Karbala International Journal of Modern Science

Volume 12 | Issue 3 Article 4

Tapping Into the Ocean's Hidden Energy: Feasibility of A 5 MW OTEC Installation in North Bali

Widodo Setiyo Pranowo
Research Center for Climate and Atmosphere, National Research and Innovation Agency (BRIN), KSTE Achmad Baiquni, Babarsari, Sleman, Special Region of Yogyakarta, Indonesia, widodo.setiyo.pranowo@gmail.com

Yani Permanawati
Marine Geological Institute, Geological Agency, The Ministry of Energy and Mineral Resources, Republic of Indonesia, Bandung 40174, Indonesia

Gisela Malya Asoka Anindita
Master Program of Marine Science, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Indonesia

Agung Kurniawan
Indonesia Naval Postgraduate Military Service School (STTAL), Ganesha Street No. 1, West Kelapa Gading, Jakarta, Indonesia

Albertus Sulaiman
Research Center for Climate and Atmosphere, National Research and Innovation Agency (BRIN), KSTE Achmad Baiquni, Babarsari, Sleman, Special Region of Yogyakarta, Indonesia

See next page for additional authors

Recommended Citation
Pranowo, Widodo Setiyo; Permanawati, Yani; Anindita, Gisela Malya Asoka; Kurniawan, Agung; Sulaiman, Albertus; Setiyadi, Johar; Burhanuddin, Safri; Radjawane, Ivonne Milichristi; Park, Hansan; and Kurniawan, Endro Sigit (2026) "Tapping Into the Ocean's Hidden Energy: Feasibility of A 5 MW OTEC Installation in North Bali," *Karbala International Journal of Modern Science*: Vol. 12 : Iss. 3 , Article 4.
Available at: https://doi.org/10.33640/2405-609X.3465

Tapping Into the Ocean's Hidden Energy: Feasibility of A 5 MW OTEC Installation in North Bali

Abstract

Indonesia is an archipelagic country surrounded by water and faces energy challenges due to the low use of renewable energy. Among the potential renewable options, marine energy is a particularly suitable resource given the country's geographical nature. Based on this discussion, seawater temperature can be used as an alternative ocean thermal en-ergy known as ocean thermal energy conversion (OTEC) by using the difference in sea surface and deep-sea water temperatures. Therefore, this study aimed to examine OTEC installations in North Bali waters using closed-cycle OTEC calculations for a 5 MW system. Following this objective, we examined the water conditions by considering physical oceanography, such as temperature, currents, wind, and waves. The CTD data were obtained from the OTEC Bali MGI 2017 Team, and the temperature, current, wave, and wind model data were downloaded from Marine Copernicus. In line with this examination, North Bali exhibits warm surface waters and cold deep-sea temperatures that are suitable for OTEC operation. These values were capable of producing a temperature difference (ΔT) of more than 20°C, which is necessary to run the OTEC system, and both surface and deep-sea temperature variability tended to be stable. Fur-thermore, the efficiency value produced was 29.03% -30.78% with net power (Pnet) worth 2.84 MW - 3.22 MW. The wind conditions, surface currents, and waves met the specified conditions. Moreover, the station considered the most ideal for OTEC installation in North Bali waters was L-4, with an efficiency of 30.78%, T of 23.75°C, and the highest average Pnet value of 3.22 MW. These findings provide a technical basis for site-specific OTEC planning and support the potential development of a pilot-scale marine renewable energy system in Indonesia. Additionally, the location was 16.23 km from Kubutambahan District, Buleleng, which was the closest distance to land compared to other stations

Keywords

Clean Energy; OTEC; Bali; Hydro-oceanography

Authors

Widodo Setiyo Pranowo, Yani Permanawati, Gisela Malya Asoka Anindita, Agung Kurniawan, Albertus Sulaiman, Johar Setiyadi, Safri Burhanuddin, Ivonne Milichristi Radjawane, Hansan Park, and Endro Sigit Kurniawan

RESEARCH PAPER

Tapping Into the Ocean's Hidden Energy: Feasibility of A 5 MW OTEC Installation in North Bali

Widodo S. Pranowo [a,b,g,*], Yani Permanawati [c], Gisela M. Asoka Anindita [d], Agung Kurniawan [b], Albertus Sulaiman [a], Johar Setiyadi [a], Safri Burhanuddin [e,g], Ivonne M. Radjawane [f,g], Hansan Park [g], Endro S. Kurniawan [a]

[a] Research Center for Climate and Atmosphere, National Research and Innovation Agency (BRIN), KSTE Achmad Baiquni, Babarsari, Sleman, Special Region of Yogyakarta, Indonesia
[b] Indonesia Naval Postgraduate Military Service School (STTAL), West Kelapa Gading, Jakarta, Indonesia
[c] Marine Geological Institute, Geological Agency, The Ministry of Energy and Mineral Resources, Bandung, 40174, Indonesia
[d] Master Program of Marine Science, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Indonesia
[e] Department of Geological Engineering, Faculty of Engineering, University of Hasanuddin, Makassar, Indonesia
[f] Faculty of Earth Science and Technology, Institut Teknologi Bandung, Indonesia
[g] Korea - Indonesia Marine Technology Cooperation and Research Center (MTCRC), Jakarta, Indonesia

Abstract

Indonesia is an archipelagic country surrounded by water and faces energy challenges due to the low use of renewable energy. Among the potential renewable options, marine energy is a particularly suitable resource given the country's geographical nature. Based on this discussion, seawater temperature can be used as an alternative ocean thermal en-ergy known as ocean thermal energy conversion (OTEC) by using the difference in sea surface and deep-sea water temperatures. Therefore, this study aimed to examine OTEC installations in North Bali waters using closed-cycle OTEC calculations for a 5 MW system. Following this objective, we examined the water conditions by considering physical oceanography, such as temperature, currents, wind, and waves. The CTD data were obtained from the OTEC Bali MGI 2017 Team, and the temperature, current, wave, and wind model data were downloaded from Marine Copernicus. In line with this examination, North Bali exhibits warm surface waters and cold deep-sea temperatures that are suitable for OTEC operation. These values were capable of producing a temperature difference (ΔT) of more than 20 °C, which is necessary to run the OTEC system, and both surface and deep-sea temperature variability tended to be stable. Fur-thermore, the efficiency value produced was 29.03%−30.78% with net power (Pnet) worth 2.84 MW−3.22 MW. The wind conditions, surface currents, and waves met the specified conditions. Moreover, the station considered the most ideal for OTEC installation in North Bali waters was L-4, with an efficiency of 30.78%, T of 23.75 °C, and the highest average Pnet value of 3.22 MW. These findings provide a technical basis for site-specific OTEC planning and support the potential development of a pilot-scale marine renewable energy system in Indonesia. Additionally, the location was 16.23 km from Kubutambahan District, Buleleng, which was the closest distance to land compared to other stations.

Keywords: Clean energy, OTEC, Bali, Hydro-oceanography

1. Introduction

Renewable energy is derived from continually available and environmentally friendly natural resources [1−4]. This type of energy can replace fossil fuels, which are increasingly scarce and cause environmental damage [5,6]. Despite this record of scarcity and environmental damage, electricity generation in Indonesia is highly dependent on fossil fuels [7,8]. Fossil fuels generate more than

Received 16 September 2025; revised 10 May 2026; accepted 14 May 2026.
Available online 23 July 2026

* Corresponding author at: Research Center for Climate and Atmosphere, National Research and Innovation Agency (BRIN), KSTE Achmad Baiquni, Babarsari, Sleman, Special Region of Yogyakarta, Indonesia.
E-mail address: widodo.setiyo.pranowo@gmail.com (W.S. Pranowo).

https://doi.org/10.33640/2405-609X.3465

88% of electricity. Approximately 60% of the energy is produced from coal, 22% from natural gas, and 6% from oil, while only 12% is generated from renewable energy. As reported by Lestari, (2021) [9], Indonesia's low use of renewable energy is a part of the energy problems that should be addressed. The research and development aspects are a challenge in developing the use of renewable energy. Therefore, the country's analytical activities related to renewable energy need to be increased.

Marine energy is a source of renewable energy that can be used in Indonesia, a country surrounded by waters due to its archipelagic nature. Currently, marine renewable energy contributes almost 0% to Indonesia's national energy mix [10], despite the country's vast maritime area and significant ocean energy potential. This gap underscores the importance of site-specific feasibility studies, such as OTEC assessments, to support future marine energy development and inform national energy planning.

The potential for marine energy is very large in countries with vast seas [11–14]. Some marine energy resources include tides, waves, deep currents, and ocean thermal energy [15–19]. Seawater temperature is used as an alternative ocean thermal energy or OTEC (ocean thermal energy conversion) by exploiting the temperature difference (ΔT) between the sea surface and deep [20–24]. OTEC uses ΔT between the sea surface and the deep (minimum 20 °C) to operate generators and produce electrical energy while maximizing energy production [20,24]. In this discussion, a working system of technology is divided by [25] into four cycles, namely, open, closed, hybrid, and Kalina, which can be land-based and floating platform-based. Moreover, land-based OTECs have higher piping and land use installation costs. Floating platform installations have relatively lower land use and impact, requiring network cables to be laid ashore, resulting in higher construction and maintenance costs. In addition [26], found that OTEC could provide renewable energy sources required to meet various energy challenges in Indonesia with the vast sea surface when effectively and on a large scale.

The OTEC potential in 17 locations was explored and estimated to be 41 GW. The potential for marine thermal energy in Indonesian waters is estimated to produce around 240,000 MW of power [27]. It is important to know that the eastern part of the country, such as Bali waters, has a greater ΔT value than the western part, where the sea temperature in the deep layer is higher at the same depth, thereby offering significant potential for OTEC-based electricity production. However, not all locations are suitable for building ocean thermal energy plants due to the requirement for several supporting aspects in the construction. Following the discussion, it is crucial to determine the precise location of OTEC construction in waters.

A previous study by [28] examined the thermal characteristics of North Bali waters and found that surface temperature ranges between 28 and 31 °C. Meanwhile, deep sea water temperature was relatively stable at 5.75 °C, representing ocean thermal energy potential. In this context, calculation of a 100 MW turbine capacity as proposed by [29] can be considered. By using this method, the estimated energy potential reaches 71,709 MW. In addition to the discussion [30], also found that North Bali waters are ideal for OTEC power plants to generate electricity for small Islands because regional seas have an average monthly ΔT between 28 °C–31 °C and a maximum temperature efficiency of 0.78 reaching 69.4 kW. At $\Delta T = 20$ °C, the maximum Carnot efficiency is $\eta\_Carnot = 0.78$, which results in a thermal power of ~69.4 kW per flow rate of 1 kg/s.

The current seabed morphology in North Bali waters is the impact of marine geological processes on the environment. A part of the geological environment characteristic impacts on oceanographic situation is the division of Arlindo current route to Indian Ocean. However, this effect is triggered by the shape of the seabed in southern part of the Makassar Strait, where there is a Dewakang Threshold with a depth of up to 680 m [31,32]. Based on this study, Dewakang Threshold acts as a barrier between East and West Canal. North Bali waters are also a route for Arlindo which flows from West Canal to Indian Ocean [33–35]. A previous study by [36] stated that Arlindo had a relatively constant and cold temperature, ranging from 5 °C to 10 °C. Even though North Bali waters are located in a tropical area, surface current circulation in this region is influenced by monsoon patterns, which lead to seasonal changes. As a result of this pattern, surface layer currents however change direction twice a year due to the influence of seasonal changes which cause variations or characteristics of water density in North Bali waters.

The exploration examines OTEC installations in North Bali waters using the design of [37] through closed-cycle OTEC calculations based on the study of Nihous in 2007 with adjustments to the values of warm and cold-water flow rates for a capacity of 5 MW. In this context, water conditions are studied by considering physical oceanographic aspects such as temperature, currents, wind, and waves appropriate to the provisions of the concept design for the technology installations [38]. These basic conditions include a minimum sea surface temperature of 26 °C (annual average) in the range of 24–28 °C and deep-sea temperatures in the range of 4–5 °C. This study explicitly considers several critical environmental thresholds for a floating OTEC platform's successful and safe operation. The significant wave height must be less than 6 m [38], wind speed should not exceed 20 m/s [39], and the sea surface current must be less than 1.5 m/s [40]. These explicit limits serve as crucial evaluation benchmarks throughout the analysis. This study only covers physical surface oceanographic factors and does not include the type and strength of OTEC installation materials for internal waves propagating from the Indian Ocean to the Bali Sea through the Lombok Strait [41,42].

A study of OTEC installation with oceanographic conditions including temperature, currents, wind, and waves in North Bali waters needed to be conducted to determine conditions and the most ideal station points in technology installation to develop exploration related to renewable energy in Indonesia. Additionally, the result is performed through analysis of six station points which are considered representative of these waters (Fig. 1). Consequently, the selection of points is also based on water depth conditions with a depth of 700–900 m, therefore, ΔT value can exceed 20 °C appropriate to OTEC system requirements.

2. Methods and materials

2.1. Location of the study

This study used primary data, such as field temperature information and models, as well as secondary data to support information processing. Specifically, field temperature data were collected using Sea-Bird Electronics (SBE) 19 Plus V2 Conductivity Temperature Depth (CTD). The instrument was obtained from a survey conducted by P3GL in 2017 by Bali OTEC Team, Marine and Regional Energy R&D Implementation Group, Northern Waters region of Bali. Global Ocean Physics Reanalysis vertical temperature model data was downloaded from https://marine.copernicus.eu. [43]. Moreover, secondary data included Indonesian Base Map, bathymetry data from BATNAS BIG 2022, surface current data from CMEMS Global Ocean Physics Reanalysis, ocean wave data from Global Ocean Waves Analysis, and wind data from ASCAT.

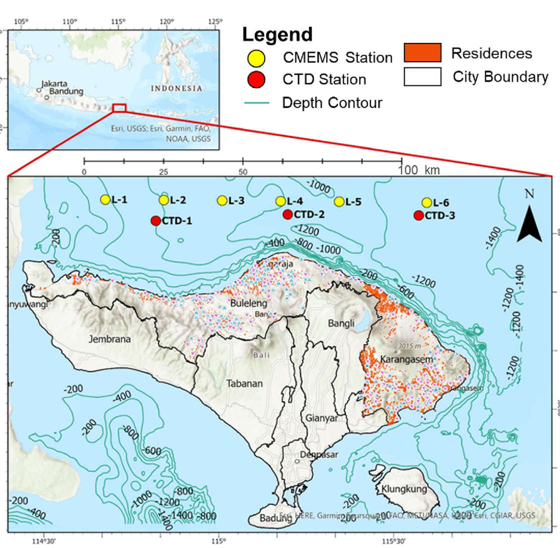

Fig. 1. Map of study location.

The selection of stations L1–L6 was based on data availability and technical suitability for OTEC operation, particularly water depths of approximately 700–900 m to ensure a temperature difference (ΔT) exceeding 20 °C. Distance to population centers was considered at a later evaluation stage to identify the most practical location for potential deployment.

2.2. Temperature data validation

The accuracy of the processing results on field data was determined in percentage values by calculating the relative error value. The model results were validated to examine the model's suitability. This step included comparing the model results with the field-measured results. Moreover, this study used two validation metrics, namely, mean relative error (MRE) and mean absolute error (MAE), where the equations were as follows:

$$RE = \frac{|x - c|}{x} \tag{1}$$

$$MRE = \frac{\sum_{i=1}^{n} RE}{n} \tag{2}$$

Description: x represented field data, c was model data, and n represented the amount of data. When the percentage error was low and the processed data closely matched field data, the processed results accurately represented the real-world situation [44]. MAE values in the range of 0–0.5 had good modeling quality [45] and the formula was calculated as follows:

$$MAE = \frac{\sum_{i=1}^{n} |a - b|}{n} \tag{3}$$

Description:

a presented model data.
b was field data.
n represented the amount of data.

2.3. Temperature variability

Water had quite a high urgency in OTEC system. Regions with significant temperature fluctuations were not suitable for OTEC installations as these led to inconsistent power production, which eventually failed to meet the minimum heat resource required for OTEC operations. Relating to this study, the method used included analyzing the standard deviation of monthly temperatures over 9 years at each location point, similar to the method used by [46]. The results of this study showed that a high standard deviation value showed large temperature variability, therefore, stability was reduced. The exploration used standard deviation for warm water temperature collected from a depth of 18.5 m (T_2) and cold-water temperature from a depth of 902.5 m (T_1) with the following equation:

$$SD=\sqrt{\frac{1}{N-1}\sum_{i=1}^{n}(T_i-\overline{T})^2} \quad (4)$$

N refers to the total number of observations, while T_i denotes the i-th individual value within the dataset. The term stands for the mean (or average) of all observed values. The expression $(T_i - \bar{T})$ calculates the deviation of each value from the mean, and squaring this difference $(T_i - \bar{T})^2$, ensures that all deviations are positive and that larger deviations are given more weight. The $\bar{T}$ indicates that these squared deviations are to be added up across all observations. Dividing this sum by $N - 1$, rather than N, applies Bessel's correction, which is used when calculating the standard deviation of a sample rather than a full population, ensuring an unbiased estimate of the population variance. Finally, taking the square root of this entire expression brings the units back to the original scale of the data, completing the calculation of the standard deviation.

2.4. Efficiency and power calculation

The calculation of the maximum thermodynamic efficiency for a Rankine cycle OTEC power system was described in [38,47]. In addition to this calculation, small losses in the electrical conversion steps, such as mismatches in the expansion and compression of the working fluid, were considered to reduce the gross electrical power output, leading to a gross OTEC conversion efficiency (α in %).

$$\alpha=\varepsilon_{tg}\frac{\Delta T}{2T_2} \quad (5)$$

Description: ε_{tg} represented a turbo generator efficiency with a value of 75%. The amount of gross electrical power P_g produced was from the evaporator heat load and thermodynamic efficiency which was calculated using the following equation.

$$P_g=\frac{3\gamma p Q_{cw}C_p(T_1-T_2)^2}{16(1+\gamma)T_2} \quad (6)$$

Description:
ρ ~ 1025 kg/m^3 represented the average density of seawater.
C_p ~4 kJ/kg K was the specific heat of seawater.
$\gamma = \frac{Qww}{Qcw}$ was a ratio that represented the surface flow rate of warm (Q_{ww} = 10.72 m^3/s) and cold seawater (Q_{cw} = 6.43 m^3/s).

The values of Q_{ww} and Q_{cw} were used to take reference from the 5 MW OTEC system design by [36]. The net power output (P_{net}) of a closed-cycle OTEC system can be estimated by combining the theoretical gross power potential and the parasitic losses due to seawater pumping. The gross power term is derived from the endoreversible heat engine model introduced by [44], where the optimal power output is achieved when thermal conductance is distributed evenly between the evaporator and condenser. The equation depends on the cold seawater volumetric flow rate (Q_{cw}), the seawater specific heat capacity (C_p), its density (implicitly included if Q_{cw} is converted to mass flow), the temperature difference squared ($\Delta T^2 = (T_1 - T_2)^2$), the cold source temperature (T_2), the flow ratio between cold and warm water (γ), and the generator efficiency ($\sum_{i=1}^{N}$).

The factor 16=(1+ γ)T^2represents the optimal thermal configuration of the system under ideal reversible conditions. The final term (1−σ) accounts for the fraction of power lost to operate the pumps and auxiliary components, where σ is 0.25 based on system design. Thus, this formula provides a more realistic estimation of net electrical output than idealized gross power calculations, by integrating both thermodynamic and operational efficiency considerations, see equation below:

$$P_{net}=\underbrace{\frac{3\gamma}{16(1+\gamma)T_2}}_{P_g^{max}}Q_{cw}C_p\Delta T^2\varepsilon_{tg}\times(1-\sigma) \quad (7)$$

The formula used in this exploration was based on [47] equation which was also used in previous studies by [38,48]. This equation was used to calculate power generated by OTEC system that operated on closed-cycle simulations.

A 5 MW plant capacity was selected following the floating OTEC conceptual design proposed by Hamedi and Sadeghzadeh (2017), representing a realistic pilot-scale system suitable for site-specific feasibility assessment.

3. Results and discussion

3.1. CMEMS and CTD data validation

The Temperature data were validated using the MRE and MAE methods [49], indicating the need for this validation step to show the compatibility between the two types of existing data. The model temperature data at stations L-2, L-4, and L-6 were validated using the in-situ field temperature data of the CTD instrument. The MRE calculations in Table 1 produced values ranging from 0.1 to 1.83%. Furthermore, the result supported the statement by [41] that low percentage error values indicate that the model data accurately represented the field temperature conditions. This circumstance was supported by validation data processing using the MAE method, which had a value range of 0.47−0.75. According to [45], the validation results indicate good model performance. The correlation between the model and field data is also shown in Fig. 2. Moreover, the three stations represented blue dots closely in line along a linear trend with a regression value of 0.992, showing a high level of agreement between the CMEMS model data and field CTD data. Based on the results of data validation calculations and correlation graphs, the temperature model data of the Copernicus Marine Environment Monitoring Service (CMEMS) was considered capable of representing temperature data in North Bali waters from 2012 to 2020.

3.2. Seawater temperature distribution

North Bali waters had a surface temperature in the range of 27.7−29.7 °C and deep sea water temperature of 5−6.5 °C. Relating to this study, water at the sea surface had a relatively warm temperature of around 28 °C, and water at a depth of around

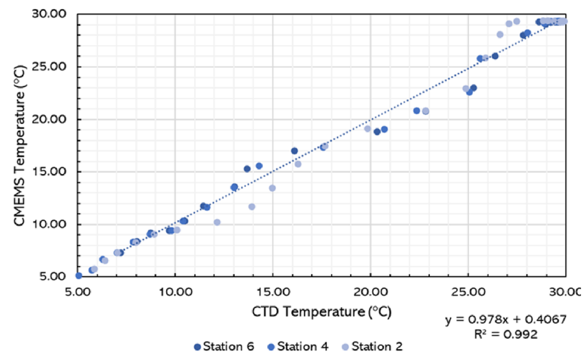

Fig. 2. CMEMS and CTD data correlation.

1000 m below sea level had a temperature of around 5 °C [50]. Tropical sea areas such as Bali waters had relatively constant temperatures in the year [51]. Additionally, sea surface temperature was influenced by weather conditions where various elements such as the amount of rainfall, evaporation rate, air humidity content, air temperature, wind speed, and intensity of sunlight performed a role in the high and low sea surface temperatures. Water at the sea surface was naturally warmer because it was exposed to sunlight during the day. However, when wind blew, a stirring process occurred, leading to mixing in the surface layer to a depth of around 50−70 m. This stirred layer had temperatures up to 28 °C, which was often called homogeneous layer. Seawater temperature decreases with increasing depth due to the attenuation of solar radiation in the upper ocean and the stratified nature of the water column, which limits vertical heat transfer. Cooler temperatures in deep sea water and warmer temperatures at the sea surface were used to run OTEC system. In addition to the discussion, North Bali waters reached ΔT of 20 °C at a depth of 500−600 m (Fig. 3).

3.3. Characteristics of sea water masses

Temperature-Salinity (T-S) diagram showed that in North Bali waters, there were eleven water mass characteristics identified based on [52] mass classification. This section discusses the vertical

Table 1. Station coordinates and validation data.

CMEMS Station	Latitude	Longitude	CTD Station	Latitude	Longitude	MRE	MAE
L-1	−7.91	114.66	–	–	–	–	–
L-2	−7.91	114.83	C-1	−7.95	114.81	1.83%	0.75
L-3	−7.91	115	–	–	–	–	–
L-4	−7.91	115.16	C-2	−7.95	115.187	0.40%	0.47
L-5	−7.91	115.33	–	–	–	–	–
L-6	−7.91	115.58	C-3	−7.95	115.54	0.01%	0.49

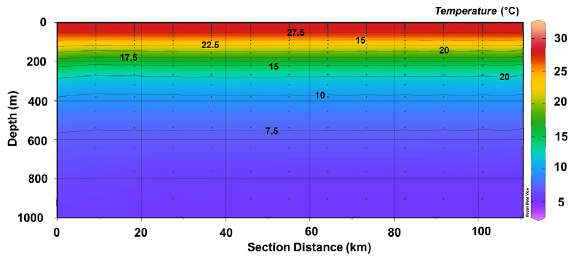

Fig. 3. Temperature distribution in North Bali waters.

distribution of seawater temperature with depth, emphasizing the contrast between surface and deep-sea layers relevant to the feasibility. Water mass of each region was characterized by the different temperature and salinity. For example, in Bengal Bay Water (BBW), temperature and salinity were 25–29 °C and 28–35 psu, respectively. South Indian Central Water (SICW) was cooler with temperature of 8–25 °C and salinity between 34.6 and 35.8 psu. Indonesian Upper Water (IUW) was between 8 and 23 °C and 34.4–35 psu, respectively, while that of Indian Equatorial water (IEW) was 8–23 °C and 34.6–35 psu. These four water masses originated and flowed from Indian Ocean. Eastern South Pacific Central Water (ESPCW) had respective temperature and salinity of 8.0–24.03 °C and 34.4–36.4 psu. The Western South Pacific Central Water (WSPCW) was between 6 and 22 °C, and 34.5–35.8 psu. Eastern North Pacific Central Water (ENPCW) was 12–20 °C and 34.2–35 psu, while Eastern South Pacific Transition Water (ESPTW) was 14–20 °C and 34.6–35.2 psu. In addition, the Western North Pacific Central Water (WNPCW) was 10–22 °C, and 34.2–35.2 psu, but Pacific Equatorial Water (PEW) was 7–23 °C and 34.5–36 psu, respectively. Typically, these six water masses originated from Pacific Ocean. Moreover, South Atlantic Central Water (SACW) mass was characterized by temperature of 5–18 °C and salinity of 34.3–35.8 psu (Fig. 4).

3.4. Temperature variability of warm and cold sea water

The annual variation in the average temperature in Indonesian waters was less than 2 °C, except in a few places such as Arafura, Timor, and southern Java Sea which had higher temperature variations of 3–4 °C [53]. Theoretically, temperature fluctuations in the waters were triggered by solar radiation hitting the sea surface and also influenced by other variables such as surface currents, cloud conditions, horizontal and vertical movement of water masses, and upwelling processes. The spatial distribution of temperature is often associated with seasonal

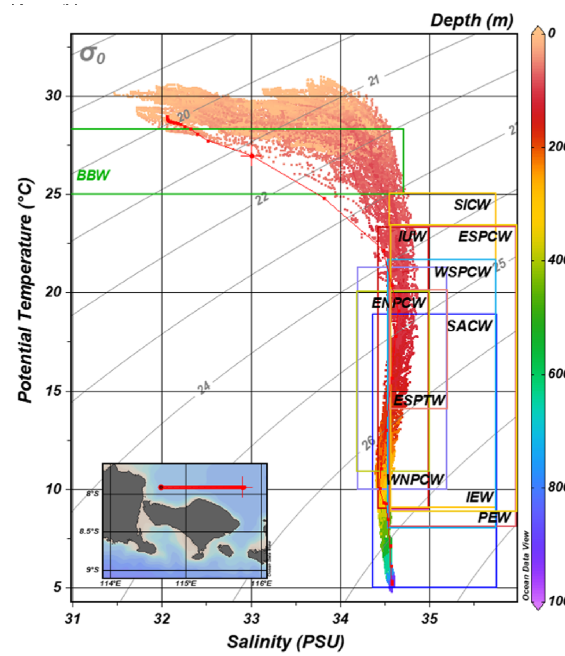

Fig. 4. Characteristics of water mass in North Bali waters.

changes [54]. Fig. 5 shows that the monthly variability lines tend to coincide, indicating that the temperature changes in North Bali waters were typically minimal. Moreover, the average temperature variability values were 0.664 for warm seawater (*Tws*) and 0.089 for cold seawater (*Tcs*), indicating that *Tws* tended to be higher than *Tcs*. This occurrence occurred because the temperature at the sea surface was strongly influenced by the monsoon, whereas *Tcs* was not influenced by monsoon conditions due to the depth was farther from the impact of external factors. Additionally, *Tws* and *Tcs* were calculated to determine the magnitude of the temporal temperature changes at each station point [46]. stated that OTEC resources were quite sensitive to temperature changes; therefore, testing temperature variability to assess the feasibility of implementing an OTEC system was of high urgency. The variability value in the waters of North Bali was considered sufficient for the technology operation.

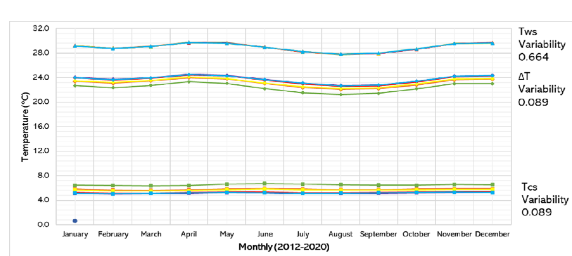

Fig. 5. Tws, Tcs, and ΔT variability in 2012–2020.

3.5. OTEC efficiency and power potential

The efficiency value was closely correlated with the OTEC power potential, and the power produced improved as the value increased. The efficiency, gross, and Pnet values in North Bali waters were shown in Table 2. The efficiency of the OTEC system in North Bali ranged from 28.5% to 31.1%. This value was calculated from minimal losses in the electrical conversion stage, such as the irreversible expansion and compression of the working fluid, which was considered to reduce the electrical power output. The highest efficiency value, with a maximum value of 31.1%, was observed at station L-4. This was related to the difference in the warm and cold sea water temperatures (T), which also had the highest value at the station. However, a high T value would further increase the efficiency of the OTEC system.

The gross electrical power (*Pg*) produced was the result of the evaporator heat load and thermodynamic efficiency with a 5 MW turbine, the calculation produced a value range of 4.78 MW–6.09 MW with a total average. The station with the lowest gross power potential value was at L-1 station and the highest at station L-4. Following this study, the difference in values was caused by different T values at each location point. *Pnet* calculation was estimated by considering the energy used to run OTEC system in driving the large flow speed of seawater through the system reaching 30% of the gross power [47]. In addition, *Pnet* in North Bali waters ranged from 2.69 MW to 3.42 MW, having station L-1 with the smallest value and station L-4, the largest value. The monthly average *Pnet* in North Bali waters from 2012 to 2020 showed relatively low variability, with a difference between months typically less than 1 MW, showing stable power generation in the year. Moreover, the maximum *Pnet* was in April and the minimum was in August. During west season, southwest value tended to be higher compared to east season. This development happened because the temperature in west season tended to be greater than east season as shown in Fig. 6. Relating to this study, the annual average *Pnet* showed insignificant variability, the variation from 2012 to 2020 was less than 0.5 MW. Additionally, Fig. 7 showed that for 9 years, the potential for stable power production in North Bali was evident, showing feasibility for installing OTEC system based on sea water temperature, variability, and calculation of *Pnet*.

Table 2. Efficiency, power gross, and net power in 2012–2020.

Station	Efficiency		Pg (MW)		Pnet (MW)	
	Min	Max	Min	Max	Min	Max
L-1	28.5%	29.6%	4.78	5.54	2.69	3.11
L-2	29.8%	30.5%	5.23	5.87	2.94	3.31
L-3	30.3%	31.0%	5.44	6.07	3.06	3.41
L-4	30.4%	31.1%	5.49	6.09	3.09	3.42
L-5	29.9%	30.6%	5.28	5.90	2.97	3.32
L-6	30.4%	31.0%	5.49	6.05	3.09	3.40

3.6. Physical oceanographic conditions (surface currents, wind and waves)

Physical factors such as surface currents, wind, and waves also were considered in OTEC installations for durability when floating in the middle of the sea. These physical factors were influenced by monsoon, prompting a study on climatology and seasonal classification. Relating to this discussion, the direction and speed of wind were shown in Fig. 8. West Monsoon was characterized by wind pattern moved from northwest to southeast, occurring in December, January, and February in the Java as well as Bali Seas. Moreover, this monsoon occurred because a center of high air pressure developed over Asian continent, and a center of low air pressure was created over Australian continent. East Monsoon was characterized by wind pattern moved from southeast to northwest which occurred in June, July, and August

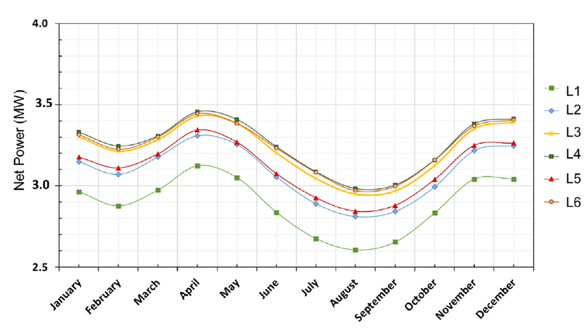

Fig. 6. Monthly average of OTEC net power.

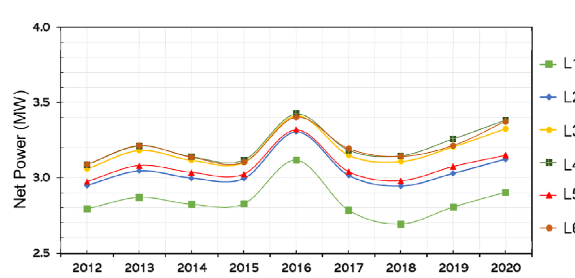

Fig. 7. Annually average of OTEC net power.

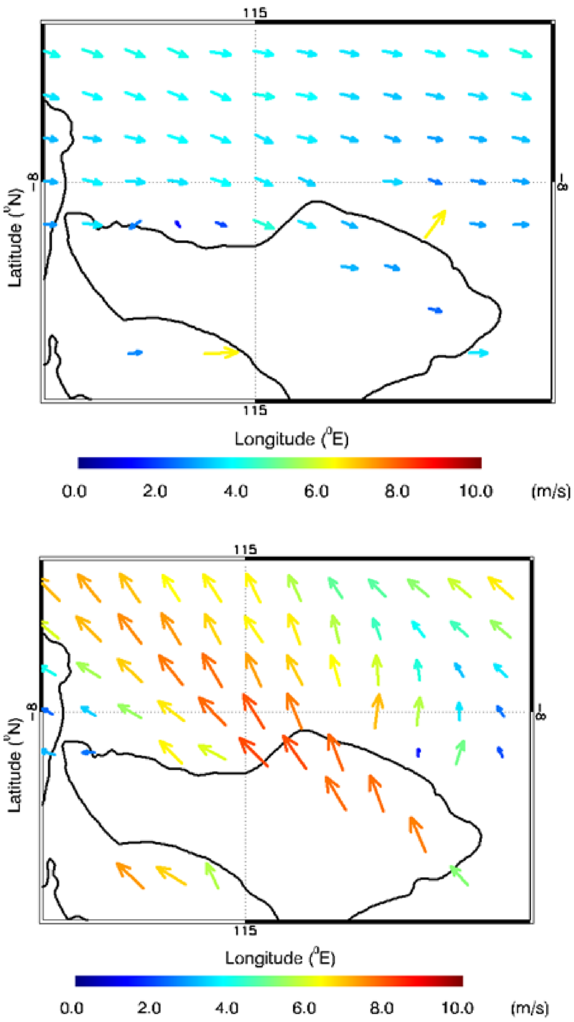

Fig. 8. Climatology Wind Condition in West Mon-soon and East Monsoon respectively.

in Java Sea as well as Bali. In addition, East Monsoon occurred due to a center of low air pressure that happened over Asian Continent and a center of high air pressure over the Australian Continent [53,55].

In the west season, the wind moved from the Asian continent toward Australia through Bali Island from west to east, whereas in the east season, the wind moved from the southeast toward the northwest through Bali Island from Australia toward Asia. Wind speed ranged from 0.1 to 6.0 m/s in west season and 0.1–8.0 m/s in east season. Concerning the discussion, wind speed also influenced the seawater temperature. The higher the speed, the more turbulence it caused in waters which led to the surface temperature becoming cooler and reduced ΔT between surface seawater and deep-sea water. In addition, wind conditions met the basic conditions for OTEC which was less than 20 m/s, where the climatological condition of sea currents was shown in Fig. 9. The pattern of surface currents was also influenced by wind, during west season, the current moved toward the east, and in east season, the current moved west. Furthermore, surface currents in west and east seasons tended to have the same value, which was around 0.1–0.4 m/s. Surface conditions were included in the ideal category for OTEC installations considering that the maximum speed for basic conditions was less than 1.5 m/s. Moreover, the significant wave height in Fig. 10 showed a direction pattern coming from west-southwest towards east with a range of 0.13–0.81 m in west season.

Wave heights in west season tended to be lower than in east season due to the lower wind influence in west season. During east season, stronger wind conditions also led to higher waves. Following this discussion, as wind was stronger and longer, the wave formation was higher. Wave conditions in

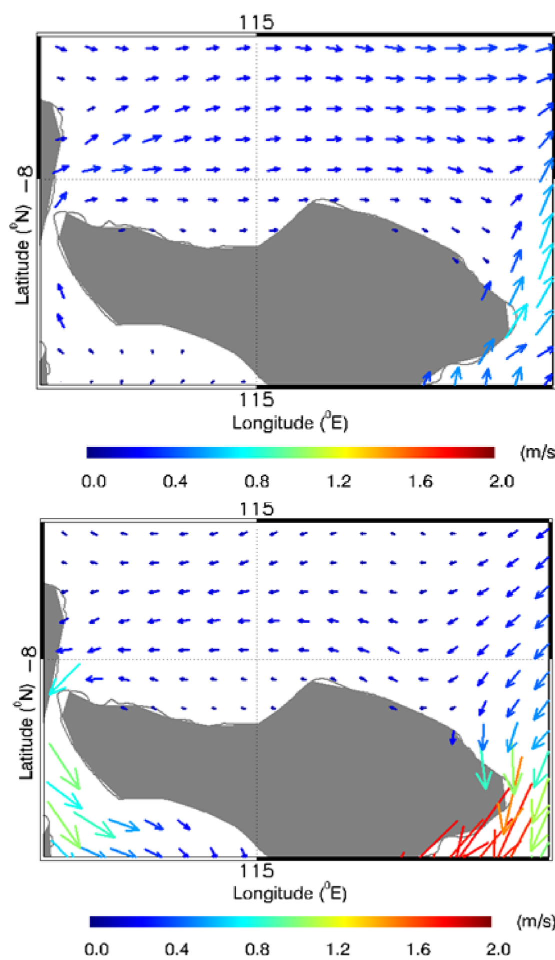

Fig. 9. Climatology Sea surface current condition in West Monsoon and East Monsoon respectively.

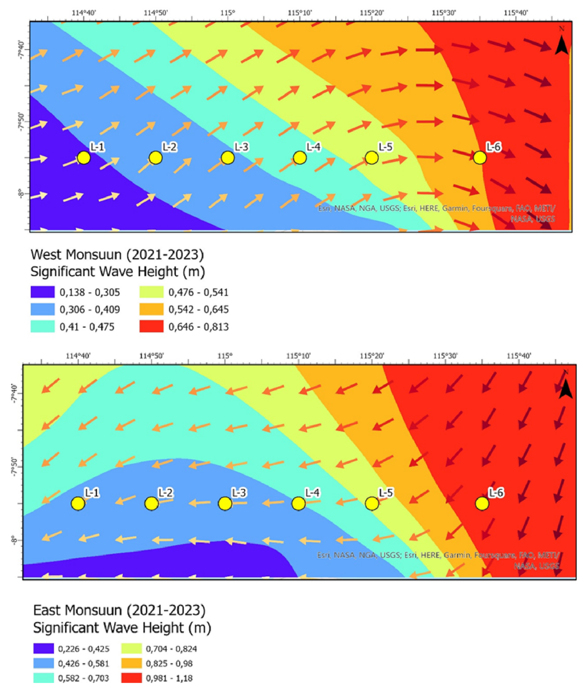

Fig. 10. Wave Condition in past 3 years in West Monsoon and East Monsoon respectively.

east season had a value of 0.22 m–1.18 m with the direction of the waves coming from northeast to west. In addition to the situation in west season, the dominant wind moved from north to west, pushing the waves to come in that direction. The dominant east monsoon wind blowing from northeast also promoted waves to come from that direction. Aside from being influenced by wind speed, wave conditions were also influenced through the persistence of the direction of wind. As the direction of wind in an area became uniform, the occurrence of wind increased. This occurred because wind blowing consistently in the same direction formed constructive waves that reinforced each other, allowing for the collection of wind energy. Moreover, stations L-1, L-2, L-3, and L-4 were in locations with very safe waves having a maximum wave range of only 0.5 m. At L-5 station, the wave height reached 0.8 m and at L-6 station the waves reached 1.18 m high. Relating to the result, the wave value according to basic conditions was still sufficient, which was less than 6 m. However, locations with minimal waves were considered to have more potential in OTEC installations.

The ΔT values among the six stations range from 22.39 °C to 23.75 °C, with station L-4 exhibiting the highest and most stable ΔT. This higher ΔT directly contributes to increased thermal efficiency and net power output compared to the other locations. Stations with slightly lower ΔT values show correspondingly lower efficiency and Pnet, highlighting the sensitivity of OTEC performance to thermal gradients.

3.7. OTEC installation ideal station

The selected station points in North Bali waters met the basic requirement set, as all stations had ΔT between surface and deep seawater of more than 20 °C. This study used OTEC design of [36] with a floating platform capacity of 5 MW turbine, selecting a closed-cycle floating platform. Fur-thermore, Table 3 showed the stations and the distance from the coastline. Northern part of Bali Island was dominated by Buleleng and Ka-rangasem Regencies as shown in Fig. 1. In this area, there were residential, hospitals, buildings, and government regions, indicating the need for electricity. Moreover, the selection of the most ideal station was determined by the amount of Pnet produced and the distance to the coastline where electricity was distributed [56]. Station L-4 had an efficiency of 31.1%, T of 23.63 °C, and the highest average Pnet value among the other stations, namely 3.22 MW. Additionally, the lo-cation was 16.23 km from the Kubutambahan District, which was the closest distance to land compared to other stations. Wind, surface cur-rents, and wave conditions at this location were quite potential. Concerning this study, station L-4 was the most ideal station for installing OTEC system.

The results of this study align well with, and extend beyond, prior OTEC potential investigations in the waters of North Bali. Previous study identified surface temperatures of 28–31 °C maximum Carnot efficiency is 0.78, which theoretically suggests that OTEC is an alternative energy because of

Table 3. Temperature difference (ΔT), efficiency, pnet, max depth, distance and subdistrict.

Station	ΔT (°C)	Efficiency (%)	Average *pnet* (MW)	Max depth (m)	Distance (km)	Subdistrict
L-1	22.39	29.03	2.84	643.56	23.47	Gerokgak
L-2	23.14	29.98	3.04	763.33	29.15	Gerokgak
L-3	23.64	30.64	3.18	902.33	22.43	Sawan
L-4	23.75	30.78	3.22	902.33	16.23	Kubutambahan
L-5	23.25	30.13	3.08	763.33	21.30	Tejakula
L-6	23.72	30.70	3.21	763.33	30.80	Tejakula

its minimal negative impact on the environment, especially using a close-cycle system [30], in line with this study which focuses on a 5 MW closed-cycle floating-platform system, applying the design framework of [37] and the thermodynamic formulations [47]. This is a clear advance over [29], who reported maximum Carnot efficiency of 0.78 (≈69.4 kW per 1 kg/s of seawater flow) based on $\Delta T = 20\ ^{\circ}C$, but did not assess multi-year variability or ancillary physical factors such as currents, wind, and wave conditions.

Another point of novelty lies in the integrated evaluation of wave, wind, and surface current climatology alongside thermal resource assessment. Previous studies [28,30] largely focused on temperature-only feasibility, or on large (≥100 MW) land-based or shoreline OTEC conceptual designs. By contrast, our study incorporates ASCAT wind data and Global Ocean Waves Analysis over the past three years to confirm that wind speeds remain below 8 m/s and significant wave heights below 1.2 m at all stations during both monsoon seasons. Similarly, CMEMS surface current data show speeds of 0.1−0.4 m/s, well under the 1.5 m/s threshold for floating-platform stability. To our knowledge, this is among the first studies physical oceanographic tolerances (wind, current, waves) have been jointly evaluated with thermal resource stability for North Bali's floating OTEC sites. This multidimensional approach not only corroborates the thermal analysis but also ensures that platform survivability and steady operation are feasible, which previous single-factor studies did not explicitly address.

The station-level comparison highlights both consistencies and improvements over prior work. Ilahude et al., (2020) identified general zones around Tejakula, and Kubutambahan as thermally promising; however, they did not quantify net electrical output (P_{net}) or factor in distance to land for distribution infrastructure. Our results show that station L-4 (near Kubutambahan) combines the highest average P_{net} (≈3.2 MW) with an efficient ΔT of 23.75 °C yielding thermal efficiency up to 30.78% in peak months and lies only 16.23 km from the nearest power demand center. In contrast, Ilahude et al. assumed a 100 MW plant in the general North Bali region but did not specify optimal platform siting or validate model temperatures against field CTD. By validating CMEMS data (MRE 0.01−1.83%, MAE 0.47−0.75) at L-2, L-4, and L-6, we confirm that the model accurately represents real-time conditions, thus increasing confidence in the finer spatial recommendations.

From a technical vantage point, choosing a 5 MW closed-cycle design offers clear benefits. Hamedi & Sadeghzadeh, (2017) demonstrated that smaller, modular floating plants can be scaled more flexibly than large land-based facilities, reducing upfront capital barriers. Our study not only confirms the thermodynamic viability of a 5 MW design in Bali's waters but also quantifies pump parasitic losses (σ ≈ 0.30) and identifies minimal monthly P_{net} variability (Δ < 1 MW). The stable P_{net} profile correlating with April maxima and August minima indicates that even during the less favorable east season, power output remains commercially acceptable (≥2.84 MW). This addresses a key limitation in earlier conceptual assessments, which did not account for seasonal power fluctuations. The novelty, therefore, resides in demonstrating that a modest-scale floating OTEC plant can deliver reliable baseload power to nearby coastal communities throughout the year.

From a practical standpoint, the selection of station L-4 as the optimal site effectively addresses both technical and logistical considerations. Its relatively short distance from the shoreline (16.23 km) significantly reduces the cost of submarine cable installation to Kubutambahan, which is an important factor that has been largely overlooked in previous studies. Economically, with an average net power output of 3.2 MW and a thermal efficiency of approximately 30.78%, OTEC presents a viable source of sustainable clean energy for the Buleleng region, contributing to the reduction of dependence on fossil fuels, which currently account for approximately 88% of electricity generation in Indonesia. The successful integration of in-situ observations and long-term reanalysis data further establishes a methodological foundation for OTEC site planning in other regions of Indonesia with similar geophysical characteristics, such as the northern coast of East Java or the southern coast of Sulawesi. From a research perspective, these findings offer novel insights into the thermal stability of tropical ocean heat reservoirs for medium-scale energy systems, thereby enriching the existing body of literature, which has predominantly focused on laboratory-scale experiments or large-scale theoretical projections (≥100 MW).

Accordingly, this study not only reinforces the evidence that Northern Bali is a highly promising site for OTEC development, but also underscores the value of an integrated approach with combining field data, model reanalysis, and evaluation of physical oceanographic factors, in delivering more reliable and practically applicable site recommendations. As a practical implication, local governments and energy stakeholders may consider the development of a 5 MW OTEC pilot plant at station L-4, while also utilizing our methodological framework as a guideline for identifying other potential sites across tropical regions.

Despite the promising results, this study is subject to several limitations that should be acknowledged. The computation analysis is primarily based on in-situ and reanalysis datasets, and does not explicitly address economic feasibility, platform construction considerations, or detailed environmental impact assessments. Consequently, the findings should be interpreted as a preliminary technical assessment that provides a foundation for more comprehensive, multidisciplinary investigations in future OTEC development studies.

4. Conclusions

In conclusion, North Bali waters exhibit favorable conditions for the implementation of an OTEC system, characterized by sufficiently warm surface waters and cold deep-sea temperatures capable of producing a temperature difference exceeding 20 °C. Both surface and deep-sea temperature variability tend to be stable, supporting the continuous operation of the OTEC system. In addition, wind conditions, surface currents, and wave characteristics in the study area meet the basic operational requirements for floating OTEC installations. Among the six evaluated locations, station L-4 is identified as the most suitable site for OTEC deployment in North Bali waters. This station demonstrates comparatively higher thermal performance and net power output, while also being located closest to the shoreline, which provides logistical advantages for power transmission to land. These characteristics make station L-4 particularly favorable for a medium-scale floating OTEC installation. The present study demonstrates that a 5 MW closed-cycle floating OTEC plant is technically feasible in North Bali waters. The integration of thermal characteristics and physical oceanographic conditions provides a comprehensive basis for site selection and highlights the potential of OTEC as a reliable source of baseload electricity. Overall, the findings support the development of a pilot-scale 5 MW floating OTEC installation at station L-4 as a strategic step toward advancing sustainable marine renewable energy utilization in Indonesia.

Ethics information

This study did not involve human participants, human data, or animal subjects. Oceanographic field data (CTD) were collected through institutional survey activities and do not require ethical approval. Therefore, ethics approval is not applicable to this study.

Funding

This research did not receive any specific grant or funding from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The author(s) declare(s) that they have no competing interests.

Acknowledgements

The authors greatly acknowledge Marine Geological Institute (Balai Besar Survey dan Pemetaan Geologi Kelautan (BBPSGL) which formerly was Pusat Penelitian Geologi Kelautan (PPGL)) for providing CTD data survey. Secondary data was obtained from CMEMS Marine Copernicus. The study was conducted on the Marine Geological Institute Labs in Bandung and continue in Hydro-Oceanography Labs of the Indonesia Naval Postgraduate Military Service School (STTAL) in Jakarta, for the framework of Fusion-Oceanography database development. We also thank The Korea – Indonesia Marine Technology Cooperation and Research Centern (MTCRC) for facilitating online discussions. We also thank Research Center for Climate and Atmosphere (PRIMA), National Research and Innovation Agency (BRIN), and thank Department of Oceanography, University of Diponegoro, and Faculty of Geography, University of Gadjah Mada. Widodo Setiyo Pranowo, Yani Permanawati, and Gisela Malya Asoka Anindita were main contributor in this study. All authors discussed results and commented on the manuscript.

References

[1] T. Güney, Renewable Energy, Non-renewable energy and sustainable development, Int. J. Sustain. Dev. World Ecol. 26 (2019) 389–397, https://doi.org/10.1080/13504509.2019.1595214.

[2] S. Hazim, M.T. Janan, A. Elouatouati, A. Benazzouz, A. Ghennioui, B. Ikken, Modeling the velocity of marine currents resources on a Moroccan coastal (Tarfaya) using SWAN model, Proc 9th Int Renew Energy Congr. (IREC) (2018) 1–4, https://doi.org/10.1109/IREC.2018.8362571.

[3] S. Shayanmehr, R. Radmehr, E.B. Ali, E.K. Ofori, T.S. Adebayo, B.A. Gyamfi, How do environmental tax and renewable energy contribute to ecological sustainability? New evidence from top renewable energy countries, Int. J. Sustain. Dev. World Ecol. 30 (2023) 650–670, https://doi.org/10.1080/13504509.2023.2186961.

[4] J. Tian, S.A. Culley, H.R. Maier, A.C. Zecchin, Is renewable energy sustainable? Potential relationships between renewable energy production and the sustainable development goals, npj Clim Act 3 (2024) 1–7, https://doi.org/10.1038/s44168-024-00120-6.
[5] Z. Wang, Q. Li, S. Kong, W. Li, J. Luo, T. Huang, Analysis of renewable energy consumption and economy considering the joint optimal allocation of ‘renewable energy + energy storage + synchronous condenser’, Sci. Rep. 13 (2023) 1–13, https://doi.org/10.1038/s41598-023-47401-4.
[6] M.M. Rahman, A.K. Mohanty, M.H. Rahman, Renewable energy, forestry, economic growth, and demographic impact on carbon footprint in India: does forestry and renewable energy matter to reduce emission? J. Environ. Stud. Sci. 14 (2024) 415–427, https://doi.org/10.1007/s13412-024-00912-6.
[7] D. Hartono, S.H. Hastuti, A. Halimatussadiah, A. Saraswati, A.F. Mita, V. Indriani, Comparing the impacts of fossil and renewable energy investments in Indonesia: a simple general equilibrium analysis, Heliyon 6 (2020) e04120, https://doi.org/10.1016/j.heliyon.2020.e04120.
[8] D. Arinaldo, J.C. Adiatma, Indonesia's Coal Dynamics, Institute for Essential Services Reform, 2019, pp. 1–12. https://iesr.or.id/download/spm-indonesias-coal-dynamics-pdf.
[9] P.V. Lestari, Ringkasan Permasalahan Dan Tatangan Program Peningkatan Kontribusi Energi Baru Dan Terbarukan Dalam Bauran Energi Nasional, Pusat Kajian Akuntabilitas Keuangan Negara, 2021, pp. 1–5.
[10] Ministry of Energy and Mineral Resources Republic of Indonesia, Handbook of Energy and Economic Statistics of Indonesia, Ministry of Energy and Mineral Resources Republic of Indonesia, 2025.
[11] S. Riyanto, Kajian pemanfaatan potensi suhu air laut sebagai sumber energi, Jurnal Inovtek Polbeng 7 (2017) 20–28. https://uisi.ac.id/assets/upload/media/e561d3135da225b8d63a752f7b521633.pdf.
[12] Y. Cui, H. Zhao, Marine renewable energy project: the environmental implication and sustainable technology, Ocean Coast Manag 232 (2023) 106415, https://doi.org/10.1016/j.ocecoaman.2022.106415.
[13] K. Malik, W.S. Pranowo, N.B. Sukoco, D. Adrianto, J. Setiyadi, D. Handoko, Hydrodynamic characteristics of the Lombok Strait during the 2022 West Monsoon peak and estimation of ocean current power generation potential, Comput. Exp. Res. Mater. Renew. Energy. 6 (2023) 72, https://doi.org/10.19184/cerimre.v6i2.43786.
[14] M.Z.H. Majumder, M.T.A. Shampa, M.A. Islam, S.A. Deowan, F. Hafiz, Marine renewable energy harnessing for sustainable development in Bangladesh: a technological review, Energy Rep 11 (2024) 1342–1362, https://doi.org/10.1016/j.egyr.2024.01.001.
[15] M. Nachtane, M. Tarfaoui, A. El Moumen, D. Saifaoui, Numerical investigation of damage progressive in composite tidal turbine for renewable marine energy, in: Proc. Int. Renew. Sustain. Energy Conf. (IRSEC), 2017, pp. 559–563, https://doi.org/10.1109/IRSEC.2016.7984026.
[16] P. Quero García, J. García Sanabria, J.A. Chica Ruiz, Marine renewable energy and maritime spatial planning in Spain: main challenges and recommendations, Mar Pol 127 (2021) 104444, https://doi.org/10.1016/j.marpol.2021.104444.
[17] J.V. Ringwood, Marine renewable energy devices and their control: an overview, IFAC-PapersOnLine 55 (2022) 136–141, https://doi.org/10.1016/j.ifacol.2022.10.421.
[18] M. Penalba, J.I. Aizpurua, A. Martinez-Perurena, G. Iglesias, A data-driven long-term metocean data forecasting approach for the design of marine renewable energy systems, Renew. Sustain Energy Rev. 167 (2022) 112751, https://doi.org/10.1016/j.rser.2022.112751.
[19] Y. Theodora, S. Piperis, Marine renewable energy perspectives in the mediterranean region: planning priorities in a climate neutrality era, Ocean Coast Manag 229 (2022) 106307, https://doi.org/10.1016/j.ocecoaman.2022.106307.
[20] A. Hossain, A. Azhim, A.B. Jaafar, M.N. Musa, S.A. Zaki, D. N. Fazreen, Ocean thermal energy conversion: the promise of a clean future, in: IEEE Conf. Clean Energy Technol. (CEAT), 2013, pp. 23–26, https://doi.org/10.1109/CEAT.2013.6775593.
[21] S. Hoseinzadeh, E. Assareh, A. Riaz, M. Lee, D. Astiaso Garcia, Ocean thermal energy conversion (OTEC) system driven with solar-wind energy and thermoelectric based on thermo-economic analysis using multi-objective optimization technique, Energy Rep. 10 (2023) 2982–3000, https://doi.org/10.1016/j.egyr.2023.09.131.
[22] Y. Du, H. Peng, J. Xu, Z. Tian, Y. Zhang, X. Han, Y. Shen, Performance analysis of ocean thermal energy conversion system integrated with waste heat recovery from offshore oil and gas platform, Case Stud Therm Eng 54 (2024) 104027, https://doi.org/10.1016/j.csite.2024.104027.
[23] C. Fan, C. Zhang, W. Gao, Improving the ocean thermal energy conversion by solar pond, Sol Energy 274 (2024) 112583, https://doi.org/10.1016/j.solener.2024.112583.
[24] A. Rashid, T.H. Nakib, T. Shahriar, M.A. Habib, M. Hasanuzzaman, Energy and economic analysis of an ocean thermal energy conversion plant for Bangladesh: a case study, Ocean Eng 293 (2024) 116625, https://doi.org/10.1016/j.oceaneng.2023.116625.
[25] J. Koto, Potential of ocean thermal energy conversion in Indonesia, Int. J. Environ. Res. Clean Energy. 4 (2016) 1–7. http://isomase.org/IJERCE1.php.
[26] M.L. Syamsuddin, A. Attamimi, A.P. Nugraha, S. Gibran, A. Q. Afifah, N. Oriana, OTEC potential in the Indonesian seas, Energy Proc 65 (2015) 215–222, https://doi.org/10.1016/j.egypro.2015.01.028.
[27] Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, Potensi Energi Laut Indonesia Terbesar di Dunia. Kementerian Energi Dan Sumber Daya Mineral Republik Indonesia, 2017. https://www.esdm.go.id/id/media-center/arsip-berita/potensi-energi-laut-indonesia-terbesar-di-dunia.
[28] D. Ilahude, A. Yuningsih, Y. Permanawati, M. Yosi, R. Zuraida, N. Annisa, Site determination for OTEC turbine installation of 100 MW capacity in north Bali waters, Bull Mar Geol 35 (2020) 1–12, https://doi.org/10.32693/bomg.35.1.2020.594.
[29] H. Uehara, Y. Ikegami, Optimization of a closed-cycle OTEC system, J Sol Energy Eng 112 (1990) 247–256, https://doi.org/10.1115/1.2929931.
[30] A.R. Sinuhaji, Potential ocean thermal energy conversion (OTEC) in Bali, KnE Energy 1 (2015) 5, https://doi.org/10.18502/ken.v1i1.330.
[31] A.L. Gordon, C.F. Giulivi, A.G. Ilahude, Deep topographic barriers within the Indonesian seas, Deep Sea Res Part II Top Stud Oceanogr 50 (2003) 2205–2228, https://doi.org/10.1016/S0967-0645(03)00053-5.
[32] A. Atmadipoera, S. Horhoruw, M. Purba, D. Nugroho, Variasi Spasial dan Temporal Arlindo di Selat Makassar, J. Ilmu Teknol. Kelaut. Trop. 8 (2016) 299–320. http://itk.fpik.ipb.ac.id/ej_itkt81.
[33] R.D. Susanto, A. Ffield, A.L. Gordon, T.R. Adi, Variability of Indonesian throughflow within Makassar Strait, 2004-2009, J Geophys Res Oceans 117 (2012) 1–16, https://doi.org/10.1029/2012JC008096.
[34] A.L. Gordon, R.D. Susanto, A. Ffield, B.A. Huber, W. Pranowo, S. Wirasantosa, Makassar Strait throughflow, 2004 to 2006, Geophys Res Lett 35 (2008) L24605, https://doi.org/10.1029/2008GL036372.
[35] A.L. Gordon, J. Sprintall, H.M. Van Aken, D. Susanto, S. Wijffels, R. Molcard, A. Ffield, W. Pranowo, S. Wirasantosa, The Indonesian throughflow during 2004–2006 as observed by the INSTANT program, dyn. Atmos, Oceans 50 (2010) 115–128, https://doi.org/10.1016/j.dynatmoce.2009.12.002.
[36] N.H. Raharjo, Studi Pemanfaatan Energi Panas Laut Dan Gelombang Laut Untuk Sistem Kelistrikan Di Kabupaten Karangasem Bali, Institut Teknologi Sepuluh Nopember. 2011. Bachelor Thesis.

[37] A.S. Hamedi, S. Sadeghzadeh, Conceptual design of a 5 MW OTEC power plant in the Oman Sea, J. Mar. Eng. Technol. 16 (2017) 94−102, https://doi.org/10.1080/20464177.2017.1320839.
[38] A. Devis-Morales, R.A. Montoya-Sánchez, A.F. Osorio, L.J. Otero-Díaz, Ocean thermal energy resources in Colombia, Renew Energy 66 (2014) 759−769, https://doi.org/10.1016/j.renene.2014.01.010.
[39] J.N. Goundar, M.R. Ahmed, Marine current energy resource assessment and design of a marine current turbine for Fiji, Renew Energy 65 (2014) 14−22, https://doi.org/10.1016/j.renene.2013.06.036.
[40] G.M.A. Anindita, D.N. Sugianto, Y. Permanawati, Potential of ocean thermal energy conversion (OTEC) in the north waters of lembata, NTT, Bull Mar Geol 38 (2023) 1−13, https://doi.org/10.32693/bomg.38.1.2023.789.
[41] R. Dwi Susanto, L. Mitnik, Q. Zheng, Ocean internal waves observed in the Lombok Strait, Oceanography 18 (2005) 81−87, https://doi.org/10.5670/oceanog.2005.08.
[42] Y. Pratomo, W.S. Pranowo, H. Setiadi, Identifikasi Penjalaran Gelombang Panjang Samudera Hindia Ke Selat Lombok Berdasarkan Komponen Harmonik Arus, Omni-Akuatika, 12, 2016, pp. 22−29, https://doi.org/10.20884/1.oa.2016.12.1.26.
[43] N. Ferry, Global Ocean Reanalysis Products GLOBAL-REANALYSIS-PHYS-001-009, 2023.
[44] L.F. Ichsari, G. Handoyo, H. Setiyono, A. Ismanto, J. Marwoto, M. Yusuf, A. Rifai, Studi Komparasi Hasil Pengolahan Pasang Surut Dengan 3 Metode (Admiralty, Least Square Dan Fast Fourier Transform) Di Pelabuhan Malahayati, Banda Aceh, Indones, J Oceanogr 2 (2020) 121−128, https://doi.org/10.14710/ijoce.v2i2.7985.
[45] T. Chai, R.R. Draxler, Root mean square error (RMSE) or mean absolute error (MAE)? Geosci Model Dev 7 (2014) 1247−1250, https://doi.org/10.5194/gmd-7-1247-2014.
[46] T. Suprijo, P.R. Poerbo, H. Park, A.R. Kartadikaria, M. Yosi, Potential ocean thermal energy conversion in Indonesian waters territory, J Coast Res 114 (2021) 285−289, https://doi.org/10.2112/JCR-SI114-058.1.
[47] G.C. Nihous, A preliminary assessment of ocean thermal energy conversion resources, J Energy Resour Technol 129 (2007) 10−17, https://doi.org/10.1115/1.2424965.
[48] W. Suparta, Marine heat as a renewable energy source, Widyakala J 7 (2020) 37, https://doi.org/10.36262/widyakala.v7i1.278.
[49] D.H. Ismunarti, M. Zainuri, D.N. Sugianto, S.W. Saputra, Pengujian reliabilitas instrumen terhadap variabel kontinu untuk pengukuran konsentrasi Klorofil- A perairan, Bull. Oseanogr. Mar. 9 (2020) 1−8, https://doi.org/10.14710/buloma.v9i1.23924.
[50] B. Halimi, Amonia Sebagai Fluida Kerja Pembangkit Listrik Tenaga Panas Laut Alternatif Solusi Kelistrikan di Indonesia, in: Seminar Nasional Sains Dan Teknologi, 2018, pp. 1−2. https://jurnal.umj.ac.id/index.php/semnastek/article/view/1909.
[51] M. Widyartono, R. Rahmadian, Potensi OTEC Di Provinsi Papua Indonesia, Indones, J Electr Electron Eng 2 (2019) 17−21, https://doi.org/10.26740/inajeee.v2n1.p17-21.
[52] W.J. Emery, Water types and water masses, Encyclopedia of Ocean Sci. (2001) 3179−3187, https://doi.org/10.1006/rwos.2001.0108.
[53] K. Wyrtki, Physical oceanography of the Southeast Asian waters, Naga Report 2 (1961).
[54] S.B. Atmadja, D. Nugroho, H.T. Suwarso, Pengkajian Stok Ikan di Wilayah Pengelolaan Perikanan (WPP) Laut Jawa, in: Prosiding Pengkajian Stok Ikan Laut Di Perairan Indonesia, 2003, pp. 23−24. Jakarta.
[55] S.N. Siregar, L.P. Sari, N.P. Purba, W.S. Pranowo, M.L. Syamsuddin, Pertukaran Massa Air di Laut Jawa Terhadap Periodisitas Monsun dan Arlindo pada Tahun 2015, Depik, 6, 2017, pp. 44−59, https://doi.org/10.13170/depik.6.1.5523.
[56] C. Julianto, Studi Potensi Pemanfaatan OTEC (Ocean Thermal Energy Conversion) Menggunakan Siklus Terbuka untuk Mengatasi Krisis Listrik dan Air Bersih di Pulau Lembata, Nusa Tenggara Timur, in: Prosiding Seminar Nasional Teknik Kimia “Kejuangan” Pengembangan Teknologi Kimia Untuk Pengolahan Sumber Daya Alam Indonesia, 2020. https://jurnal.upnyk.ac.id/index.php/kejuangan/article/view/3631.