Marine Renewable Energy (MRE) in the Tropics

An Overview of MRE Potential in Oaxaca, Mexico

April 2022

Jamie Oman
Report produced from an undergraduate intern
University of Washington

Pacific Northwest National Laboratory

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Abstract

Conventional sources of energy, such as fossil fuels, produce carbon emissions and are depleting as global demand increases. Marine renewable energy (MRE) offers a cleaner way of generating electricity by using waves, tides, currents, and salinity or thermal gradient resources. Although tropical and subtropical regions have a great potential for some of these MRE resources, industry progress in these areas has been slow. One of the main barriers to the development of MRE is the uncertainty surrounding potential environmental and socioeconomic effects. This study focuses on Oaxaca, Mexico, and aims to describe the MRE resources available in the region and provide information on socioeconomic and biological aspects to consider for future MRE development. Off Oaxaca, there is high potential for wave, current, and ocean thermal energy. Local communities, artisanal fishers, and regulatory agencies are key stakeholders to engage with for discussing important habitats, species presence along the coast, potential socioeconomic impacts, and public acceptance. In the area offshore of Oaxaca, there are several marine mammal, fish, seabird, and sea turtle species, and critical habitats such as mangroves and coral reefs. Based on the information gathered, potential interactions between MRE devices and the environment in tropical regions are defined.

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Acronyms and Abbreviations

MRE	Marine renewable energy
OES	Ocean Energy Systems
EMF	Electromagnetic fields
MPA	Marine protected area
WEC	Wave energy converter
OTEC	Ocean thermal energy conversion
CONANP	National Commission of Natural Protected Areas, Mexico
CONAPESCA	National Commission of Fisheries and Aquaculture, Mexico
CEMIE-Océano	Mexican Center for Innovation in Ocean Energy

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1.0 Introduction

Marine renewable energy (MRE) can be used to generate cleaner electricity compared to fossil fuels and to reduce the release of carbon into the atmosphere by providing an alternative to fossil fuel combustion. There are various ways to harness MRE from the waves, tides, thermal and salinity gradients, and ocean currents. Devices capable of harnessing MRE include tidal and current turbines, wave energy converters, and ocean thermal energy conversion (OTEC) systems. Although the use of MRE is increasing worldwide, the industry is still emerging, and siting and permitting processes are slowed by concerns about potential environmental effects from these devices.

Environmental effects are defined by the interactions between MRE devices and the marine environment. These interactions can be described in terms of stressors and receptors (Boehlert and Gill 2010). Stressors are parts of an MRE device that may harm the marine environment; receptors are the marine animals, habitat, oceanographic processes, and ecosystems that could be affected by these stressors. Key stressor-receptor interactions include collision risk, underwater noise, electromagnetic fields (EMFs), changes in habitat, changes in oceanographic systems, and entanglement (Copping and Hemery 2020).

Collision risk describes the likelihood of a marine organism colliding into moving parts of a device such as turbine blades. Underwater noise is the sound emitted from devices, project construction, and development that may disrupt the animal's capability to perceive sounds, impacting their behavior and natural physiological processes. EMFs are physical fields generated by electrically charged objects such as underwater cables and may affect animals that are sensitive to the fields such as sharks or crustaceans. The presence of a MRE device in the water column cause changes in pelagic and benthic habitats that can disrupt or create new habitat for marine animals. Oceanographic systems consider the changes in processes (e.g., tides, waves, currents) that can impact water quality, nutrients, sediment transport, or water circulation. Entanglement refers to the potential for marine organisms to get caught or wrapped up in mooring lines, anchors, and cables running throughout the water column. Assessments on the level of risk from these interactions are currently being conducted.

Most information available on the interactions between MRE and the environment comes from studies conducted in temperate regions (Copping and Hemery 2020). While the use of MRE as a power source is currently rare in tropical areas, wave, tidal, and temperature gradient resources are widely available (Martínez et al. 2021). Tropical coastlines have some of the highest, untapped sources of MRE, which in turn can increase sustainable development (Hernández-Fontes et al. 2019). Some of the greatest wave energy resources can be found in tropical regions, however, utilization is delayed due to the immaturity of the technology and concerns about environmental effects (Felix et al. 2019). Identifying areas within tropical regions where MRE is feasible can help accelerate MRE development. Evaluating the potential environmental and socioeconomic effects of MRE devices will help identify these feasible areas and increase the opportunity for and probability of future deployments.

Mexico has one of the longest coastlines and many available renewable energy resources go untapped due to regulations and restrictive policies in place. After comparing ocean resources along the Mexican coast based on available studies, the state of Oaxaca was found to be best suited for MRE deployment with the potential for three types of MRE devices offshore (wave, current, thermal gradient). In this report, MRE resources off the Pacific coast of Oaxaca are synthesized and an assessment is performed to identify the stressors, receptors, and environmental interactions of interest. As a developing state, Oaxaca has many settlements without electric power, and reducing fossil fuel emissions while providing a sustainable, renewable source of electricity could be beneficial in addressing public energy needs (Hernández-Fontes et al. 2020). The people and culture of Oaxaca are also important factors that must be considered before MRE devices are installed. Cultural, industrial, and environmental aspects, and public opinion are assessed to better understand the community.

2.0 Methods

Focusing on coastal Mexico, a literature review was carried out to identify information on energy resource potential, socioeconomic considerations, and the presence of marine life in tropical regions. Using *Tethys*, a U.S. Department of Energy knowledge base that houses information on the environmental effects of MRE, and several websites such as Science Direct and ResearchGate, information was collected from scientific journals and reports regarding energy and environmental studies in Oaxaca. Based on this literature review, the stressors and receptors of interest in the region were identified to assess the potential effects of MRE devices on the marine environment and local communities. Specific knowledge on energy resources, socioeconomic considerations, and occurrences of marine fauna off Oaxaca was then gathered from the literature.

3.0 Overview of Resources

The MRE sector in Mexico is still at its initial stage of development (Wojtaroaski et al. 2021). Near the southwestern tip of Mexico, just offshore of Oaxaca, wave, current, and thermal energy gradients were reported as the most viable energy resources (Figure 1). In this report, this location was chosen for the overlap of these resources in a small spatial scale area and the proximity of the area to inland communities. The following sections describe these MRE resources.

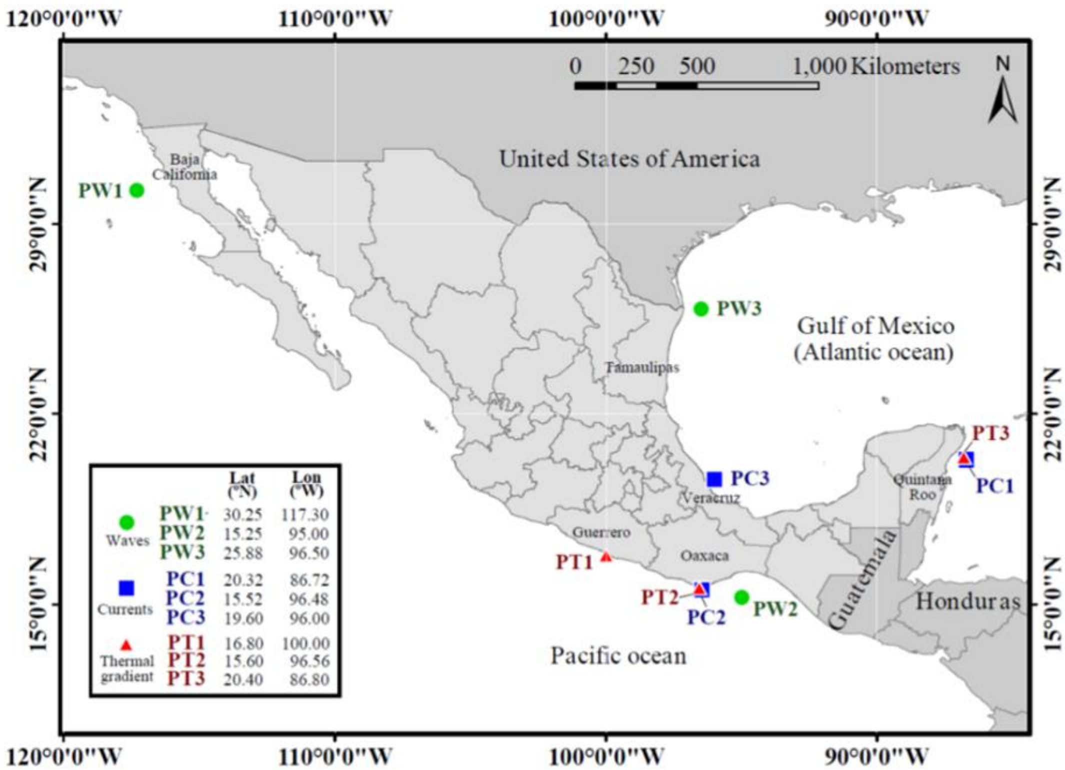

Figure 1. Wave, current, and ocean thermal gradient resources around Mexico. Each shape represents a specific resource on the map and the location where it might be harnessed (green circle for waves, blue square for currents, and red triangle for thermal gradients). Note the proximity of all three resources offshore of Oaxaca. Figure from Hernández-Fontes et al. (2019). http://creativecommons.org/licenses/by/4.0/

3.1 Wave Energy

Devices capable of harnessing wave energy are known as wave energy converters (WECs). Common WEC devices include point absorbers, surface attenuators, oscillating water columns, and oscillating surge converters, which may be bottom-mounted, floating within the water column, or at the water’s surface (Figure 2). In the state of Oaxaca, wave energy can range up to 10 kW/m (Felix et al. 2019).

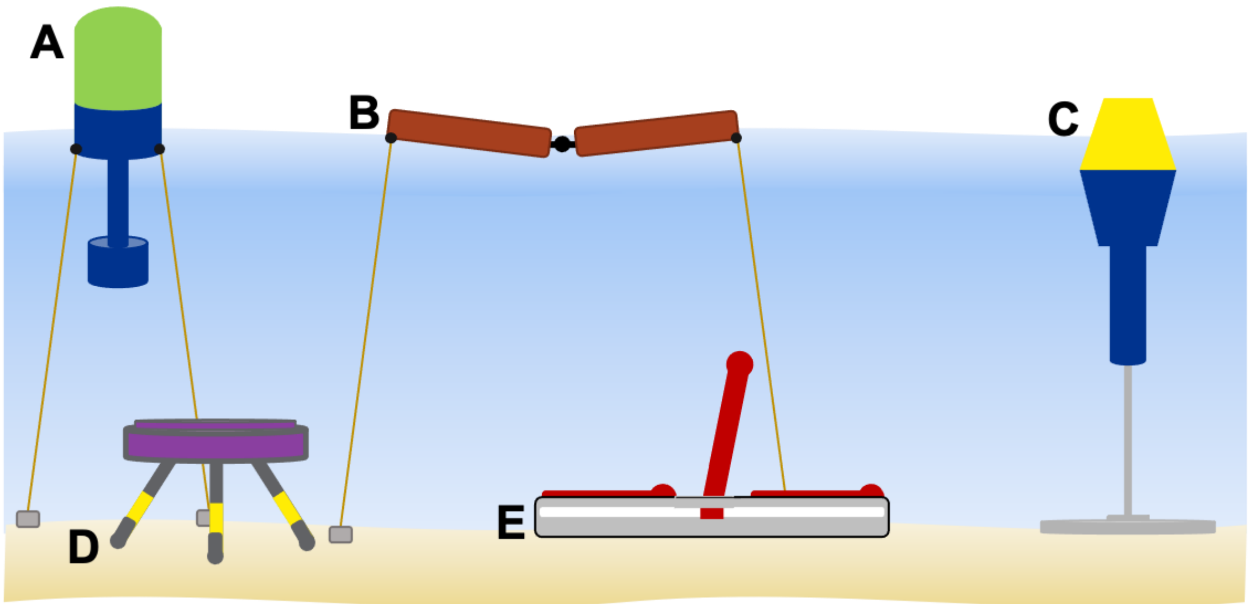

Figure 2. Diversity of wave energy converters: (A) surface point absorber with mooring lines and anchors; (B) surface attenuator with mooring lines and anchors; (C) bottom-mounted point absorber; (D) submerged point absorber; (E) oscillating wave surge converter. From Copping et al. (2021).

3.2 Current Energy

Ocean currents are caused by the combination of temperature, wind, salinity, and water depth. Ocean currents may be persistent or alter their pathways and flows seasonally. Ocean current energy devices harness kinetic energy from the flow of water (see example in Figure 3). Typical ocean current devices include but are not limited to ducted horizontal axis, horizontal axis, and vertical axis turbines, and oscillating hydrofoils. In Mexico, studies show ocean current systems as a promising source of energy because of the high-power capability (100 MW+) and predictability of the resource (Chen et al. 2018).

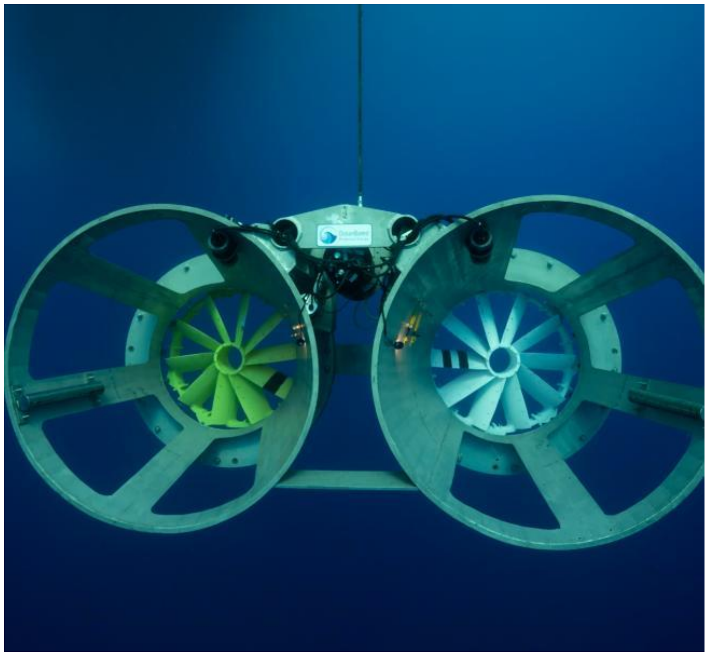

Figure 3. Ocean current turbine. Image courtesy from OceanBased Perpetual Energy.

3.3 Ocean Thermal Energy Conversion (OTEC)

OTEC uses the difference in temperature between the warm surface water and the cold, deep ocean to generate electricity. To optimally operate OTEC systems, a minimum of 1000 m depths and temperature differences between the deep layers and surface of 20˚C or greater are needed. OTEC plants may be floating at sea or shore-based, with ocean water pumped to the systems (see example in Figure 4). There are three types of OTEC systems: open cycle, closed cycle, and a hybrid of the two. Closed cycle systems use seawater and a substance with a low boiling point (such as ammonia) as a heat exchange mechanism, while open cycle systems use ocean water as the heat exchange medium. Hybrid cycle systems combine both cycles and can be used to produce both energy (100-200 MW off Mexico) and clean water. In Oaxaca, the Gulf of Tehuantepec has strong northerly winds, which alter the sea surface mixing, yielding thermal differences of over 26˚C. In Puerto Angel, a small coastal town, there is a promising area of 73 km^2 for OTEC close to cold water sources with approximately 71.19 MW of thermal power. Given the chance, this site in Oaxaca could supply 16% of the state's energy consumption (Garduño-Ruiz et al. 2021).

Figure 4. Okinawa Prefecture Industrial Policy Division ocean thermal energy conversion facility.

4.0 Socioeconomic Considerations

Social and economic aspects include those that influence people, communities, jobs, wages, and revenues (Uihlein and Magagna 2016; Freeman 2020). To accelerate MRE development, the socioeconomic benefits and adverse impacts of an MRE project need to be considered. In addition, potential challenges associated with public acceptance and governmental policies when installing MRE devices in tropical regions should be identified (Felix et al. 2019).

While MRE development may be vital for advancing the renewable energy sector in Mexico, the use of ocean resources should be reviewed carefully so as not to infringe on the rights of the diverse indigenous communities that live in Oaxaca. There are approximately 16 indigenous communities in Oaxaca, and, in 2011, 56% of people in Oaxaca considered themselves indigenous (United Nations Human Rights 2011). The main indigenous communities in Oaxaca include the Zapotec, Triqui, and Mixtec, though there are many others throughout Oaxaca, each with their own culture and history. Natural resources are highly important to native communities who depend on the environment for cultural practices, traditions, and livelihoods (e.g., fisheries).

Installation of MRE devices might conflict with other marine-based industries, such as fisheries or tourism (Bonar et al. 2015). Tourism also plays a large role in the economy of Oaxaca, such as public access to beaches. Most of the port activity is from marine vessels associated with tourism (Krishnamurthy et al. 2018). Due to many existing marine activities, there may be an overlap of resources used by industries on a similar spatial scale. Transparency between MRE developers and communities as well as careful siting for MRE devices that includes stakeholder engagement will be necessary to avoid conflict (Przedrzymirska and Zaucha 2018).

Government and federal organizations must be involved during stakeholder engagement because of any legal action and policy as well as politics. There are few integrated ocean management practices in Mexico; however, zoning programs and protected areas have been implemented (Bezaury-Creel 2005). Administrated by the National Commission for Natural Protected Areas of Mexico, marine protected areas (MPAs) can be found along the entire Pacific coast of Mexico (Figure 2). These MPAs were instated to preserve essential habitats, resources, and ecosystem services. MPAs in Oaxaca include Playa de Escobilla, Huatulco, and Lagunas De Chacahua. The Playa de Escobilla sanctuary has restricted access during the olive ridley sea turtle (*Lepidochelys olivacea*) nesting seasons, which can occur once each month and may last for up to 10 nights (Coria-Monter and Durán Campos 2017). Both Huatulco and Lagunas De Chacahua are national parks, and Lagunas De Chacahua is known for leatherback turtle (*Dermochelys coriacea*) conservation. Since Huatulco became a natural protected area in 1998, restrictions have limited hunting and fishing in the designated area.

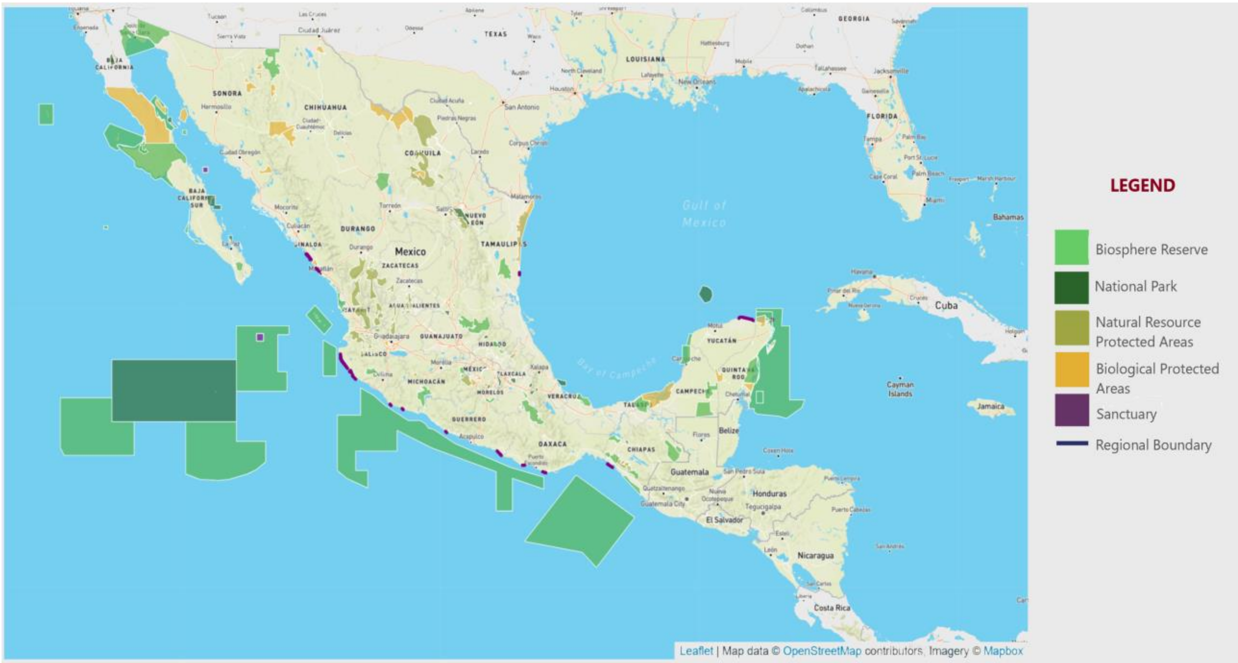

Figure 5. Locations of natural protected areas in Mexico, including sanctuaries and reserves in Oaxaca (CONANP 2021).

Educating local stakeholders on MRE will help identify local concerns and could also help increase public acceptance or even positive views of a deployment. Wojtaroaski et al. (2021) conducted interviews with adults and teenagers in Mexico to examine the natural elements they consider important in their lives as well as their understanding of MRE. Results indicate that the preservation and health of ocean ecosystems are extremely important to the local population. Most people had little to no knowledge of MRE. Assessing and addressing public exposure to MRE will help increase familiarity with the industry (Wojtaroaski et al. 2021). Researchers and developers who want to deploy off Oaxaca will need to work with a multitude of communities and stakeholders to further understand public opinion before device deployment.

5.0 Biological Assessment

The marine environment off Oaxaca supports a variety of species and habitats that must be understood before any MRE deployments are planned. One example of protection for species and habitats in Mexico is the Code of Conduct for Responsible Fisheries from the United Nations in which marine ecosystems are to be conserved. Under this code, authorities can make decisions regarding the protection of specific species. The following sections identify species and habitats around Oaxaca that may be important to consider.

5.1 Marine mammals

Many whales and other marine mammal species are often sighted offshore of Oaxaca as they have seasonal migratory corridors and breeding grounds nearby (Meraz and Sánchez-Díaz 2008). These marine mammals are listed below with the seasonal distribution noted:

- Whales:
  - Bryde's whale (*Balaenoptera edeni* - fall)
  - Blue whale *(Balaenoptera musculus* - winter/spring*)*
  - Humpback whale *(Megaptera novaeangliae* - fall/winter*)*
  - Sperm whale (*Physeter macrocephalus* - summer)
  - Dwarf sperm whale *(Kogia sima* - year-round)
  - Cuvier's beaked whale (*Ziphius cavirostris* - year-round; Figure 3)
  - Pygmy killer whale *(Feresa attenuate* - winter)
  - False killer whale (*Pseudorca crassidens* - summer)
  - Short-finned pilot whale *(Globicephala macrorhynchus* - year-round*)*

- Pinnipeds:
  - California sea lion (*Zalophus californianus* - summer*)*

- Dolphins:
  - Common dolphin *(Delphinus delphis* - year-round*)*
  - Risso's dolphin (*Grampus griseus* - fall/winter*)*
  - Fraser's dolphin *(Lagenodelphis hosei* - spring/fall)
  - Pantropical spotted dolphin (*Stenella attenuate* - year-round)
  - Striped dolphin *(Stenella coeruleoalba*- summer/fall)
  - Spinner dolphin *(Stenella longirostris* - spring)
  - Rough-toothed dolphin *(Steno bredanensis* - year-round*)*
  - Common bottlenose dolphin (*Tursiops truncatus* - winter/spring).

Figure 6. Cuvier’s beaked whale. Photograph by Sergio Martínez Aguilar.

5.2 Marine Fishes

In total, Mexico has reportedly 594 fish species constituting a species richness, unlike other countries. Some of these prevalent species include members of teleost and elasmobranchs, with perciforms representing the highest abundance (Bastida-Zavala et al. 2013). There are 204 fish species listed as endangered, threatened, potentially extinct, or protected over all of Mexico (Dzul-Caamal et al. 2012). Although freshwater species are most impacted in Mexico, many marine species are to consider. In the Huatulco Bay coral reef system alone, there were 112 species observed (López -Pérez et al. 2010). Fish contribute to the structure of the ecosystem and support many families through recreational, artisanal, and commercial fisheries. The Mexican government adopted guidelines from the Convention on Biological Diversity for the surveillance and identification of ecosystems and habitats containing an abundance of threatened or endangered species.

5.3 Sea Turtles

The olive ridley sea turtle (Figure 4) has a wide distribution and is listed as vulnerable by the International Union for Conservation of Nature (Abreu-Grobois and Plotkin 2008). These sea turtles rely heavily upon Mexican beaches for seasonal nesting grounds, specifically at La Escobilla, Oaxaca, where mass nesting occurs each month (Coria-Monter and Durán-Campos 2017). Other species that nest on Oaxacan beaches include the leatherback sea turtle and the green sea turtle (*Chelonia mydas)* (Vannini et al. 2011).

Figure 7. Olive ridley sea turtle. Photograph by Joëlle Dufour from the International Union for Conservation of Nature photo library.

5.4 Seabirds

On the west coast of Mexico, seabirds can be observed more than 3 km from the coast (Howell and Engel 2006). The most common species of seabirds documented around Oaxaca's waters include those belonging to the shearwater (*Procellariidae*), phalarope (*Scolopacidae*), booby (*Sulids*), tern (*Laridae*), and gull (*Larinae*) families (iNaturalist, accessed 2021). Many of these seabirds are observed diving and swimming offshore.

5.5 Habitats

A diversity of marine habitats used for foraging, rearing, and/or breeding are found along the coast of Oaxaca and offshore. Coastal lagoons throughout Oaxaca are home to vast expanses of mangroves, including red (*Rhizophora mangle*), black (*Avicennia germinans*), white (*Laguncularia racemose),* and buttonwood mangroves (*Conocarpus erectus*). Mangroves are some of the most productive ecosystems on earth, providing habitats that support a wide diversity of species. Mangroves also help protect shorelines from coastal erosion by stabilizing sediment (Bernal et al. 2019). Coral reefs are another important habitat in Oaxaca, displaying high species richness. Huatulco Bay, offshore of Oaxaca, contains several fringing reefs wherein many fish species have been observed (Lopéz-Pérez et al. 2010).

6.0 Potential Environmental Effects of MRE Devices off Oaxaca

The presence of MRE devices has the potential to affect marine animals and their communication, foraging, and migration or movement patterns, as well as alter marine habitats (Copping and Hemery 2020). To visualize the relationships between technology type and environmental interaction, the three most viable MRE technologies in Oaxaca and relevant stressors and receptors are noted in Table 1. Stressor-receptor interactions that may be associated with wave energy, current energy, or OTEC development include underwater noise, habitat change, collision risk, changes in oceanographic systems, entanglement, entrainment (for early life stages), and EMFs. Table 1 provides a general overview of associated environmental effects, but it should be noted that the specific device type and configuration for each technology will affect these potential interactions. For example, mooring lines from floating WECs and current devices might be a concern for entanglement, while this will not be a concern for devices placed directly on the seafloor. Similarly, shore-based OTEC plants will not emit electromagnetic fields that might harm animals in the marine environment and are considered low risk for underwater noise, while power export cables from floating OTEC systems might be a potential risk.

Table 1. Table depicting stressor-receptor interactions for wave energy, current energy, and ocean thermal energy conversion (OTEC) in Oaxaca, Mexico. Stressors are shown in columns and receptors are shown in rows.

Stressor / Receptor	Underwater Noise			Habitat Change			Collision Risk			Changes in Oceanographic Systems			Entanglement			Entrainment			Electromagnetic Fields		
Marine mammals																					
Fish																					
Sea turtles																					
Invertebrates																					
Seabirds																					
Habitat																					
Ecosystem processes																					

Legend:

Wave	Current	OTEC

7.0 Conclusion

There is high potential for the utilization of MRE resources (wave, current, and thermal gradients) as power sources off Oaxaca, Mexico. However, the different technologies available to generate electricity from each of these resources may cause various environmental and socioeconomic effects. To accelerate the development of MRE in Mexico, the potential environmental and socioeconomic effects need to be understood.

In Oaxaca, the main stakeholders to consider and consult with are indigenous groups and artisanal fishing communities, though many other stakeholders will need to be identified and engaged for each potential MRE project. Outreach to local communities with emphasis on transparent and open communication will be key to gaining public acceptance. Initial steps that MRE developers would need to take include engaging stakeholders in Oaxaca to share knowledge on MRE and the potential environmental effects, and conducting interviews to understand concerns and potential impacts on the different groups.

Off Oaxaca, the marine biodiversity is rich with many species of whales, dolphins, seabirds, sea turtles, and fish, and important marine habitats. Identifying the potential interactions between the environment and MRE devices is necessary to develop targeted studies and effective mitigation measures. Gaps in knowledge on the marine environment off Oaxaca remain, particularly on the spatial and temporal distribution of marine organisms, and on the ecosystem processes in key habitats (e.g., primary production or predator/prey interactions in coral reef habitat).

Installation of MRE devices in Oaxaca can provide many benefits to local communities. Producing sustainable electric power for those in need while reducing emissions can help decrease pollution caused by fossil fuel combustion. Improving information on the environmental effects of MRE in tropical regions can aid the global MRE sector in decision-making processes.

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