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Assessing Power Generation Potential of Mid-Scale OTEC system in the Southeastern United States

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Abstract

Marine renewable energy, including wave, tidal, and ocean thermal energy, has attracted growing attention in recent years. Among these, Ocean Thermal Energy Conversion (OTEC) is particularly well-suited for tropical regions, where the stable temperature difference between warm surface waters and cold deep seawater provides a reliable and continuous energy resource year-round. While substantial research has been dedicated to both small-scale demonstration systems and large-scale commercial concepts, mid-scale OTEC systems, ranging from 10 to 50 MW, remain relatively underexplored. Recent advances in pipeline technologies, such as the commercial availability of large-diameter HDPE pipes, have made the construction of such systems increasingly feasible.
This study presents a numerical modeling framework to evaluate the power generation potential of a mid-scale OTEC system designed around a 3-pipe bundle of 3.5 meter cold water pipes. The model is applied across several regions using daily ocean temperature profiles from the HYCOM dataset to evaluate electrical power production potential across the Southeastern United States and the Caribbean, focusing on the impact of warm and cold water temperature variations, as well as the depth of cold water intake on power generation. This assessment provides a foundation for identifying viable deployment zones for mid-scale OTEC systems.

Keywords: Ocean Thermal Energy Conversion; Marine Renewable Energy; OTEC Potential

1. Introduction

Ocean Thermal Energy Conversion is a renewable energy technology that generates electricity by using the temperature difference between warm surface seawater and cold deep seawater within a Rankine cycle. Due to the small temperature differential, the efficiency of OTEC systems is inherently low, usually ranging between 3% and 5% [1]. As a result, the viability and performance of OTEC systems are strongly site-dependent, relying on stable and sufficient thermal differences. Additionally, internal energy consumption and system losses must be carefully accounted for both the design and operational phases.

In addition to research on cycle configurations and working fluids, numerous studies have focused on the modeling and resource assessment of OTEC systems to improve system efficiency and identify viable deployment sites. Li et al. [2] developed a thermodynamic model to evaluate the performance of a small-scale closed-cycle OTEC system, emphasizing the influence of key design parameters on net power output. Vera et al. [3] developed a thermodynamic model of a small-scale OTEC system integrated with an Organic Rankine Cycle (ORC), specifically targeting remote island electrification. The study evaluated eleven working fluids, optimizing net power output and thermodynamic efficiency while accounting for pumping losses and seawater pipeline hydraulics. On the resource assessment side, Rajagopalan and Nihous [4] utilized a three-dimensional ocean general circulation model (MITgcm) to estimate the theoretical global OTEC power potential, accounting for the dynamic redistribution of ocean heat under large-scale OTEC deployment. VanZwieten et al. [5] applied the HYbrid Coordinate Ocean Model (HYCOM) dataset to assess the OTEC resources around the Florida coast, integrating ocean temperature profiles with a detailed 100 MW plant model. More recently, Ticona Rollano et al. [6] conducted a high-resolution resource assessment for Puerto Rico and the U.S. Virgin Islands using 14 years of HYCOM ocean temperature data, identifying six promising deployment zones based on thermal gradients, bathymetry, and proximity to grid infrastructure.

While these efforts have advanced understanding of OTEC performance and siting, most existing studies focus on small-scale experimental systems or large commercial concepts, with limited attention to mid-scale systems in the 10-50 MW range. Bridging this gap is essential for advancing OTEC technology toward commercial viability, as mid-scale systems provide a practical intermediate step between small-scale prototypes and large-scale commercial plants and are feasible using current pipeline technologies. To address this need, the present study develops a numerical model for a mid-scale OTEC system designed around a 3-pipe bundle of 3.5 meter pipes which is shown to deliver approximately 19 MW of net power output. The system design is constrained by commercially available infrastructure, including the use of 3.5 m diameter high-density polyethylene (HDPE) pipes, which represent the largest size currently available for deep seawater intake. The model incorporates thermodynamic performance, hydraulic losses, and ocean temperature profiles from the HYCOM dataset to evaluate feasibility and regional potential.

The remainder of this paper is organized as follows. Section 2 introduces the numerical model developed for the mid-scale OTEC system, including key design parameters and component-level assumptions. Section 3 outlines the methodology and datasets used for assessing OTEC performance across the selected study regions. Section 4 presents the simulation results and analysis of power production potential. Finally, Section 5 provides concluding remarks and outlines the implications for future mid-scale OTEC development.

2. System Modeling

This study presents the design of an OTEC system with a targeted net output power of approximately 19 MW, corresponding to a surface seawater temperature of 25.7 °C and deep cold water temperature of 4.1 °C. This capacity was selected to align with commercially available 3.5 m diameter pipes and to maintain a maximum seawater velocity of 1.5 m/s, consistent with the commonly recommended limit of 5 feet per second for PVC, PE, and HDPE piping systems [7]. The proposed system operates using a closed Rankine cycle with refrigerant R134a selected as the working fluid due to its favorable thermodynamic characteristics, broad commercial availability, and low toxicity. The model assumes a fixed flow rate for the surface warm seawater, while the deep cold seawater and working fluid flow rates are treated as dependent variables, determined by system operating conditions and thermodynamic requirements. Pumping power for both seawater and working fluid is calculated based on pressure losses due to friction in the pipelines and associated fittings. The cold water intake system comprises three 3.5 m diameter pipes, each connected to a dedicated condenser. The warm water intake system uses a single 7 m diameter pipe, which splits into two branches feeding two parallel evaporators. Key system parameters and modeling assumptions are summarized in Table 1.

The net output power, P_{Net}, is defined as in Equation (1):

$$P_{Net}(kW) = P_{Gross} \times \eta_G \times \eta_{throttle} \times \eta_{wiring} \times \eta_{inverter} - P_{ww,p} - P_{cw,p} - P_{wf,p} \quad (1)$$

where P_{Gross} denotes the gross power output of the system, $P_{ww,p}$ *and* $P_{cw,p}$ represent the pumping power required for the warm and cold seawater streams, respectively, and $P_{wf,p}$ refers to the working fluid pumping power. These parameters are defined in Equations (2), (3) and (4).

$$P_{Gross}(kW) = \dot{m}_{wf} \times (H_1 - H_2) \quad (2)$$

where H_1 *and* H_2 are the specific enthalpies of the working fluid at the turbine inlet and outlet in $\frac{kJ}{kg}$, respectively. The pumping power required for the warm and cold seawater flows can be calculated using the following equation:

$$P_{ww(cw),p}(kW) = \frac{\dot{m}_{ww(cw)} \times g \times h_{ww(cw),total}}{1000 \times \eta_{sw,p}} \quad (3)$$

Table 1. OTEC system parameters

Parameter	Value	Unit
Desired net power (P_{Net})	19	MW
Inverter efficiency ($\eta_{inverter}$)	95	%
Vapor pipe, throttle efficiency ($\eta_{throttle}$)	85	%
Turbine generator efficiency (η_G)	85	%
Warm water flow rate ($\dot{m}_{ww}$)	50000	Kg/s
Warm water temperature difference(ΔT_{ww})	2.59	℃
Evaporator pinch point ($\Delta T_{PP@E}$)	1.5	℃
Evaporator pressure drop ($\Delta P_{@Evap}$)	14.48	kPa
Cold water flow rate ($\dot{m}_{cw}$)	32306	Kg/s
Cold water temperature difference (ΔT_{cw})	4.065	℃
Condenser pinch point ($\Delta T_{PP@C}$)	1.5	℃
Condenser pressure drop ($\Delta P_{@Cond}$)	26.2	kPa
Working fluid flow rate ($\dot{m}_{wf}$)	2650	Kg/s
Seawater pump efficiency ($\eta_{sw,p}$)	82	%
Refrigerant pump efficiency ($\eta_{wf,p}$)	75	%
Seawater density (ρ_{sw})	1025	Kg/m^3
Working fluid density (ρ_{wf})	1259	Kg/m^3

where g is the acceleration of gravity in $\frac{m}{s^2}$, and $h_{ww(cw),total}$ represents the total head required for the seawater stream.

This total head can be defined as follows:

$$h_{ww(cw),total}(m) = h_{cw,static} + h_{evap\ (cond)} + h_{ww(wc),pipe} + h_{ww(cw),fitting} \quad (4)$$

the static head for the cold water, denoted as $h_{cw,static}$, is assumed to be 1 m. Head losses in the evaporator and condenser, $h_{evap(cond)}$, represent the pressure drops experienced by seawater as it flows through the heat exchangers. These can be described as follows:

$$h_{evap(cond)}(m) = \frac{\Delta P_{@Evap(@cond)}}{\rho_{sw} \times g} \quad (5)$$

Frictional head loss in the warm and cold seawater piping systems is attributed to various pipe sections along the flow path. The Hazen–Williams equation [8] is used to calculate head loss for each segment, and the total head loss is obtained by summing the contributions from all straight pipe sections, as expressed below:

$$h_{ww(cw),pipe} = \sum_n h_{pipe,n} \quad (6)$$

$$h_{pipe,n} = \frac{10.583 \times L_{pipe,n} \times \left(\frac{q}{N_{pipe,n}}\right)^{1.852}}{c^{1.852} \times d_n^{4.8655}} \quad (7)$$

where $L_{pipe,n}$ is the length of the nth pipe in meters, q is the volumetric flow rate $\left(\frac{m^3}{s}\right)$, $N_{pipe,n}$ is the number of parallel pipes in that section, c is Hazen-Williams roughness coefficient (assumed to be 150), and d_n is the inner diameter of the pipe in meters.

In addition to frictional losses in straight pipe sections, minor head losses occur due to fittings and other components. The head loss associated with each fitting is calculated individually, and the total minor losses are obtained by summing the contributions from all fittings, as described below:

$$h_{ww(cw),fitting} = \sum_n h_{fitting,n} \tag{8}$$

$$h_{fitting,n} = K_n \left(\frac{V_n^2}{2g}\right) \tag{9}$$

where K_n is minor loss coefficient and V_n is water velocity in the corresponding section.

The work required to circulate the working fluid is a function of pressure difference between evaporator and condenser, and is calculated as:

$$P_{wf,p} = \frac{\dot{m}_{wf} \times (P_{Evap} - P_{Cond})}{1000 \times \rho_{wf} \times \eta_{wf,p}} \tag{10}$$

This model was implemented in MATLAB to simulate system performance and calculate net power output under various thermal and hydraulic conditions.

3. OTEC power production assessment methodology

The OTEC model described earlier was applied to assess power generation potential across Gulf of America, the Florida Straits, Puerto Rico, and the U.S. Virgin Islands. To evaluate system performance in these areas, daily ocean temperature profiles for the year 2021 were retrieved from the HYCOM dataset. These profiles spanned depths from 300 m to 1000 m, in 100 m increments. Surface seawater temperature was approximated using the temperature at 20 m depth, aligning with standard OTEC warm water intake practices.

For each HYCOM grid point and intake depth, the OTEC model was used to simulate daily net power output by adjusting the cold water temperature, with the pipe's length fixed based on the vertical distance required to reach that specific depth. Using the simulation results, average annual net power output was calculated for each location. Seasonal trends were also analyzed by dividing the year into two periods: the wet season (May to October) and the dry season (November to April). At every grid point, the highest net power output, typically associated with the deepest intake depth, was identified. These maximum values were used to generate spatial maps illustrating OTEC power potential across the study regions.

4. Results

Figures 1 and 2 present the outcomes of the regional OTEC power production assessment. Figure 1 demonstrates the spatial and seasonal patterns of OTEC net power output for a 19 MW system across the Gulf of America and Florida Straits. The annual net power output map identifies three key regions with strong OTEC potential: the Florida Straits, the central and southeastern Gulf of America, and the Caribbean Sea south of Cuba. Sites producing 19 MW or more are consistently located in areas with access to deep cold water, typically at depths exceeding 800 to 1000 m. In the Florida Straits, steep offshore bathymetry enables access to deep water relatively close to the coast, but the presence of strong ocean currents near 80°W may complicate the installation of OTEC system. In the Gulf of America, the most productive zones are found farther offshore, where the continental shelf drops off gradually and greater depths, and thus higher thermal differences, are reached. South of Cuba, the Caribbean Sea offers several high-potential locations where deep water is accessible at short distances from shore, and annual net power output often exceeds 23 MW. These results highlight that while all three regions support viable mid-scale OTEC deployment, site selection must balance thermal performance with bathymetric and hydrodynamic constraints.

Seasonal comparisons reveal notable differences in OTEC power output across the study region. During the wet season, elevated surface temperatures strengthen the thermal gradient, resulting in widespread increases in power production. South of Cuba, net output exceeds 25 MW very close to shore, supported by steep bathymetry and consistently warm surface waters. Even in the dry season, this area maintains output levels above 22 MW, indicating minimal seasonal variability and high year-round potential. In contrast, higher-latitude regions, such as the northern

Gulf of America, exhibit significant seasonal drops, with dry-season outputs falling well below 19 MW due to reduced surface temperatures and weakened ΔT. However, locations that lie within the path of the Gulf Stream show more stable performance throughout the year. The presence of this persistent warm current helps buffer seasonal fluctuations, maintaining surface temperatures and sustaining power output even during cooler months. These patterns highlight the combined influence of latitude, bathymetry, and large-scale oceanographic features, particularly western boundary currents like the Gulf Stream, in determining the seasonal feasibility of mid-scale OTEC deployment.

Figure 2, which presents results for Puerto Rico and the U.S. Virgin Islands, indicates consistently high OTEC power potential throughout the year, particularly along the southern and southeastern coasts where deep water is accessible at relatively short distances from shore. During the wet season, several locations exceed 23 MW of net output, with some areas approaching 25 MW, driven by strong thermal gradients and favorable bathymetry. Even in the dry season, net output in these zones remains above 21 MW, demonstrating relatively low seasonal variability compared to higher-latitude regions. This year-round performance makes the region especially promising for mid-scale OTEC deployment. However, it is important to note that the HYCOM dataset used for this region has a coarser spatial resolution (1/8°) compared to the Gulf of America data (1/25°), which may limit the ability to resolve fine-scale coastal features and localized performance variability.

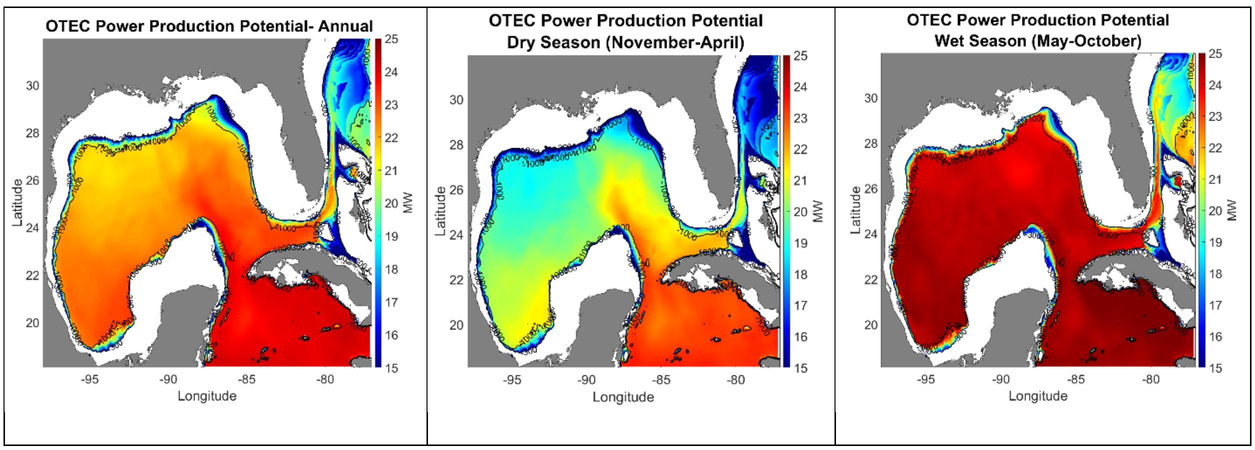

Figure 1.OTE power production potential in the Gulf of America and the Florida Straits

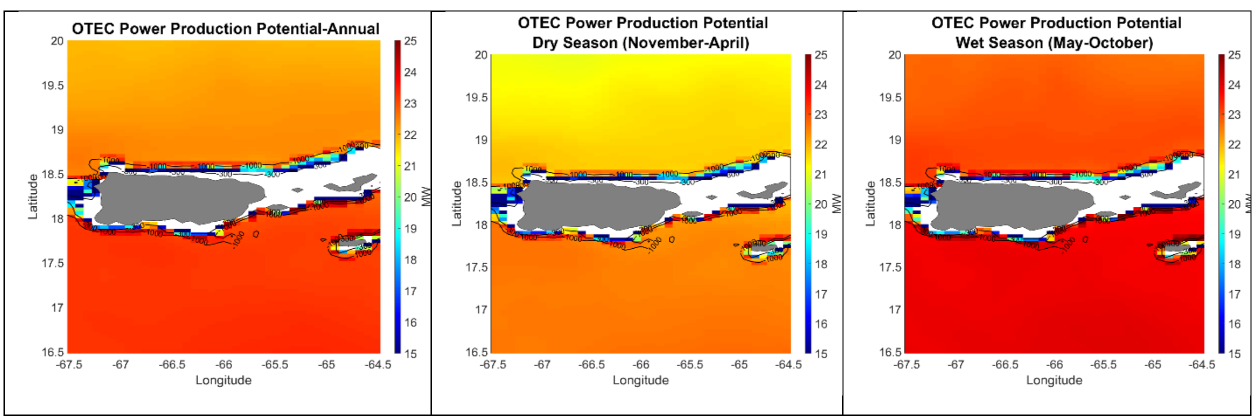

Figure 2. OTEC power production potential in Puerto Rico and the U.S. Virgin Islands

5. Conclusion

This study assessed the power generation potential of a mid-scale OTEC system using a numerical model and HYCOM temperature data. The analysis showed that while some regions, such as areas near Puerto Rico and south of Cuba, offer strong year-round performance, other regions like the Gulf of America exhibit greater seasonal variability. These insights emphasize the need for location-specific design and deployment strategies.

The power potential maps developed in this study, when used alongside seafloor contour data, offer a practical framework for identifying high-potential deployment zones and prioritizing locations for future mid-scale OTEC development, including integrated applications such as co-located aquaculture. This work represents a foundational step toward technical validation of mid-scale OTEC systems; however, to move toward commercial deployment, future efforts must incorporate detailed capital cost modeling and levelized cost of energy (LCOE) analysis to evaluate economic viability and investment potential.

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