OTEC plant impact on Chiapas

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Despite the proved potential to harness ocean energy off the Mexican coast, one of the main aspects that have restrained the development of this industry is the lack of information regarding the environmental and social impacts of the devices and plants. Under this premise, a review of literature that could help identifying the potential repercussions of energy plants on those fields was performed. The available studies carried out around the world show a clear tendency to use indicators to assess impacts specifically related to the source of energy to be converted. The information gathered was used to address the foreseeable impacts on a hypothetical case regarding the deployment of an Ocean Thermal Energy Conversion (OTEC) plant off the Chiapas coast in Mexico. From the review it was found that for OTEC plants, the most important aspect to be considered is the discharge plume volume and its physicochemical composition, which can lead to the proliferation of harmful algal blooms. Regarding the case study, it is interesting to note that although the environmental impacts need to be mitigated and monitored, they can be somehow alleviated considering the potential social benefits of the energy industry.

Keywords: ocean renewable energy ; OTEC ; tidal current energy ; environmental and social impacts

1. Introduction

Governments worldwide are encouraging the development of projects for electricity production from renewable and clean sources to mitigate climate change, manage the possible reduction of fossil fuels, and ensure energy security [1]. The actual challenge is to reduce the gaps of knowledge in order to provide better and more precise information to the technology producers than the presently available. The main sources of ocean energy (OE) are tidal currents, tidal range, wave energy, OTEC (ocean thermal energy conversion), and salinity gradient [2]. In particular, the energy from tides and waves is arguably considered infinite [3] and they could constitute sufficient energy sources to supply the global demand. Therefore, governments and industry have expressed strong interest in them and by extension on all ocean energy sources. In 2008, Mexico approved its "Ley para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética" (Renewable energy exploitation and energy transition funding law); as of its publication, the government decided to increase the allocation of public and private resources for research, development, and innovation in renewable energy (RE). This law was revoked in 2015, but it set the basis for planning and financing instruments for RE conversion technologies and aimed for the long term to cover the country's urgent energy needs. RE-based generation is forecast to grow 6.8% annually with prospects of reaching 37.7% participation in the total Mexican generation by 2030 [4][5].

Today, the development of OE in Mexico is regulated and supported by the 2015 "Ley de Transición Energética" (LTE-Energy Transition Law). The scopes of the LTE are established in the "Ley General de Cambio Climático" (General law on climate change), where it is stated that, by 2020, the Ministry of Energy and the Energy Regulatory Commission should have an incentive system for electricity generation with RE promotion. In February 2020, the "Estrategia de Transición para Promover el Uso de Tecnologías y Combustibles más Limpios" (Strategy for a transition to promote the use of technologies and cleaner fuels) was published. There, the importance of creating economic incentives to encourage RE development is expressed again, but the mechanisms to do so are not specified [6]. The goals of maximum participation of fossil fuels expressed in the LTE are 65% in 2024, 60% in 2035, and 50% in 2050 [7][8]. Unfortunately, up to 2020 Mexico is still behind the commitments established.

Other Mexican laws involved in RE regulation are the "Ley Orgánica de la Administración Pública Federal" (Public federal administration law), the "Ley del Servicio Público de Energía Eléctrica" (Electricity public service law), and the "Ley de la Comisión Federal de Electricidad" (National electricity company law). This confirms the national commitment to incorporate RE technologies in the production of electricity, through social and environmental responsibility. The "Plan Nacional de Desarrollo" (National development plan), in the past 12 years, has considered sustainable development, including the promotion of the use of RE sources and technologies to face the challenges regarding diversification, energy security, and strengthen the development of science and technology [9].

In summary, Mexico has the natural power availability for energy generation from ocean RE and a robust regulatory framework to promote their development. However, an element that has delayed the installation of OE extraction devices is the uncertainty regarding the potential impacts of the energy plants on the environment and the cost of monitoring programs [10]. The studies available in the literature are still scarce and most of them evaluate only the impacts of prototypes with short operating periods, which has caused the construction permissions to be postponed or denied due to lack of information. This evidences that more efforts are needed to create legal and technological environmental frameworks. The present study shows an extended review of the literature related to possible environmental impacts of the implementation of plants to take advantage of the OE in Mexico. In particular, several coastal Mexican communities are not connected to the national electricity grid, which causes electricity to be of poor quality, extremely pollutant, unstable in availability, or even nonexistent. Two regions of the country where this problem is very clear are the Baja California peninsula (central part) and the Southeast Pacific (Guerrero, Oaxaca, and Chiapas). These three states present the greater social and economic development lag in the country [11]. The Ministry of Energy mentions that the state of Chiapas has more than 55,000 people without a connection to the electricity grid [12]. However, in this area of the country, wave energy is not considered sufficient for direct harvesting due to the low energetic waves found in the tropical region. For this reason, special emphasis has been given to tidal currents (TC) and thermal gradient (OTEC) sources around the southeast Pacific Ocean region of Mexico [13][14]. Moreover, these communities have the human right to adequate housing and improvement of their social welfare.

2. Case study: OTEC plant off the coast of Chiapas, Mexico

Despite the government's push in recent years to promote renewable energies, Mexico is advancing in small steps in the generation of renewable energies and more slowly in the extraction of OE. Progress is currently being made within the Mexican Center for Innovation in Ocean Energy (CEMIE-O), where in the last 3 years the work has focused on the definition of theoretical potentials for each type of energy that can be extracted [14], as well as, in detailed studies for those areas where a particular extraction seems possible. Examples of this are the use of ocean currents for the Cozumel channel [15]; studies of the thermal gradient for the eastern Pacific [16] or the waves in the northwest of the country [17].

However, along the Mexican coast, it is possible to find small populations unconnected to the national electricity grid, this usually coincides with them being in a vulnerable condition to ocean threats. In the case of the coast of Chiapas as shown in Figure 1, 78% of the population is in poverty, this is broken down into extreme poverty with 29% and 49% with moderate poverty [18][19]. According to Borthwick [20] the main characteristic for an OTEC plant is to have a thermal gradient of 20 °C between the surface water and cold water from 1000 m depth. As reported by Garduño et al. close to the coast of Chiapas the temperature difference is 21.45 °C; very close to the minimum usable gradient for OTEC.

Figure 1. Potential site in the coast of Mexico for harnessing ocean thermal energy (OTEC)**.**

The National Marine Renewable Energy Center of Hawaii estimated the potential on the Chiapas coast of 124.02 GW/h with a 100 MW OTEC plant and a sea surface temperature (SST) of 26.85 °C [20]. Yet, SAGARPA [21] reports an SST > 27 °C, measured from November 2017 to February 2018 obtained by satellite images of MODIS-AQUA of NOAA. The reported months are the coldest of the year, indicating the possibility of higher available power than the reported estimates of HINMREC. This corresponds with the results of autumn and winter thermal difference between 0 and 1000 m depth described by García et al., in both seasons the differences were 25.17 and 23 °C, respectively, they used NOAA, NODC, ODV, and the Mexican Navy (SEMAR) database to analyze historical mean gradient in Mexico between surface and 1000 m depth.

Hernández-Fontes et al. presented theoretical results of the availability of OTEC on the Mexican coast. In Chiapas, the authors estimated yearly percentages of >100, >150, and >200 MW of available power. Although electric power changes as a consequence of seasonal temperature variations, one of the best sites for the operation of the OTEC offshore plant is on the Chiapas coast . However, the water pumping area is far from the coast and offshore plant studies are scarce to determine the feasibility.

The search for new energy sources is focused not only on being renewable, but also on being compatible with sustainable development. The government of Chiapas is committed to the conservation of its natural resources, so its development plan prioritizes environmental sustainability. In addition to this commitment, there is an interest in improving the quality of life of its population, and thus decrease its high level of marginalization.

Potential Impacts of an OTEC Plant on the Chiapas Coast

From the analysis of the different studies cited in this article, the parameters that allow identifying changes in the physicochemical and biological structure of the water column were determined. These could lead to negative environmental impacts in the marine area, as well as in the coastal area during the three phases of the OTEC plant (construction, establishment, and operation), the impacts identified are summarized in Table 1.

Table 1. Methods to identify changes in the water column and the terrestrial part of the Chiapas coast.

Abiotic		Biotic	
Parameter	**Method**	**Parameter**	**Method**
Temperature	Multiparameter, NOAA data or use of MLD (mixed layer depth), CTD	Abundance of species	Diversity and species richness
Salinity	Multiparameter, MLD, refractometer, CTD	NOM-059-SEMARNAT-2010	Geographic Information System (GIS)
Dissolved oxygen	Multiparameter, Winkler's method, CTD	Mangrove monitoring	Centered quadrant method
Nutrient	NO^{2-} Bendschneider method, NO^{3-} Stickland and Parsons method, NH^{4+} Koroleff method, orthophosphates method described by Murphy and Riley and total phosphorus Menzel and Corwin 13C/15N isotope technique	Chelonium distribution	Distribution data, quantification of nests and nesting females, and collection of morphological data
Chlorophyll	Spectrophotometry, satellite images	Vegetation analysis	1. NDVI (Normalized Vegetation Index) 2. SAVI (Soil Adjusted Vegetation Index)
Turbidity	Secchi disk or turbidimeter	Benthic fauna	Ekman dredge, nucleator, dives sampling
Suspended organic matter	Titration procedure	Primary production	Light/dark bottles, 14 C and satellite images

Despite the lack of information on the effects of discharges in the surrounding areas of OTEC plants, there is knowledge of discharges of nutrients caused by other anthropogenic activities, for example, the NO_3^- ion from residual discharges affects the aquatic invertebrates due to increased concentration and exposure time [22][23]. With this information, it is possible to compare the effects of the discharge plume of the OTEC plant on the surrounding environment.

Modifications of these factors would have a direct effect on the marine community [24][25][26][27]. Additionally, the Chiapas coast is a zone of upwelling, this has a relationship with the natural presence of HAB by the contribution of nutrients [24][25]. Notwithstanding, OTEC plume discharges could increase the frequency of these blooms, however, there are no studies that confirm this relationship.

It is crucial to monitor the changes associated with the HAB on the Chiapas coast since the increase of this community directly affects the fisheries, which are one of the main forms of income for the population. In addition, it also represents an alert for public health, even at a national level, different institutions in the health, production, and research sectors implement control methods for seafood contaminated with toxins to prevent the risk of poisoning [24][26].

As an offshore OTEC plant requires electric power transmission via marine cables, this can cause disturbances in the surrounding environment, as well as an increase in the capital cost for its establishment. The short-term environmental effects associated with cables include physical disturbances of the habitat as a result of their installation, resuspension of sediments. Together with the long-term effects (operational phase); heat emission, species colonization, and emission of electromagnetic fields.

The prediction of impacts by offshore plants can be supported by information on the construction of oil platforms, this may help with minimizing risks and better estimating costs. Nevertheless, the presence of the plant could cause social disagreement because of the visual impact on the landscape. This has been addressed by Gibbson who mentions the decrease in property prices as a result of the presence of offshore wind farms.

Chiapas has mostly rural municipalities where more than 50% of the population lives in communities with less than 2500 inhabitants [27]. The high degree of social backwardness manifests itself in the coastal area, where irregular human settlements with less than 100 habitants predominate. Most of these groups are disconnected from the national electricity grid. Here, microgrids are an alternative energy supply for isolated communities, even the island mode would be appropriate [28]. This method of energy supply could strongly increase social welfare.

As a first step, an evaluation of consumption should be performed to identify the benefited communities [88]; in this case, the towns would be made up of El Fortín, Playa Cocos, and Las Conchas. These localities are located outside the polygon of the La Encrucijada biosphere reserve, therefore the installation of a microgrid does not pose a threat to the environment. The beneficiary population is of approximately 431 habitants. These localities are incorporated into the Program for the Development of Priority Zones, which seeks to provide basic housing services in localities with high levels of social backwardness in the country, however, information on consumption and electricity supply is incipient. Assuming that a 5–10 MW microgrid had the viable capacity to supply the aforementioned population, it is important to take into account that its control is decentralized and the maximum use of energy is limited [29].

With the supply of these three populations, it is possible to propose the extension for neighboring settlements, in such a way that it seeks to increase social welfare. In addition, this would allow areas for small-scale tourism; for example, Costa Azul Chocohuital previously presented problems due to the lack of infrastructure and services, minimizing the growth of the tourism sector. The expansion of energy supply would provide perks to both the tourism sector to increase hotel occupancy and basic housing services for the population. They are potential applications of the by-products of OTEC plants in the economic activities, for example, the use of deep water in aquaculture in this matter is necessary to select species adapted to low temperatures as salmonids their maturation is between 9 years at 13 °C and 13 years at 18 °C in the growth-fattening phases [30], also Masutani and Takahashi [31] mention the cultivation of oysters, lobster, abalone, kelp, and nori in aquaculture.

In the coast of Chiapas, 44.2% of the population carries out activities in the primary sector [32], mainly agriculture, livestock, and fishing. There are 606 artisanal fishermen distributed in four cooperatives, the main product is shrimp and scale [33]. For this reason, it is not possible to say with certainty that it is possible to integrate the by-products into the economic activities of the area, because fishermen are not familiar with the aquaculture of the aforementioned species. Furthermore, as a technology in development, studies on the use of these by-products are incipient, therefore, it cannot be affirmed that Mexican aquaculture would benefit from the supply of deep water.

Consequently, it is imperative to perform an analysis of the viability of using by-products from an OTEC plant, through the incorporation of courses, workshops, and capacitation to motive the involvement of the inhabitants.

The creation of jobs for the population close to the area where the energy plant will be displayed is one of the criteria to promote its placement. However, the characteristics of this job offer needs to include training given that the education level of the population aged 15 and over is of incomplete basic education (55.76%), and 13.47% are illiterate. In the stages of construction and establishment of an OTEC plant, it is possible to recruit workers from the population, however, in the operation phase, equipment and workers with specific knowledge of plant management and maintenance are necessary.

The direct impact on society is exclusively the supply of energy, and there would be no creation of any type of employment or the use of any added material. The direct impacts, related to visual obstruction, could be observed if they occur near towns with a high influx of tourism. Nonetheless, tourism is low compared to other areas of Oaxaca and the biggest limitation would be the rejection by the intrusion of external companies due to unacceptable practices of its predecessors.

Figure 2 shows a summary of the main aspects to be monitored before, during, and after the deployment of an OTEC plant in order to identify and assess the environmental and socioeconomic impacts it would produce off the Chiapas coast.

Figure 2. Aspects to be monitored for environmental and social impact assessment of ocean energies, OTEC Plant case.

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