Ocean Energy Potential in Panama: An Assessment for Sustainable Energy Development

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2024 9th International Engineering, Sciences and Technology Conference (IESTEC) | 979-8-3503-7715-6/24/$31.00 ©2024 IEEE | DOI: 10.1109/IESTEC62784.2024.10820213

***Abstract* — This research aims to evaluate the potential of ocean energy in Panama as an alternative for clean and sustainable electricity production through predictive and comparative analysis, considering the descriptive variables of each alternative concerning the oceanic conditions of Panama. This analysis focuses on wave energy, tidal energy, osmotic energy or salinity gradient energy, ocean thermal energy, and ocean current energy. First, the potential of each alternative was evaluated concerning Panama's oceanic conditions. Then, the alternatives with the greatest potential were identified. As a result of this research, the energy potential of the five alternatives was categorized into high, moderate, and low, with ocean thermal energy and wave energy showing high energy potential. Subsequently, tidal energy and marine current energy showed moderate potential. Finally, osmotic energy or salinity gradient energy projected low potential due to the limited availability of freshwater bodies flowing into the seas. Additionally, it was justified that the development of technologies associated with these energy alternatives is experiencing significant and accelerated advancements that would benefit their implementation in Panama. This could significantly contribute to the diversification of the energy matrix in a sustainable manner, thus reducing dependence on fossil sources and minimizing environmental impact.**

***Keywords*— Ocean Energies, Wave Energy, Tidal Energy, Osmotic Energy, Ocean Current Energy, Ocean Thermal Energy Conversion (OTEC).**

I. INTRODUCTION

Currently, human actions have fueled the accelerated growth of sectors such as urbanization and industrialization due to the rapid population increase. All these actions have played a significant role in the rising global demand for electricity. Consequently, there has been a substantial increase in carbon dioxide emissions into the atmosphere, which has exacerbated the issue of global warming. This has resulted in irreversible environmental impacts, such as the melting of glaciers, rising sea levels, the occurrence of hurricanes and typhoons associated with higher temperatures, and frequent wildfires.

In response to these challenges, projects for electricity generation using renewable energy sources have been implemented, achieving significant advances in production efficiency and economic accessibility. Some examples include solar photovoltaic energy, hydroelectric power, and wind energy, which play a significant role in Panama's energy matrix.

However, it is important to consider that these alternatives for electricity generation are not completely clean. Many of these sources do not emit greenhouse gases during electricity generation, but they do have a direct impact on the environment. For example, the large areas of land required for their installation. Additionally, these are intermittent energy sources, as they depend on the availability of the renewable resource being used and, therefore, do not continuously meet the energy demand. Consequently, society needs to explore new alternatives to address these deficiencies.

Given the limitations faced by conventional renewable systems, along with the challenges associated with the growing energy demand, new initiatives such as ocean energy for electricity production are emerging.

It is estimated that the world's ocean waters hold approximately 10 TW of renewable energy potential, comprising wave and tidal energy, ocean thermal energy conversion (OTEC), ocean currents, and salinity gradient energy. However, these resources are currently under development and remain largely untapped [1].

Panama has approximately 3000 km of coastline along the Pacific and Atlantic Oceans, representing a vast and accessible oceanic territory. Therefore, it could benefit from ocean energy for electricity production and even evaluate the generation of other benefits [2].

Panama's oceanic scenario presents differences between high and low tides, reaching over 5 meters in the Pacific Ocean. Additionally, both oceans experience waves of varying intensities, frequencies, and sizes that could be harnessed [3]. There are also marine winds along the Caribbean coast (Atlantic Ocean) that could potentially be exploited. Although Panama has vast energy resources, their potential has not yet been fully assessed. However, the National Energy System has considered studying their potential and sustainability as part of its future actions [2], [4], [5].

II. OCEAN ENERGY

A. Theoretical Framework

Ocean, marine, or blue energies encompass all renewable energy alternatives derived from the oceans for unconventional electricity generation. However, each of these energy sources requires specific implementation methods and technologies. According to reports from the National Oceanic and Atmospheric Administration (NOAA) of the USA, it is estimated that 71% of the Earth's surface is covered by oceans . Additionally, the Earth receives approximately 173 PW of solar energy, with about 123 PW being absorbed by the oceans, making them the world's largest collectors and reservoirs of energy [6], [7].

Currently, it is estimated that conversion systems could produce approximately 20,000 to 80,000 TWh from the utilization of ocean energy. This production would be sufficient to meet the total global electricity demand, which was 20,567 TWh in 2015 [8].

It is important to highlight that technologies for harnessing ocean energy are still under development. Therefore, these energy resources are not expected to become competitive before 2030. However, they are of global interest to researchers, academics, and professionals in the industrial sector [8].

III. POTENTIAL OF OCEANIC ALTERNATIVES

Ocean energy, as defined by the *Intergovernmental Panel on Climate Change* (IPCC), encompasses the various renewable energy alternatives provided by the oceans. These include wave energy, tidal energy (both potential and kinetic), hydrokinetic energy from ocean currents, ocean thermal energy, and osmotic energy from salinity gradients [9], [10].

A. Wave Energy

Waves are surface waves resulting from the interaction between the wind and the surface waters of the oceans. The wind itself is caused by pressure differentials resulting from temperature gradients across various regions of the planet, which are ultimately a consequence of differences in solar radiation. Therefore, the sun is the tertiary source of wave energy, also known as undimotriz energy [11], [12]

The periodic behavior of waves on the surface of the oceans can be represented as a sinusoidal function characterized by its wavelength L, wave height H, and period T, as illustrated in Figure 1 [11], [12], [13].

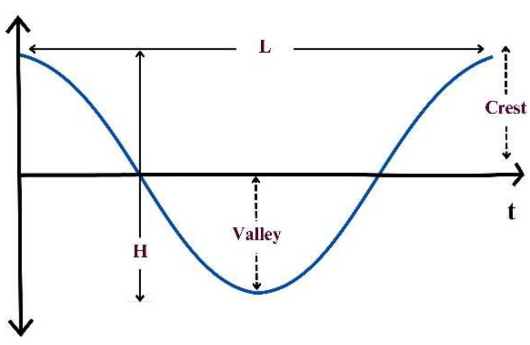

Fig. 1. Characteristics of a Pure Sine Wave [11], [13].

In the natural environment, waves exhibit a range of characteristics with varying magnitudes, from capillary waves with periods less than 0.1 seconds to semidiurnal waves with periods greater than 24 hours. However, waves suitable for energy conversion typically have periods between 1 and 25 seconds, with wavelengths ranging from 5 to 200 meters [11], [13].

The energy distribution of waves can be understood through a spectrum, where the wave energy is related to the amplitude of the wave and is plotted simultaneously against the wave frequency (Figure 2). In this image, the spectrum of waves on the west coast of Scotland is depicted, with a peak wave period of approximately 9 seconds and a range of wave periods between 2 and 16 seconds.

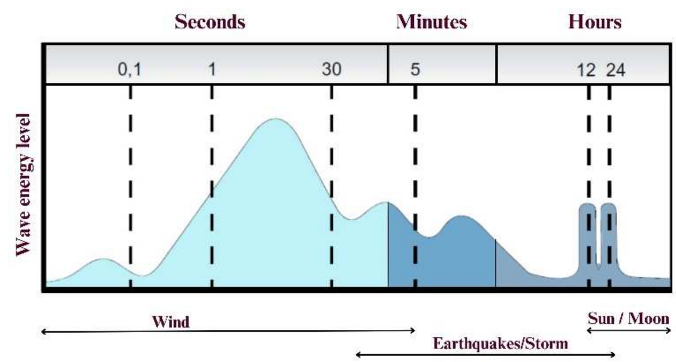

Fig. 2. Energy Distribution, Characterization, and Frequency of Waves [13].

The energy potential contained in ocean waves, measured in kW per meter of wave width, for an idealized ocean wave (a sinusoidal wave with constant amplitude and well-defined period and wavelength) can be estimated using Equation 1 [11].

$$P = \frac{\rho g^2}{32\pi} H^2 T \qquad eq.1$$

Where:

P: is the energy per meter of wave width (in kW/m).

H: is the wave height (in meters).

T: is the wave period (in seconds).

In deep water conditions where the wavelength L is much smaller than the water depth h (i.e., $L<<h$), the energy potential of ocean waves can be estimated using Equation 2 [7], [13].

$$P = \frac{\rho g^2}{64\pi} H^2 T \qquad eq.2$$

Where:

H: is the significant wave height (the average height of the highest third of waves in a record) [7], [13].

T: is the energy wave period; therefore, waves with greater amplitude and longer periods are more attractive for electricity generation [7], [13].

B. Tidal Energy: Potential and Kinetic

Tidal energy represents an oceanic alternative for electricity production derived from tidal movements. It is categorized into: Potential Tidal Energy, and Kinetic Tidal Energy [13], [14], [15]. Potential tidal energy is the energy stored in seawater due to the height difference between high and low tides. When the tide rises, water is stored in a reservoir. Then, when the tide recedes, the stored water is released through turbines that generate electricity. The difference in water levels between high and low tides creates a pressure difference that drives the turbines. A notable example is the tidal barrage at the La Rance tidal power plant in France, which uses this principle to generate electricity [14], [16].

The approximate energy potential for utilizing potential tidal energy over a year, considering the tidal histogram affecting the reservoir or barrage, where the potential energy of the reservoir is proportional to the square of the tidal range, can be estimated using Equation 3 [11], [13], [14], [15].

$$E_{nat/year} = 705{,}50\ \rho g V\ H_{rms} \qquad eq.3$$

Where:

705,5: represents the number of tidal cycles per year.

$E_{nat/year}$: annual energy (kW/year)

ρ: density of seawater (kg/m³)

g: gravitational acceleration (m/s²)

V : volume of the reservoir (m³)

H_{rms}: root mean square of the tidal range over a year.

Kinetic tidal energy is derived from the movement of water caused by tidal currents. Tidal currents are water flows moving in and out due to the gravitational attraction of the moon and the sun. This water flow can turn underwater turbines, generating electricity in a manner similar to how wind turbines generate power. Tidal current turbines, such as those installed in the *MeyGen* tidal energy project in Scotland, harness the kinetic energy of tidal currents to produce electricity [14], [16].

To estimate the energy potential of kinetic tidal energy, it is necessary to consider the velocities of tidal currents and the efficiency of the tidal turbines. Therefore, the corresponding energy potential can be estimated using Equation 4 [11], [13], [14], [15].

$$P = \frac{1}{2}\ \rho g A v^3 \eta \qquad eq.4$$

Where:

P: energy (kW/h)

ρ: density of seawater (kg/m³)

g: gravitational acceleration (m/s²)

A: area swept by the turbine rotor (m²)

v: velocity of the water current (m/s)

η : efficiency of the turbine

Both types of tidal energy offer a renewable and predictable energy source, although their implementation and viability depend on local conditions, such as tidal range and current speed. The World Energy Council (WEC) has estimated the total annual tidal energy to be approximately 22,000 TWh. However, it is considered that only about 200 TWh of this energy could be economically viable for exploitation [11], [13].

Figure 4 shows the amplitude of global oceanic tides. It also illustrates that the Pacific coasts of Panama have amplitudes of approximately 4 meters, which represents significant potential for tidal energy utilization.

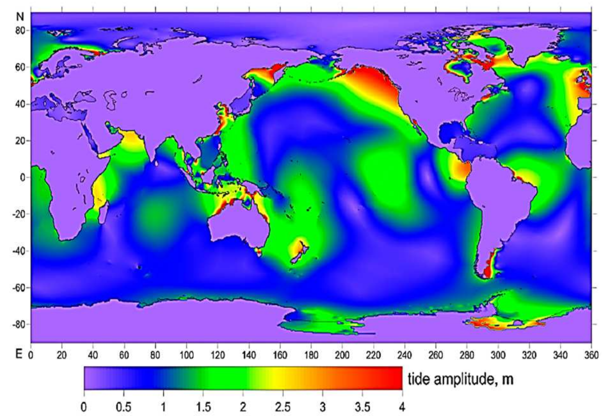

Fig. 4. Amplitude of global oceanic tides [17], [18] .

Figure 5 depicts the amplitude of tides specific to the Panamanian oceanic scenario. The 2n scale corresponding to oceanic tides refers to a simplified tidal model considering sea level variations due to the combined gravitational forces of the Sun and the Moon. This model accounts for tidal components that are multiples of 2, indicating semidiurnal tides (two tidal cycles per lunar day) and their harmonics. Note that the Pacific coasts of Panama present a potential scenario for the exploitation of tidal energy.

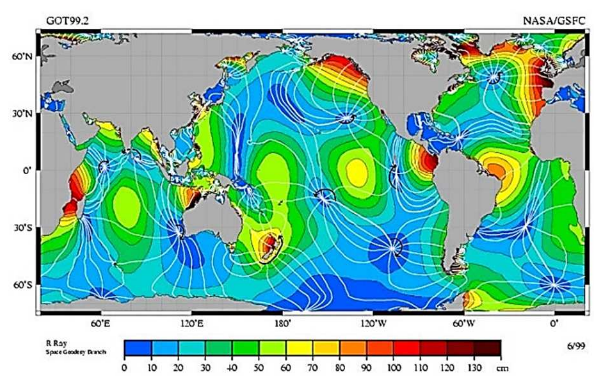

Fig. 5. Amplitude of Oceanic Tides (NASA, 2019).

C. Osmotic Energy or Salinity Gradients.

Salinity gradient power (SGP) is a renewable energy source with significant potential that has gained recent attention but has not been extensively researched [19].

Salinity Gradient Power (SGP) is generated by mixing solutions with different salt concentrations. In river estuaries, where fresh water mixes with seawater, this energy production is possible. The salinity gradient between rivers and oceans acts like a large charged battery. The Gibbs free energy (G) calculates the theoretical value of energy obtained from mixing such solutions. Thermodynamically, it is described as the change in Gibbs free energy (ΔG) between the initial states (river and sea) and the final state (mix) [22]. Theoretically, mixing 1m³ of river water with infinite seawater generates 0.8 kW of energy, equivalent to the energy produced by a 280-meter waterfall. Recent studies estimate the global potential of SGP to be between 1.4 and 2.6 TW, which corresponds to 3% of the world's energy demand. The Gulf of Mexico, the Mediterranean Sea, and the Caribbean Sea are identified as having the greatest technical feasibility for harnessing this new renewable energy source [19].

In addition to natural SGP, treated wastewater and seawater desalination can expand the reach of salinity gradient energy. Synthetic high-salinity solutions, such as ammonium bicarbonate, are also used to recover residual heat in closed-cycle osmotic engines. This significant energy potential drives the development of technologies to generate electricity from SGP [20].

One such technology is Reverse Electrodialysis (RED), which uses membranes to harness the salinity pressure gradient (SGP). RED stands out for its ability to generate continuous electricity. In a RED stack, cation and anion membranes are alternated between the anode and cathode to create compartments with low and high salinity. As solutions enter the stack, the selective transport of ions through the membranes creates an electrochemical potential that generates electricity through redox reactions at the electrodes [20].

Recent advancements in RED technology have enabled pilot-scale energy production evaluations. For instance, the pioneering plant in Sicily, Italy, has an installed capacity of 1 kW, the REDStack® pilot plant in the Netherlands has an installed capacity of 50 kW, and the most recent plant in South Korea, which utilizes wastewater for electricity generation, has a production capacity of 95.8 W [21].

D. Marine Current Energy.

Compared to wave and tidal energy in coastal areas, substantial flows of ocean currents also exist in the deep ocean.

These extensive water circulations are driven by global variations in wind patterns, temperature, and salinity. Ocean currents move in a predominant direction and are more intense near the surface. Numerous projects are implemented globally, particularly in Europe, for harnessing the energy from marine currents [13], [15], [22].

Marine currents, in addition to being a clean and renewable energy source, have the potential to supply a significant amount of electricity. Europe (253 MW) and Asia (261 MW) contributed nearly equally to the global marine current energy capacity, which ranged from 517 MW to 524 MW between 2019 and 2022, generating just under 1 TWh per year [23].

The energy potential for marine current turbines is estimated at 50 GW annually worldwide. This potential can be harnessed through various technologies, with marine current turbines being among the most promising. The calculation of energy potential is carried out using Equation 4 [13], [15], [22].

The theoretical potential of ocean current energy is estimated to be approximately 0.5 TW [16], [18], with the Florida Current responsible for 20 to 25 GW. This figure can be reduced to 1 to 4 GW when realistic technical constraints are applied [4]. The higher figure (20 to 25 GW) is particularly interesting, as it approximately matches the average electricity demand of the state of Florida [16], [18]. The implementation and development of projects in this area could significantly contribute to global sustainable energy generation, especially in countries with access to major marine currents, such as Panama [24]. Figure 6 shows global surface marine currents, depicting their distribution relative to the equator and their predominant direction. Currents represented by blue arrows illustrate cold water currents, while those in red indicate warm water currents.

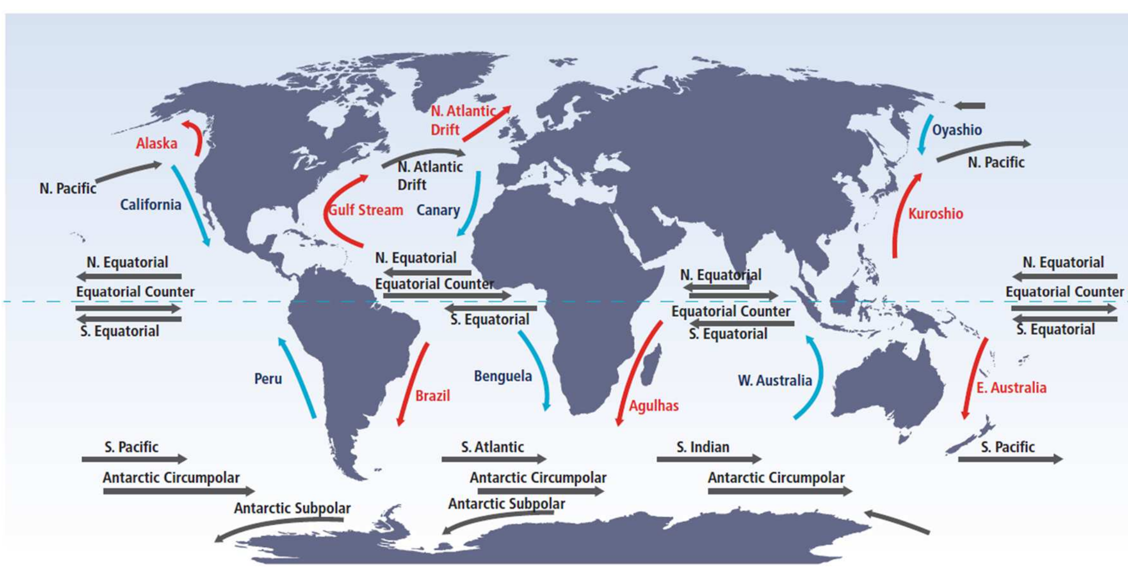

Figure 6. Surface ocean currents, showing warm (red) and cold (blue) systems [18].

E. Ocean Thermal Energy.

Ocean thermal energy represents an alternative that oceans offer not only for generating electricity but also for producing other byproducts such as air conditioning and refrigeration, as well as supporting activities in the fishing and pharmaceutical industries, among other benefits [10], [25], [26], [27].

The conversion of ocean thermal energy utilizes the thermal gradient between warm surface waters and deep seawater. This differential is exploited using condensation and evaporation circuits in an Organic Rankine Cycle (ORC) to generate electricity. The OTEC (Ocean Thermal Energy Conversion) technology employs organic working fluids that can undergo phase changes at low temperature [10], [25], [26], [27].

Generally, OTEC operates with temperature differentials of around 20°C or more, corresponding to warm surface waters compared to deep cold seawater with temperatures of approximately 4°C located at a depth of 1000 meters [4], [5], [27]. The global distribution of warm surface waters can be seen in Figure **7**, while the distribution of deep cold seawater for Panama is illustrated in Figure 8 [26], [28]

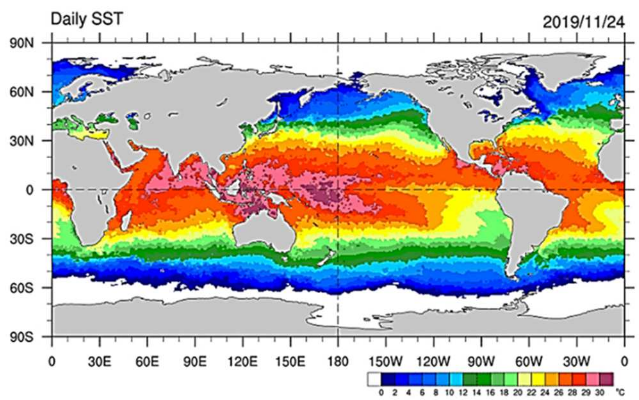

Figure 7. Global Distribution of Warm Surface Temperature (NOAA 2021).

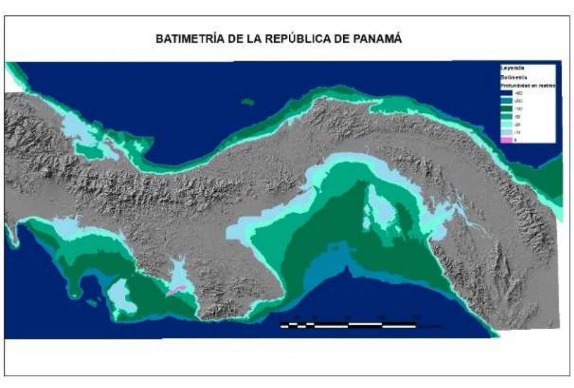

Figure 8. Bathymetry Map of Panama (CINEMI-UTP 2019).

It is estimated that the potential of ocean thermal energy is approximately 4,000 times the energy currently consumed by humanity. If implemented on a commercial scale, OTEC technology could induce one of the largest global energy shifts [7], [25], [27], [28]

The U.S. National Renewable Energy Laboratory (NREL) estimates that 250 billion barrels of oil represent approximately the energy absorbed by 23 million square miles of tropical sea in an average day. Thus, if at least 0.001% of this energy contained in the water masses were exploited, it could supply more than 20 times the total energy demand of the United States for any average day [7], [25], [27], [28].

The energy potential of OTEC is estimated using Equation 5.

$$P = \dot{W}_T - \dot{W}_{HP} - \dot{W}_{HC} \qquad eq.5$$

Where:

$\dot{W}_T$: net power corresponding to the turbine work.

$\dot{W}_{HP} - \dot{W}_{HC}$: work of the warm and cold-water pumps, respectively.

IV. RESULTS

Table 1 shows the potential of oceanic energy alternatives considering the respective environmental and oceanographic variables for Panama. The energy potential was categorized as high, moderate, and low, based on the variables justifying the energy potential associated with each alternative and the oceanic conditions related to each.

Table. 1. Energy Potential of Oceanic Energy Alternatives in Panama's Ocean Territory.

Oceanic Energy	Potential in Panamá
Wave Energy	High due to the extensive Pacific and Atlantic coastlines, with strong waves in some regions.
Tidal Energy	Moderate, as some regions may have significant tidal differences.
Ocean Thermal Energy	High due to the warm Caribbean waters offering a significant thermal gradient. However, in the Pacific, deep cold waters are found at shorter distances from the shore, favoring the exploitation of this resource.
Ocean Current Energy	Moderate, especially in areas with significant currents such as the Gulf of Panama and other coastal regions.
Osmotic Energy	Low, due to the limited availability of large bodies of freshwater flowing into the sea.

As identified, the alternatives with the highest potential are wave energy and ocean thermal energy, projecting a high potential given their operational conditions and the fulfillment of these by Panama's oceanic environment. Subsequently, with moderate potential are tidal energy and ocean currents, and lastly, osmotic energy.

V. CONCLUSIONS

The potential for marine energy in Panama is promising to consider the real conditions of Panama's oceanic scenario. Additionally, technological advancements represent significant attributes for the implementation of these technologies. It is also crucial to consider aspects such as cost feasibility and resource investment, as well as detailed categorization and characterization of the different alternatives, including their respective infrastructures, technologies, and social and environmental impacts. These considerations will help determine and justify the development, implementation, and sustainability of oceanic energy in Panama.

Panama has an oceanic environment where blue energies and Ocean Thermal Energy Conversion (OTEC) represent promising alternatives to address energy challenges and the responsibilities associated with progress in harmony with the environment. Studying each of these to harness the energy provided by the oceans will enable the sustainable development of regional and national economies. Furthermore, these activities are connected to the advancement of science, potentially leading to new research avenues and future contributions to the scientific field.

Panama possesses an oceanic territory with significant thermal potential. It exhibits a stable and minimally variable annual thermal energy resource with respect to seasonal changes. Its location in the intertropical zone near the terrestrial equator, with coastlines bordering the Atlantic and Pacific Oceans, categorizes it among the 98 nations with the highest potential for thermal energy in their oceanography. However, the lack of data, research, and specialists in this scientific field limits the implementation of this technology within its territory. Additionally, there are currently no legislations that promote and regulate the adoption of this technology.

VI. ACKNOWLEDGMENTS

This project was developed in collaboration with the Ocean Energies and Material Sciences research group at the Faculty of Mechanical Engineering, Universidad Tecnológica de Panamá. We would like to express our gratitude for providing us with this opportunity. The support, guidance, and continuous encouragement were essential for achieving success in this research.

REFERENCES

[1] N. Khan, A. Kalair, N. Abas, and A. Haider, "Review of ocean tidal, wave and thermal energy technologies," 2017, *Elsevier Ltd*. doi: 10.1016/j.rser.2017.01.079.

[2] Irena, *Evaluación del Estado de Preparación de las Energías Renovables: Panamá*. 2018. [Online]. Available: www.irena.org/publications

[3] I. Valiela *et al.*, "Increased rainfall remarkably freshens estuarine and coastal waters on the Pacific coast of Panama: Magnitude and likely effects on upwelling and nutrient supply," *Glob Planet Change*, vol. 92–93, pp. 130–137, Jul. 2012, doi: 10.1016/j.gloplacha.2012.05.006.

[4] C. Matthew, "DEVELOPMENT OF A MARINE ENERGY ROADMAP FOR PANAMA Masters of Mechanical Engineering with Renewable Energy Individual Project," 2016.

[5] P. British Embassy and P. Panama, "AN EXAMINIATION OF OCEAN ENERGY POTENTIAL IN PANAMA IDENTIFYING THE NEXT STEPS," 2016.

[6] M. Z. A. Khan, H. A. Khan, and M. Aziz, "Harvesting Energy from Ocean: Technologies and Perspectives," May 01, 2022, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/en15093456.

[7] R. S. Casarín, G. P. Vanegas, J. Gutiérrez Lara, and A. F. Delgado, *Energías del Océano (1)*, vol. 1. 2021.

[8] Y. Sang, H. B. Karayaka, Y. Yan, N. Yilmaz, and D. Souders, "Ocean (Marine) Energy," in *Comprehensive Energy Systems: Volumes 1-5*, Elsevier, 2018, pp. V1-733-V1-769. doi: 10.1016/B978-0-12-809597-3.00120-6.

[9] M. A. Shields and A. I. L. Payne, *Marine Renewable Energy Technology and Environmental Interactions*. 2014. [Online]. Available: http://www.springer.com/series/11481

[10] A. Felix Delgado, "Energía marina," in *La Década del Océano en México 2021-2030: La Ciencia que Necesitamos*, EPOMEX-UAC, 2023, pp. 405–428. doi: 10.26359/epomex01202314.

[11] J. A. Carta González, R. C. Pérez, A. C. Santos, and M. A. Castro Gil, *Centrales de energías renovables Generación eléctrica con energías renovables*. Pearson, 2009.

[12] A. Pecher and K. Jens Peter, *Handbook of Ocean Wave Energy*, 7th ed., vol. 7. 2016.

[13] S. P. Neill, "Introduction to Ocean Renewable Energy," 2021. [Online]. Available: www.cefas.co.uk/cefas-data-hub/wavenet/

[14] I. Renewable Energy Agency, "Tidal Energy Technology Brief," 2014. [Online]. Available: www.irena.org

[15] T. Xu, K. A. Haas, and B. Gunawan, "Estimating annual energy production from short tidal current records," *Renew Energy*, vol. 207, pp. 105–115, May 2023, doi: 10.1016/j.renene.2023.02.107.

[16] World Energy Council Marine, *World Energy Resources Marine Energy | 2016*. 2016.

[17] P. N. Shebalin and A. A. Baranov, "Aftershock Rate Changes at Different Ocean Tide Heights," *Front Earth Sci (Lausanne)*, vol. 8, Dec. 2020, doi: 10.3389/feart.2020.559624.

[18] A. Lewis and Estefen Segen, "Ocean Energy Coordinating Lead Authors: Lead Authors: Review Editors," 2011.

[19] O. A. Alvarez-Silva, A. F. Osorio, and C. Winter, "Practical global salinity gradient energy potential," Jul. 01, 2016, *Elsevier Ltd*. doi: 10.1016/j.rser.2016.03.021.

[20] H. Gao, B. Zhang, X. Tong, and Y. Chen, "Monovalent-anion selective and antifouling polyelectrolytes multilayer anion exchange membrane for reverse electrodialysis," *J Memb Sci*, vol. 567, pp. 68–75, Dec. 2018, doi: 10.1016/j.memsci.2018.09.035.

[21] J. Y. Nam *et al.*, "Assessing the behavior of the feed-water constituents of a pilot-scale 1000-cell-pair reverse electrodialysis with seawater and municipal wastewater effluent," *Water Res*, vol. 148, pp. 261–271, Jan. 2019, doi: 10.1016/j.watres.2018.10.054.

[22] B. Multon, *Marine renewable energy handbook*. ISTE, 2012.

[23] R. Samsó, J. Crespin, A. García-Olivares, and J. Solé, "Examining the Potential of Marine Renewable Energy: A Net Energy Perspective," *Sustainability (Switzerland)*, vol. 15, no. 10, May 2023, doi: 10.3390/su15108050.

[24] C. Galdaméz and J. Guevara-Cedeño, "Analysis for the installation of an electric power generation site from ocean currents in Panama," in *Proceedings of the 2022 IEEE 40th Central America and Panama Convention, CONCAPAN 2022*, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/CONCAPAN48024.2022.9997643.

[25] G. L. Tenorio, M. De Los, A. Ortega, D. Rosario, A. James, and F. Jurado, "OTEC Alternative for the Electric Power Generation in Panama," 2019.

[26] G. Lopez, M. de los A. Ortega Del Rosario, A. James, and H. Alvarez, "Site Selection for Ocean Thermal Energy Conversion Plants (OTEC): A Case Study in Panama," *Energies (Basel)*, vol. 15, no. 9, May 2022, doi: 10.3390/en15093077.

[27] E. Paola Garduño Ruiz *et al.*, "Estado del Arte Colección Energías Renovables del Océano," 2017.

[28] D. Vera, A. Baccioli, F. Jurado, and U. Desideri, "Modeling and optimization of an ocean thermal energy conversion system for remote islands electrification," *Renew Energy*, vol. 162, pp. 1399–1414, Dec. 2020, doi: 10.1016/j.renene.2020.07.074.