Chapter

Environmental Impact Assessment of the Operation of an Open Cycle OTEC 1MWe Power Plant in the Cozumel Island, Mexico

Enrique Celestino Carrera Chan,
María Fernanda Sabido Tun, Juan Francisco Bárcenas Graniel and Estela Cerezo Acevedo

Abstract

An environmental impact assessment (EIA) was made for the operation of a 1MWe open-cycle OTEC plant on Cozumel Island, Quintana Roo. Due to its bathymetric characteristics and its proximity to the population center, the ideal location for the placement of the OTEC plant is in the western coastal area of the island. An environmental inventory was developed in which the susceptible factors to be impacted were described (air, soil, water, landscape, geology and flora). The essential components of the OC-OTEC PLANT operation process were studied: vacuum pump, flash evaporator, turbine, condenser and pipes. An impact matrix (Leopold matrix) was created, which prompts to impacts on the environment list, generated by the OC-OTEC PLANT operation: CO2 emissions; nutrients dragged to the surface; artificial reef effect/contamination by heavy metal salts; drag and compression of organisms; redistribution of oceanic water bodies; impacts by organic antifouling chemicals; noise; illumination; turtle nesting alteration; brine discharges; cause significant public controversy; alteration and interruption of migration routes; and waste, among others. Once the most significant impacts were assessed through the Leopold matrix, corrective and preventive measures were established on those actions, in order to minimize their negative impact on the environment.

Keywords: environmental impact assessment, open-cycle OTEC, Leopold matrix, Cozumel

1. Introduction

Energy is a conserved physical quantity, and the first law of thermodynamics states that energy can be transformed from one form to another but can be neither created nor destroyed. It is under this precept that we can argue that in nature there are endless ways to obtain energy by transforming it from a primary source.

A common source of sustainable energy is the ocean, which has six categories of energy generation: waves, tides, tidal currents, ocean currents, ocean thermal conversion and salinity gradient [1]. Taking into account the large proportion of water that exists on the planet, oceans can be considered as a large energy storage system.

Ocean Thermal Energy Conversion (OTEC) uses the difference in temperature (thermal gradient) between the surface of the sea (the hot spot) and the waters of the deep sea. Mexico has a high thermal energy gradient; therefore, it is in a favorable location for ocean energy use, through the implementation of OTEC plants [2].

Currently, studies exist and research has been conducted on the useful energy of OTEC plants, both for open cycle (OC) and closed cycle (CC). These lack a deep development in the estimates of environmental impact of construction, running and/or decommissioning of projects of this magnitude. Therefore, it has not been possible to determine, predict or interpret the impacts that could result as an effect from the anthropogenic activities related to the operation of an OTEC plant.

This project aimed to demonstrate that the operation of an open-cycle 1MWe OTEC plant generates relevant environmental impacts (positives or negatives) on environmental factors such as air, soil, geology, water, landscape, flora, population and fauna, corresponding to a polygon of the coastal zone western of Cozumel Island.

This project is part of an agreement between Universidad del Caribe and Centro Mexicano de Innovación en Energía del Océano (CEMIE-Océano) belonging to the research line called "Detección de lugares de aprovechamiento de gradientes de temperatura con potencial energético de explotación en México para determinar la factibilidad de construcción de una planta tipo OTEC (GLE-1)" (Detection of places of use of temperature gradients with energy potential of exploitation in Mexico to determine the feasibility of building an OTEC type plant (GLE-1)).

2. Methodology

The methodology used for the environmental impact assessment (EIA) of the operation of the OC-OTEC plant project is an adaptation of the one proposed by the author Gómez Orea (1998) [3], which has 4 phases in which the environmental impacts resulting from the interaction of activities that are developed theoretically during the extraction of the operating water resource of an OC-OTEC PLANT are identified, characterized, assessed and interpreted, as well as the rejection of water that comes from the plant and that goes toward ocean mass and other secondary activities that are broken down during maintenance and operation. This will be evaluated in a polygon of 1096 m^2 located in the western coastal area of Cozumel Island, Quintana Roo, the four phases of this methodology are mentioned below.

2.1 Phase 1: description of the project

During this phase, the bases covered by the scope of the general vision of the project were raised and fleshed out. A zone was defined where the OC-OTEC plant would be theoretically located. Chosen based on a series of parameters that would suit the operation of the plant, two alternative sites for the project were registered that due to state environmental legislation had to be discarded, as well as an ethnographic study that aided in the knowledge of public acceptance, which allowed us to measure the reception the project would have based on the perception of the inhabitants of Cozumel Island. The points described above, as well as others, are recorded in **Table 1**.

2.2 Phase 2: description of the project environment and environmental inventory

The description of the project's surroundings allows the categorization of the area that will be affected directly and indirectly by the activities of the OC-OTEC

No	Parameters to be described
1	Name of the project
2	Head of the project/responsible person or agency
3	Location
4	Production process and manufactured products
5	Other possible locations
7	Activities that might have impact
8	Jobs created in the operation phase
9	Public acceptance

Table 1.
Parameters for phase 1.

plant in such a way that each environmental factor was delimited by a series of geographic borders in order to narrow the research space. In this way, polygons were drawn according to the different areas of involvement.

Similarly, an environmental inventory was prepared so that those factors that could be transformed during the operation phase of the open-cycle OTEC plant will be described. For this, an analysis of the natural environment will be made and the possible effects will be contrasted once the OTEC plant enters into operation; in this way, the magnitude of the impact will be known.

Table 2 lists factors that will be described during the environmental inventory.

Medium	Environmental factor	Parameters for inventory
Inert	Air	Winds
		Hurricanes
		Weather
		Acoustic contamination
	Soil	Type of soil
		Potential land use
	Geology	Geology
	Water	Ocean water
		Surface water
		Ground water
		Geohydrology
Perceptual	Landscape	Visual
	Flora	Flora
	Population	Demographics
		Economic activities
	Fauna	Sea fauna
		Birds

Table 2.
Factors considered for the environmental inventory.

2.3 Phase 3: identification and assessment of impacts

During this phase, an environmental impact assessment tool was used, which helped us to quantify the environmental impacts from the convergence between the actions presented during the operation stage of an OC-OTEC plant (mentioned in phase 1) with the environmental factors that were identified in phase 2. This tool is called Leopold matrix and belongs to a group called *cause-effect matrices.*

2.4 Phase 4: proposal of corrective and preventive measures

Of the actions identified as having the highest impact (described in phase 3), corrective and preventive measures will be proposed that minimize their negative impact.

3. Results

3.1 Phase 1: description of the project

The project was titled "Environmental Impact Assessment of the operation of a 1MWe open-cycle ocean thermal energy utilization (OTEC) plant in Cozumel, Quintana Roo, Mexico." CEMIE-O (Spanish acronym for Centro Mexicano de Innovación en Energía del Océano), the promoter of this project, is a multidisciplinary entity that includes a large number of researchers, companies and government institution. CEMIE-O focuses on the generation of knowledge and its application in different research lines, in order to raise and offer information about various forms of use of energy from the ocean.

As a reference area for the project, a polygon of 1096 m^2 corresponding to that of a 1MWe OTEC plant located in India [4] was established, which required to be a vegetation-free space that could be leveled and compacted according to the standards and construction specifications. This site was located in the western coastal area of Cozumel Island, located at km 3, South Coast, South Hotel Zone, of San Miguel de Cozumel, belonging to the municipality of Cozumel, Quintana Roo, Mexico.

In order to select the ideal physical positioning site of the OC-OTEC PLANT, a series of criteria were taken into account, which will be detailed below:

3.1.1 Thermal gradient

An ideal area within the Mexican Caribbean region to place an OTEC plant is Cozumel Island, Quintana Roo, as it has sufficient energy resources to take advantage of them [5].

The frame of reference that was used to know the temperatures that exist in the oceanic region of the western area of Cozumel Island was the historical database of the Naval Oceanographic Office (NAVO), who make use of temperature profiled buoys and salinity known as ARGO, which reach depths close to 2000 m [6].

The ARGO buoy with close geographical match to the area of study has the key number 4901644, with a starting trajectory that goes from the Caribbean Sea in an area near Honduras and Jamaica and reaches the coasts of Isla Mujeres, passing through the western section of Cozumel Island.

The measurement points closest to the study area are # 46 and # 47, and these measurements were made on October 21 and 25, 2014 (currently the buoy is inactive, so reference data were taken on the mentioned dates).

According to recorded temperature profiles, the surface temperatures of the measuring points 46 and 47 reach as high as 29°C, while those found at a depth of 400 m at both points oscillate around 10.5°C.

The theoretical energy conversion efficiency of an OTEC plant is 8% [7]; however, due to the entropy generated at various parts of the cycle, an efficiency of 3–4% is obtained. Taking into account that it is a relatively low percentage compared to conventional power plants, it should be noted that the energy obtainable from an OTEC plant comes from a renewable resource.

The energy conversion of the proposed OC-OTEC plant that will be found in the western coastal area of Cozumel Island will be around 6.12%, as can be confirmed with the Carnot efficiency formula (η) (Eq. 1):

$$\begin{aligned}&\text{Carnot efficiency: } \eta = \frac{T_1 - T_2}{T_1}\\&\eta = \frac{(302.15\ \text{K}) - (283.65\ \text{K})}{(302.15\ \text{K})}\\&\eta = 0.0612\\&\text{In percentage: } \eta = 0.0612{*}100 = 6.12\%\end{aligned} \tag{1}$$

where T_1 = surface temperature = 29°C = 302.15 K; T_2 = temperature at depth = 10.5°C = 283.65 K.

3.1.2 Bathymetry

The bathymetric profile corresponding to the ocean surface close to the western coast of Cozumel Island is 400 m, which is based on the vector data set in the International Bathymetric Chart of the Caribbean Sea and Gulf of Mexico, sheets 1-7 [8]. In the mentioned bathymetric line, a thermal gradient that falls within the energy efficiency range of the OC-OTEC plant can be obtained.

The distance that exists from the western coast, where the OC-OTEC plant would be located to the bathymetric line of interest, is 3.83 km; therefore, it meets the guidelines for the operation of a thermal gradient plant, which require a distance of less than 10 km.

3.1.3 Protected natural area (PNA)

The protected areas on Cozumel Island are composed of the three fundamental ecosystems that are predominant on the island environment: 1) the jungle ecosystem, 2) the coastal mangrove-dune and 3) the marine-reef zone. The area that was selected for the positioning of the OC-OTEC plant is outside the Flora and Fauna Protection Area called "La porción norte y la franja costera oriental, terrestres y marinas de la Isla de Cozumel" (The northern portion and the eastern coastal strip, terrestrial and marine of the Cozumel Island), as well as the protected natural area "Arrecifes de Cozumel" (Cozumel Reefs) [9].

3.1.4 Closeness to the population center

The polygon where the OC-OTEC PLANT will be located is 27.77 m away from the main avenue named *Rafael E. Melgar*. This avenue is the direct communication route that links to the population center.

The distance between the proposed surface of the OC-OTEC plant and the population center of San Miguel de Cozumel, Quintana Roo, is 2.92 km, and this satisfies the guidelines [10, 11] that state that the maximum distance at which an OTEC plant should be located in relation to the population center must be less than 10 km, because exceeding this distance would incur a significant loss of electrical energy in the course of transmission to the population center.

3.1.5 Urban infrastructure

3.1.5.1 Electrical energy

The supply of energy from Cozumel is provided by a subaquatic aqueduct from a substation in Playa del Carmen, which provides two radial circuits of 34.5 kV. In turn, this energy comes from the thermo-electric plant in Valladolid, Yucatan [12].

The supply comes from the continental side of Cozumel Island, which has two plants: one belonging to the substation of "Comisión Federal de Electricidad" (CFE, acronym in Spanish for Federal Electricity Commission) and the other has a private owner.

The private plant is owned by "Energía y Agua Pura de Cozumel S. de R.L. de C.V. Chankanaab," which uses a mixture of diesel and fuel oil for the generation of energy, while the substation of the CFE called "C.T.G. Chankanaab" has generators using diesel and operates during exceptional circumstances [13].

The annual electricity consumption in the municipality of Cozumel was 238.51 gigawatt-hours in 2012, which corresponds to 2.32% of consumption with respect to the peninsular zone and 0.086% with respect to the whole country. The expense for this same concept in 2012 was $ 396,722,000 [14].

Due to Cozumel Island's touristic importance, it is required to guarantee the supply of electricity [15]. By 2024, the current transmission infrastructure to the island, even with the installation of the capacitor banks proposed by 2021, will not be sufficient to cover the maximum demand, so it becomes an area of opportunity for the implementation of renewable technologies, as per example the use of energy from the ocean.

The inhabited private homes on the island of Cozumel that may have access to power correspond to 99.64% [16].

3.1.5.2 Water availability

"ACUERDO por el que se dan a conocer los estudios técnicos de aguas nacionales subterráneas del acuífero isla de Cozumel, clave 2305, Estado de Quintana Roo" (AGREEMENT by which the technical studies of national underground waters of Cozumel Island aquifer are disclosed, code 2305, State of Quintana Roo), published in 2013, mentions that the only source of supply for Cozumel Island is groundwater. The aquifer has an average annual availability of 35.341442 million cubic meters and the total annual extraction volume amounted to 8.2 million cubic meters per year on that year, of which 62.5% is destined for urban public use (wells destined for this use are found in the central part of the island), 24.1% for services, 13.3% for industrial use, and 0.1% for agricultural, domestic and watering uses.

Nearly 95.43% of the population of Cozumel Island has access to water inside their home, while the remaining 4.57% obtains it outside the home but within the land. Corresponding to water obtained by hauling, 79.45% corresponds to the wells that support obtaining water for urban public use [17].

3.1.5.3 Telephone/mail

Cozumel Island has local and long-distance services, national and international, both by operator and automatic, provided by Teléfonos de México S.A. de C.V. (TELMEX). The company has placed several booths in the downtown area, as well as the concession for the time/cost service in order to meet the extra demand in holiday seasons.

There are services that combine conventional services with shipments and collections of money orders, fax, and parcels; there is also a cable-television system station, Internet communication systems, cell phone and state-run print media.

3.1.5.4 Means of transport

Terrestrial: transport inside the city is designed based on tourist activity and is based primarily on the taxi service. The city also has a reduced bus service for the use of local population.

Marine: given its geographical condition, Cozumel Island has developed various port services that allow the berthing of tall and cabotage vessels, as well as the traffic and movement of various types of cargo. Two concessionary companies operate the regular Cozumel-Playa del Carmen passenger service and vice versa, with daily round trips that dock at the Island's Fiscal Dock, located in the center of the town, guaranteeing their service by an adequate passenger transport fleet. These same companies give the service of offers to tourist cruises that do not have the possibility of docking at the two positions of the current tourist dock. The companies are Cruceros Marítimos del Caribe, S.A. from C.V. and overseas.

The criteria explained determine that the location of the mentioned site met the ideal characteristics that would allow an optimal performance of the OC-OTEC PLANT project. On the other hand, two alternative positioning sites were analyzed, which were discarded since they did not meet these characteristics. The alternate sites (yellow) and the final location (red) can be compared in **Figure 1**.

The productive process of the operation of the OC-OTEC PLANT project in main components (vacuum pump, flash evaporator, turbine and condenser) and pipes [10] was examined for the identification of the processes performed by the subsystems headed by the main components, each one being of high importance

Figure 1.
OC-OTEC plant located in the occidental side on the Cozumel island. Source: Google Earth.

because within these the transformation or transportation processes may become environmental impacts. Production process is summarized and schematized as a flow chart in **Figure 2**.

3.2 Phase 2: description of the project environment and environmental inventory

3.2.1 Air

3.2.1.1 Winds

The Caribbean region, in general, has the influence of trade winds, which blow from the East to the Southeast, with an oscillating force between 15 and 20 knots during most of the year. During the first hours of the day and during the night, there is a land breeze due to a reduction in the speed of the trade winds. During the day, the sea breeze causes an acceleration in speed. Winds from the west sometimes occur, after the passage of a cold front or when a tropical cyclonic alteration approaches [18].

3.2.1.2 Hurricanes

A total of six hurricanes of different categories have had a place of entry to land, as well as influence on Cozumel Island, with the highest impact being Emily and Wilma in 2005, with maximum winds of 269 and 324 km/h, respectively, followed by Rina in 2011, with 174 km/h [19].

3.2.1.3 Atmospheric contamination

Municipal data in this area, as part of Plan de Acción Climática Municipal (PACMUN, Spanish acronym to Municipal Climate Action Plan), show that greenhouse gas emissions gained importance and were shown as tons of CO_2 equivalent. Cozumel takes records of a total of 176, 463 tons of CO_2 Eq. [20].

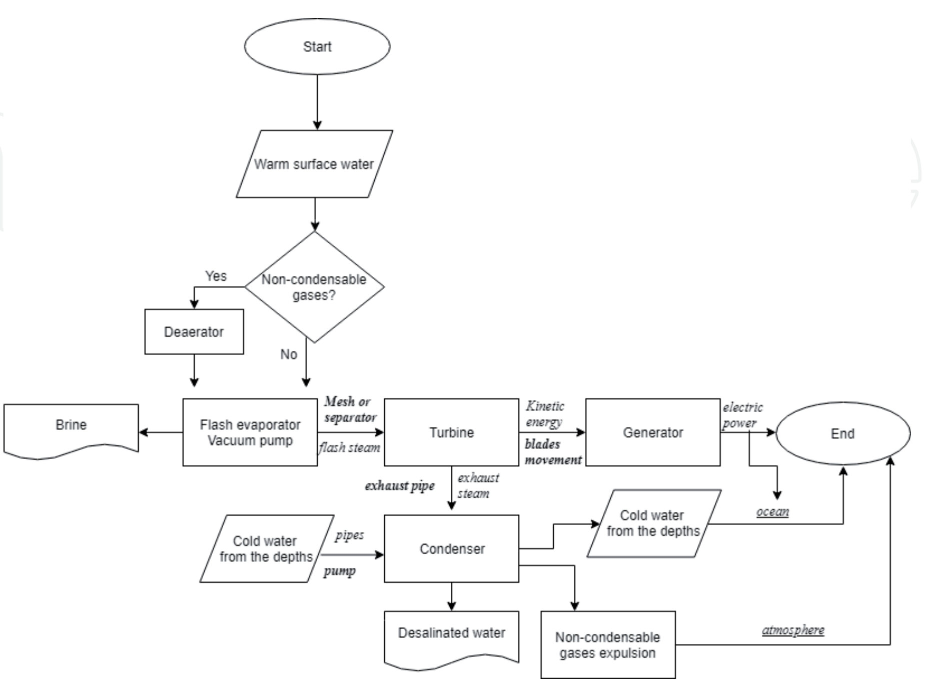

Figure 2.
Open-cycle OTEC plant process flow chart.

Of those productive sectors that contributed a relevant percentage to these emissions, the energy sector was the main contributor, followed by waste and finally agriculture.

3.2.2 Weather

The weather of Cozumel Island is warm-subhumid (Aw) with rains in summer and over 40 mm in the driest month [21]. It also has two rainfall maximums separated by two "dry" seasons, one long in the cold half of the year and one short during the rainy season [21]. The precipitation fluctuates between 27 and 45.3 mm, and the average temperature of the coldest year is 6.3° C.

The average annual ambient temperature of Cozumel island in 2016 is 29.6° C, with the month of July (during the summer season) being the hottest that year. In summer, the Caribbean Sea and the eastern Atlantic off the coast of East Africa suffer from overheating causing surface air masses to form and a decrease in atmospheric pressure, thus causing hurricane formation [22].

3.2.3 Noise pollution

Water noise measurements from a 1 MWe anchored (off-shore) OTEC-CC facility near Keahole, Hawaii, determined that seawater pumps are the maximum noise source of the OC-OTEC PLANT project, as they present a broadband spectrum that does not exceed the expected levels by more than 10 dB [23].

The corresponding Mexican official standard, "NOM-081-SEMARNAT-1994, Norma Oficial Mexicana que Establece los Límites Máximos Permisibles de Emisión de Ruido de las Fuentes Fijas y su Método de Medición", states: "*The maximum permissible noise emission level in fixed sources it is 68 dB (A) from six to twenty-two hours, and 65 dB (A) from twenty-two to six hours …*" [24]. The operation of an OC-OTEC plant is diurnal and the value corresponding to the maximum permissible levels is not exceeded, since only 10 of 68 dB is allowed are emitted.

3.2.4 Soil

3.2.4.1 Soil type

Throughout the entire insular surface, four main groups of soils with different extensions (rendzinas, solonchak gleyico, regosol calcarico and gleysol malico) are broken down [25].

The theoretical polygon proposed for the positioning of the OC-OTEC PLANT project is on the type of rendzina soil (lithosols or leptosols as they are usually known in different classifications) that are genetically young soils and have a single horizon A thin in some. It is prostrated on a small horizon B or, if necessary, on the unchanged parental material. Leptosols have a color ranging from brown to dark red and their texture is usually clayey, and they have a basic pH (close to 8), well drained, with high water retention and lamellar stones [26].

3.2.4.2 Potential land use

This project is located on Cozumel Island, which is an Área Sujeta a Ordenamiento Ecológico (ASO, acronym in Spanish for Area Subject to Ecological Management) as stipulated by Programa de Ordenamiento Ecológico

Marino y Regional del Golfo de México y Mar Caribe (POEMRGMyMC, acronym in Spanish to Marine and Regional Ecological Management Program of the Gulf of Mexico and the Caribbean Sea), and is also located in the Unidad de Gestión Ambiental (UGA, acronym in Spanish for Environmental Management Unit) # 141, regards to the Programa de Ordenamiento Ecológico Local (POEL, acronym in Spanish for Local Ecological Management Program). This ASO prohibits the drilling of new domestic wells for water extraction from the aquifer, the disposal of wastewater in bodies of water, open-air dumps for the disposal of solid waste, burning of solid waste, the installation of any kind of fences that obstruct the movement of native wildlife, the introduction of species and the extraction of sand from beaches.

3.2.5 Geology

The Yucatan Peninsula is composed of marine compounds of calcareous composition belonging to the Tertiary and Recent period [27]. As for antiquity, the geological framework is formed by cretaceous limestone and dolomitized, solidified and recrystallized limestones belonging to the Paleocene, with clear coloration that emerge in the southern portion in the State of Yucatan and have a thickness up to several hundred meters.

3.2.6 Water

3.2.6.1 Marine waters

Cozumel Island is located in the Atlantic Ocean, in its northern part, and also in the Caribbean Sea. The semi-enclosed seas around the North Atlantic coasts have different oceanographic and bathymetric regimes, as well as ecosystems with many characteristics determined by local processes and pressures.

About waves, it is known that most of the year the winds from the East and Southeast are the dominant ones in the area, except in winter, when the direction of these changes to the North-Northwest. This causes windward coast to be the most deployed to the wave energy, causing the development of breaker sites, with steep step shape and tiny cliffs. The leeward coast is protected most of the year and is only damaged during the "nortes" season (north winds) [28].

3.2.6.2 Surface waters

Only a small fraction of the water that passes through the hydrological cycle resides in fresh surface water bodies, such as creeks and lakes [29]. Due to limestone karst erosion in the Cozumel island, there is an absence of surface water channels and an underground body of fresh water, which lies on the salty marine waters with greater density and gets maximum thickness in the central-eastern part of the island [30].

3.2.6.3 Groundwater

Comisión Nacional del Agua (National Water Commission) has divided México into 13 Regiones Hidrológicas-Administrativas (RHA, acronym in Spanish for Hydrological-Administrative Regions). Cozumel Island belongs to two RHA regions, RHA XII Yucatan Peninsula and Hydrological Region number 32 Northern Yucatan.

Wells for urban public use (which are the only source of supply for Cozumel Island) are located in the central part of the island, where the thickness of fresh water is greater. Tap water demand has increased due to the island's demographic growth as well as the growing tourism influx. Of the 486 groundwater catchments, 264 are allocated to urban public use, 59 are used in services, 21 are for industrial use, 130 for agricultural use, 2 for domestic use and 9 for the watering hole [31].

3.2.6.4 Geohydrology

The Yucatan Peninsula is mainly composed of limestones and dolomites of high permeability. That is why the high rainfall, the great infiltration capacity and the reduced topographic slope favor the renewal of the underground water of the peninsula [32].

3.2.7 Flora

The predominant flora in the polygon is the medium subdeciduous forest, which is mainly composed of two tree layers that vary between 8 and 20 m high. There is also a small shrub-herbaceous layer consisting of young specimens of the dominant species of the tree layers. The soil is poor in organic matter, as well as underdeveloped; however, there are regions of the island, especially the center, where the vegetation becomes more complex, attributed, surely, by greater land grabbing, showing a well-defined layer physiognomically and floristically, which has few climbers and epiphytes. Approximately half of the species are deciduous [28].

3.2.8 Population

3.2.8.1 Demography

According to the 2015 census, 86,415 inhabitants were reported on Cozumel Island, Quintana Roo [17]. Of the total population, men correspond to 49.27%, while women correspond to 50.73%.

Regarding the population's geographical distribution, 98.5% is concentrated in San Miguel de Cozumel. The localities that occupy a second place in number of inhabitants are El Cedral, San Lorenzo and Huerto Familiar, with around 50 people. There are fifteen locations whose population varies between 7 and 43 inhabitants. Around 500 people live dispersed in 121 locations.

3.2.8.2 Economic activities

Agricultural: Grains, seeds and vegetables are grown in the municipality regions. Most of the products obtained are destined for self-consumption since it is an area defined as temporary and is associated with low yields. The areas destined for agricultural activities are located along Carretera Transversal de Cozumel (Cozumel Transversal Highway) and in El Cedral population center. Some of the harvested vegetables in the region are corn, pumpkins, beans and chili.

Livestock farming: Livestock farming in the area has had a decrease in recent years as well as its dynamics and number of species. The areas destined for these activities are in adjacent areas to the agricultural ones along Carretera Transversal de Cozumel, El Cedral and in some pastures in San Gervancio area.

Fishing: Cozumel Island is the third municipality with the largest fishermen number in the region. Main products include lobsters, snails, and low incidence of shellfish. Fishermen are usually grouped in cooperatives, while in a small proportion, they are usually arranged in distributors.

Tourism: This is Cozumel Island's main economic activity. Land uses suitable for tourism are located in the north and south of the island west coast, as well as in the coastal urban area part.

3.3 Phase 3: identification and assessment of impacts

The environmental impact assessment (EIA) is an environmental policy instrument whose main purpose is designing strategies for the regulation of activities that impact (positive or negatively) on terrestrial and marine environmental systems. These strategies become functional when it is possible to prevent or regulate the changes that the environmental systems' structure, composition and function may suffer due to natural or anthropic causes.

The Leopold matrix methodology was used, which is a tool that allows for visualizing the OC-OTEC plant operation impacts in a practical way. In **Figures 3** and **4**, the Leopold matrix is presented; activities that might have impact (characterized in phase one) are arranged in columns, additionally the environmental inventory, which is represented in rows (characterized in phase two). In some cases, there will be a convergence between rows and columns, which will lead to an evaluation; for this case, three items will be evaluated:

1. The sort of effect, represented with a positive or negative sign (+/-), which indicates if the impact will have benefits (positive) or damages (negative).

2. The impact magnitude, indicated in the upper left, is the spread of the impact or scale impact. The magnitude is scored from 1 to 10 (1 if the alteration is minimal and 10 if it is maximum).

3. The intensity degree or incidence degree, which means how important is the impacting action on a factor from the environmental inventory, is placed in the lower right and is scored from 1 to 10.

			ACTIVITIES THAT MIGHT HAVE IMPACT																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ENVIRONMENTAL INVENTORY	AIR	Wind																				
		Hurricane																				
		Atmospheric contamination			+7/1			-3/2														
		Weather						-2/1														
	SOIL	Type of soil											-1/3								-2/1	-1/1
		Potential land use																				
	GEOLOGY																					
	WATER	Ocean water		-3/1		-3/1	-3/1	-6/2	-8/9	-6/3		-9/8	-3/4				-10/9					
		Surface water																				
		Ground water		+5/3																		
		Geohydrology																				

Figure 3.
Leopold matrix made for the OC-OTEC PLANT project (part 1).

ENVIRONMENTAL INVENTORY		ACTIVITIES THAT MIGHT HAVE IMPACT																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
LANDSCAPE		-3/3																			
FLORA		-4/2					-2/2						+3/1								
POPU	Demographics	+1/8	+2/8	+6/8	+4/1	+1/1							-1/1	-3/2				-5/5			
POPU	Economic activities	+1/6	+1/6	+1/6	+1/4	+1/4							-1/1								
FAUNA	Sea Fauna							-8/7	-7/7	-4/1	-3/2	-7/7			-2/1	-7/7					
FAUNA	Birds	-2/1																	-2/2		

1	Energy source
2	Freshwater production
3	Production of cooling systems
4	Mineral production
5	Lithium production
6	CO_2 emissions
7	Dragging nutrients to the Surface influences
8	Artificial reef effect / contamination by heavy metal and salts influences
9	Organism drag and compression influences
10	Redistribution of ocean water bodies influences
11	Impact by organic antifouling chemicals influences
12	Noise
13	Lighting
14	Turtle nesting alteration
15	Brine discharge
16	Cause sociocultural impacts
17	Significant public controversy
18	Migration routes interruption
19	Waste
20	Sanitary discharges from the station

Figure 4.
Leopold matrix made for the OC-OTEC PLANT project (part 2) and activities that might have impact explained.

A lack of convergence between the rows and the columns will imply that there is no continuous affectation.

As a result of the Leopold matrix made, we have a total of 43 recognized impacts, explained below:

1. Activity # 1 Energy source interacts with the environmental inventory, causing the following impacts:

   a. The first impact is negative and corresponds to the landscape transformation due to the electric energy transportation (recorded with magnitude 3) toward the population center, which would be through a power line and electricity posts, modifying the landscape in about 2.92 km (distance between the plant and the urban center of Cozumel Island). Intensity degree is 3 because the landscape modification will occur during the construction process. Therefore, reflected intensity during the operation will be relatively low.

   b. During the OC-OTEC plant operation, maintenance of the exteriors is contemplated, so the natural flora will be negatively affected with a 4 magnitude and a 2 intensity degrees due to the modification to the plant species so it is planned not to greatly affect protected species.

   c. The demography will have a positive impact since the inhabitants' projection who can have access to electric energy coming from the OC-OTEC PLANT project in a calendar year amounts to 1772 who corresponds to 2% of the total population (magnitude 1). Although the magnitude is relatively low, it is considered an 8 intensity degrees since the impact it generates on the population's perspective will increase as the character of natural resources use becomes known.

   d. The economic activities will have a positive impact contemplating that the generation of jobs by the production of electric energy through the

OC-OTEC PLANT project is reduced because the workforce is five employees (magnitude 1). The intensity degree is six since the jobs will be filled by personnel in charge of the plant, which will become areas of opportunity for professionals that cover the work profile.

e. Migratory birds whose routes contemplate the polygon will have an impact with magnitude 2 since some species could collide with infrastructure. The intensity degree is 1 because the OC-OTEC PLANT project does not interfere within the migratory routes of the birds that were studied, so it becomes an area of opportunity for future studies.

2. Activity #2 Freshwater production influences the following environmental factors:

    a. In the marine waters, it has an influence of a magnitude 3 because marine water extraction is carried out in the surface and in the depth, which a through time could become a significant impact. Intensity degree is 1; compared to the existing water bodies and ocean distribution, the extraction of seawater that is carried out for the OC-OTEC PLANT operation is not significant being as there is a return of the same.

    b. According to our calculations, an OC-OTEC PLANT generates 1,485,586,365 l of desalinated water per day; therefore, the extraction of fresh water through wells would be reduced, generating a positive impact with magnitude 5 and 3 intensity degrees because the demand for the use of wells on Cozumel Island would be reduced, but not 100%, since the OC-OTEC PLANT could only supply fresh water to 3.24% of the inhabitants per year. On the other hand, not all residents of the island would adapt to the use of new technologies; in addition, there is no exact count of clandestine wells on the island.

    c. The demography will have a positive impact with magnitude 2 since an OC-OTEC PLANT could only satisfy a total of 10,194 people with fresh water, which in comparison to the total population of the island that is 86,415 inhabitants represents only 11.79%. Intensity degree is 8 since it implements the use of innovative alternatives for the production of fresh water, which can serve as an example for the development of projects.

    d. Economic activities have a positive impact with magnitude 1 by implementing the use of innovative alternatives for freshwater production, which can serve as an example for project development. Intensity degree is 6 since the job profiles that are sought to work in an OC-OTEC PLANT are with high academic degrees (master's, doctorate, and specialties).

3. Activity #3 Production of cooling systems influences:

    a. In relation to atmospheric contamination, magnitude 7 is positive since Chlorofluorocarbons (CFCs) that come from conventional cooling systems (air conditioners) are part of the Greenhouse Gases that cause global warming. The production and installation of "natural" cooling systems from the OC-OTEC PLANT would reduce the effect caused by hotel rooms that have such conventional systems on Cozumel Island. Although the production of the cooling system would reduce the amount of CFCs when replacing conventional systems, emissions to the atmosphere that are simply based on water (1 intensity degree) are still being produced.

b. The demography would have a positive impact with magnitude 6 by being able to satisfy a large number of people on the island from cooling systems as around 337.5 tons per year would be generated. The refrigeration system would supply the population, replacing several conventional systems by means of a production coming from an alternative energy (8 intensity degrees).

c. The economic activity would have a positive impact because installation of the cooling system to homes or hotels would generate jobs at the same time as it would be an ecotourism environmental option for those who acquire it (magnitude 1). It is considered that the generation of jobs and capital, by providing an ecotourism environmental option, would come from an alternative energy that would supply lodging centers on the island (6 intensity degrees).

4. Activity #4 Mineral production influences:

a. Marine waters will have an impact of a negative nature with a magnitude 3 because the extraction of minerals from marine waters could cause an imbalance to marine environmental systems in the future, so it becomes an area of opportunity for future studies. Intensity is considered insignificant when obtaining degree 1 because there is a circulation of oceanic waters in the area so the damage will be minimal; even with this, the study in the future should not be ruled out.

b. The demography will have a positive impact with magnitude 4. The water that is extracted from the depths is rich in minerals essential for the human body so that nearly 15,000 bottles that would be generated would benefit the population of Cozumel Island. Being a product that is not marketed in the area, it could have a low yield (1 intensity degree).

c. The economic activity will have a positive impact with magnitude 1 because the staff of collaborators in an OC-OTEC PLANT is very small, so it would only benefit a few people, and the job profiles that are sought to work in an OC-OTEC PLANT are with high academic degrees (4 intensity degrees).

5. Activity # 5 Lithium production influences:

a. In marine waters, it will have a negative impact with magnitude 3 since the extraction of lithium chloride from marine waters could cause an imbalance to marine environmental systems in the future, so it becomes an area of opportunity for future studies. While the intensity degree is 1 and considered insignificant, because there is a circulation of ocean waters in the area that causes the damage to be minimal, even taking this into consideration should not rule out studies in the future.

6. Activity #6 CO2 emission influences:

a. Atmospheric contamination, since emissions from the OC-OTEC PLANT contribute to the increase of this factor; however, when compared with those resulting from a thermoelectric plant, they are lower, resulting in magnitude 3 and a negative nature. Dispersion can lower this, ensuing to 2 degrees of intensity.

b. Climate, as CO2 emissions are recorded in the Kyoto Protocol as 1 of the 6 greenhouse gases (GHG) that enliven climate change and could compensate for the occurrence of typical meteorological phenomena in the area, is a negative impact but with a magnitude of 2. Being minimal quantities, which are dispersed, they contribute to an increase of climate change, leading to 1 degree of intensity.

c. Marine waters, because the emissions come both from the extraction of these and from the operation of the OC-OTEC PLANT, which manage to spread on the sea surface (negative impact and magnitude 3). On the other hand, when CO2 is found in the ocean in a natural way, the minimum emissions of said compound, when diffused in the ocean and the marine surface, would not significantly unbalance the marine environment (2 intensity degrees).

d. Flora, with a magnitude of 2 and negative impact, since only the one closest to the plant would be affected, since being a short distance away, they would be the main captors of the emissions. It receives 2 intensity degrees since despite being minimal emissions to the vegetation closest to the plant, it is considered that environmental stress may occur, as a result of an increase in the amounts of CO2 normally collected.

7. Activity #7 Dragging nutrients to the surface influences:

a. Marine waters: Although the deepwater extraction zone for the OC-OTEC PLANT is not large, there would be a constant alteration of nutrients to the same ecosystem by the movement of nutrients, which could be dispersed in the surrounding areas thanks to the currents, resulting in a negative impact with magnitude 8. The characteristics of the deepwater zone, from which the necessary water flows will be extracted, are different from the shallowest areas where they would be reinjected, producing a harmful effect by altering the amounts of normal nutrients in both areas for the functioning of the ecosystem (eutrophication), so its intensity degree is 9.

b. The marine fauna will have a negative impact since some marine species live in specific conditions of the area where they are found, and introducing different amounts of nutrients (or increasing them) can cause alterations to these organisms and, therefore, throughout the trophic chain of the own and surrounding ecosystem (magnitude 7). On the other hand, when most of the marine fauna are found at different levels of the area, those that are close to the OC-OTEC PLANT can affect the species belonging to its trophic chain by traveling at different levels (8 intensity degrees).

8. Activity #8 Artificial reef effect/contamination by heavy metal salts influences:

a. Marine waters: With magnitude 6 as negative impact, the protective coatings that are placed in the pipes inlets that prevent the generation of artificial reefs contain components that are in direct contact with the oceans and are made from soluble solid compounds (salts of heavy metal). The most commonly used are Copper (Cu), Mercury (Hg), Zinc (Zn) and Arsenic, which can alter the sustainability of trophic chains causing risks to the environment and society. In the same way, it obtains 3 intensity degrees, since the protective coatings are not placed in all the pipes, only in the inlet nozzles.

b. Marine fauna, negative impact and with magnitude 7: The majority of marine species live in specific conditions of the area where they are; therefore, when introducing heavy metals, an alteration in these organisms can occur and, therefore, in the whole trophic chain of the ecosystem. The purpose of placing heavy metals in the nozzles of the pipes is beneficial to the plant, since the formation of artificial reefs is avoided, and maintenance costs are reduced. On the other hand, it would become a relevant issue if, due to corrosion, there was a leak or spillage of heavy metals into the ocean, resulting in 7 intensity degrees.

9. Activity #9 Organism drag and compression influences:

a. Marine fauna: Because the marine species that inhabit the zones of extraction of marine waters are latent subjects to enter the pipes and perish, that is a reason why it is considered a negative impact and magnitude 4. Also, there are technologies that prevent the passage of marine species, such as gratings or retention ponds, where they can be manually removed, resulting in 1 intensity degree.

10. Activity #10 Redistribution of ocean water bodies influences:

a. Marine waters: The water rejection discharges that are used as working fluid within the operation of the OC-OTEC PLANT project are at a temperature in the condenser of 10.5°C and in the evaporator of 21.5°C, which is different from the one that occurs in the ocean at the time of the discharge, which causes to score with this impact as negative and a magnitude of 9. Similarly, at the time of the discharge of water rejection, it will come into contact with the ocean, producing a shock term that will dilute until reaching a balance within the water column, thus resulting in 8 intensity degrees.

b. Marine fauna, negative impact and magnitude 3, since the temperature at 150 m is 24.5°C, while the discharge of water from the evaporator is 21.5°C, that small temperature change of 3° C can favor the relocation of fish in search of an optimal ecosystem for their reproduction, feeding and growth. Likewise, the OC-OTEC PLANT is located in the western part of Cozumel Island, so that the said area does not converge with coral species that may be affected (2 intensity degrees).

11. Activity #11 Impact by organic antifouling chemicals influences:

a. The type of soil, as a negative impact and with magnitude 1, during the OC-OTEC PLANT maintenance, only antifouling chemicals will be used in the flash evaporator; therefore, only in case of any leakage, spillage or mishandling of products could this affect the earth's crust. The only chemical used in the OC-OTEC PLANT is chlorine and its greatest impact would be only if there are critical leak situations. Chlorine reacts docilely with the chemical components of the soil in the region forming chlorides that, depending on their solubility, are easily washed with water. A spill of liquid chlorine could temporarily freeze the affected soil area (3 intensity degrees).

b. Marine waters, considered as negative impact and with magnitude 3, would only be affected if at the time of maintenance (washing) of the evaporator, this remains with chlorine residues that are dragged into the ocean. It is not an impact that happens frequently only in case there is a mishandling of chemicals so the way it would affect would be the following: chlorine rapidly hydrolyses in water forming hypochlorous acid and hydrochloric acid. Free chlorine reacts quickly with organic compounds. Concentrations of up to 0.05–0.15 mg/l cause significant changes in the composition of marine phytoplankton species, thus obtaining 4 intensity degrees.

c. Marine fauna, as a negative impact with magnitude 7, since chlorine is a substance considered toxic, therefore, it affects marine species, and thus produces effects on marine fauna, which would affect the food chain and the ecosystem in general, giving it 7 intensity degrees.

12. Activity #12 Noise influences:

a. Flora, as a positive impact and magnitude 3: The operation of the OC-OTEC PLANT project has noise emissions that are below those established in Mexican standards, to this we must add that being surrounded by plant species creates a natural barrier that prevents the propagation of noise to neighbors. Similarly, the intensity is negligible because the OC-OTEC PLANT alone does not exceed Límites Máximos Permisibles (Maximum Permissible Limits) stipulated in NOM-080-STPS-1993 (1 intensity degree).

b. Demography, negative impact and only with magnitude 1, since there are no urban centers of population nearby. There are shops 197.48 meters to the northeast and 183.18 meters to the northwest, but because they are separated by a large distance where natural dissipation barriers are found, the OC-OTEC PLANT project will not affect neighboring buildings. On the other hand, flora is a natural barrier that will prevent the transport of noise and vibrations, so it will not affect neighboring buildings, thus obtaining 1 intensity degree.

c. Demography, of a negative nature and only with magnitude 1, because there are no urban centers of population nearby. There are shops 197.48 meters to the northeast and 183.18 meters to the northwest, but because they are separated by a large distance where natural dissipation barriers are found, the OC-OTEC PLANT project will not affect neighboring buildings. On the other hand, flora is a natural barrier that will prevent the transport of noise and vibrations so it will not affect neighboring buildings, thus obtaining 1 intensity degree.

13. Activity #13 Lighting influences:

a. Demography, being a negative impact with magnitude 3, because it could be the cause of causing disturbances at two different levels: Internally, it could affect work comfort and externally in vehicular traffic. Norma Oficial Mexicana NOM-025-STPS-2008, Condiciones de iluminación en los centros de trabajo (Official Mexican Standard NOM-025-STPS-2008, lighting conditions in the workplace), establishes only Límites Mínimos (Minimum Limits) for the correct performance in the workplace as well as a section in which the employee must be informed about the risks of glare, so it is ambiguous how to standardize it. While on the outside, there are no regulations in force that stipulate Límites Máximos Permisibles for outdoors. However, the intensity degree is 2 because although it could generate disturbances outdoors as well as indoors they would be in very isolated cases.

14. Activity #14 Turtle nesting alteration influences:

a. Marine fauna: It is considered as a negative impact and with magnitude 2 since the OC-OTEC PLANT has artificial lighting at night time due to safety reasons, but due to its location, it does not alter the nesting of turtles. Also, the OC-OTEC PLANT is located in a site that is not considered to be the site of nesting turtles of any of the 6 species, so it only has 1 intensity degree.

15. Activity # 15 Brine discharge influences:

a. Marine waters, with a negative nature and magnitude 10, due to the excess of sodium chloride in the brine resulting from the operation of the OC-OTEC PLANT, which when discharged to the marine waters, will increase the normal concentrations of salts in the ocean. Its intensity degree is 9 due to the different sea currents that interact in nearby marine areas and high salt concentrations can cause great dispersion and affectation to different ecosystems.

b. Marine fauna has a negative impact and magnitude 6. The increase in salinity of certain waters disturbs the osmotic balance of marine species with their environment, which in turn produces dehydration of the cells and decrease in the pressure of the turgidity and can lead to the death of the species. Marine species close to the OC-OTEC PLANT are the most likely to be affected by the increase in salt concentrations, which can lead to the said alteration in these organisms due to their participation in the food chain and when they reach other places. This results in 6 intensity degrees.

16. Activity # 16 causing socio-cultural impacts does not interfere in any way with any type of activity described.

17. Activity # 17 Causing significant public controversy influences:

a. Demography with a negative nature and magnitude 5. This is due to the fact that there are an infinite number of aspects (lack of market studies, lack of job opportunities for local inhabitants, irregularities in construction, damage to ethnic groups and the public image) due to that the society of Cozumel Island can take arguments to oppose the operation of the project. It depends largely on the information provided to the inhabitants of the island about the OC-OTEC PLANT project, resulting in 5 intensity degrees.

18. Activity # 18 Disruption of interruption of migration routes influences:

    a. Birds, as a negative impact and magnitude 2, since the exterior lighting of the OC-OTEC PLANT project will be lit at night due to internal security issues, which could generate disturbances to migratory species, even with this some bird species were characterized and it was verified that none of it has a migration route close to the facilities of the OC-OTEC PLANT project. This is not an impact that happens frequently; however, it must be taken into account for future projects, thus having 2 intensity degrees.

19. Activity # 19 Waste influences:

    a. Type of soil, as a negative impact and magnitude 2. The OC-OTEC PLANT project is a small generator of Urban Solid Waste (MSW) since an annual projection would produce an approximate 6 kg/day or 2190 kg per year. Intensity degree is low (1) because an external company will be responsible for the collection and final disposal of it, so the only way for contamination to exist is due to its poor handling.

20. Activity # 20 Sanitary discharges from the station influences:

    a. Type of soil, as a negative impact and only magnitude 1, since the wastewater in the OC-OTEC PLANT project will come from a bath that will be connected to the sewer system of Cozumel Island. Its intensity degree is 1 because the workforce is made up of 5 employees, so the wastewater will be minimal.

3.4 Phase 4: proposal for corrective and preventive measures

According to the Leopold matrix corresponding to the OC-OTEC PLANT operation project, it was found that of the 20 impacts identified as likely to occur during the operation of the project, only 4 of them are significant because they have a greater amount of negative impacts and have a greater weighting over other impacts, in order to reduce the probability of causing greater damage to the environment and components of the environmental inventory, a series of corrective and/or preventive measures that can be used in the facilities of the OC-OTEC PLANT project.

3.4.1 Dragging nutrients to the surface

A measure for the reduction of impacts, caused by pumping cold water from the depths of the ocean carrying nutrients, could be the alternative uses for wastewater (water with nutrients), to avoid reinjection into the ocean. One of the options would be to filter to separate the nutrients from the water, which would consist of passing the liquid through a filter to retain some of its components; in this way, we would have two waste materials (water/nutrients) that could be used separately for other purposes. For example, water through a purification process can be distributed and sold on the island. On the other hand, nutrients can be dehydrated in the sun and sold dry as salt or fertilizer; in this case, a relevant study would have to be done.

3.4.2 Redistribution of ocean water bodies

Alternative uses can be given to rejection waters from the evaporator and condenser in order to reduce the impact on the environment. Some of the options are as follows:

1. Temperature regulator: The cold rejection water will pass through a continuous reactor in which temperature regulators will be placed to match the temperature of the water with that of the ocean.

2. Aquaculture: Use of deep sea cold water to grow commercial organism crops such as fish, molluscs, crustaceans and algae that reproduce in cold water in tropical areas.

3. Agriculture (cold water): Cold water from the depths is piped and moves under arable soil to cool it (indirectly). This process helps the plant roots to stay cold and generates condensation of the moisture present near the soil (approximately 10° C). As the water continues to cool, it penetrates through the soil until it reaches the coldest point of the root zone. Plants from temperate and semitemperate areas could be grown in tropical areas, such as the following plant species: strawberries, grapes, carrots, onions, apples and peaches.

3.4.3 Impact by organic antifouling chemicals

The chosen organic antifouling chemical for the OTEC plants maintenance is chlorine, which, together with other chemical compounds (metal ions, ammonia, detergents, polychlorinated biphenyls, etc.), is the main toxin that causes damage to marine ecosystems.

Since this may occur in specific and / or isolated cases due to improper use of the product or by residues contained in the OC-OTEC PLANT evaporator, it is relevant to mention that the establishment of a preventive measure rather than corrective measures is preferable to reduce the presence of pollutants.

The prevention would be carried out by the development, implementation, use and/or updating of an "Environmental Management Plan," which will help to avoid, mitigate and/or progressively compensate the acting of personnel in extraordinary situations. Some of the activities described in the environmental management plan would be:

1. In compliance to Norma Oficial Mexicana NOM-005-STPS-1998, Relativa a las condiciones de seguridad e higiene en los centros de trabajo para el manejo, transporte y almacenamiento de sustancias químicas peligrosas (Official Mexican Standard NOM-005-STPS-1998, concerning the conditions of safety and hygiene in workplaces for the handling, transport and storage of hazardous chemical substances), which stipulates conditions that will help to prevent and protect the health of workers, avoid damage to work facilities and cause adverse damage to the environment.

2. Implementation of chlorine neutralization systems (or as they are also known as scrubbers) that allow emergency emergencies to be leaked, by passing the

chlorine gas through an extractor (Venturi scrubber), which contains a dry or moisturizing neutralizing medium that will help dissipate said product in nontoxic amounts to the environment.

3. Emergency plan to react on time if that event occurs with training for employees is contemplated.

3.4.4 Brine discharge

As alternatives to avoid reinjection into marine waters, and recognizing the importance of mangroves throughout the state area, a preventive measure of the impacts of brine discharge is their collection for use in mangrove reforestation processes. These processes can be focused on direct reforestation in disturbed mangrove areas or reforestation with nursery seedlings, of which, in the latter, it is important to preadapt them to conditions similar to the place where they are sown to ensure greater survival, with salinity being especially important, so it is in this case where the use of the necessary amounts of the "natural" brine from the OC-OTEC PLANT operation would come in. Several studies indicate that *A. germinans*, or black mangrove, has a high tolerance to salinity, so it is highly recommended for use from seedlings of that species. Following the same line of alternatives, the brine can be transferred to be used in salt-obtaining equipment or for forced osmosis systems (osmosis by means of difference in salt concentrations), taking into account that the final residues of these processes also can be used for mangrove reforestation.

On the other hand, as some methods to minimize the impacts of the discharge, as no alternatives to reinjection are contemplated, various desalination projects recommend predilution processes with seawater or discharge through diffusers, to equalize marine concentrations.

4. Discussion

Among the factors to consider for OTEC commercialization, the environmental impacts exists as well as public acceptance, so it is necessary to address potential impacts and risks of OTEC during a plant's planning, design, construction, commissioning and operation, from a technical and scientific point of view, in order to explicitly present the impacts, potential risks and mitigation strategies to the interested parties and general population, all the aforementioned being, the initial starting point of this document, focused on the open-cycle OTEC plant operation [33].

One way to identify and evaluate environmental impacts is through instruments such as checklists or various types of matrices (Leopold, Cause and Effect, Batelle-Columbus, etc.), which are applicable to the different phases of the realization of a project (construction, operation and abandonment). For this project, the Leopold matrix was used, which has evaluated projects such as a thermoelectric plant [34] in which it has been very useful for measuring environmental impacts.

Globally, environmental impact assessments, or similar, focused on OTEC technology, have been developed with various tools and have concluded in different impacts, as well as mitigation and prevention strategies.

For example, a Final Environmental Impact Statement prior to 1981 is available in Hawaii [35], which must be updated to current oceanographic and engineering standards. Based on the high research done on Hawaii's oceanography, a report is presented that highlights some of the most important contributions in terms of OTEC development, as well as the gaps in knowledge, and finally proposes a protocol for monitoring the environmental baseline, focusing on a set of ten chemical oceanographic parameters relevant to OTEC and addresses the gaps in the knowledge of the ecology and oceanography of the area chosen for the development of OTEC.

In Beijing, China, it is considered that site selection is a key factor for the success of an OTEC project, and in turn, it is a problem of multiple-criteria decision-making (MCDM) with a series of conflicting criteria involved. Classic MCDM methods tend to fail for these projects [36]. Therefore, an extended TDCM method is proposed and a new decision-making framework is established to select the optimal location. First, a complete system of evaluation criteria is established for the OTEC site's selection from sustainability point of view with 16 criteria involved, among which it mentions that environmental sustainability evaluations are necessary to assess the ecological and environmental impact of carbon in the environment before decision-making, resulting in the criterion named possible environmental effect (C51), which covers biological and environmental impacts during the operation of the plants; however, their method does not offer any kind of recommendation or mitigation plan for such impacts.

Another case is from the island of Martinique, in France, where bibliography was studied in detail, both for the evaluation of the site and for the impacts of other projects in the world with similarities relevant to OTEC; a thematic synthesis was subsequently carried out for each physical, biological and human theme that could be affected by the project, resulting in a total of 28 issues, all of the above with the objective of establishing priorities for specific evaluations [37]. This last case is shown as the most similar to this document, since it is known, it involved a documentary investigation on the physical and biological environment of the study site in Cozumel and its impacts, throwing 37 topics addressed (20 activities that might have impacts and 17 environmental inventory factors) that are not so far from the number of issues in the case in question and taking into account that in both, priorities were selected for further study.

On the other hand, of the different impacts described for the OC-OTEC project, it is possible to contrast some impacts from data obtained with those of other similar works, such as the production of electrical energy knowing that of the 86,415 inhabitants of the island from Cozumel, about 1772 would benefit. The distribution of energy through an OTEC PLANT is a viable option in Martinique, France, as it would benefit 2187 inhabitants, a number quite close to the case of Cozumel Island [38]. Likewise, there are other works [39] where we talk about the environmental impacts corresponding to an open-cycle OTEC plant, such as atmospheric effects from CO_2 and marine impacts, which are also discussed in this work.

As mentioned previously [33], one of the factors to consider for the commercialization of OTEC is the degree of public acceptance, which, by reviewing different impact evaluations, can be found to be of no significant importance. For example, in 2012, Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT, acronym in Spanish for Ministry of Environment and Natural Resources) rejected a project for the implementation of a Wind Farm in Cozumel due to citizen opposition, from businessmen and academics, since they argued that it put the habitat, biodiversity and species at risk in serious danger of extinction. In this civil power lies the importance of knowing the social environment at the time of carrying out projects likely to affect the environment.

Around the world, research on OTEC plant technology has been developed in places like Mexico (Bárcenas, 2014), Hawaii (Vega, 1991), and India (Ravindran &

Raju, 2002), among others. Finally, the places with plants currently in operation are Kumejima in Okinawa (Japan); Saga University (Japan); Goseong (South Korea); Reunion Island (France); and Makai, Island of Hawaii (United States) [40].

5. Conclusion

The elaborated Leopold matrix results made it possible to establish a series of preventive and corrective measures aimed at protecting the environment of the polygon studied. Despite having gathered enough information for the EIA on both the matrix and the environment of Cozumel Island, as well as the impacts produced by the operation of the plant, the low existence of recent data represented a limitation in that aspect. We had to work mainly with data from management programs and preliminary evaluations of the different protected natural areas of the island, being quite useful in aspects of protection, as well as for the establishment of an OC-OTEC plant. The importance of developing these studies on environmental impact is highlighted, since considering their findings, such as the protection of mangrove areas, the existence of land uses determined by law to avoid this kind of construction in specific zones, a 51% approval of a population sample, and sharing the benefits from water desalination, the environment and the immediate society are contemplated, thus leading to renewable energies such as OTEC to an advanced sustainability.

Acknowledgements

We would like to express our gratitude to Centro Mexicano de Innovación en Energía del Océano (CEMIE-O), especially its participants MSc. Luis Mariano Sánchez Avelar and MSc. Alejandro García Huante, for their interest in this research and advices provided for its development. Likewise, we appreciate the valuable collaboration of Departamento de Inglés (Language Department) and Departamento de Desarrollo Humano (Humanities Department) belonging to Universidad del Caribe, especially to Ms. Jane Acosta Holmes, the Language Department head, and MPhil Roberto Parra Dorantes, research professor at the Humanities Department, as well to Elvira Acuña Gonzalez, Thelma Canto Burgos and Magdalena Avila Pardo, professors in the Language Department, for their counseling, support and commitment for the translation of this chapter.

Author details

Enrique Celestino Carrera Chan, María Fernanda Sabido Tun,
Juan Francisco Bárcenas Graniel* and Estela Cerezo Acevedo
Universidad del Caribe, Centro Mexicano de Innovación en Energía del Océano (CEMIE-O), Cancún, México

*Address all correspondence to: jbarcenas@ucaribe.edu.mx

References

[1] Ocean Energy Systems - International Energy Agency. 2017. 2017 Annual Report: An overview of Ocean Energy Activities in 2017. Available from: https://report2017.ocean-energy-systems.org/

[2] Bárcenas J. Evaluación del Potencial energético Renovable del Caribe Mexicano. Master's Degree Thesis Not Published. México, DF: Instituto de Ciencias del Mar y Limnología. UNAM; 2014

[3] Gómez D. Evaluación de Impacto Ambiental. 2nd ed. Madrid, España: Editorial agrícola española; 1998

[4] Ravindran, M. & Raju, A. The Indian 1 MW demonstration OTEC plant and the development activities. Oceans '02 MTS/IEEE. 2002. DOI: 10.1109/oceans.2002.1191877

[5] Aviña H. Factibilidad de Instalar Una Planta OTEC (Ocean Thermal Energy Conversion) en Las Costas de México (Bachelor's Thesis). México, DF: Universidad Nacional Autónoma de México; 2007

[6] Institut français de recherche pour l'exploitation de la mer (IFREMER). 2014. APEX Profiling Float SBE_6587. (Database). Available from: http://www.ifremer.fr/co-argoFloats/float?detail=false&active=false&ocean=P&lang=en&ptfCode=4901644

[7] Vega L. OTEC overview, by LA Vega, Ph.D. Ocean Thermal Energy Conversion (OTEC). OTEC News. 1999. Available from: http://www.otecnews.org/portal/otec-articles/ocean-thermal-energy-conversion-otec-by-la-vega-ph-d/#open

[8] International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico (IBCCA). 2016. Conjunto de datos vectoriales Carta batimétrica internacional del Mar Caribe y Golfo de México (IBCCA) Hoja 1-07. (Base de datos). Available from: https://datos.gob.mx/busca/dataset/conjunto-de-datos-vectoriales-carta-batimetrica-internacional-del-mar-caribe-y-golfo-de-mexico-/resource/fdafd79a-326f-4f52-b5c4-8329ce1251b2?inner_span=True

[9] Comisión Nacional de Áreas Naturales Protegidas (CONANP). 2017. Reservas de la Biosfera, Parques Nacionales, Monumentos Naturales, Áreas de Protección de Recursos Naturales, Áreas de Protección de Flora y Fauna, Santuarios de CONANP (Database). Available from: https://datos.gob.mx/busca/dataset/informacion-espacial-de-las-areas-naturales-protegidas-181

[10] Avery W, Wu C. Renewable Energy from the Ocean. A Guide to OTEC. New York: Oxford University Press; 1994. pp. 446

[11] Vega L. Economics of Ocean Thermal Energy Conversion (OTEC): An Update. Offshore Infrastructure Associates, Inc. [thesis]. USA, Hawaii: University of Hawaii; 2010

[12] Secretaria de Energía. Evaluación rápida del uso de la energía Cozumel, Quintana Roo, México. [Internet]. 2016. Available from: https://www.gob.mx/cms/uploads/attachment/file/170882/7__Cozumel.pdf [Accessed: 10 March 2019]

[13] Secretaria de Energía. Programa de desarrollo del sistema eléctrico nacional 2015-2029. [Internet]. 2015. Available from: https://www.gob.mx/cms/uploads/attachment/file/54139/PRODESEN_FINAL_INTEGRADO_04_agosto_Indice_OK.pdf [Accessed: 17 February 2019]

[14] Instituto Nacional de Estadística y Geografía. Anuario estadístico y

geográfico de Quintana Roo 2013. [Internet]. 2013. Available from: http://bibliotecasibe.ecosur.mx/sibe/book/000011171 [Accessed: 05 January 2019]

[15] Secretaria de Energía (SENER). Programa de desarrollo del sistema eléctrico nacional 2018-2032. México: Secretaria de Energía; 2018 pp. 107, 110, 175, 244, 284

[16] Instituto Nacional de Estadística y Geografía (INEGI). Anuario estadístico y Geográfico de Quintana Roo 2016. Quintana Roo, México: Autor; 2016

[17] Instituto Nacional de Estadística y Geografía (INEGI). Viviendas particulares habitadas por municipio y su distribución porcentual según disponibilidad de energía eléctrica Al 15 de marzo de 2015. Dirección General de Estadísticas Sociodemográficas. (Encuesta intercensal); 2015. Available from: www.inegi.org.mx

[18] Instituto Nacional de Ecología (INE). 1998. Programa de Manejo Parque Marino Nacional Arrecifes de Cozumel. Available from: https://www.conanp.gob.mx/que_hacemos/pdf/programas_manejo/cozumel.pdf

[19] Instituto Nacional de Estadistica y Geografia. Anuario estadistico y geografico de Quintana Roo 2016. [Internet]. 2017. Available from: https://www.datatur.sectur.gob.mx/ITxEF_Docs/QROO_ANUARIO_PDF.pdf [Accessed: 13 January 2019]

[20] Alcérreca I. Plan de Acción Climática Municipal (PACMUN) (Power Point dispositive). 2012. Available from: http://www.pincc.unam.mx/congresonacional2012/sis_admin_pres/archivos_2012/pacmun_octubre_2012.pdf

[21] García E, Comisión Nacional para el conocimiento y uso de la Biodiversidad (CONABIO). 2004. Climas. (Base de datos) Available from: http://www.conabio.gob.mx/informacion/metadata/gis/clima1mgw.xml?_xsl=/db/metadata/xsl/fgdc_html.xsl&_indent=no

[22] Orellana R, Nava F, Espadas C. El clima de Cozumel y la Riviera Maya. Biodiversidad acuática de la isla de Cozumel. 1st ed. México: Centro de Investigación Científica de Yucatán; 2007. p. 422

[23] Spellman F. The Science of Renewable Energy. 2nd ed. Florida: CRC Press; 2016

[24] Secretaría de Medio Ambiente y Recursos Naturales. 1994. Norma Oficial mexicana NOM-081-SEMARNAT-1994 Que Establece los Límites Máximos Permisibles de Emisión de Ruido de las Fuentes Fijas y su Método de Medición. Available from: http://biblioteca.semarnat.gob.mx/janium/Documentos/Ciga/agenda/PPD02/081.pdf (Norma Oficial Mexicana publicada originalmente en el Diario Oficial de la Federación el 23 de abril de 2003)

[25] Instituto Nacional de investigaciones Forestales y Agropecuarias (INIFAP)–Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). 1995. Edafología. (Database). Available from: http://www.conabio.gob.mx/informacion/metadata/gis/eda251mgw.xml?_httpcache=yes&_xsl=/db/metadata/xsl/fgdc_html.xsl&_indent=no

[26] Bautista F, Maldonado D, Zinck AJ. La clasificación maya de suelos. Ciencia y desarrollo. 2012;**260**:64-70

[27] Butterlin J, Bonet F. Información básica para la interpretación geohidrológica de la Península de Yucatán. México, DF: Secretaria de Recursos Hidráulicos; 1960

[28] Instituto Nacional de Ecología (INE). 1998. Programa de Manejo Parque Marino Nacional Arrecifes de

Cozumel. Available from: https://www.conanp.gob.mx/que_hacemos/pdf/programas_manejo/cozumel.pdf

[29] Skinner B, Murck B. 2011. The blue planet: an introduction to earth system science (No. 504.3/.7 SKI)

[30] Comisión Nacional de Áreas Naturales Protegidas (CONANP) and Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). 2018. Programa de Manejo Reserva de la Biosfera Caribe Mexicano. Available from: https://www.conanp.gob.mx/programademanejo/RBCMPM.pdf

[31] Cámara de Diputados del H. Congreso de la Unión. (21 de mayo de 2013). Acuerdo por el que se dan a conocer los estudios técnicos de aguas nacionales subterráneas del acuífero isla de Cozumel, clave 2305, Estado de Quintana Roo. Available from: http://www.dof.gob.mx/nota_detalle.php?codigo=5299571&fecha=21/05/2013 (Acuerdo publicado originalmente el 21 de mayo de 2013 en el Diario Oficial de la Federación)

[32] Rivera M. Estudio Geofísico e hidrogeológico para un banco de materiales, en Playa del Carmen Quintana Roo, México. [Thesis]. México, D.F.: Universidad Nacional Autónoma de México; 2013

[33] Romero A. Evaluación del potencial maremotérmico en costa Norte y Sur del Estado de Veracruz. (Master's degree thesis). Veracruz, México: Universidad Veracruzana; 2013

[34] Garza, R. 36 CC Baja California III (Sitio: La Jovita), Modalidad: Productor Externo de Energía (PEE). Manifestación de Impacto Ambiental. 2010. Available from: sinat.semarnat.gob.mx/dgiraDocs/documentos/bc/eUstudios/2010/02BC2010E0007.pdf

[35] Comfort C, Vega L. Environmental Assessment for Ocean Thermal Energy Conversion in Hawaii. Available data and a protocol for baseline monitoring. OCEANS'11 MTS/IEEE KONA. 2011

[36] Zhang J, Xu C, Song Z, Huang Y, Wu Y. Decision framework for ocean thermal energy plant site selection from a sustainability perspective: The case of China. Journal of Cleaner Production. 2019;**225**:771-784. DOI: 10.1016/j.jclepro.2019.04.032

[37] Auvray C, Ledoux S, Diaz B, Yvon C, Pouget-Cuvelier A. Environmental impact assessment for an OTEC Plant in Martinique Island. La Houille Blanche. 2015;**2**:60-66

[38] Devault D, Péné-Annette A. Analysis of the environmental issues concerning the deployment of an OTEC power plant in Martinique. Environmental Science and Pollution Research. 2017;**24**(33):25582-25601

[39] Quinby-Hunt M, Wilde P, Dengler A. Potential environmental impacts of open-cycle thermal energy. Environmental Impact Assessment Review. 1986;**6**:77-93

[40] Garduño E, García A, Rodríguez Y, Bárcenas J, Alatorre M, Cerezo E, et al. Conversión de Energía Térmica Oceánica (OTEC) Estado del Arte. 2017. Available from: https://cemieoceano.mx/downloads/libros/CEMIEOceano_Gradiente_Termico.pdf