in proximity of 14 kilometers for the sector of Jaramijó.

Therefore, it takes the reference point on the coast and measures the distance in the sea:

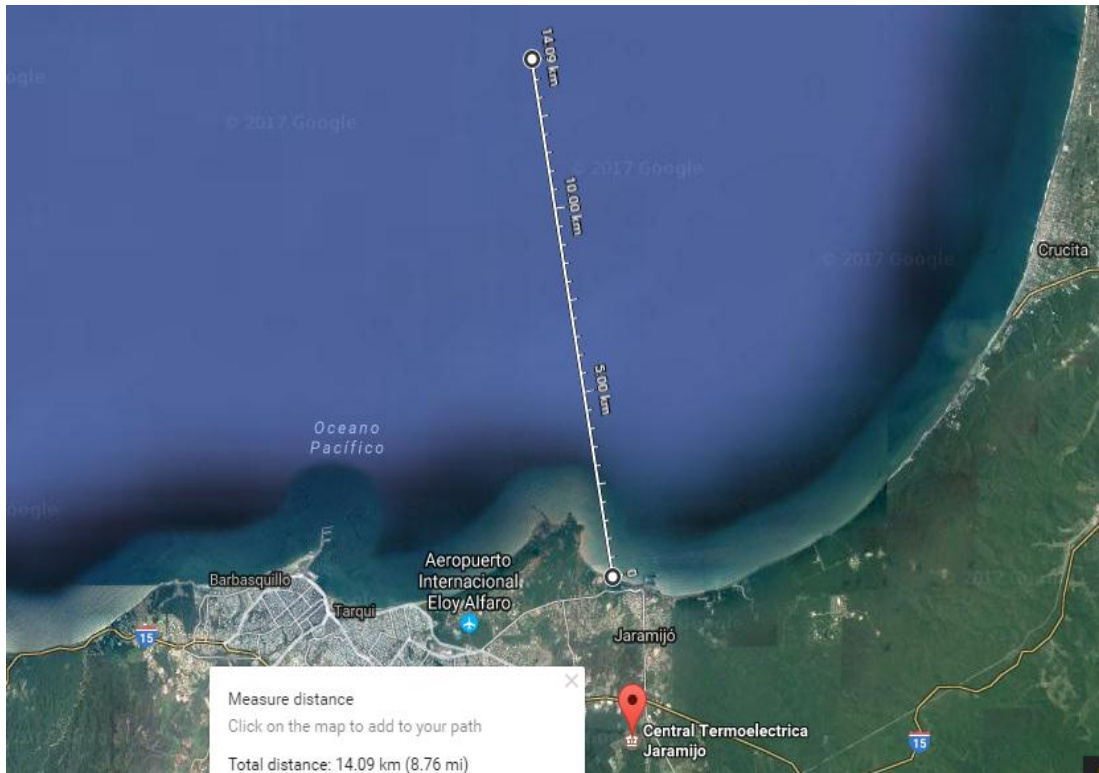


Figure 3.39 Marine distance to a point proposed for generation

Source: Prepared by the author / google.com.ec / maps

With this measure, the coordinates of the marked point are:

0°49'01.3"S 80°40'07.0"W

Always maintaining the proximity to the equatorial axis.

2. Thermal Power Station in Manta, Manta, Manabí

This plant has an installed capacity of 20.4 MW and operates through 12 generators of 1.7 MW each. The fuel used is the fuel oil. The location is shown below in the next image of maps.



Figure 3.40 Satellite capture, location of the Manta Thermolectric

Source: Prepared by the author / google.com.ec / maps

With the same procedure as the first case studied in section 3.4.1, in this case the distance is closer, 2.7 kilometers. It is also observed that the axis of energy consumption is located around this thermal generator.

Table 3.6 Distance and depth date, Manta

Distance from coast x (km)	Depth of the sea y (m)
0.96	10
1.44	20
1.61	30
1.77	40
3.395	100

Source: INOCAR

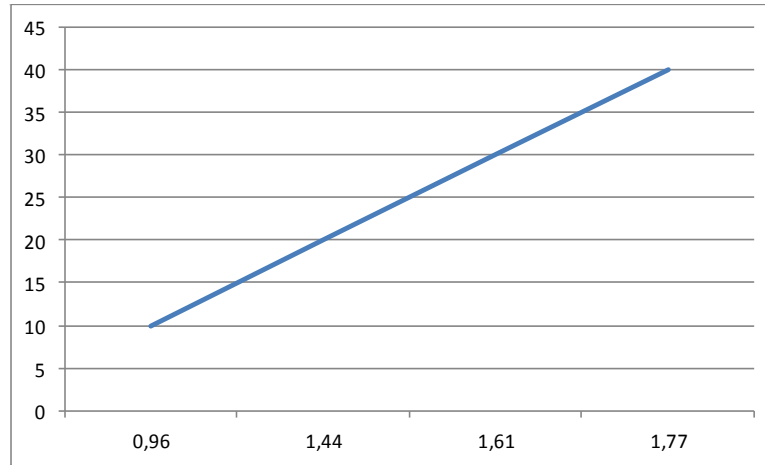


Figure 3.41 Distance from a reference point on the central coast

Source: Prepared by the author /google.com.ec/maps

In this case, the depth values provided by the Oceanographic Institute are linear. For this reason, the distance from the coast to the depth of 100 meters is 3.4 km.

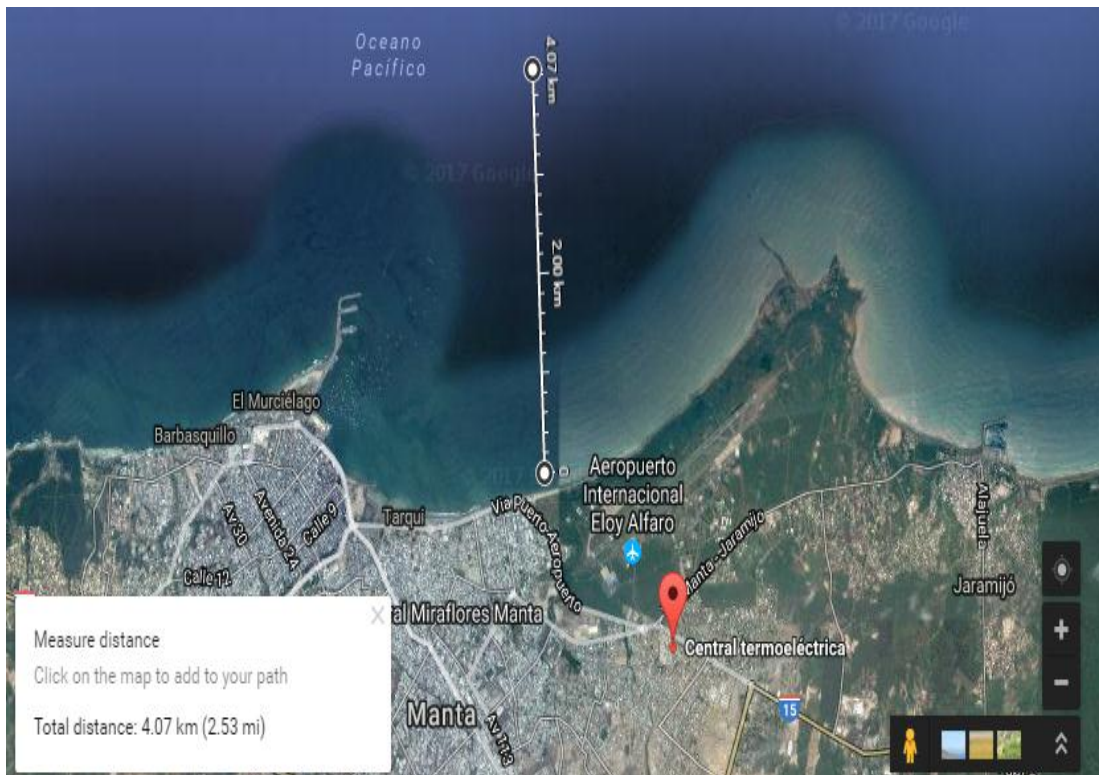


Figure 3.42 Marine distance to a point proposed for generation

Source: Prepared by the author / google.com.ec / maps

With this relatively short distance, coordinates of the proposed point are:

0°54'37.6"S 80°41'48.3"W

Coordinates that are within the proposed lower margin of 1° to the south.

3. Thermal Power Plant Miraflores, Manta, Manabí

This plant has an installed capacity of 42 MW, consisting of a gas turbine that generates 20 MW, 4 internal combustion engines of 2.5 MW each fed with diesel and two engines of 6 MW each powered by fuel oil.

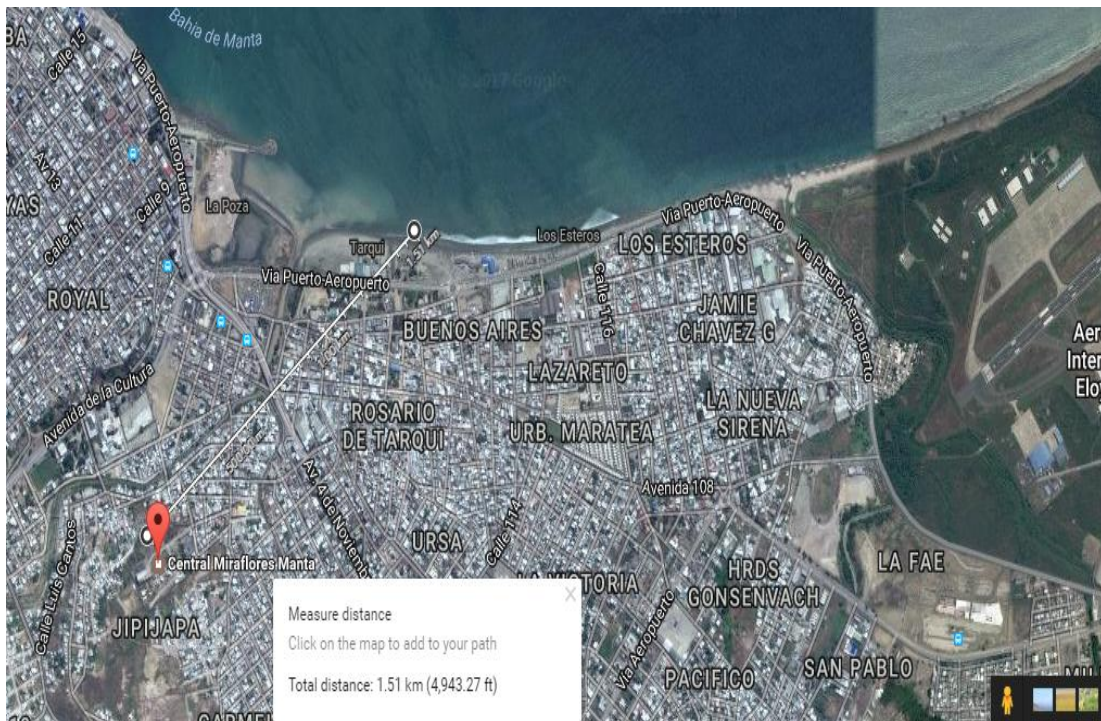


Figure 3.43 Satellite take, location of Miraflores Thermoelectric

Source: Prepared by the author / google.com.ec / maps

The distance to a reference point in the coast of Manta is the shortest of those observed with 1.5 kilometers, just as the field of consumers is observed around so it can be said that the thermal power station is in the heart of the city of Manta.

The analysis to calculate the distance to which the necessary depth would be found is the same as that of the previous observation because it is the same section of coast of the same city. For this reason, it can be stated on the basis of preliminary calculations that a depth of 100 meters is 3.4 kilometers.

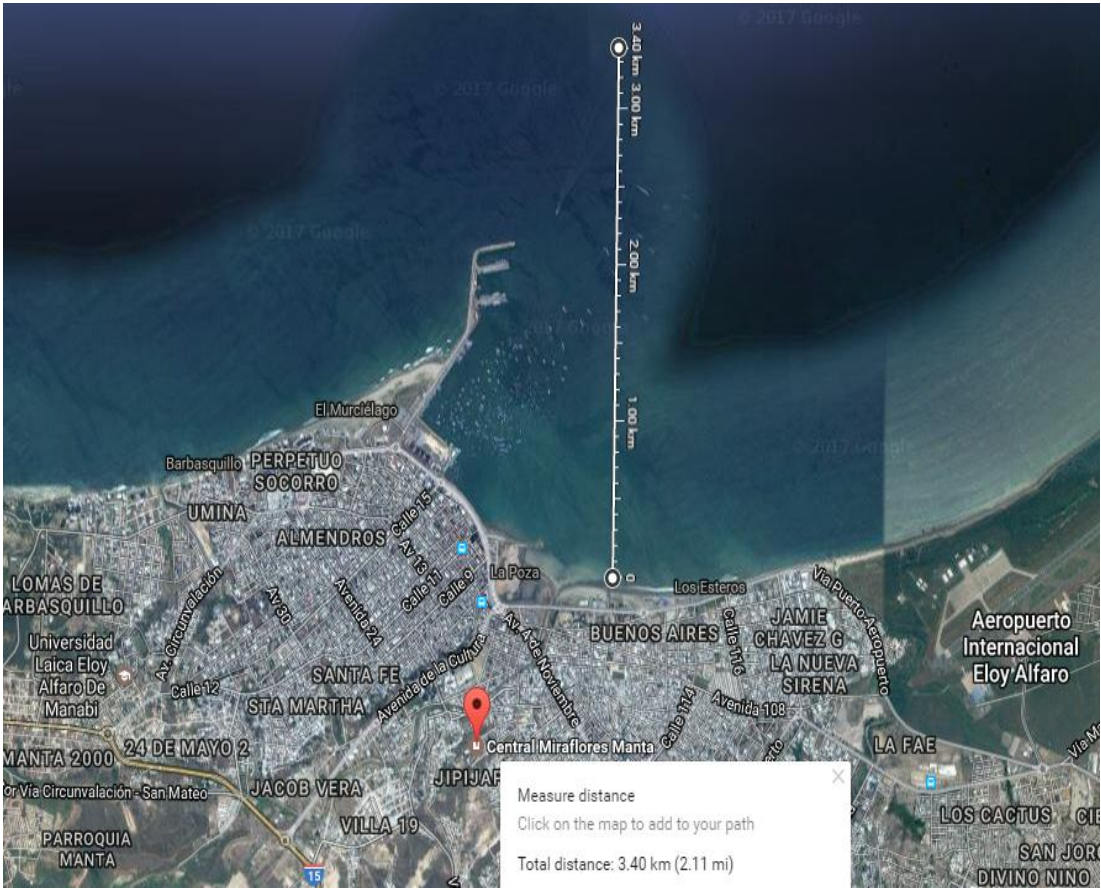


Figure 3.44 Marine distance to a point proposed for generation

Source: Prepared by the author / google.com.ec / maps

The graph shows proximity to the port of Manta, however this doesn't influence the study because the generation that is proposed consists of transmission by submarine cables.

The coordinates of the proposed point are:

0°55'05.3"S 80°42'44.1"W

3.4.2 Coastal Sector Province of Esmeraldas

1. Thermoelectric Power Plant "Termo Esmeraldas", Esmeraldas

It is a steam power station, with a nominal power of 132.5 MW, the fuel used in it is diesel and fuel oil, supplied in its entirety by the Esmeraldas Refinery adjacent to the generating company.

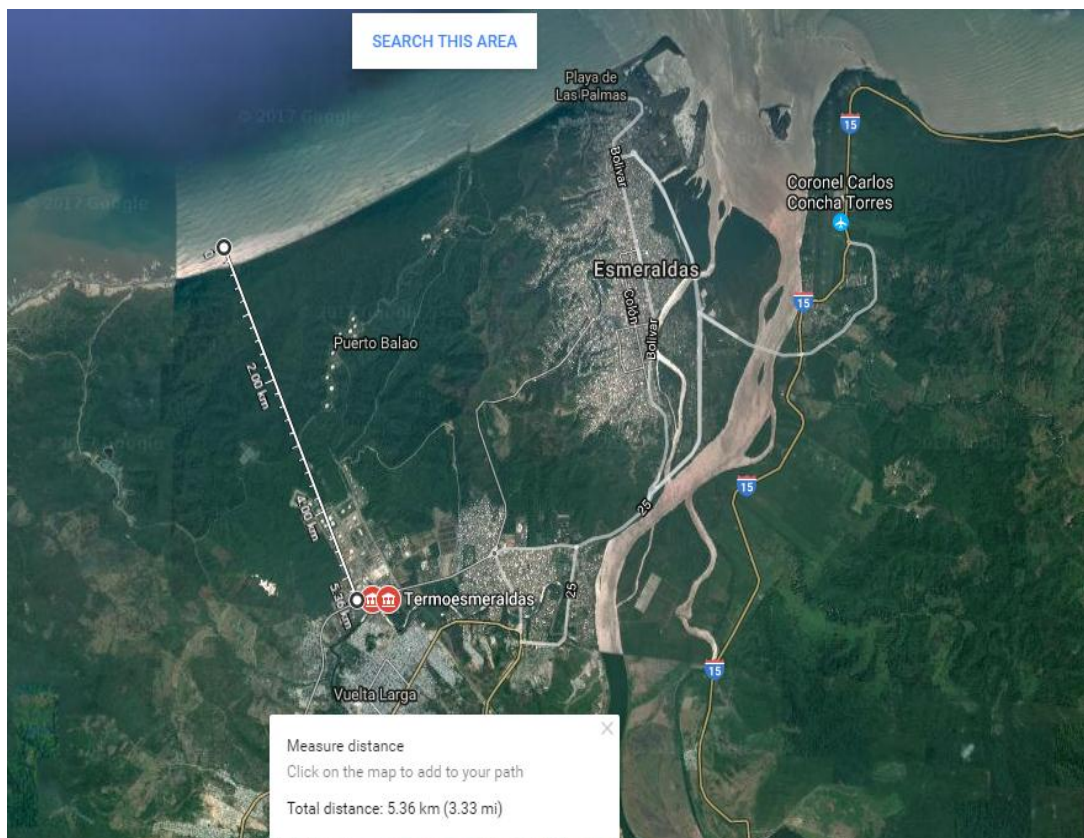


Figure 3.45 Satellite, location of "TermoEsmeraldas"

Source: Prepared by the author / [google.com.ec / maps](https://www.google.com.ec/maps)

The plant is very close to the coast, just 5.36 kilometers from it, which is an advantageous feature.

Table 3.7 Distance and depth data, Esmeraldas

Distance from coast x (km)	Depth of the sea y (m)
24	25
128	2900

Source: INOCAR

In the case of "TermoEsmeraldas" no distance calculation is performed to obtain 100 meters of depth, because as shown in the table, and logically, if only 24 kilometers away from the sea is reached 25 meters deep, certainly a distance of the greater coast to this one should not be considered because they generate high expenses by transmission of energy.

Below is a table summarizing the characteristics of each location analyzed in this study section, by which it is possible to define the most advantageous place for the implementation of an electric power project from the sea currents.

Table 3.8 Summary of the characteristics of the possible places for implementation of energy project

Location	Power Installed (MW)	Distance to the coast (km)	Sea distance (Km)	Fuel
Jaramijó	140	4.5	14	Fuel Oil #6
Manta	20.4	2.27	4	Fuel Oil #6
Miraflores	42	1.51	4	Gas (20 MW) Fuel Oil #6 (12 MW) Diesel (10 MW)
Esmeraldas	132.5	5.36	>24	Diesel Fuel Oil

Source: Prepared by the author

As you can see, the place that leads to receive a marine energy project is the Manta city, at the height of the Manta Thermal Power Station, the reasons for which is considered are:

- It has the smallest marine distance (4 km) to obtain the 100 meters of depth required by the characteristics of the marine currents
- It works in its entirety with fuel oil # 6 (Bunker), which is the most polluting product in the table, so it would be compatible with one of the priorities of the study, which is to reduce pollution levels when electricity is generated, the environmental analysis is presented in the following chapter
- Its geographical surroundings are advantageous with respect to the sector Miraflores, because there is less incidence population and of construction, this could facilitate works that are required when implementing a marine technology
- The selected coastal area is not an approved tourist site, which leaves open the possibility of doing energy projects.

Once the technology has been defined in this chapter to take advantage of Ecuador's sea energy and the potential site where to be located, the next chapter focuses on analyzing economic and financial feasibility through indicators that show the profitability of the project or its defects, prejudice.

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4. ECONOMIC ANALYSIS AND THE COST EVALUATION OF THE PROPOSED SYSTEM

In the previous chapter the different technological options were analyzed to take advantage of the renewable energy of the ocean, arriving at the conclusion that the best alternative for Ecuador is to take advantage of the Cromwell current by using the machine created by the american company Verdant Power, named Gen 4 KHPS.

In order to carry out an economic and cash flow analysis of the proposed system, by evaluating, on the one hand, expenditures such as initial investment and operation and maintenance costs and, on the other, revenues from energy sales that would generate in the plant. Of course, technical aspects such as energy losses at transmission and transformation points should be considered. In order to present the complete economic scenario, the indicators that evaluate the feasibility of the project will be obtained, such as: Net Present Value (NPV) and Internal Rate of Return (IRR).

4.1 Revenue from the plant

The economic income of a project based on sea energy depends precisely on the energy available at the site, depending on the different periods of the year. In the case of the proposed system, utilization of marine currents, the economic parameters are analyzed below based on the information available for the site and technology chosen.

4.1.1 Income from the sale of energy

To evaluate this revenue, the plant size is considered using the selected technology, with a total installed capacity of 20 megawatts, taking into account the need to install 115 equipment of 175 kilowatts of power each.

The energy potential of the marine currents, as described in the third chapter, has an annual constant of the Cromwell current of at least 1.5 m/s. In this scenario, discarding the variations and the important increases that this speed can suffer by the "El Nino Phenomenon" or the Humboldt Current, which appears periodically on the coasts of Ecuador, the most critical case will be considered for future economic analysis.

If the machines to be installed deliver a nominal power of 20 megawatts with a marine current velocity of 2 m/s, it can take 75% of the power value since the considered speed is 1.5 m/s (the output power in this machine is linear) and the calculation is done with 15 megawatts effective.

The price of energy to be supplied to the distribution company is taken as a reference in the CONELEC Regulation No. 001/13, which is not currently in force but serves its conceptual application, which aims to promote the generation of electricity through non-conventional renewable energies. The same in the section 5.1 presents the table that expresses for a power station that uses kinetic energy of the marine currents in the continental territory the cost of kilowatt per hour is of 32.43 US cents.[46]

Therefore, the price of the energy generated in the projected power station would be of 324.3 dollars megawatt per hour. With the important condition that the generators that use non-conventional renewable primary energies have priority in the dispatch, since the source, in this case the marine currents, is of variable character and its use has a zero cost.

For this study, the sale of energy is considered as the only way to generate economic income in the project, since it doesn't have a contract reference or financial agreement through the sale of carbon credits that helped boost projects of this type and it is not

intended to address issues such as the residual value or depreciation of assets at the end of the useful life of the project, as it is considered irrelevant as seen in the bibliography [27] this represents an insignificant percentage of income.

4.2 Costs of the plant

There are several costs both in the construction phase and in the operation of a project of this type and also direct and indirect costs are generated. It will address the most important data within these two fields, always with the intention that this financial approach is not far from reality.

4.2.1 Investment Costs or Capital for Implementation

As shown in Table 3.4 of section 3.3 of this study, the cost of installing a plant with the proposed technology is US \$ 3.77 million per megawatt installed, then to install the proposed power that would replace the thermoelectric plant of 20 MW; it is necessary 75.4 million dollars.

To this value the submarine installation must be added to evacuate the generated energy. The calculations of the appropriate driver's cost are based on the Chilean wave power project, [27] which approximates US \$ 3.8 million in distances considered feasible for the project between 10 and 15 kilometers. From this reference it is obtained that the cost of submarine connection by a distance of 4 km is approximately a cost of 1.3 million.

To these values, the underground connection must be added until reaching the existing substation, approximately 2.2 km from the seashore, and whose cost is 240 thousand dollars, according to Table 4.1.

Table 4.1 Analysis of approximate unit prices for underground connection

<i>Línea subterránea de 20 kV en canalización entubada bajo acera, formada por 3 cables unipolares HEPRZ1, con conductor de aluminio, de 150 mm² de sección y dos tubos protectores de polietileno de doble pared, de 160 mm de diámetro</i>					
Ru bro	Uni dad	Descripción	Cantid ad	Costo Unitario	Costo Parcial
Materiales					
1	m ²	Arena de 0 a 5 mm de diámetro	0.065	14.160	\$ 0,92
	m	Tubo curvable, suministrado en rollo, de polietileno de doble pared (interior lisa y exterior corrugada), de 160 mm de diámetro nominal, para canalización enterrada, resistencia a la compresión 250 N, con grado de protección IP 549, hilo guía incorporado	2,000	9.530	\$ 19.06
	m	Cable unipolar HEPRZ1, con conductor de aluminio clase 2 de 150 mm ² de sección, con aislamiento de etileno propileno de alto módulo (HEPR), pantalla de corona de hilos de cobre y cubierta de compuesto termoplástico a base de poliolefina libre de halógenos (Z1), siendo su tensión asignada 12/20 kV. Según UNE-HD 620-9E	3,000	28.030	\$ 84.09
	Ud	Material auxiliar para instalaciones eléctricas	0.200	2.070	\$ 0.41
Subtotal Materiales					\$ 104.48
Equipo y maquinaria					
2	h	Dumper de descarga frontal de 2t de carga útil	0.007	8.58	\$ 0.06
	h	Pisón vibrante de guiado manual, de 80 kg, con placa de 30x30 cm, tipo rana	0.053	3.24	\$ 0.17
	h	Camión cisterna de 8 m ² de capacidad	0.004	37.16	\$ 0.15
Subtotal Equipo y maquinaria					\$ 0.38
Mano de obra					
3	h	Albañil	0.056	4.18	\$ 0.23
	h	Peón de albañil	0.056	2.54	\$ 0.14
	h	Electricista	0.236	4.32	\$ 1.02
	h	Ayudante de electricista	0.184	2.64	\$ 0.49
Subtotal mano de obra					\$ 1.88
Herramienta menor					
4	%	Herramienta menor	2	106.74	\$ 2.13
Costo directo (1+2+3+4)				\$ 108.88	

Source: ecuador.generadordeprecios.info/espacios_urbanos/Instalaciones/Urbanas/IUM_

[Lineas_subterráneas_de_alta_te/IUM015_Linea_subterranea_de_20_kV](#)

Table 4.2 presents the summary of the total cost of evacuating the energy that is generated in the ocean until arriving at the existing substation, where it happens to be jurisdiction of the distributing company, covering approximately 6.2 kilometers.

Table 4. 2 Energy transmission costs

COST OF CONNECTION TO THE ELECTRICAL NETWORK AND INSTALLATION OF SUBMARINE CONDUCTORS	
DESCRIPTION	COST (MMUSD)
Installation 4 km Underwater Conductor 1,3	1.3
Connection To The Network 2,2 km	0.240
<i>Total Cost Of Transmission (6.2 Km)</i>	<i>1.54</i>

Source: Generated by the author

Therefore, the cost of implementing the system to connect it to the predefined substation is of \$ 77 million, which would be invested in the first two years that arose the construction of the same.

4.2.2 Operation and Maintenance Costs

To evaluate these costs is of paramount importance to the economy of scale of the proposed project, since in the same it is intended to have more than a hundred machines. The manufacturer estimates that for a plant of the proposed dimensions, the costs of operation and maintenance fluctuate between 3% and 5% of the investment necessary to implement the generating equipment.[40]

It is considered the most critical scenario (5%) so the value to operate and maintain the plant amounts to 3.85 million dollars annually.

In addition, it should be considered that the costs of replacing larger parts or repairs are not addressed in annual maintenance. This consideration should be made in the middle of the useful life, at ten years and would arrive as a maximum cost to 25% of the implementation investment. Then, the replacement / repair cost is \$ 19.25 million.

4.2.3 Expenses

4.2.3.1 Direct labor

This item considers the expenses of the staff that will be in charge of the operation of the generating plant; these expenses are calculated from the year that the plant comes into operation.

Table 4.3 Direct labour costs

Position	Salary (USD)
Director of Operations	2000
Operators (2)	1600
TOTAL	3600

Source: Generated by the author

4.2.3.2 Administrative expenditure

For the management of a project of this type, the following staff is considered necessary.

Table 4.4 Administrative personnel expenses

POSITION	SALARY (USD)
Manager	4000
Financial Management	1500
Electrical Direction	2000
Civil Management	2000
Accounting	500
TOTAL	10000

Source: Generated by the author

The salary data are placed in reference to several renewable energy projects built in the country [47], the accounting is not directly contracted with the company, no charge is

created for it, it would be performed by an accountant outside the project by the cost of this work is relatively low compared to other contracts.

4.2.3.3 Indirect costs

Within these expenses are considered inputs for stationery or furniture needed to set up an office, in addition to the expense that covers the rent of the property together with basic services expenses, all this money that would be necessary during the life of the project.

Table 4.5 details these expenditures and reference information has been taken from a similar project developed in the country.[47]

Table 4.5 Indirect expenditures

CONCEPT	VALUE
Office Supplies	2600
Furniture and Fixtures	4000
Office Equipment	4000
Space Rent	5000
Basic Services	2500
Replacement of Expenses	5000
General Expenses	10000
Travels and Training of Technical Staff	100000
TOTAL	133100

Source: Generated by the author

The indirect costs include costs that the company requires only once every certain period, such as furniture and office equipment that will be renewed four times in the life of the project, as opposed to expenses such as rent or basic services that are of monthly character, as well as the need to travel for training the technical and operations staff of the plant is considered during the construction stage, in the first two years. This will display the values in the money flow analysis that follows.

4.3 Cash Flow

In order to carry out the cash flow in which the income and the annual expenses are detailed, it is important to make it clear that both revenues in this case from the sale of energy and the expenses generated at each stage of the project are restricted and subject to various movements or obligations such as taxes, interests or obligations with the state.

Firstly, for the sale of energy a value of US \$ 32.43 per MWh was set, but according to the regulation cited in section 4.1.1, the generating company does not own this value in its entirety, since according to the plan of good living covered by the Ecuadorian constitution, any energetic project or industry implemented in the country has social responsibilities. For this case study of the marine currents was established 8.42 cents for investment in the good living territorial, according to the regulation taken as reference. That is, the net value per sale of energy would reach 24.01 cents.

In the annual operating time for reasons of maintenance, it is considered a 20 day decrease, so the number of hours worked in general corresponds to 345 days a year, that is, 8,280 hours. In addition in the tenth year of operation of the plant to be in the half of its useful life it is necessary to carry out the general repair or major repair, for this process it is necessary a lapse of two months, for that reason the hours of operation in the tenth year have a notable reduction.

In the case of being a private company, the profits of an energy project are subject to taxes, a biomass energy project developed in the region named "Pichacay" will be taken as a reference, which has as income tax a percentage of 25%.

It is also important to consider that the capital necessary for the implementation of the project can be a credit that will undoubtedly generate interest, for the calculation of the payment of the same is taken as a reference to the annual rate established by the State Bank that is 7.11% per annum, for loans with a selected term.

After presenting this criteria, the cash flow table (Table 4.6) is elaborated, which details all the money movements that occur during the life of the energy project. It should be mentioned that this preliminary study presents in a general way each group of investments or the different expenses or costs, where as in a feasibility study it is necessary to detail and disintegrate the cost of each equipment necessary to implement or construct a project of this type.

Table 4.6 Financial assessment: Cash flow

DESCRIPCIÓN	EVALUACIÓN DEL PROYECTO ENERGÉTICO MEDIANTE CORRIENTES MARINAS											EVALUACIÓN DEL PROYECTO ENERGÉTICO MEDIANTE CORRIENTES MARINAS										
	PERÍODO EN AÑOS											PERÍODO EN AÑOS										
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
INGRESOS FINANCIEROS	\$ 85,000,000.00																					
Precio de venta kWh			\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243	\$ 0.3243
Potencia del mar (kW)			15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000
Horas de trabajo			8280	8280	8280	8280	8280	8280	8280	8280	8280	7320	8280	8280	8280	8280	8280	8280	8280	8280	8280	8280
Energía (kWh/año)			124200000	124200000	124200000	124200000	124200000	124200000	124200000	124200000	124200000	109800000	124200000	124200000	124200000	124200000	124200000	124200000	124200000	124200000	124200000	124200000
INGRESOS OPERATIVOS			\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 35,608,140.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00	\$ 40,278,060.00
Implementación	\$ 50,000,000.00	\$ 35,000,000.00																				
Reparación mayor												\$ 19,250,000.00										
INVERSIÓN	\$ 50,000,000.00	\$ 35,000,000.00										\$ 19,250,000.00										
Mano de obra directa			\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00	\$ 43,200.00
Operación y Mantenimiento			\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00	\$ 3,850,000.00
COSTOS OPERACIONALES			\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00	\$ 3,893,200.00
Personal Administrativo		\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00	\$ 120,000.00
Gastos Indirectos	\$ 60,000.00	\$ 86,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00	\$ 36,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00	\$ 36,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00	\$ 36,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00	\$ 28,200.00
GASTOS ADMINISTRATIVOS	\$ 60,000.00	\$ 206,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00	\$ 156,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00	\$ 156,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00	\$ 156,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00	\$ 148,200.00
Intereses		\$ 6,043,500.00	\$ 5,619,992.85	\$ 5,166,374.34	\$ 4,680,503.56	\$ 4,160,087.36	\$ 3,602,669.57	\$ 3,005,619.38	\$ 2,366,118.92	\$ 1,681,149.97	\$ 947,479.73	\$ 161,645.54										
Amortización		\$ 5,956,500.00	\$ 6,380,007.15	\$ 6,833,625.66	\$ 7,319,496.44	\$ 7,839,912.64	\$ 8,397,330.43	\$ 8,994,380.62	\$ 9,633,881.08	\$ 10,318,850.03	\$ 11,052,520.27	\$ 2,273,495.68										
PAGO DE CRÉDITO		\$ 12,000,000.00	\$ 12,000,000.00	\$ 12,000,000.00	\$ 12,000,000.00	\$ 12,000,000.00	\$ 12,000,000.00	\$ 12,000,000.00	\$ 12,000,000.00	\$ 12,000,000.00	\$ 12,000,000.00	\$ 2,435,141.22										
UTILIDAD LIBRE DE IMPUESTOS		-\$ 12,206,200.00	\$ 24,236,660.00	\$ 24,236,660.00	\$ 24,236,660.00	\$ 24,236,660.00	\$ 24,236,660.00	\$ 24,228,660.00	\$ 24,236,660.00	\$ 24,236,660.00	\$ 24,236,660.00	\$ 29,131,598.78	\$ 36,228,660.00	\$ 36,236,660.00	\$ 36,236,660.00	\$ 36,236,660.00	\$ 36,236,660.00	\$ 36,228,660.00	\$ 36,236,660.00	\$ 36,236,660.00	\$ 36,236,660.00	\$ 36,236,660.00
Sumak Kawsay (0,08 USD/kWh)			\$ 6,291,836.94	\$ 6,291,836.94	\$ 6,291,836.94	\$ 6,291,836.94	\$ 6,291,836.94	\$ 6,289,760.14	\$ 6,291,836.94	\$ 6,291,836.94	\$ 6,291,836.94	\$ 7,562,563.04	\$ 9,404,960.14	\$ 9,407,036.94	\$ 9,407,036.94	\$ 9,407,036.94	\$ 9,404,960.14	\$ 9,407,036.94	\$ 9,407,036.94	\$ 9,407,036.94	\$ 9,407,036.94	\$ 9,407,036.94
Impuesto a la renta (25%)			\$ 4,486,205.77	\$ 4,486,205.77	\$ 4,486,205.77	\$ 4,486,205.77	\$ 4,486,205.77	\$ 4,484,724.97	\$ 4,486,205.77	\$ 4,486,205.77	\$ 4,486,205.77	\$ 5,392,258.93	\$ 6,705,924.97	\$ 6,707,405.77	\$ 6,707,405.77	\$ 6,707,405.77	\$ 6,705,924.97	\$ 6,707,405.77	\$ 6,707,405.77	\$ 6,707,405.77	\$ 6,707,405.77	\$ 6,707,405.77
UTILIDAD NETA		-\$ 12,206,200.00	\$ 13,458,617.30	\$ 13,458,617.30	\$ 13,458,617.30	\$ 13,458,617.30	\$ 13,458,617.30	\$ 13,454,174.90	\$ 13,458,617.30	\$ 13,458,617.30	\$ 13,458,617.30	\$ 16,176,776.80	\$ 20,117,774.90	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,117,774.90	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,122,217.30
Depreciación			\$ 2,114,000.00	\$ 2,114,000.00	\$ 2,114,000.00	\$ 2,114,000.00	\$ 2,114,000.00	\$ 2,114,000.00	\$ 2,114,000.00	\$ 2,114,000.00	\$ 2,114,000.00	\$ 2,114,000.00										
FLUJO DE CAJA	\$ 34,940,000.00	-\$ 12,206,200.00	\$ 11,344,617.30	\$ 11,344,617.30	\$ 11,344,617.30	\$ 11,344,617.30	\$ 11,344,617.30	\$ 11,340,174.90	\$ 11,344,617.30	\$ 11,344,617.30	\$ 11,344,617.30	\$ 14,062,776.80	\$ 20,117,774.90	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,117,774.90	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,122,217.30	\$ 20,122,217.30

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Source: Generated by the author

4.4 Calculation of Net Present Value (NPV)

This method calculates the present value of a certain number of future cash flows, originated by an investment. Using a rate, a methodology that can be applied to determine the equivalence of values at time zero (present value) to compare it with the initial outlay.

The formula for calculating this indicator is as follows:

$$VAN = \sum_{t=1}^n \frac{F_t}{(1+i)^t} - I_0$$

In which:

F_t represents the cash flows in each period t

I_0 is the value of the initial outlay or investment

n is the number of periods considered

i is the interest rate used

Using the Excel application as a tool to calculate the NPV, we obtain that the value is:

NPV \$40'186,653.49

For the interpretation of this parameter, the following table can be referenced:

Table 4.7 Criteria for interpretation; NPV

Value	Meaning	Decision to be taken
NPV > 0	The investment would produce profits above the required return	The project can be accepted
NPV < 0	The investment would produce losses below the required return	The project can't be accepted
NPV = 0	The investment would produce neither profits nor losses	Since the project doesn't add monetary value above the required return, the decision should be based on other criteria, such as obtaining a better market position or other factors

Source: Investment Decisions, Gava I.; E. Roperio; G. Serna and A. Ubierna / Editorial Delta / (2008)

With the result obtained can be interpreted that the project is viable, and that the investment will generate profitability and profits. It has a positive starting point by calculating this indicator.

4.5 Calculation of the Internal Rate of Return (IRR)

Likewise, through Excel you can obtain that the Internal Rate of Return of the project is:

IRR 11%

This rate relates the value of expenses to the income and to compare them, it becomes an interest rate through which the investment is recovered. It also indicates the maximum rate of interest that can be borrowed in order to not lose money with the investment being made.

The IRR calculated using the cash flow allows to mention that the investment is recommended.

4.6 Payback Period

It can be assumed that this is the most important indicator in the decision making process for an investment, since this financial tool indicates the period of time in which the initial investment would be recovered.

It is calculated by means of cash flows, it seeks to cover the outstanding debt in each period and the result is given when the flow of money covers the last outstanding installment to be paid.

According to the previously established cash flow, the recovery time of the investment in this electric generation project would be 9 years and 3 months. Stating that this period includes or is covered the expenditure that would be realized in the half of the useful life of the project through the major repair.

4.7 Summary of Results of the Financial Study

Table 4.8 Summary financial results

FINANCIAL RESULTS	
Description	Value
NPV	40'186,653.49
IRR	11%
PAYBACK	9 years 3 months approx.

Source: Generated by the author

By means of these results it is possible to conclude that there is feasibility for an investment of this type, the three indicators coincide in giving feasibility to the project, and economically it can be described as viable, however besides the money flows, one could consider the socio-environmental externalities that the project produces. For example, a commitment to the sustainability of the planet and the search for mechanisms to obtain clean energy and mainly to alleviate pollution in the greatest amount possible from research and engineering studies. This could mean, for example, the reduction of greenhouse gases emissions, by replacing thermoelectric plants.

The energy impact in the country with projects of this type and, in particular, the potential environmental benefits are presented in the next chapter of this study.

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5. IMPACT ON THE ENERGY MATRIX OF ECUADOR

In order to determine the impact that the proposed project would have on Ecuador's energy matrix, it is important to know the supply-demand behavior of the national electricity system. The following is a historical summary of the energy demand behavior in Ecuador and the types of energy that have served the National Interconnected System (NIS).

Table 5.1 History of Ecuador's energy demand

			Measures									Variación (%)
			Energía (GWh)									Tipo Central
			Tipo Central									Tipo Central
Año	Tipo de Energía	Sub tipo Central	↕ - Todos	↕ Biogas	↕ Biomasa	↕ Eólica	↕ Hidráulica	↕ Interconexión	↕ Solar	↕ Térmica	↕ + Todos	
- Todos	+ Todos	+ Todos	336,997.24	17.54	3,297.36	350.38	177,743.67	13,137.81	108.69	142,341.78		
1999	+ Todos	+ Todos	10,331.88				7,176.73	23.76		3,131.39		
2000	+ Todos	+ Todos	10,612.44				7,611.23			3,001.21	2.64 %	
2001	+ Todos	+ Todos	11,072.03				7,070.65	22.23		3,979.15	4.15 %	
2002	+ Todos	+ Todos	11,943.86				7,524.26	56.30		4,363.30	7.30 %	
2003	+ Todos	+ Todos	12,665.74				7,180.42	1,119.61		4,365.71	5.70 %	
2004	+ Todos	+ Todos	14,226.46		3.24		7,411.70	1,641.61		5,169.90	10.97 %	
2005	+ Todos	+ Todos	15,127.47		102.86		6,882.64	1,723.45	0.01	6,418.51	5.96 %	
2006	+ Todos	+ Todos	16,686.32		145.56		7,129.49	1,570.47	0.01	7,840.79	9.34 %	
2007	+ Todos	+ Todos	18,197.52		218.75	0.96	9,037.66	860.87	0.02	8,079.27	8.30 %	
2008	+ Todos	+ Todos	19,108.69		208.32	2.68	11,293.33	500.16	0.03	7,104.16	4.77 %	
2009	+ Todos	+ Todos	19,385.37		216.52	3.20	9,225.41	1,120.75	0.01	8,819.48	1.43 %	
2010	+ Todos	+ Todos	20,382.76		235.56	3.43	8,636.40	872.90	0.00	10,634.46	4.89 %	
2011	+ Todos	+ Todos	21,838.73		278.20	3.34	11,133.09	1,294.59	0.06	9,129.45	6.67 %	
2012	+ Todos	+ Todos	23,086.16		296.35	2.40	12,237.72	238.20	0.33	10,311.16	5.40 %	
2013	+ Todos	+ Todos	23,922.67		295.79	56.70	11,038.82	662.34	3.66	11,865.35	3.50 %	
2014	+ Todos	+ Todos	25,143.95		399.47	79.74	11,457.90	836.74	16.48	12,353.62	4.86 %	
2015	+ Todos	+ Todos	26,462.01		407.75	98.81	13,096.27	511.81	36.06	12,311.31	4.98 %	
2016	+ Todos	+ Todos	27,395.52	12.88	476.52	83.96	15,833.84	81.66	38.75	10,867.91	3.41 %	
2017	+ Todos	+ Todos	9,407.66	4.67	12.46	15.15	6,766.12	0.34	13.27	2,595.65	-191.20 %	

Source: Arconel, 2017

From the Table 5.1; it can be made the analysis of the energy composition of the country. Despite having updated data until June 2017, it proceeds with the analysis of the

year 2016 since there is information of all the months and the total of electricity consumption in Ecuador in that year.

5.1 Composition of the energy matrix of Ecuador

Table 5.2 Energy balance of Ecuador in 2016

Energy balance and contribution of clean energies to Ecuador (GWh %)								
2016 Summary	Total	Biogas	Biomass	Wind	Solar	Hydraulic	Thermic	Interconection
	27395.52	12.88	476.52	83.96	38.75	15,833.84	10,867.91	81.66
	100%	0.05%	1.74%	0.31%	0.14%	57.80%	39.67%	0.30%
		Non-Conventional Renewable Energy						
100%	612.11		2.23%		57.80%	39.67%	0.30%	

Source: Generated by the author from the historical energy demand presented in Table 5.1

According to Table 5.1, it can be seen that non-conventional renewable energies only contribute 2.23% of the electric energy consumed in the country. This percentage is undoubtedly very low compared to the contribution of these technologies in other countries that have similar resources. The following result that can be deduced from this table is the country's energy dependence on the water source that supplies 57.8% of the national demand. Finally, the most relevant data for the present analysis is the high percentage of thermal energy, 39.67%, energy that leads to pollution and comes from a source or non-renewable energy form that is leaving a very large "ecological footprint" for the future of the country.

5.2 Replacement of thermal generation by sea energy

The proposal of this project in this study is the substitution of energy generated in the thermoelectric plant located in the city of Manta, in the province of Manabí. The "Termoeléctrica Manta" has a nominal power of 20.4 MW, and would be replaced by a power plant with primary energy from the sea currents, located approximately 6 km from the thermoelectric plant.

According to the calculations elaborated in chapter 4, the power plant to be implemented would deliver an approximate of 124.2 GWh annually.

Table 5.3 Energy balance of Ecuador implemented the project

Energy balance and contribution of clean energies to Ecuador (GWh)								
	<i>Total</i>	<i>Biogas</i>	<i>Biomass</i>	<i>Wind</i>	<i>Solar</i>	<i>Hydraulic</i>	<i>Thermic</i>	<i>Interconnection</i>
2016	27395.52	12.88	476.52	83.96	38.75	15,833.84	10,867.91	81.66
	100%	0.05%	1.74%	0.31%	0.14%	57.80%	39.67%	0.30%
		Non-Conventional Renewable Energy						
	100%	612.11			2.23%	57.80%	39.67%	0.30%
		Energy from the Marine Current						
		124.2			0.45%		10731,29	
TOTAL	100%	736.31			2.68%	57.80%	39.22%	0.30%

Source: Generated by the author

Table 5.3 presents the calculations of energy contribution to the Ecuadorian electricity generation matrix, implementing the proposed project with marine energy.

The most relevant data that can be observed is the increase of the contribution of clean energies, in 0.45% of the total supplied to the country, that despite being a relatively

low percentage within the energy matrix, the only implementation of this project represents about 21% of energy growth in the field of non-conventional renewable energy.

As a consequence of this change, the thermal generation would reduce its contribution by 124 GWh annually, which entails a process that goes from the extraction, processing and transportation of fuel to the plant, to the pollutant emissions produced in it. These characteristics are discussed below.

5.3 Economic savings due to changes in the type of electricity generation

Within the thermal plants that are in operation in the country, the raw material to obtain energy can be gas or some other fuel like diesel or fuel oil # 6 better known as bunker.

The Manta thermal power station, which would be replaced or related to the generation proposed by this study, uses for its generation fuel oil # 6. Every day 256,000 gallons of this fuel are transported by land, by tanks from the Esmeraldas Refinery.[44] The fuel is carried out from monday to friday, if it were possible to transport them by sea could generate very representative savings, this possibility is not very far away since the Jaramijó Thermal Power Station uses this means of transport.

The cost of transporting each gallon of fuel is \$ 0.11.[44]

Table 5.4 Economic summary for bunker transport

Economic analysis fuel transport	
Daily Fuel Monday-Friday (gal)	256000
Cost to transport each gallon (\$)	\$ 0.11
Total daily Cost (\$)	\$ 28,160.00
Weekly Cost (\$)	\$ 140,800.00
Monthly Cost (\$)	\$ 563,200.00
Yearly Cost (\$)	\$ 6 758,400.00

Source: Generated by the author

Therefore the thermoelectric company has an annual expense of 6 758,400.00 dollars for fuel transportation. It should be emphasized that the country's electricity service is largely subsidized by the State, so this very representative expenditure is part of the economic obligation with which the country has to pay.

5.4 Reduction of environmental impact

To approximate the environmental impact generated by a 20.4 megawatt thermoelectric plant, it is very important to know the amount of carbon dioxide (CO₂) emissions that originates by the operation of the machines in the thermoelectric plant to obtain electricity.

The emission factor estimated and calculated by the MAE in the operations of the national electricity system is 0.7079 tons of CO₂ for each megawatt per hour delivered to the grid.[48]

Table 5.5 CO₂ emissions reduced when technology changed

Calculation of reduced emissions by technology change	
CO ₂ emission factor (tCO ₂ / MWh)	0.7079
Annual energy (GWh)	124.2
Annual energy (MWh)	124,200.00
Annual CO₂ emissions (tonnes)	87,921.180

Source: Generated by the author

By generating electricity through the proposed clean energy source, 87,921.180 tons of CO₂ emissions annually would be reduced.

It is also important to mention that this reduction only refers to the generation of electricity, but if this project is implemented, pollution is also reduced in other fields such as fuel transportation.

If this amount of emissions is taken to the carbon bond market, the transactions that have been generated per ton of CO₂ are currently in the order of 5 dollars.[49]

Within the region of South America, in Colombia, have been paid values ranging from 2 to 12 dollars.[50]

Table 5.6 presents the collection of carbon bonus in two scenarios based on information taken as reference.

Table 5.6 Economic bonuses for reduction of CO₂ emissions

Calculation of emission reduction bonds		
Annual CO ₂ emissions (tonnes)	87,921.180	
Price per tonne of CO ₂ reduced (US \$)	\$ 2.00	\$ 5.00
Bonus collection (dollars)	\$ 175,842.36	\$ 439,605.90

Source: Generated by the author

This economic value is an important reference of the cost that has contaminated or the savings of investing in clean energy and give way to new sources that replace the conventional forms of generation and especially the thermal plants that use fossil fuels.

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6. CONCLUSIONS AND RECOMMENDATIONS

This exploratory study shows that there is potential energy in the section of ocean belonging to Ecuador. A project of electricity generation of at least 20 MW is feasible, starting from the Cromwell marine current, as the technical-economic parameters indicate it. In this way, sea energy becomes an additional path towards the national objective of having a cleaner electricity generation matrix. There is no similar study in the country but this may be the beginning to investigate our marine resources.

In addition, the presence of the marine current in the equatorial axis energetically involves the Galapagos Islands, specifically Isabela Island. However, considering two factors, it is concluded that energy projects cannot yet be developed in this region of Ecuador. The first is the environmental impact that would be generated during the installation in this area of high eco-system diversity worldwide, and the second is that the energy demand of the urban area of the island in addition to being small, is significantly different from the sector where a marine energy project could be implemented and the expenses in energy transmission would increase the costs of the same.

It is also important to note that the proposed technology is not limited to implementation in the oceans; in fact, the first tests of the proposed machinery were carried out in a river located in New York, United States. This feature leaves open the possibility of carrying out studies of implementation in water movements such as bays or rivers of considerable flow in Ecuador such as the Guayas River and its tributaries, which has a great demand for electrical energy in its basin.

To select the resource and the technology that is used, some possibilities of electricity generation are excluded, however, marine resources and technological advances allow us to investigate new forms of exploitation and more efficient machines that fit the marine resources of Ecuador as the wind or wave for example.

In this research the analysis is performed with the fourth generation machine but it is important to emphasize that the same manufacturer recently presented the fifth generation that obviously shows more efficient features and better performance.

Ecuador is a developing country and has the necessary resources to generate all the electricity demanded in a clean way.

Authorities managing Ecuador's energy matrix should allocate resources to research of this type and seek potential solutions to eliminate the use of fossil fuels to generate electricity.

With respect to the energy of the sea, the data and information necessary to raise electricity generation projects are scarce. Ecuador has an important portion of the ocean and it is necessary to have potentials and energy data that give viability to these projects.

There are several marine points in the country where such studies can be applied, the government should motivate researchers to look for ways to use energy.

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