Potential environmental effects of marine renewable energy in tropical and subtropical ecosystems

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I. Introduction

MARINE renewable energy (MRE) is under development in many parts of the world. Although the MRE industry is advancing, several challenges have slowed its growth such as uncertainties associated with environmental effects [1]. So far, studies examining the environmental effects of MRE have primarily focused on deployments in temperate regions and countries in the Northern Hemisphere. As MRE development expands into tropical and subtropical countries (between 35°N and 35°S), there is a need to examine the potential environmental effects specific to these regions and their unique habitats and species.

As of 2023, substantially fewer MRE deployments have occurred in tropical and subtropical regions than in temperate areas. However, over the last several decades, various MRE device prototypes have been tested and full-scale projects planned or deployed (Fig. 1). Because many tropical and subtropical marine animals and habitats are already experiencing the disproportionate impacts of climate change, MRE development may present additional risks that could contribute to reduced biodiversity and ecosystem resilience [2]. Tropical and subtropical ecosystems host a diverse range of sensitive benthic and pelagic habitats such as coral reefs, mangroves, and seagrass beds that provide feeding, breeding, spawning, and nursing grounds for a wide variety of marine animals, including commercially important, endangered, and keystone species. To adapt MRE device deployments and develop appropriate monitoring methods and mitigation measures, the MRE community needs to better understand how potential environmental effects may differ between tropical/subtropical and temperate ecosystems.

Tropical and subtropical regions have access to all types of MRE resources: wave energy, tidal energy, and ocean current energy, as well as thermal and salinity gradients. While wave energy resources are much lower around the equator than in temperate regions, resources are typically high in subtropical regions [3] and energy from waves could be captured in places like western Australia, South Africa, off the central coast of Chile, and around islands in the north and south Pacific Ocean and in the south Indian Ocean (e.g., Mauritius). Several tropical and subtropical areas also have significant tidal resources, like Indonesia, the northern coast of Brazil, the western coast of Central America (especially near Panama and Colombia), the northwest coast of Australia, and the Mozambique canal [4]. Harvestable ocean currents, generated further offshore than tidal streams, are generally located in tropical and subtropical areas, such as off the coast of Florida and in Asia from Japan to the Philippines [5]. Temperature gradients that have sufficient thermal power capacity to generate power are non-existent in temperate regions but abound in tropical and subtropical regions [6], [7]. Ocean thermal energy conversion (OTEC) is especially regarded as a preferred source of renewable energy by tropical island nations with access to cold deep water close to shore. Finally, areas with the greatest potential extractable salinity gradient energy resources are located at river mouths along warmer coastlines, especially islands in the Caribbean, along the Gulf of Guinea coast, and in the southeast Mediterranean Sea [8].

To better understand the environmental effects of MRE in tropical and subtropical ecosystems and aid in developing MRE projects in a responsible manner, the international initiative Ocean Energy Systems (OES)-Environmental has begun to compile scientific information. So far, OES-Environmental has conducted a literature review, distributed a public survey, engaged with local experts, and conducted workshops to collect existing information, identify knowledge gaps, and determine future research needs.

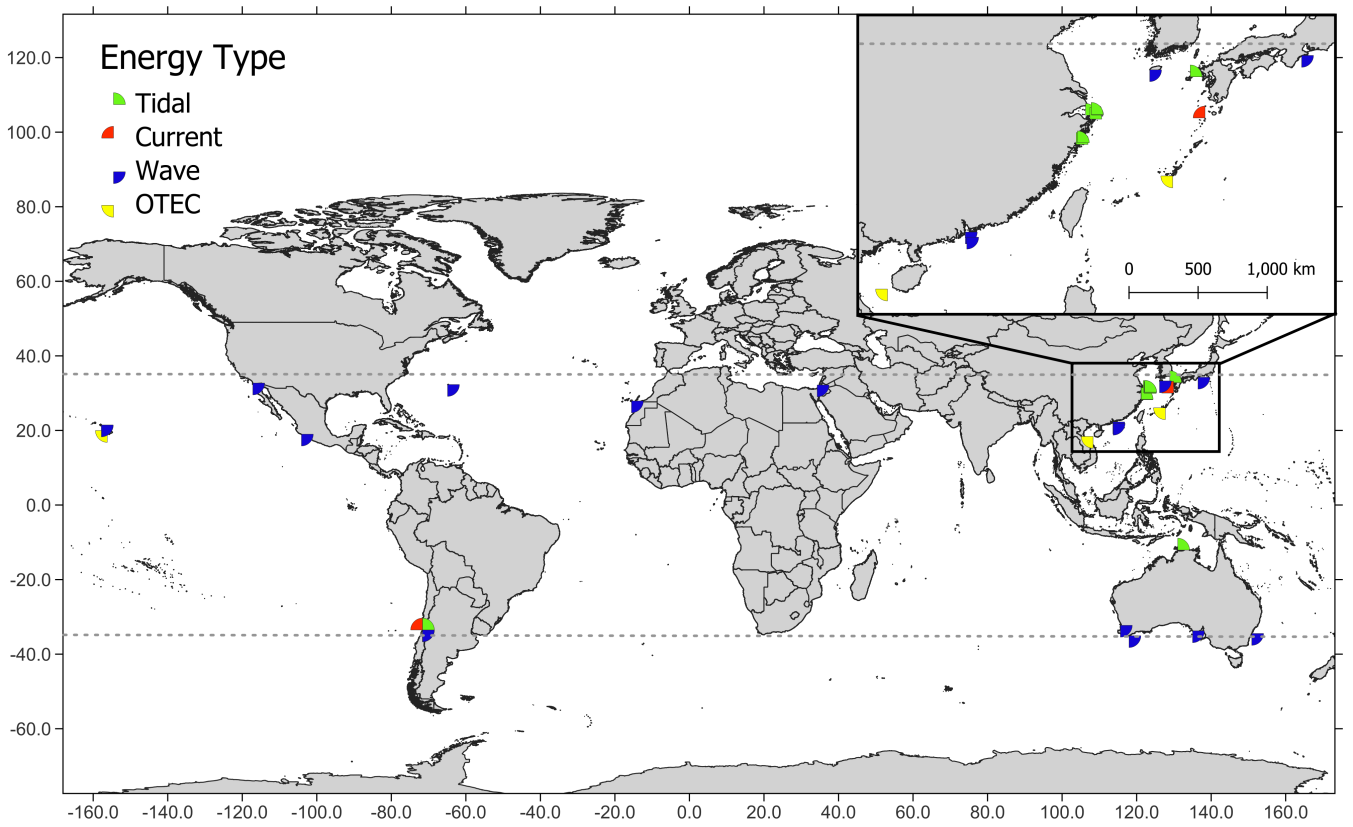

Fig 1. Marine renewable energy projects in tropical and subtropical regions, by technology type (tidal, current, wave, OTEC [ocean thermal energy conversion). Inset highlights the projects in China and Japan. Dashed lines represent the latitude range for the subtropical and tropical regions. [1]

II. Stressor-Receptor Interactions in Tropical and Subtropical Ecosystems

The potential environmental effects of MRE in tropical and subtropical ecosystems can be described through specific stressor-receptor interactions [9]. Stressors are those parts of an MRE device or system that may stress or harm the marine environment. Receptors are marine animals, habitats, oceanographic processes, or ecosystem functions that could be harmed by stressors. Stressor-receptor interactions can differ depending on the MRE technology.

A. Stressors of concern

The stressors potentially affecting the marine environment in tropical and subtropical regions are similar to those identified in temperate regions: collision risk, underwater noise, electromagnetic fields, changes in oceanographic systems, changes in benthic and pelagic habitat, and entanglement risk. These stressors are specifically relevant for wave, tidal, and ocean current energy except for collision risk which is relevant for tidal and ocean current energy only. The prevalence and perceived importance of these stressors may differ in tropical and subtropical regions, likely due to the unique receptors susceptible to change. Changes in habitat, underwater noise effects on marine life, collisions between turbine blades and marine animals, and changes in oceanographic systems have been identified by experts as the most important effects to consider in tropical and subtropical regions.

The potential stressors associated with OTEC may be similar to those associated with other MRE technologies (e.g., artificial reef effects, effects on habitats, changes to migratory routes, entanglement, and pathways for invasive species). However, there are several unique components used in an OTEC system, such as the deep cold water uptake pipe and seawater return pipe, that may present additional risks. The unique effects associated with OTEC are the cold water return which could affect the oceanographic processes in an area, entrainment of marine life in deep cold water pipes, and chemical discharges. Closed OTEC systems use ammonia or other chemicals as the heat exchange medium, and accidental leakage of these chemicals in gaseous form could be harmful to human and marine life. There have been few investigations into potential effects of salinity gradients energy extraction so far.

B. Receptors of concern

The sensitivity of the ecosystems that characterize potential MRE sites in tropical and subtropical regions is a common concern expressed by experts and stakeholders.

[1] https://tethys.pnnl.gov/

For example, in Mexico and Colombia, areas with the greatest MRE resource potentials often overlap fragile ecosystems such as seagrass meadows and mangrove swamps. In Brazil, experts have raised concerns around potential impacts on coral reef areas during installation, especially given the extreme vulnerability of these ecosystems and the potential irreversibility of any negative effects. Potential impacts on marine mammals from MRE development in Brazil is also an area of study.

Effects on biodiversity and ecosystems functions have been identified as the most important concern and there is a need to consider all species of an ecosystem, as well as interactions between species, when examining the environmental effects of MRE in tropical and subtropical regions, instead of focusing on a limited number of key species (e.g., sea turtles) as it is commonly done in temperate regions. Several species in tropical and subtropical regions contribute to the high biodiversity of marine ecosystems and are often listed as endangered or threatened (e.g., sea turtles, whale sharks, whales, manta rays, dolphins, corals).

III. Socio-economic concerns in tropical and subtropical regions

In tropical and subtropical regions, MRE development may have significant socioeconomic effects on nearby coastal and island communities if these needs are not considered during the project planning phase. These coastal and island communities are often small, isolated, and reliant on expensive diesel fuels for electricity generation.

As it is often the case with new renewable energy projects, impacts on local communities and tourism are important concerns for coastal communities. The acceptance of MRE projects along coastlines may be challenging due to impacts to viewsheds, to existing uses of the ocean, or in conflict from the "not in my backyard" effect. These concerns are often expressed as environmental concerns, as there is insufficient information about environmental effects of MRE. Coastal communities are keen observers of new project developments in their marine space and often participate in development process, so their social perceptions play a crucial role which can slow down or stop projects.

More than in temperate areas, coastal communities in tropical and subtropical regions rely heavily on nearshore fisheries and tourism activities to support their economies. In Chile for example, the Lafkenche law, passed in 2008, provides exclusive access rights to coastal areas and resources to indigenous communities. A need for new policies has been expressed in Chile to allow the co-existence of artisanal fisheries and MRE, based on potential interactions of MRE installations and support infrastructure with the fisheries. Other potential conflicts include interactions with tourism and recreation activities (e.g., wave energy and surf tourism), ports and navigation infrastructure, naval operations, etc. For instance, MRE projects in Brazil can be easily halted due to negative public perceptions and community opinions if perceived as a risk to the fishing and tourism activities in vulnerable coastal communities.

IV. Research needs and knowledge gaps

When considering the development of MRE in tropical and subtropical ecosystems, there is a lack of scientific information about the possible environmental effects, as compared to temperate regions. This lack of scientific information is largely due to the scarcity of MRE projects deployed in these ecosystems so far, as well as limited research funding available to investigate potential effects. The slow development of the MRE industry in these regions is generally linked to the lack of investment from government entities and to environmental and social constraints. The lack of long-term baseline environmental data prevents a comprehensive understanding of the natural variations of ecosystems, which is needed to evaluate the potential effects of MRE projects [10].

To get a better understanding of the environmental effects of MRE in tropical and subtropical ecosystems, studies need to go beyond the framework of stressor-receptor interactions that is being used in temperate regions. Except for interactions related to OTEC technologies that can only be deployed in tropical and subtropical regions, there are no interactions entirely specific to the tropical and subtropical regions; differences lie in the species and habitats that are potentially impacted. Therefore, considering the whole ecosystem and the linkages between species is key [11].

Social perception also plays a crucial role across tropical and subtropical regions and can become a barrier to the development of the MRE sector [12]. Concerns could be mitigated with strong community involvement from the inception of an MRE project, by engaging and consulting with local leaders and residents, and by educating stakeholders on MRE in general and environmental effects in particular. Awareness and education are key to community acceptance.

While access to research funding is often more limited in tropical and subtropical regions, baseline environmental research is needed to address concerns for environmentally protected marine areas that may include endangered or threatened species, coupled with socioeconomic research that will enable understanding of the potential impacts on local communities. Several recent studies have combined the investigation of both environmental and social effects to select sites for MRE projects in Mexico for salinity gradients [13], wave energy, current energy, and OTEC [14], and in China [15] and Colombia [16] for OTEC.

V. Conclusion

Tropical and subtropical marine ecosystems are composed of diverse habitats and complex ecological

interactions spanning from the shoreline to the open ocean [17]. These ecosystems face unprecedented anthropogenic threats and are vulnerable to environmental variations [18]. All countries considered to be megadiverse are in the tropical zone and there is a clear overlap between these biodiversity hotspots and MRE resources [2]. These characteristics make tropical and subtropical ecosystems highly sensitive and increase their vulnerability to the cumulative effects of anthropogenic activities at sea, including MRE development.

To advance the knowledge on the environmental effects of MRE and enhance the acceptance of a MRE project in tropical and subtropical ecosystems, it is necessary to identify priority and vulnerable habitats to avoid when siting, engage with stakeholders from the planning stages, and develop eco-friendly technologies and structures to limit the negative impacts on the ecosystems.

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