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Development of wave technology as an energy efficiency mechanism in Ecuador: Esmeraldas case study

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Abstract

In recent years, technologies based on the use of renewable alternative energies have been incorporated into different activities in productive sectors, becoming a viable alternative to reduce energy consumption and contribute to the environmental impact, generating clean and non-polluting energies; one of them being wave energy, which takes advantage of the movement of the waves to receive and retain the energy contained in them, transforming it through electromagnetic induction processes into electrical energy. For this reason, it was proposed in this research to develop a proposal for the development of wave energy technology as a mechanism for energy efficiency in the coastal area of the canton of Esmeraldas, Ecuador. For this purpose, a study based on applied research was established because it is based on solving a specific problem or specific approach, focusing on the search and consolidation of knowledge for its application and, therefore, for the enrichment of cultural and scientific development. Among the conclusions identified during the analysis of the energy potential of waves, it was found that there are favorable results in the canton of Esmeraldas as a possible means of generating alternative energy

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from the sea, presenting the necessary environmental parameters for capturing energy from wave characteristics such as the average annual wave height, the constant period of the wave, the density of sea water and the average speed, being a sustainable alternative for the supply of electricity in the coastal area of the canton of Esmeraldas, Ecuador.
Key words: Renewable energy, wave energy, technology, energy efficiency.

Desarrollo de la tecnología undimotriz como mecanismo de eficiencia energética en Ecuador: Estudio de caso Esmeraldas

Resumen

En los últimos años las tecnologías basadas en el aprovechamiento de energías alternativas renovable, se ha incorporado a diferentes actividades en sectores productivos, convirtiéndose en una alternativa viable para disminuir el consumo energético y contribuir con el impacto ambiental, generando energías limpias y no contaminantes; siendo una de ellas la energía undimotriz, la cual aprovecha el movimiento de las olas para recibir y retener la energía contenida en ellas, transformándola mediante procesos de inducción electromagnética en energía eléctrica. Por esta razón, se propuso en esta investigación, desarrollar una propuesta para el desarrollo de la tecnología undimotriz como mecanismo de eficiencia energética en la zona costera del cantón Esmeraldas, Ecuador. Para ello, se estableció un estudio basado en Investigación Aplicada debido que esta se fundamenta en resolver un determinado problema o planteamiento específico, enfocándose en la búsqueda y consolidación del conocimiento para su aplicación y, por ende, para el enriquecimiento del

desarrollo cultural y científico. Entre las conclusiones identificadas durante el análisis efectuado sobre el potencial energético del oleaje, se encontró que existente en el cantón de Esmeraldas resultados favorables como posible medio de generación de energía alternativa proveniente del mar, presentando los parámetros ambientales necesarios de captación de energía proveniente de las características del oleaje como el promedio de altura del oleaje anual, el período constante de la onda, la densidad del agua del mar y la velocidad promedio, siendo una alternativa sustentable para el suministro de energía eléctrica en la zona costera del cantón Esmeraldas, Ecuador.
Palabra clave: Energía renovable, undimotriz, tecnología, eficiencia energética

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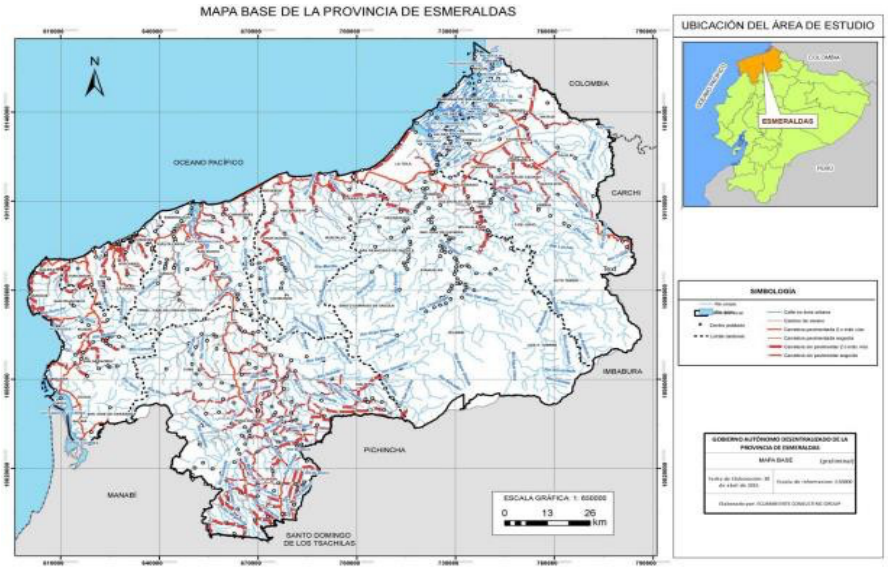
INTRODUCCIÓN

La investigación se circunscribe en el cantón Esmeraldas, provincia de Esmeraldas. Ecuador; esta se encuentra ubicada al extremo noroeste del territorio nacional, nombrada por sus visitantes como la provincia verde del Ecuador por su vegetación exuberante. Posee aproximadamente el 70% un territorio con grandes extensiones de planicies donde se observan pequeñas colinas que alcanzan hasta los 300msnm. Sin embargo, su territorio se encuentra bordeado por laderas y colinas, se observa al oeste una cordillera montañosa de poca altura llamada Montañas de Cojimíes, donde además se tienen las montañas de Muisne y Atacames.

Figura 1. Mapa base de la provincia de Esmeraldas



Source: Population Census and VI Housing Census, INEC (2010).

In the last decade, Ecuador has gone through a process of political and social change, based on the current legal framework, taking the Constitution as a basis. In this legal context that harmonizes a coexistence of preservation and respect for human beings and their ecosystem, this allows the incorporation of systems that propose energy efficiency and the use of alternative energies as ways for environmental conservation and energy savings based on renewable sources.

Due to the particular conditions of the province of Esmeraldas, which is located in front of the Pacific coast and opting for the proposal to implement the use of wave energy as a support mechanism for businesses and companies in the productive sector, taking advantage of both climatic conditions and its geographical location, and in particular of the Esmeraldas canton which has been the territorial space for the implementation of this research, for

being considered one of the provinces that continues to grow and develop tourism but nevertheless, it has remained with the same provision and energy supply for more than two decades, being the only energy server the thermoelectric plant of the Public Company Termoesmeraldas. In this sense, the implementation of alternative sources could present a viable proposal for future generations and investments in the region.

Given the current energy situation, research, development and innovation in alternative energies becomes more important and valuable, as it helps to generate and adapt the scientific and technological knowledge necessary to take advantage of the energy potential of natural resources as alternative sources of supply, thus contributing to social welfare (Niño and De Miguel, 2018).

In addition to the above, Latin America contains extensive and unexploited renewable energy resources. Where various countries have consolidated electricity markets, attracting investors and renewable energy companies to develop projects due to geographical diversification, a situation that has benefited countries such as Argentina, Brazil, Chile, Costa Rica, Mexico and Uruguay in terms of renewable energy, increasing considerably for some years the non-polluting energy potential, increasing by 2019 in the region 12 gigawatts (GW) of total energy capacity from alternative sources such as photovoltaic technology, which, according to the International Renewable Energy Agency (IRENA), projects that by 2050 more than 280 gigawatts (GW) can be generated through solar panels.

This, if there is a large endowment of resources and solid support policies. Likewise, within the energy mix adapted to the geographic diversification of the region, geothermal, wind and bioenergy can be included, all with low carbon emissions (Organización Latinoamericana de Energía [OLADE], 2020).

In the case of Ecuador, the use of renewable energies has also become a highly relevant objective, due to the benefits it offers to both people and the environment. Therefore, Ecuador ratified its commitment to the Sustainable Development Goals (SDGs) and declared the 2030 Agenda as public policy of the National Government. The National Assembly, for its part, adopted a resolution in which it commits to the implementation of the SDGs and places them as a mandatory reference for its work. At the local level, several decentralized autonomous governments have articulated their planning for the fulfillment of the global agenda. The private sector, civil society and academia have also joined this national commitment, under the premise of walking together towards common goals to ensure equal opportunities and a decent life for all people (United Nations in Ecuador, 2022).

Undoubtedly, the environmental impact is the main trigger for the generation of alternative mechanisms or technologies for the non-polluting production of non-aggressive electric energy for the environment, because each electricity generating plant has a different effect on the environment, for example, the consumption of natural resources, the destruction of the ecosystem for the exploitation of deposits implies soil erosion, loss of vegetation and biodiversity, and water and soil pollution (Figueredo and Fidel, 2022).

In addition, the burning of fossil fuels generates greenhouse gas emissions (CO2, CH_4, N_2O), sulfur oxides, nitrogen and particulates that, together with discharges of different compositions, negatively alter the environment. To this should be added the damage caused by the use of water dedicated to the cooling of the plants, which is returned to the environment with a higher temperature than that found naturally, producing an increase in temperature and considerable effects on the aquatic flora and fauna. In addition, the generation of waste, such as, for example, the ash produced in

combustion plants. Of particular importance, however, are the radioactive wastes from nuclear power plants, due to their dangerousness, contamination capacity and difficult treatment.

This is why there is a need to produce electrical energy focused on decarbonization and reduction of polluting gases, contributing to mitigate the pollution of the atmosphere, and one of them is wave energy, since it does not require large facilities, allowing to obtain electrical energy from the movement of waves and immersed mechanical energy, In order to complete this process, research must be conducted on the characteristics of the waves in the coastal zone of Ecuador supported with programmed monitoring and located in key areas, preferably between 50 - 100 meters deep and removed two kilometers from the Ecuadorian coast.

To which, Calero and Viteri (2018) refers that currently the studies developed on the usable energy potential of the sea are insufficient and its importance lies in wave energy for being an alternative energy adaptable to currently relevant coastal countries.

Considering that waves are an inexhaustible and zero-cost energy resource, it has been identified that Ecuador has an electric potential along the entire coast. This makes it interesting to start studying the feasibility of producing electricity from sea waves, in order to contribute to the diversification of the generation mix and discourage the use of fossil fuels for this purpose in the country.

Evaluating the possible supply of wave-transformed electricity with wave technology as an alternative for the coastal area of Esmeraldas, Ecuador, is a viable solution to preserve the local ecosystem, mitigating pollution and emission of carbon dioxide (CO2) and the greenhouse effect caused by the generation of electricity from fossil fuels. However, the energy transition is projected in the medium term due to the traditional reliable energy culture and tangible investments in power plants that technologically limit new energy horizons.

For this reason, this study proposes to contribute clean energy to the coast of the Esmeraldas canton, which offers business opportunities and in turn a sustainable energy contribution, where companies assume a leading role in the Sustainable Development Goals proposed in the United Nations Agenda 2030, from an energy alternative that significantly reduces the environmental impact for the consumption of electricity in the different economic sectors that make life in this area.

Wave energy is clean, because in its transformation process it does not generate combustion, emissions or explosions, nor does it generate waste or expulsion of waste into the sea. It also has a great potential, because it does without existing resources in the canton with the necessary environmental parameters to store more energy such as the density of sea water and wind speed that produce waves suitable for transformation, calculating that for each wave of one meter in height can produce between 20 to 40 KW.

Consequently, on the social justification can be defined as the contributions reduce the amount of CO2 that is expelled into the atmosphere offering the solution to the demands of society, on the different pollutants, present and future generations will benefit, to be a source of a better quality of life Vergara and Ruiz (2020) elaborate a research whose general objective was to design the Wavestar Model to improve the supply of electricity in the beach Costanera- Huanchaco, Trujillo-Peru, supported by the descriptive methodology with a transversal-applicational approach and thus apply a survey to the coastal population, allowing to collect information on the perception about the design, analyze the wave behavior of the sea of Huanchaco and its parameters such as wave height and period using equations for short distance waves. A general description of the design was also made and a budget was prepared for its installation and economic evaluation. Likewise, the power demand generated by the prototype and the power

required by the dwellings were determined. As a result, 80% of the population expressed their acceptance of the proposed renewable energy. It was evidenced that the energy flow and the total energy are adequate because the wave height of Huanchaco oscillates between 1m and 2m, generating 30 kW per buoy. In conclusion, wave energy can generate electricity and the project is viable.

Romero and Guevara in the year (2020) carried out an article whose objective was to propose a technological alternative for the use of wave energy in the state of Zulia. The research was framed in the modality of feasible project, descriptive type with a documentary design. The population consisted of studies and scientific research and technical reports related to wave energy. The data obtained were evaluated using statistical analysis for the study of the Zulian electricity market, analysis matrices to characterize the devices under study, comparison matrices to determine their technological maturity, dominance, impact and gap analysis; finally the evaluation of the economic aspects.

The results showed that there is a serious environmental impact in the region, as well as a deficit in the supply of electricity by the current systems of 1472 mW. The technologies studied are in the commercial phase, however, they present high investment costs. The Energy Buoy device was selected because it has a capacity suitable for the Venezuelan waves, as well as the greatest market dominance, with the lowest environmental impact among the technologies evaluated, which allowed selecting it as the ideal alternative for the use of wave energy in the state of Zulia.

According to Figueredo and Fidel (2022) in the research entitled Evaluation of wave energy as a sustainable alternative for supplying an artificial lift system in a semi-submersible platform. Intending to evaluate the supply of electric energy in an electro-submersible pumping system in an oil platform with wave power generation as a sustainable alternative through the selection of an offshore well

in Brazil that met the characteristics for the study, such as the artificial lift system suitable for the properties of the selected well; the simulation in software specialized in renewable energies to obtain the performance data, definition of environmental parameters for the identification of potential environmental impacts; and the comparison with a traditional energy alternative, together with an analysis of costs and financial feasibility.

Obtaining economically unfavorable results for the implementation of wave energy, since very little electrical energy is produced and the investment cost is very high. It is necessary to implement 4 buoys or wave energy converters to achieve the energy supply to the artificial lift system. While, in the cost scenario for the buoys it is necessary to invest millions of dollars while for a combustion electric generator it is necessary to invest a few thousand dollars. From the point of view of environmental and social impacts, the implementation of wave energy is justified by using diesel generators with negative impacts when contrasting the conventional process of these, with the estimates of the environmental impacts caused by electric generators.

Thus demonstrating that not all contexts are adaptable to the requirements needed to implement wave energy technology, that beyond being an option for obtaining electricity with less environmental and social impacts, the location where a possible implementation is projected must have the appropriate environmental parameters as the main resource. In addition, the study tends to highlight the socioeconomic and cultural impact, without taking into account the environmental impact and the repercussions in the future.

In turn Perdomo and Diaz (2018) conducted an article where they analyze the possibility of generating electricity from waves on the north coast of the Colombian Pacific, which will reduce the environmental impact of the current power generation from diesel

or gasoline, reduce energy generation costs due to the cost and transportation of this fuel, which will allow these communities to have electricity throughout the day. Most of the communities in the Pacific zone are not connected to the National Electric Energy System, and these areas are also rich in water and maritime resources, with an enormous potential, not only for fishing but also for energy. The generation of electricity from wave energy seeks to take advantage of the periodicity and amplitude of the kinetic and potential energy of the waves, to generate electricity from a wave energy converter that is less harmful to the environment.

METODOLOGÍA

El estudio se basa en la Investigación Aplicada debido que se caracteriza por buscar la aplicación o uso de los conocimientos adquiridos, adquiriendo a su vez, otros conocimientos, después de implementar y sistematizar la práctica basada en la investigación. A su vez, tiene por objetivo resolver un determinado problema o planteamiento específico, enfocándose en la búsqueda y consolidación del conocimiento para su aplicación y, por ende, para el enriquecimiento del desarrollo cultural y científico. Donde la utilización del conocimiento y los resultados del estudio generan una forma rigurosa, organizada y sistemática de conocer la realidad (Murillo, 2008).

Aunado, incluye esfuerzos sistemáticos y socializados por resolver problemas o intervenir en situaciones donde se prescinda de innovación técnica, artesanal e industrial como la propiamente científica, requiriendo a teorías científicas previamente validadas, para la solución de problemas prácticos y el control de situaciones de la vida cotidiana y concebida como experiencias de investigación con propósitos de resolver o mejorar una situación específica a o particular, para comprobar un método o modelo mediante la aplicación innovadora y creativa de una propuesta de

intervención, en este caso de índole Orientadora, en un grupo, persona, institución o empresa que lo requiera, (Padrón, 2006).

Por consiguiente, este tipo de investigación al buscar necesidades sociales o del sector productivo, siendo el caso de la energía limpia, se adapta al estudio en desarrollo por proponer una sistema de tecnológica undimotriz inexistente en el cantón Esmeraldas como mecanismo de eficiencia energética en la zona costera del cantón Esmeraldas, Ecuador; basado en el contexto donde se desarrolla; aportando a la ciencia información o posibles soluciones desde el punto de vista de la innovación técnica (Murillo, 2008).

La investigación aplicada constituye un enlace importante entre ciencia y sociedad. Con ella, los conocimientos son devueltos a las áreas de demanda, ubicadas en el contexto, donde se da la situación que será intervenida, mejorada o transformada. Al prescindir de este tipo de investigaciones se aísla el conocimiento científico de los contextos donde interviene, quedando cada profesional en manos del acontecer externo y de teorías ajenas a la evidencia de la realidad que enfrenta en su práctica profesional.

La investigación como actividad científica resulta ser densa y compleja, propia de personas especializadas; no obstante, constituye una forma ágil y placentera de resolver situaciones problema (Morin, 2001).

Contribuyendo a la divulgación de conocimientos basados en la evidencia de realidades dadas, plausibles, comprobando la utilidad inmediata de la aplicación. Es por ellos, que investigar con criterios claros sobre la propia acción, además de la fundamentación científica, elevan, sin lugar a duda, el rango de la disciplina en la producción científica de contextos reales con parámetros sincrónicos (Dugarte, 2006). Así mismo, la efectividad de investigar bajo el lineamiento de investigación aplicada, es buscar solucionar de manera práctica una situación problema, de

tal forma los estudios bajo esta modalidad se piensan y se construyen de manera más ejecutiva, concreta y sintética, con la finalidad de definir las características que adquiere (González, 2010) y, su aplicabilidad consiste en ello, que permitirá determinar los parámetros ambientales del cantón Esmeralda en el contexto real, buscando solucionar el consumo energético con energías alternativas que pueden ser generados con los recursos naturales propios del cantón para definir si son adaptables a la tecnología undimotriz.

Se utiliza un enfoque o método de investigación cuantitativo, tipo descriptivo y un diseño documental, no experimental. Además, se llevó a cabo desde lo deductivo el cual representa una estrategia de razonamiento lógico con la finalidad de llegar a conclusiones a partir de una serie de premisas o principios. Por esta razón, se considera que va desde lo general (leyes de la energía undimotriz) a lo particular (comportamiento de la energía undimotriz en las costas de Esmeraldas – Ecuador).

Estas premisas permiten identificar patrones de comportamiento que luego aportan a la selección de tecnologías que mejor se adapten a las condiciones particulares del entorno analizado, donde aspectos como el impacto ambiental, el ahorro energético, la eficiencia, entre otros juega un papel fundamental en la investigación.

La población objeto de estudio está conformada por las instituciones públicas del Estado e instituciones privadas que se encuentran en la zona costera del cantón Esmeraldas y que son potencialmente aptas para la implementación de esta tecnología undimotriz, desde ellas se tomarán datos asociados la investigación y además de considerar las estadísticas institucionales de control marítimo, tal como información del Instituto Geofísico de la Armada para determinar el potencial energético undimotriz de la provincia de Esmeraldas. Para ello, se

utilizará una matriz de efectos ambientales, sociales y económicos de la energía undimotriz, donde se considera como relevante los valores relacionados a las variables potencial energético y parámetros ambientales que permitirán el desarrollo de la energía undimotriz

RESULTS

During the phases established for the research, different theoretical positions related to energy generation were evaluated, which are part of the results of this study, where it is pointed out that although the bibliographic review points out that the first steps of the implementation of these proposals in remote areas and islands, nowadays they have been very useful to create sustainable tourism spaces that make the economic and social development of communities with industrialized designs more attractive. However, currently, the projects focused on generating electricity are aimed at developing their own prototypes, for example, various electrical sectors of European communities have implemented some wave power test areas in the open sea with a variety of models to study their functions and adaptations.

In order to make a diagnosis related to the energy use of waves and their impact on the quality of life of communities, in addition to aiming at the contribution to the SDGs established in the UN 2030 agenda, a detailed review of their characteristics, elements and indicators was carried out to frame the general ideas that then in each of the objectives were generating the necessary contribution for decision-making for the development of wave energy on the coasts of the province of Esmeraldas.

Wave energy is characterized by:

- It is a renewable and continuous energy because it takes advantage of natural resources that are inexhaustible.

- The generation of electricity is thanks to the kinetic energy produced by the movement of the waves.
- Wave power is an autochthonous energy source, without dependence and widely available. Any country with a coastline can produce it.
- It generates non-polluting and clean electricity, with no impact on climate change as it does not emit greenhouse gases (CO2) into the atmosphere.
- Electricity production is discontinuous throughout the day because it depends on the waves and their degree of strength or height. But it can be produced at night.
- More electricity is produced if the installations are far from the coast, although it is difficult to obtain its energy due to the destructive force of the swell.
- Its generation promotes the supply of electricity to remote coastal regions, where the supply service may be deficient.
- It contributes to the production of secondary fuels and the generation of drinking water from the sea.
- Wave power plants are small in size compared to other alternative energy generating plants, and the kinetic energy from waves is 1,000 times greater than that of the wind, and their devices are located under the surface of the sea or at distant lengths from the coast (high seas).

The Constitution of the Republic of Ecuador (CRE, 2008) in Article 14 recognizes the right of the population to live in a healthy and ecologically balanced environment that guarantees sustainability and good living, and declares of public interest the preservation of the environment, the conservation of ecosystems, biodiversity and the integrity of the country's genetic heritage, the prevention of environmental damage and the recovery of degraded natural spaces. Furthermore, wave energy should not be underestimated due to its importance in the diversification of the energy mix,

Chozas (2012), because it is a tertiary derivative of solar energy due to the fact that heating of the earth's surface generates wind and this, in turn, generates wave energy, which acts as an energy accumulator capable of receiving energy, transporting it from one place to another and storing it. This is how 0.3% of the solar energy that reaches the earth's surface with the help of technological innovations can be transformed into wave energy (Garcia, 2019).

Spreading over thousands of kilometers along the surface of the sea for great lengths with minimal energy losses, culminating at the continental edge, so that the energy accumulated in any part of the ocean is concentrated on the coasts driven by the wind, dynamics that allows through the movement of the waves to generate in support of physical or chemical transformations, to be able to generate wave energy, Chozas (2012).

However, the energetic power of the waves will depend on the intensity, duration of the wind and the extension of the surface over which it blows (effect called fetch), parameters that define the disturbance and consequently the characteristics of the waves, which can be of capillary or gravity type, being the capillary waves the most effective quantitative for the accumulation of energy, by obtaining energy from the thrust of the wind.

To measure the environmental phenomenon of the wind force and the state of the sea, the work scale of other authors is used, which consists of a graduation that for the wind will be the speed and for the sea the height of the waves, and thus from the wind force it is possible to estimate its correspondence in the sea.

Allowing to identify the wind speed of knowing the height of the waves or vice versa and the higher the wind speed, the higher will also be the values of energy and power of the wave. Being favorable areas to implement wave energy are those that present energy flows corresponding to waves with an average height

between 2 to 3 meters and large periods between 7s to 10s, estimating an energy of 8 kw/m of coastline.

The Esmeralda canton belonging to the coastal system of Ecuador has a warm climate and a maritime extension of 1,338 km2 so its sustainable activity is fishing, characterized by a swell valued at an average of 14KW/m of power, while in deep water maintains a constant average swell of 1500 to 2000 m in height with a period of 12 to 15 seconds not exceeding 1 m/s (Instituto Oceanográfico de la Armada de Ecuador, [INOCAR], 2022). In this sense, taking into consideration the geographic location and the potential sources of exploitation, it is suggested to locate the wave energy park in the coastal area of the Esmeraldas canton.

Finally, there is a third wave-driven system adapted to the parameters of the Ecuadorian coasts called PELAMIS or also known as robotic sea serpent is an articulated, semi-submerged structure, composed of cylindrical sections joined by hinged joints. The wave produces an induced motion of these joints that is resisted by hydraulic cylinders, which the high-pressure fluid pump through the hydraulic motors of the accumulators smoothes. The hydraulic disc motors are electric generators.

The power of all joints is fed by a cable on the seabed. Several devices can be connected to each other and linked to the shore via a single cable from the seabed. The current production machines are 180m long and 4m in diameter, with power conversion modules. Each machine can generate 750 kW and can meet the annual electricity demand of approximately 1500 households.

One of the challenges facing energy efficiency is to produce electrical energy proportional to the energy consumed, so production should not be projected at low percentages. In addition, the aforementioned systems have the particularity that the more energy they produce, the better their performance will be,

otherwise the energy would decrease, presenting development difficulties.

In 2004, the Pelamis device came into operation on the coast of Portugal; a device in the form of a snake composed of segments articulated between them. The movement of the waves causes undulations in the mechanism, which moves the joints that have a piston mechanism that injects oil under pressure to a turbine coupled to an electric generator. Its generation potential was estimated at 750 kW.

While for the year 2011, in the Basque town of Mitriku a wave power plant was installed with an installed power of 300 kW and 16 turbines supported by a budget of 2.3 million euros and uses the technology called oscillating water column. However, in 2014, a model for freshwater buoy with an arm that drives a hydraulic system of pistons in a closed circuit, which feeds a Pelton turbine anchored to an electric generator, creating another wave power system that works with mechanical arms staying in contact with the water and ending in a float ring with a diameter of 10 m generating a continuous impact of the waves on the structure producing up and down movements in the extremities, compressing the freshwater in a high pressure system.

CONCLUSIONS

The analysis carried out on the energy potential of the existing waves in the canton of Esmeraldas generated favorable results as a possible means of generating alternative energy from the sea, offering the necessary environmental parameters from the characteristics of the waves as the average annual wave height, the constant period between the wave wave wave, the density of sea water and the average speed.

Being those adaptable to the environmental conditions of the canton, the OPT (Ocean Power Technologies) wave power

technology, with hydraulic turbines consisting of a buoy that is installed far from the coast (offshore) transforming the energy of the waves into mechanical force through the kinetic energy produced by the waves. The second option is the Oscillating Water Column (OWC) system, which uses the energy resource of the oscillations of the waves and collects it inside columns where the water goes up and down, representing the operation of a piston compressing and decompressing the air, transported to a turbine where electricity is generated; The third known robotic sea serpent system is an articulated, semi-submerged structure composed of cylindrical sections joined by hinged joints and hydraulic disc motors capable of generating renewable energy for populations of no more than 500 homes.

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