POTENTIAL OF OCEAN THERMAL ENERGY CONVERSION (OTEC) IN THE NORTH WATERS OF LEMBATA, NTT

POTENSI KONVERSI ENERGI TERMAL LAUTAN DI PERAIRAN UTARA LEMBATA, NTT

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ABSTRACT: Ocean thermal energy conversion is an attempt to convert potential energy in the variances heat content of seawater into other energy by utilizing the temperature change between the sea surface and deep sea at least 20°C. The Lembata waters is near to the equator, sea surface temperature tends to be warm and stable. This research was conducted to estimate the potential energy generated from a closed cycle OTEC system in North Lembata Waters. This study used temperature data from Global Ocean Physics Reanalysis from Copernicus Marine Environment Monitoring Service (CMEMS) for 9 years (2012-2020) in 6 stations. Validation was performed using the primary CTD Lembata OTEC Team of the Marine Geological Institute (MGI). Temperature data validation results on the MSE (Mean Square Error), RMSE (Root Mean Square Error), and MAPE (Mean Absolute Percentage Error) methods are considered to represent field temperature conditions. The variability value shows the station point in the North Lembata Waters has a temperature with slight differences. The vertical temperature change (ΔT) shows between 20.98°C to 23.44°C. Potential electric power resulting from the OTEC system using the technical estimation formula. The average net power generated from those temperature gradients ranges from 5.65 MW-7.56 MW, respectively. The Lembata waters have temperature conditions suitable for OTEC installations. Station C-4 has a power potential of 6.84 MW with a depth of 763 m and the distance of 1.86 km from the coastline. Station C-4 in the Omesuri sub-district is the best point for OTEC installation in North Lembata Waters.

Keywords: potential energy, seawater temperature, OTEC, Lembata

***ABSTRAK**: Konversi energi termal lautan merupakan upaya untuk mengubah energi potensial berupa perbedaan kandungan panas/bahang air laut menjadi bentuk energi yang lain dengan memanfaatkan perbedaan suhu antara permukaan laut dan laut dalam minimal 20°C. Perairan Lembata dekat dengan garis ekuator sehingga suhu permukaan air laut cenderung hangat dan stabil. Penelitian ini dilakukan untuk memperkirakan energi potensial yang dapat dihasilkan dari sistem OTEC siklus tertutup, jika sistem tersebut dipasang di Perairan Lembata Utara. Studi ini menggunakan Global Ocean Physics Reanalysis dari data suhu Copernicus Marine Environment Monitoring Service (CMEMS) selama 9 tahun (2012-2020) dari 6 stasiun dan divalidasi menggunakan data primer CTD yang diambil oleh Tim OTEC Lembata P3GL. Hasil verifikasi data suhu pada metode MSE (Mean Square Error), RMSE (Root Mean Square Error), dan MAPE (Mean Absolute Presentage Error) dinilai dapat merepresentasikan kondisi suhu lapangan. Nilai variabilitas suhu menunjukan bahwa titik stasiun di Perairan Utara Lembata memiliki suhu dengan perbedaan yang kecil. Perbedaan suhu air laut hangat dan dingin (ΔT) berkisar 20,98°C-23,44°C. Potensi daya listrik yang dihasilkan dari sistem OTEC telah diestimasi menggunakan rumus estimasi teknis. Daya Bersih rerata yang dapat dihasilkan berkisar antara 5,65 MW-7,56 MW. Perairan Lembata diketahui memiliki perairan dengan kondisi suhu yang sesuai untuk instalasi OTEC. Stasiun C-4 memiliki potensi daya sebesar 6,84 MW pada kedalaman laut 763 m dan jarak dengan garis pantai sejauh 1,86 km. Stasiun C-4 yang terletak di kecamatan Omesuri merupakan titik terbaik untuk instalasi OTEC di Perairan Utara Lembata.*

***Kata Kunci:** energi potensial, suhu air laut, OTEC, Lembata*

INTRODUCTION

Data from British Petroleum (2021) states that in 2020 the use of fossil energy in Indonesia will reach 93% with the use of coal energy (40%), oil (35%), and natural gas (18%). Although the increasing demand for public energy causes reserves of fossil energy sources to dwindle, the Ministry of Energy and Mineral Resources press release number: 311.pers/04/SJI/2020 said that efforts need to be made to maintain Indonesia's energy availability in the future, it is necessary to shift the use of fossil energy to New and Renewable Energy (NRE) and Clean Energy.

Indonesia has several energy potentials; one of the potentials for clean energy is marine energy. Yosi (2014) states that the energy that can be utilized from the sea includes ocean currents, wave energy, energy due to differences in water levels due to tides, microalgae as biodiesel, and Ocean Thermal Energy Conversion (OTEC). Some energy experts stated that the optimal use of OTEC can generate billions of watts of electrical power (Vega, 1992; Bassam et al., 2013; Syamsuddin et al., 2015; Ilahude et al., 2020). Theoretically, OTEC generates electricity indirectly from solar energy by utilizing a temperature difference of at least 20°C between the sun-warmed tropical ocean surface and calmer deep waters (Masutani and Takahashi, 2001).

The tropics always get solar heating with relatively warm and stable surface temperatures throughout the year. Lembata Island is one of the tropical areas that have the potential to use OTEC. These waters are located in the eastern part of the Flores Sea and the southwest of the Banda Sea. These waters influence the Indonesian Throughflow (ITF) and monsoon currents from the Makassar Strait. ITF has a temperature heat transported around 0°C - 4°C (Vranes et al., 2002), which can be used as an intake for cold seawater for the OTEC system in North Lembata Waters.

The morphology of the seabed in the northern waters of Lembata cannot be separated from the influence of marine geological processes. One of the effects of geological settings on oceanographic conditions causes the Indonesia Throughflow (ITF) to branch into the Indian Ocean due to the morphology of the seabed in the southern part of the Makassar Strait, the Dewakang Threshold at 680 m (Gordon et al. 2003; Atmadipoera et al. 2016). The Dewakang threshold is the barrier between the East and west canals. The condition of the Lembata waters is that one branch of the Indonesia throughflow (ITF) from the eastern canal to the Flores Sea, then the Banda Sea and exits the Timor Sea and Ombai Strait, while the other branch flows through the western canal and then to the Lombok Strait (Susanto et al. 2012; Radjawane and Hadipoetranto. 2014); Permanawati et al. 2016). The northern waters of Lembata, like waters in the tropics, are influenced by the monsoon system due to the change of seasons, so it shows that the circulation of surface layer currents occurs twice a year in the opposite direction. Therefore, under certain conditions, there are times when the mass of water from the Flores Sea meets the mass of water that comes out of the Makassar Strait and flows together into the Java Sea due to changing seasons (Ilahude & Gordon 1996; Gordon 2005; Permanawati et al. 2016).

Previous research conducted by Tim OTEC Lembata. (2017) stated that the northern waters of Lembata are generally quite deep, with a depth of 1000 meters, only about 3-7 km from the coastline. The maximum temperature is 29.48°C on the surface and a minimum of 3.58°C at a depth of 1000 m, ranging from 20.39 – 25.30°C. The temperature difference can be used to construct OTEC by calculating the gross power with the Nihous equation (2007) ranging from 1.34-0.88 MW, assuming a large cold water discharge of 2 m^3/s. OTEC analysis in Lembata waters has also been carried out by Julianto (2020) using the assumption of an open cycle OTEC that produces 2.5 MW of electrical power with a location point distance of 3 km from a coastline and a depth of 900 m.

This study will examine the potential of OTEC in the northern waters of Lembata, East Nusa Tenggara, using the Vega design (2002) through closed-cycle OTEC calculations based on the Nihous study (2007) by adjusting the value of warm water flow rate and cold water flow rate for a capacity of 5 MW. First, the condition of the waters is assessed by considering the fundamental aspects of the provisions in determining the installation location to have all concept definitions for the design of the OTEC system (Vega and Michelis, 2010; Morales et al., 2014). These primary conditions include the following aspects:

1. Sea surface temperature of at least 26 °C (annual average), in the range of 24°C - 28°C.
2. Deep sea temperature at a depth of approximately 1000 m (annual average), in the range of 4 °C - 5°C.
3. Steep topographic slope (15-20°) towards the high seas and relatively smooth seabed.
4. Significant wave height of up to 6 m (9,6 second period), wind speed of 20 m/s, and sea surface current of fewer than 1,5 m/s.
5. The probability of earthquakes, tropical storms, and other natural disasters is relatively low

CMEMS (Copernicus Marine Environment Monitoring Service) data is the GLOBAL_MULTIYEAR_PHY_001_030 which has a resolution of 1/12° (approximately 8 km) at 50 depth levels. The temperature model data is validated using the MSE, RMSE, and MAPE methods to compare values between the three methods so that validation will be more accurate. In addition, the CMEMS temperature data has a more detailed correction value than the HYCOM model, so it becomes the author's basis for using the temperature data model.

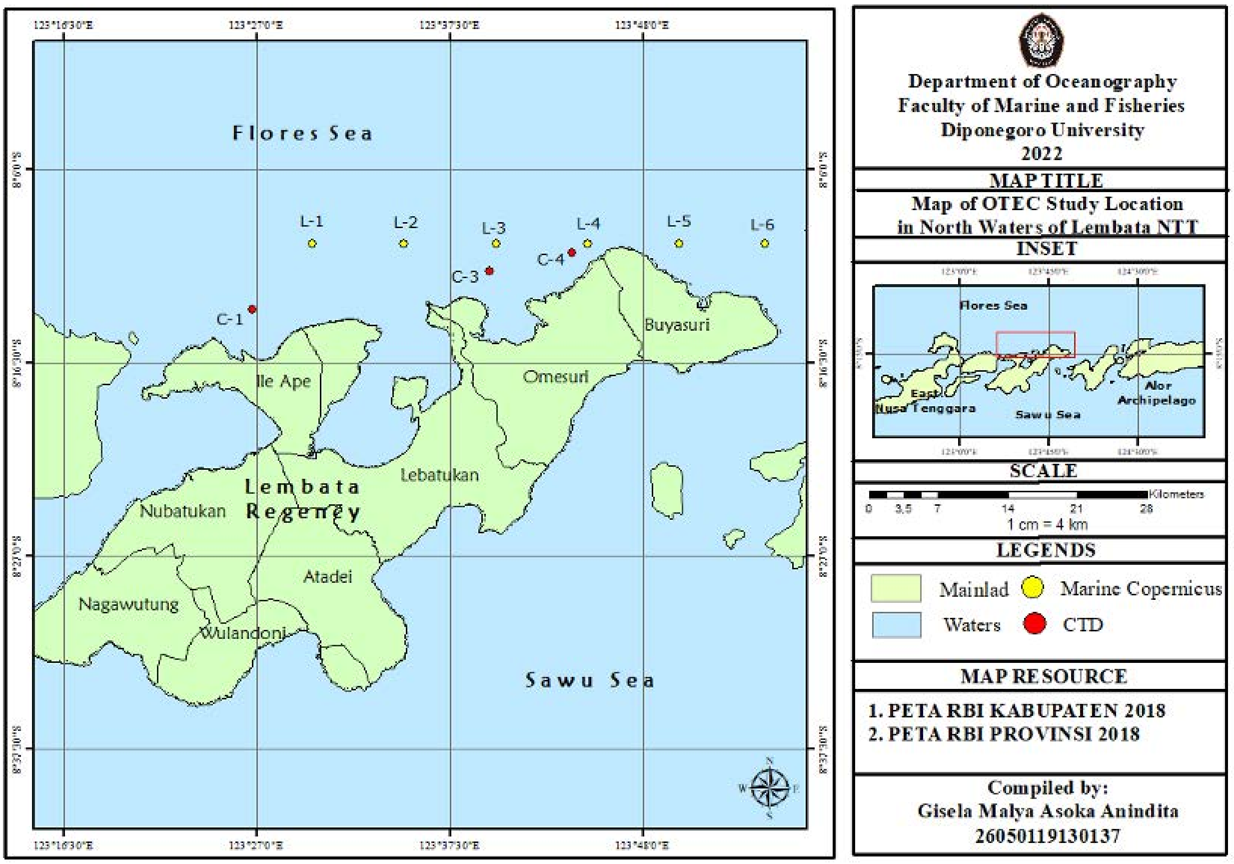

Figure 1. Map of OTEC Study Location

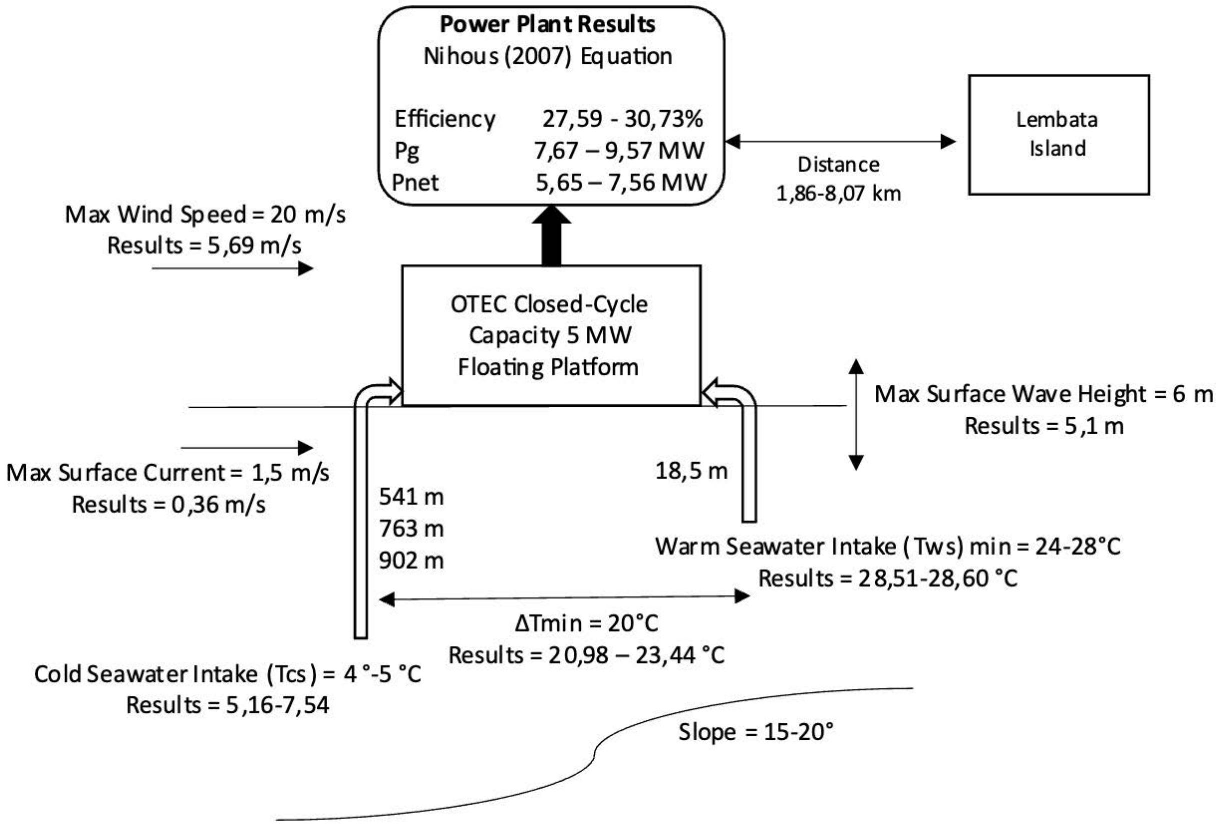

Figure 2. Graphical abstract in determining the installation location for OTEC system design

A study on the potential for Ocean Thermal Energy Conversion (OTEC) installations in the northern waters of Lembata, East Nusa Tenggara, needs to be carried out because there is yet OTEC research that examines the ideal station installation according to primary conditions of the waters including oceanographic conditions. Therefore, the study was carried out in the waters of Lembata Island, which is located at positions 8°10' - 8°11' S and 123°12' - 123°57' E through an analysis of six stations that are considered representative of the North Lembata waters (Figure 1). Figure 2 provides a graphical abstract for this study.

METHODS AND MATERIAL

The material used in the research consists of primary data sources, which are field temperature data and models, as well as secondary data used to support data processing. Temperature field data was taken with the Conductivity Temperature Depth (CTD) Sea-Bird Electronic (SBE) 19 Plus V2 instrument obtained from a survey conducted by the Marine Geological Institute (MGI) by the OTEC Team, Marine Energy Research and Development Group 2017 in the North Waters of Lembata. The vertical temperature model data for CMEMS Global Ocean Physics Reanalysis GLOBAL_MULTIYEAR_PHY_001_030 is downloaded on the website https://marine.copernicus.eu. Secondary data used in the research include the Indonesian Earth Map, bathymetry data from BATNAS BIG 2022, surface current data from CMEMS Global Ocean Physics Reanalysis GLOBAL_MULTIYEAR_PHY_001_030, Ocean significant wave data from Global Ocean Waves Reanalysis WAVERYS GLOBAL_MULTIYEAR_WAV_001_032, and wind data from ERA5 ECMWF Reanalysis.

Temperature Data Validation

Analysis of the accuracy of the field data processing results can be seen in the percentage value by calculating the relative error value.

$$MSE = \frac{\sum_{i=1}^{n}(X_{obs\,i} - X_{model\,i})^2}{n} \quad \text{......(1)}$$

Ichsari et al. (2020) write that if the percentage value of the error results is small and the comparison of processing data is close to field data, it can be said that the processing results provide an overview of the actual situation in the field. Mignac et al. (2015) have validated the model temperature data with field data using RMSE, and the equation is as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs\,i} - X_{model\,i})^2}{n}} \quad \text{...... (2)}$$

Where:
$X_{obs\,i}$ is the value of the observation data,
$X_{model\,i}$ is the value of the model data,
i is the data-, and
n is the number of data.

Testing the accuracy of the model data can also be done using Mean Absolute Percent Error (MAPE). The equation can be calculated by:

$$MAPE = \sum_{t=1}^{n} \left| \frac{Xt - Ft}{Xt} \right| \left(\frac{100\%}{n}\right) \quad \text{...... (3)}$$

Where:
MAPE in presentage (%)
n the amount of data,
Xt is the actual result value, and
Ft is the forecast value

The lower the MAPE value, the better the ability of the forecasting model. According to Lewis (1982), the range of MAPE values can be seen in Table 1.

Table 1. Range of MAPE method by Lewis (1982)

Range MAPE	Interpretation
< 10 %	Highly accurate forecasting
10 - 20 %	Good forecasting
20 - 50 %	Reasonable forecasting
> 50 %	Inaccurate forecasting

Calculation of Temperature Variability

The study of temperature variability at a depth of OTEC water intake in warm and cold water was carried out by analyzing the standard deviation of the monthly average temperature for 9 years at each station as in the study conducted by Suprijo et al. (2021). The study stated that a high standard deviation indicates the area's high variation and low-temperature stability. Areas with high-temperature variations are unsuitable for OTEC installations as they can generate unstable power and may eventually not reach the minimum OTEC thermal resource requirements. The equation calculating the standard deviation of the warm water and cold water intake temperature in the study was taken at a depth of 18.5 m and a maximum depth of each station with a depth limit of 902 m. The equation is below:

$$SD = \sqrt{\frac{\Sigma x^2}{N}} \quad \text{...... (4)}$$

Where:
SD is the standard deviation,
Σx^2 is the total number of data squared, and
N is the number of data.

Efficiency and Power Plant Calculation

The calculation of the maximum thermodynamic efficiency for a Rankine cycle OTEC power system is described with technical estimation formula in Nihous (2007).

$$\mu = \frac{T_2 - T_1}{2(T_2 + 273)} \quad \text{...... (5)}$$

Where:
μ is the maximum thermodynamic efficiency
T_1 is the deep water temperature (°C)
T_2 is the sea surface temperature (°C)

Minor losses in the electrical conversion steps, such as mismatches in the expansion and compression of the working fluid, are considered to reduce the gross electrical power output, leading to gross OTEC conversion efficiency (α, in %)

$$\alpha = \varepsilon_{tg} \frac{\Delta T}{2T_2} \quad (6)$$

Where:
ε_{tg} is the efficiency of the turbogenerator with a value of 75%.
ΔT is the temperature difference between the sea surface and deep-sea temperature (°C)
T_2 is the sea surface temperature (°C)

The gross electric power (P_g) generated comes from the heat load of the evaporator and the thermodynamic efficiency, which the equation can calculate:

$$P_g = \frac{Q_{cw}\rho C_p 3\gamma \varepsilon_{tg}}{16(1+\gamma)T_2} \quad (7)$$

Where:
P_g~ Mega Watt (MW)
ρ~ 1025 kg/m^3 is the average density of seawater,
C_p~ 4 kJ/kg K is the specific heat of seawater, and

$\gamma = \frac{Q_{ww}}{Q_{cw}}$ is a ratio representing warm water's surface flow rate ($Q_{ww} = 26.4\ m^3/s$) and cold water flow rates ($Q_{cw} = 13.9\ m^3/s$). The surface flow rate of warm water is higher than the cold water flow rate to achieve performance according to the 5 MW capacity OTEC simulation. The fluid flow rate affects the performance improvement of the OTEC system, The values of Q_{ww} and Q_{cw} are used in the 5 MW OTEC system designed by Vega (2002). Furthermore, the net power (P_{net}) ~ megawatt (MW) is calculated by considering the required power consumption to drive a significant seawater flow rate through the OTEC generator ~30% of P_g with the design conditions ($\Delta T_{design} = 20$). The calculation can use the equation:

$$P_{net} = \frac{Q_{cw}\rho C_p \varepsilon_{tg}}{8T_2} \{\frac{3\gamma}{2(1+\gamma)}\Delta T^2 - 0.18\Delta T^2_{design} - 0.12\frac{\gamma^{2.75}}{2}\Delta T_{design} \quad (8)$$

The calculation formula in this study uses the equation belonging to Nihous (2007), which is also used in Morales' research (2014) on calculating OTEC power with a closed cycle system simulation.

RESULTS AND DISCUSSIONS

Temperature Data Validation

The model temperature data used is CMEMS (Copernicus Marine Environment Monitoring Service). Based on the results of the validation value, the data has a better value than the HYCOM model data. CMEMS GLOBAL_MULTIYEAR_PHY_001_030 data has a small regional bias value (less than 0.4 °C). Along the equator, the temperature profile is consistent with the observation data, with RMSD (Root mean square error) values generally less than 0.4 °C at the water column (Copernicus, 2021).

Table 2. Coordinate and Validation Results of CMEMS Data and CTD Data

CMEMS Station	Latitude	Longitude	CTD Station	Latitude	Longitude	MSE	RMSE	MAPE (%)	Distance (km)
C-1	-8.167	123.500	L-1	-8.227	123.445	0.67	0.82	2.53	8.79
C-2	-8.167	123.583	-	-	-	-	-	-	-
C-3	-8.167	123.667	L-3	-8.192	123.660	0.36	0.60	2.22	2.88
C-4	-8.167	123.750	L-4	-8.175	123.735	0.22	0.47	1.85	1.83
C-5	-8.167	123.833	-	-	-	-	-	-	-
C-6	-8.167	123.910	-	-	-	-	-	-	-

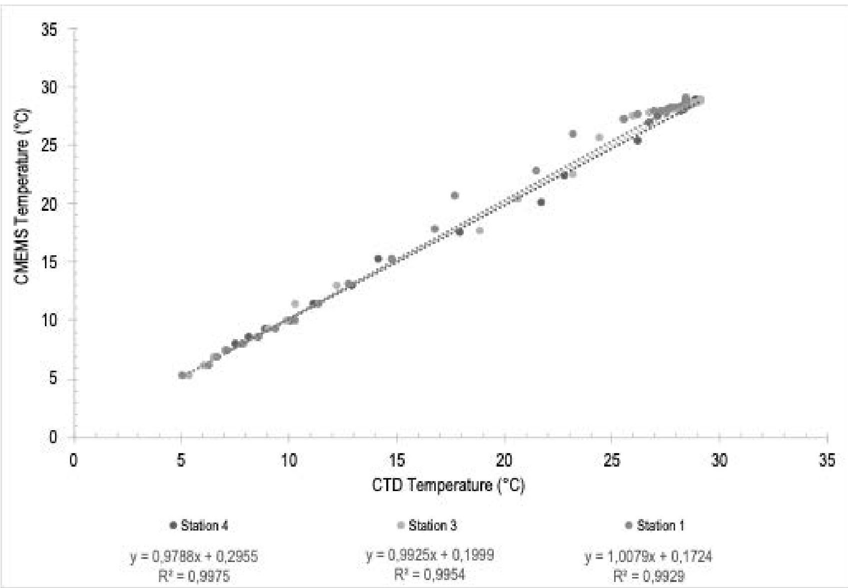

Figure 3. Correlation Between Temperature Copernicus and CTD

Validation of temperature data is carried out using the MSE (Mean Square Error), RMSE (Root Mean Square Error), and MAPE (Mean Absolute Percent Error) methods. These methods are used to measure the accuracy of the estimated results of the model data. Although validation is carried out with three station points, as seen in Table 2, the value of the results of the MSE and RMSE methods validation shows good enough results because the value is close to zero. The validation of the MAPE method produces a value of 1.85-2.53-3%, which is included in the very high accuracy category. Based on the validation values of the three methods, CMEMS model temperature data can represent field temperature data in North Lembata waters.

The graph of the correlation between the CMEMS and CTD temperature data at the three stations can be seen in Figure 2. Based on the figure, the relationship between the CMEMS temperature and the CTD temperature shows good results because the data distribution is close to a linear line.

Distribution of Vertical Temperature

The surface temperature of the CMEMS model primary daata, located at the northern waters Lembata has a range of 27-29.5 °C. This result is in accordance with the statement of Widyartono and Rahmadian (2019), which states that the temperature of surface seawater in the tropical ocean areas (coordinates between 15° N and 15° S) has a relatively constant temperature reaching the range of 28° C throughout the year. Seawater temperature tends to decrease with increasing depth; related to the reduction of sunlight intensity. The temperature characteristics described by Santoso (2005) can be influenced by topography or depth associated with sunlight penetration variability in each water layer. Based on data processing, sunlight penetration variability, directly adjacent to the Flores Sea and passed by the Indonesian Throughflow (ITF), is around 7°C at a 500 m water depth. This result similar with the statement of Raharjo (2011), which stated that Indonesian Throughflow (ITF) has a relatively constant cold seawater temperature (5°C -10°C). The distribution of vertical temperature profile is presented in Figure 4. The difference between warm and cold seawater temperatures in Lembata waters reaches 20°C at 550-600 m water depth, suggests the area is potential for OTEC installation locations.

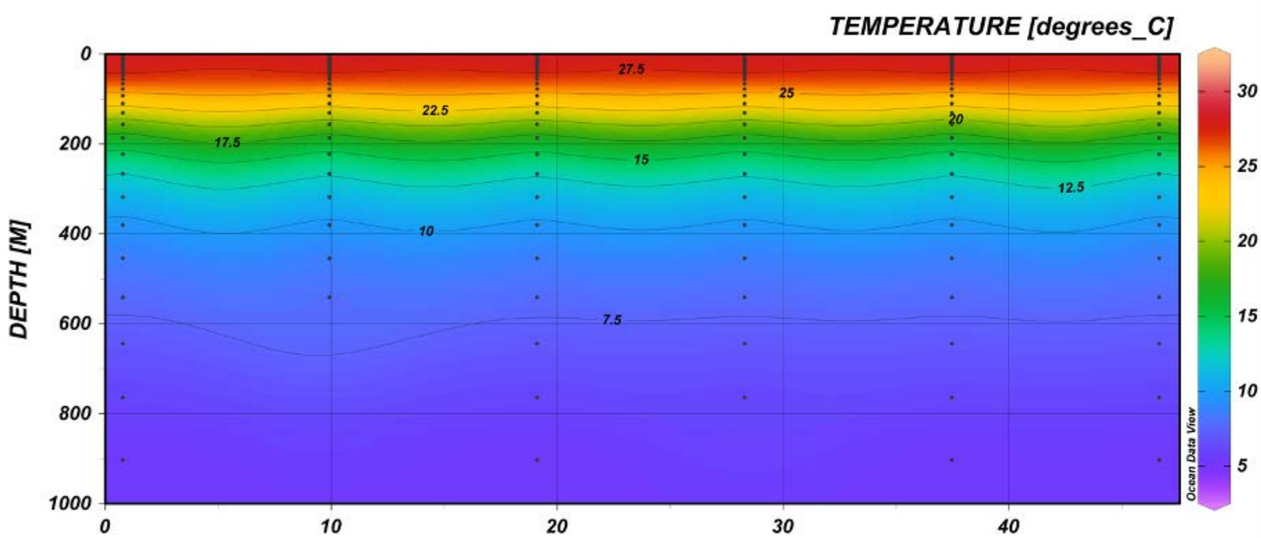

Figure 4. Distribution of Vertical Temperature

Temperature Variability of Warm Seawater and Cold Seawater

The temperature variability of warm seawater (Tws) and cold seawater (Tcs) is calculated to determine the temporal temperature change at each station. In this study, the warm seawater temperature is measured from 18.5 m water depth, while the cold seawater temperature is measured at the maximum depth of each station down to 902 m water depth. OTEC resources are sensitive to temperature changes. Therefore, it is essential to test the temperature variability to assess the feasibility of its implementation, as mentioned by Suprijo et al. (2021).

Tws variability values at each station ranged from 0.75-0.80, the highest variability value is at station C-6 with a value of 0.80 (table 3). The monsoon winds resulting the temperature variability of the warm seawater at the surface. During the East season, the easterly wind strength will increase. Stronger gusts of wind will make the turbulence in the surface layer more vital and can block sunlight penetration to the sea. Therefore, the seawater temperature during the East monsoon tends to be lower. Seawater temperature will decrease when the wind gusts are in contrast and increase when the wind gusts are weak. Cold seawater temperature variability tends to be small because monsoon winds do not affect the temperature in

Table 3. Tws and Tcs Variability from 2012-2020

Station	C-1	C-2	C-3	C-4	C-5	C-6
Tws Variability	0.75	0.76	0.77	0.78	0.79	0.80
Tcs Variability	0.06	0.16	0.06	0.09	0.06	0.06

Data source: primary data (CMEMS GLOBAL_MULTIYEAR_PHY_001_030)

the deep-sea layer—the deeper water layer, the smaller the external influence. The variability of Tcs ranged from 0.05 to 0.16; Seawater temperature will be more stable with increasing depth because it is not affected by external factors such as monsoon winds or anthropogenic activities. The value of temperature variability at each potential point in the northern waters of Lembata is quite suitable for OTEC installations because the variation value is low.

Carnot Efficiency and Potential of OTEC Power

The efficiency values and OTEC power potential of all stations are presented in Table 4 below,

Table 4. Efficiency and Potential Power at North Lembata Waters

Station	Efficiency		Pg (MW)		Pnet (MW)	
	Min	Max	Min	Max	Min	Max
C-1	30.40%	30.88%	8.53	10.32	6.51	8.32
C-2	27.28%	27.79%	6.86	8.35	4.84	6.34
C-3	30.38%	30.88%	8.48	10.29	6.46	8.28
C-4	29.27%	29.88%	7.86	9.56	5.84	7.55
C-5	30.37%	30.86%	8.45	10.22	6.42	8.21
C-6	30.41%	30.92%	8.48	10.28	6.45	8.28

Data source: primary data (CMEMS GLOBAL_MULTIYEAR_PHY_001_030)

which has the slightest temperature difference and efficiency. Although based on the data analysis in Table 4, the OTEC efficiency ranges from 27.28%-30.92%. This value is relatively low compared to the efficiency of other power plants.

The turbine used in the power calculation simulation in this study uses a capacity of 5 MW with the value of the warm seawater and the cold seawater rate from the Vega design (2002). The minimum requirement for temperature difference to run the OTEC system, according to Masutani and Takahashi (2001), is 20°C. In the northern water of Lembata, this delta T value can be achieved at 550 - 600 m water depth. This study's calculation of OTEC power uses the maximum depth of each station with a depth limit of 902 m. The calculation of the monthly average power from 2012-2020 in Table 4 shows that the Gross Electricity (Pg) production is the result of the evaporator heat load and thermodynamic efficiency with a maximum value of 10.28 MW at station C-6 and a minimum of 8.35 MW which is at station C-2. Nihous (2007) states that the net power calculation is estimated by considering the energy used to

The calculation results of the monthly average efficiency of 2012-2020 have a maximum value of 30.92% at station C-6 and a minimum value of 27.28% at station C-2. The efficiency value relates to the temperature difference between warm and cold seawater (ΔT). The higher ΔT value, the greater the efficiency. This statement is evident from station C-6, which has the most significant temperature difference and efficiency, and station C-2,

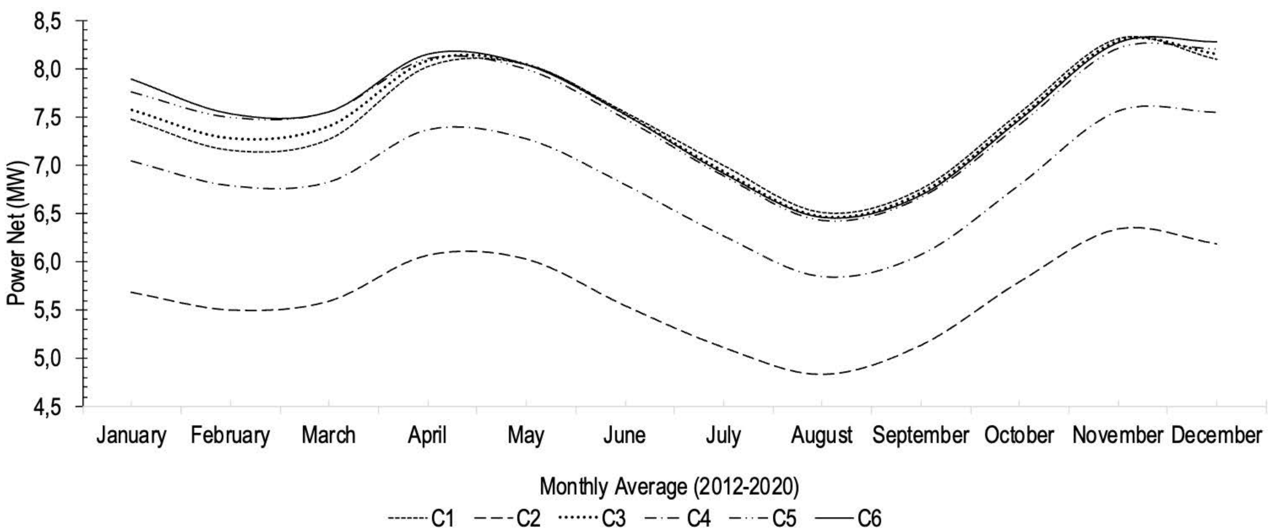

Figure 5. Monthly Average of Power Net 2012-2022

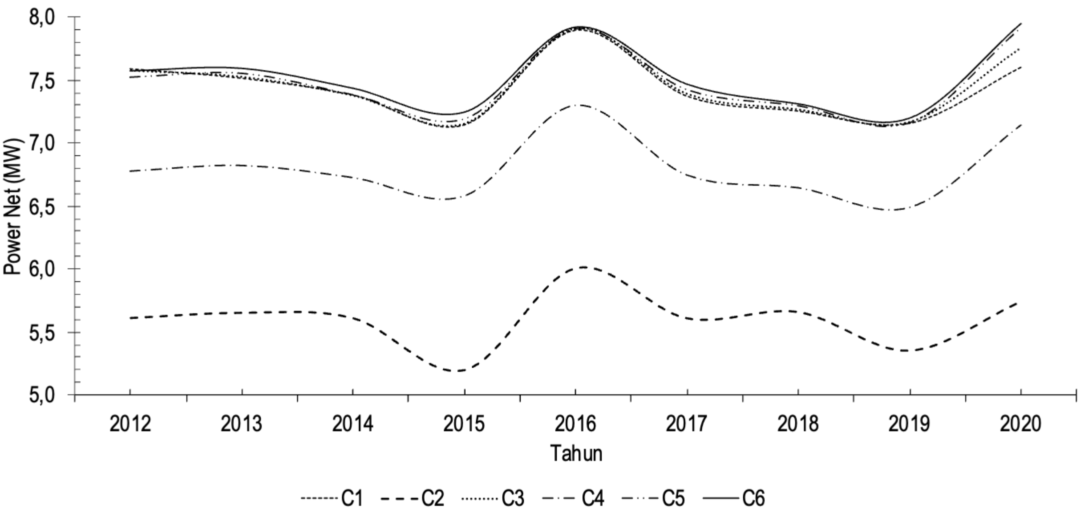

Figure 6. Annual Average of Power Net OTEC 2012-2020

run the OTEC system in pushing the large seawater flow through the OTEC system, as much as 30% of the gross power. Therefore, the maximum monthly average net power value (Pnet) is at station C-6, which is 8.28 MW, and the minimum monthly average is at station C-2, which is 4.84 MW. Figure 5 presents a graph of each station's monthly average OTEC net power for 2012-2020.

The power calculation results from 2012-2020 in Figure 6 show the power potential in the northern waters of Lembata temporally. The power potential decreased from 2012-2015, then rose again in 2016. Furthermore, the power potential decreased until 2019 and rose again in 2020. The largest power potential was in 2020, and the smallest was in 2015. The graph shows that the annual net power results did not significantly change for 9 years. The significant difference in the net power produced each year does not reach 1 MW, so it can be seen that the net power output in the North Lembata waters is relatively constant. These waters have potential in OTEC installations considering the conditions of temperature, depth, and the results of power calculations.

OTEC Installation Ideal Station

The potential point in the northern waters of Lembata Island has a fairly warm surface temperature and is relatively constant throughout the year with a range of 27.1 -29.6°C with cold sea water temperatures ranging from 5-7°C. Seawater temperature (ΔT) differences range from 20.97°C -23.44°C. According to the difference in temperature of warm seawater and cold seawater, North

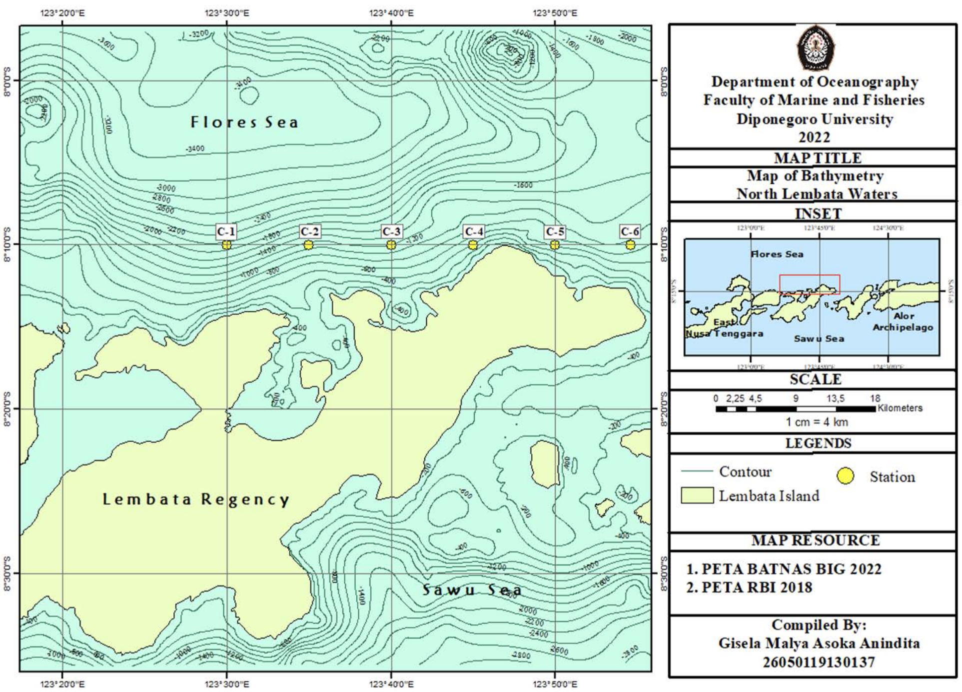

Figure 7. Map of Bathymetry Condition North of Lembata Waters

Lembata waters have great potential for utilizing the OTEC system, which has a minimum requirement of a temperature difference of 20°C.

In addition to temperature differences, the topographic slope is required to determine the appropriate location for installing the OTEC system. The topographical conditions of Lembata are mentioned in Permanawati and Hernawan's research (2018). The morphology of Lembata waters is included in the steep-very steep category, with a slope of 9-40°. Some water locations are sloping areas – slightly steep, with a slope below 9°, located around the bay area (Tim OTEC Lembata, 2017). The condition of the Lembata waters bathymetry can be seen in Figure 7. The topographical and morphological conditions in the waters are suitable for installing an OTEC system. The topography suitable for OTEC system installation is 15-20°.

Indonesia (BNPB, 2016), including earthquakes, tsunamis, and volcanic eruptions with low-risk levels in the Lembata area. Therefore, according to those parameter conditions mentioned above, the condition of the North Lembata Waters is considered to have potential in an OTEC installation it has all concept definitions for the design of the OTEC system, according to Vega and Michelis (2010) which are also mentioned in Morales et al. (2014).

The six potential station points in the northern waters of Lembata can reach the minimum requirements for the difference in warm seawater temperature and cold seawater temperature to operate the OTEC system. Table 6 displays data on potential stations for OTEC installations. Vega's design (2002) with a floating platform is an ideal OTEC system chosen in this research. The potential benefits of OTEC can only be recovered on a large scale through developing a sustainable floating-plant program.

Table 5. Maximum Surface Current, Wind, and Wave Data in North Lembata Waters 2012-2020

Parameter	**Value**
Maximum Surface Current	0.36 m/s
Maximum Wind Speed	5.69 m/s
Maximum Surface Wave Height	5.02 m

Data source: Secondary data (CMEMS GLOBAL_MULTIYEAR_PHY_001_030), Copernicus Reanalysis ERA 5, and Global Ocean Waves Reanalysis WAVERYS)

Table 6. Mean Data on Potential Stations for OTEC Installation

Station	ΔT (°C)	Efficiency (%)	Pnet (MW)	Max Depth(m)	Distance (km)
C-1	23.34	30.70	7.48	902	8.07
C-2	20.98	27.59	5.65	541	6.23
C-3	23.35	30.69	7.49	902	5.69
C-4	22.54	29.59	6.84	763	1.86
C-5	23.39	30.68	7.52	902	2.64
C-6	23.44	30.73	7.56	902	4.88

Oceanographic factors such as temperature, currents, and waves affect OTEC system installation. The temperature affects the OTEC system running, which utilizes the difference in surface and deep sea temperatures. Waves, wind, and currents affect the system's resistance to the surrounding aquatic environment, so a review is needed regarding the value of these parameters. Table 5 shows the processing of secondary data with the maximum values of currents, winds, and significant wave heights in the North Lembata waters. Based on the processing of wind, wave, and current data from 2012-2020, North Lembata waters have the highest significant wave height of 5.02 m and a maximum wind speed of 5.69 m/s. The most significant surface current among all station points is at station C-6, which reaches 0.36 m/s. These values are smaller than the maximum limit for the primary conditions of the OTEC installation.

Further studies are carried out by reviewing natural disasters in a study area. Rysnawati et al. (2017) stated that the level of vulnerability to earthquakes in Lembata Regency, NTT, was included in the low category. This statement in line with the map of disaster risk level in

Furthermore, an ideal station point is determined by calculating the distance of the point from the coastline, where the electricity is distributed, and the amount of net power generated under Julianto's statement (2020). If we consider the station that is closest to the shoreline, then station C-4 is the best option, with a depth of 763 m and power potential of 6.84 MW. The station with the highest net power value is station C-6, with a depth of 902 m with a power of 7.56 MW. The distance difference between the two stations is quite different. Station C-4 is 1.86 km away from the coastline, while station C-6 distance is 8.07 km away from the coast. The distance from the OTEC installation location to the coastline will affect the construction cost; as stated by Julianto (2020) and Morales et al. (2014), the closer the OTEC installation location to the coastline, the cost will be lower.

The warm seawater temperature of C-4 is between 27.15-29.55°C while the value of cold seawater temperature ranged between 5.89-6.18°C. The temperature difference (ΔT) at this station reaches the range of 21.19-23.47°C. The temperature value tends to be stable throughout the year, so the temperature variability value is small (0.74). The resulting efficiency reaches

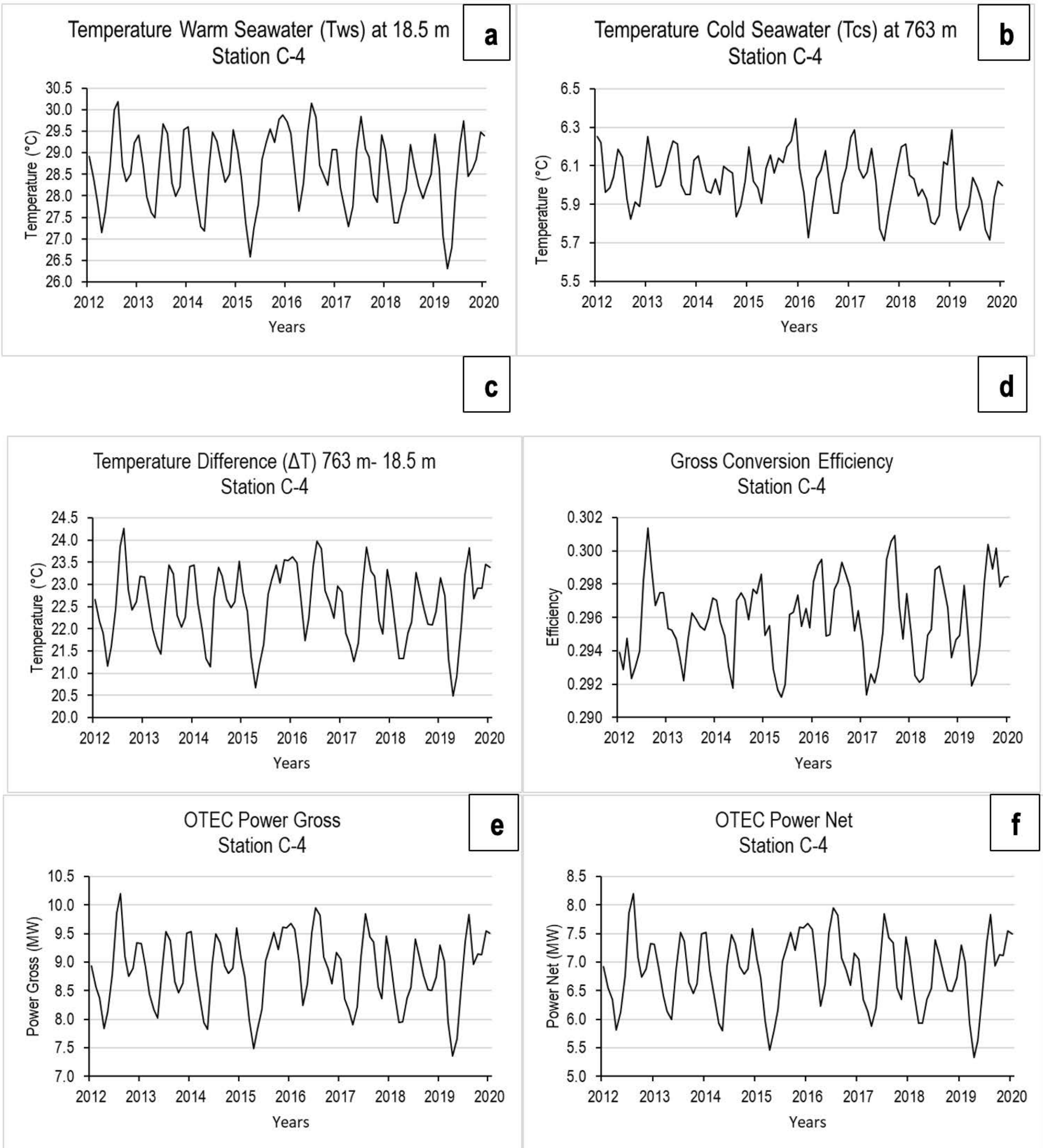

Figure 8. Result of Data Processing Analysis of Ideal Station OTEC Installation at Station C-4

29.27%-29.88%, with the gross power generated reaching a maximum value of 8.85 MW and net power reaching a maximum value of 7.55 MW. Based on the data processing results the ideal OTEC installation station is at station C-4 in Figure 8, the station reaches the minimum temperature difference requirements to run the OTEC system, according to Masutani and Takashi (2001). A small variability value indicates that the power generated tends to be stable, supporting running OTEC resources sensitive to temperature differences, as stated by Suprijo et al. (2021). The potential OTEC power generated at station C-4 has a minimum value of 5.84 MW, so it is under the simulation of a closed-cycle system with a capacity of 5 MW.

Figure 9 presents the surface current velocity at station C-4, wind speed near station C-4, and significant wave height near station C-4 for 9 years. The maximum surface current at station C-4 reaches 0.26 m/s, maximum wind speed reaches 5.69 m/s, and significant wave height reaches 5.1 m. Based on a review of ideal water conditions for the installation of the OTEC system according to Vega and Michaelis (2010), the current velocity at station C-4 is

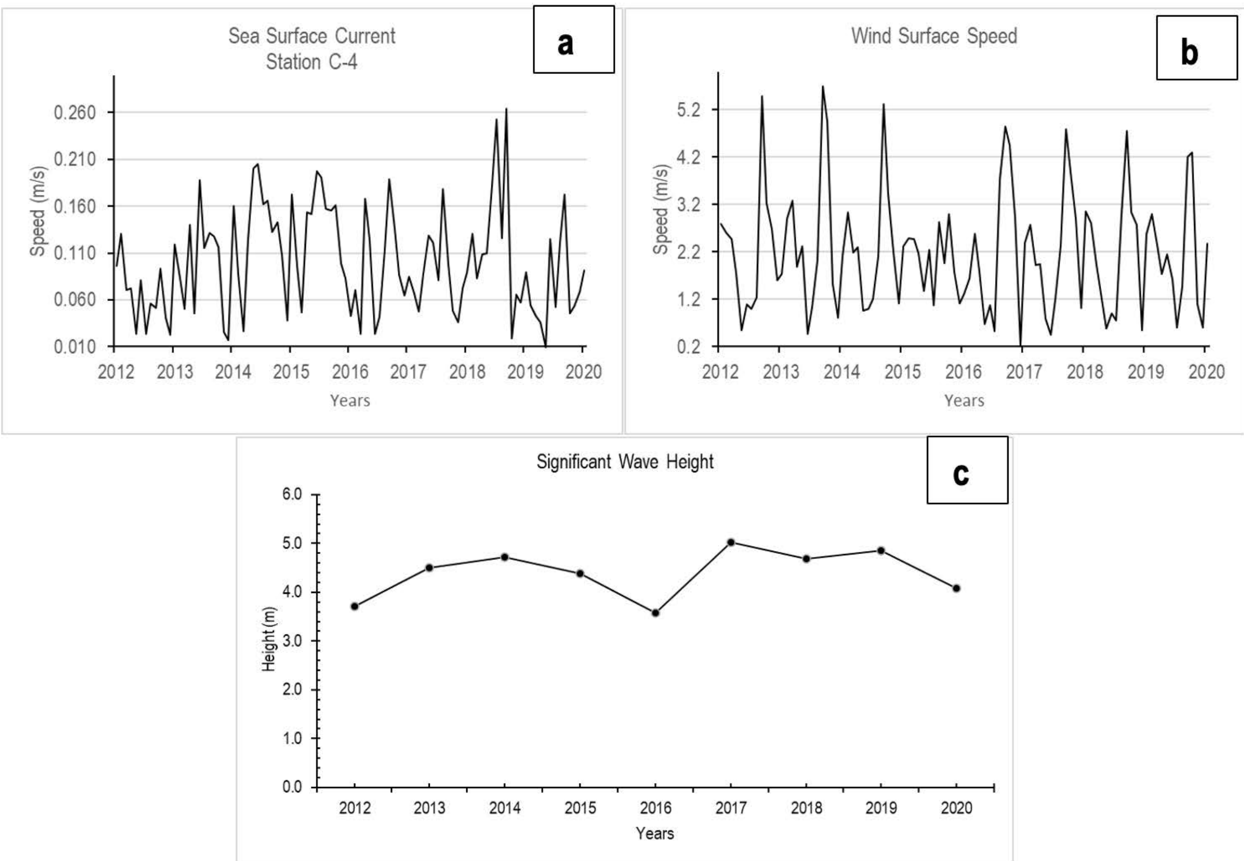

Figure 9. Sea Surface Current GLOBAL_MULTIYEAR_PHY_001_030 (a), Surface Wind Speed ERA5 ECMWF Reanalysis (b), dan Significant Wave Height WAVERYS GLOBAL_MULTIYEAR_WAV_001_032

less than 1.5 m/s, the maximum wind speed is less than 20 m/s, and significant wave heights < 6 m. Based on these data results, station C-4 has water conditions supporting the OTEC system's installation. Therefore, when considering the overall requirements for the ideal station for OTEC installations, including temperature conditions, comparison of distance to shoreline, clean power, and primary water conditions, the C-4 station located in the Omesuri sub-district is considered the most ideal for OTEC installations in North Lembata waters.

CONCLUSIONS

The water condition of Northern Lembata have a potency for the installation of an Ocean Thermal Energy Conversion (OTEC) system. The results of primary data processing include temperature data CMEMS Reanalysis produces a temperature difference value between warm seawater and cold seawater with a range of 20.97°C - 23.44°C. The variability of temperature value is relatively small, indicates relative stable throughout the year. The efficiency value that can be generated is 27.28%-30.92% with a gross power range of 6.86 MW-10.32 MW, and the net power that can be generated has a range of 5.65 MW-7.65 MW. According to the condition of bathymetry, currents, waves, and winds, and the disaster potency derived from secondary data processing, it is suggested to apply a floating platform of OTEC installation. The maximum surface current only reaches to 0.36 m/s, the wave height is 5.1 m, and the maximum wind speed is 5.69 m/s. The ideal station for the installation of the OTEC Closed-Cycle system with a capacity of 5 MW is a C-4 °C station. It has a depth of 763 m with a temperature difference (ΔT) of 21.20 °C -23.47 °C. The efficiency value at the station is 29.27%-29.88%, which can produce a net power of 5.84 MW-7.55 MW. The distance between the station and the mainland in the Omesuri sub-district is 1.86 km. This distance is considered close enough to the location of the electricity distribution.

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