A System Design of a Solar and Geothermal Hybrid Power Plant for Flores Island

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Abstract. Solar and geothermal hybrid system will be promising in the upcoming years, Flores has both energies potential. The use of diesel electric power plant (PLTD) may harmed the environment, the hybrid system with storage energy can be an alternative solution to substitute PLTD. Hence, there is an opportunity to design and implement a hybrid geothermal and solar power plant for Flores Island. Based on existing geothermal fluid characteristics in Flores Island, a hybrid power plant is designed to comprising of a single flash geothermal power generation, a solar collector system with parabolic trough collectors (PTC) either in an East-West (E–W) or a North-South (N–S) alignment, and a thermal energy storage (TES) system with synthetic oil for heat transfer fluid (HTF) and a mixture of salts for storing thermal energy. The hybrid power plant's operation is designed based on the result of the electricity load study for Flores Island. Solar energy potential for Flores Island is predicted by combining clear sky model empirical formulas and 2017–2019 sunshine duration data from local weather station. Steady mass and energy balance analyses via Aspen HYSYS were performed to obtain electric power generation capacity for each standalone geothermal power plant and hybrid power plant. Besides, a comparison of carbon dioxide emission from the same capacity of a diesel-electric power plant, a standalone geothermal power plant, and a hybrid power plant is presented. The hybrid power plant is designed to have a solar collector system with a N–S alignment PTC system in which daily average solar irradiation is predicted to be 5.5 kWh/m2/day and a TES volume of 3,000 m3. The land area to be cleared for the solar collector system is estimated as 3.0 hectares (7.5 acres). For a steam turbine inlet pressure of 10 bar, a condenser pressure of 0.08 bar, and 1,215 operation hours per year, the hybrid power plant can produce 5,450 MWh/year of electric energy. The carbon dioxide emission reduction for standalone operation and a hybrid operation are 86% and 93%, respectively, compared to that of a PLTD.

1. Introduction
The world needs alternative energy, which is clean and is affordable to maintain the increasing global temperature below 2° Celsius [1]. Promoting the use of clean energy is essential in terms of shifting to a new sustainable structure [2]. According to general planning for national energy (RUEN) in 2017, the Indonesian government wants increase renewable energy in energy mix by 23% but there is a gap between current situation in amount of 9 GW by the end 2020. In terms of Indonesia's electrification
ratio, at the end of 2018, the lowest electrification ratio is in East Nusa Tenggara (NTT) by 84% per September 2019. Whereas NTT has many renewable energy sources, and according to MEMR 2268K/30/MEM2017, Flores was selected to be a Geothermal Island with 776 MWe and 17 fields. Furthermore, based on RETScreenExpert software, the annual solar energy potential is 5.6 kWh/m2/day. Thus, increasing the NTT’s electrification ratio is feasible with utilizing renewable energy resources (e.g., solar and geothermal) and support with high electricity generation cost (BPP) as a concern for the payback period. Geothermal energy is very stable, not affected by weather, it can be used for baseload, and has a capacity factor of over 90% [3]. Based on the Indonesia electricity supply business plan (RUPTL), the existing geothermal power plants (PLTP) are Ulumbu and Mataloko, with a total of 12.5 MW [4].

According to the state electricity company (PLN), in the future, Flores will rely on geothermal power plants as the primary source of energy. This work aims to design a solar geothermal hybrid system in Ulumbu, Flores, to increase steam quality using a heat exchanger. The primary system of the geothermal power plant will select based on natural characteristics. The solar collector alignments will be evaluated from E–W and N–S alignment to select the best daily energy collected from two-alignment. Solar energy will be stored in thermal energy storage (TES) while the sun is shining and released after sunset to supply heat exchanger. This system will supply electricity peak demand in the evening and reduce a diesel power plant (PLTD). In the end, compare the carbon dioxide emissions from each power plant and the design can be an alternative solution for the government to substitute PLTD in the evening.

2. Literature Review

2.1. Local Characteristics of Location Target

One of the electricity suppliers in Manggarai’s System is Ulumbu, and this system has installed capacity in the amount of 35.4 MW with a 23.0 MW peak load. PLTP Ulumbu is in Flores island and supplies the baseload system while PLTD supplies the system in peak load. The highest demand is in 18–20 local time, and the lowest is in 6–18 local time. Besides electricity, the sun’s characters in the last three-year duration of sunshine (LPM) is less than two hours until more than nine hours. The dominant LPM is from four hours until eight hours. The information is shown in (Figure 1).

![Figure 1](a) Local characteristics (a) electricity profile [4] (b) LPM in Flores.

2.2. Solar Geothermal Hybrid System

There have been many reports and papers on the combination of geothermal and solar energies to hybridize solar-geothermal in recent decades. One of the advantages of the combination is to increase the steam quality of geothermal. From Table 1, the data show the research that has been conducted
from several conditions. According to the literature available, the advantages are solar preheating configuration where solar radiation is used to preheat the brine either by increasing the brine temperature or its dryness fraction, solar superheating configuration in which solar radiation is mainly used to superheat the working fluid of the geothermal power cycle. In this geothermal preheating configuration, geothermal energy is used to preheat the feedwater in a steam Rankine cycle type solar thermal power plant.

Table 1. Previous research of the hybrid solar-geothermal system.

| Authors, year | Geothermal power plant (existing/hypothetical) and its location | Geothermal reservoir temperature and brine flow rate | The type of primary power cycle | Working fluid | Hybridization approach and operating mode |
|---------------|---------------------------------------------------------------|---------------------------------------------------|-------------------------------|---------------|-------------------------------------------|
| Manente et al., 2011 [5] | Existing, USA | 154.5°C and 457.1 kg/s | Organic Rankine Cycle (ORC) | Isobutane industrial grade | Brine preheat mode |
| Ayub et al., 2015 [6] | Existing, Nevada, US | 135°C and 620 kg/s | ORC | Isopentane | Incorporate solar system |
| Zhou et al., 2011 [7] | Hypothetical, Australia | 180°C and 50 kg/s | ORC | Isopentane | Brine preheat mode |
| Mir et al., 2011 [8] | Hypothetical, Chile | 250°C | Single-flash geothermal plant | Steam | Working fluid superheat mode |
| Mathur, 1979 [9] | Hypothetical, USA | 90–300°C | ORC with a feedwater heater | Steam | Brine preheat mode |
| Lentz and Almanza, 2006 [10] | Existing, Carre Prieto, Mexico | 300°C and 44.92 kg/s | Geothermal double flash plant | Steam | Brine preheat mode |

The most mature technology of solar collectors to support a hybrid system is PTC [11], with two tracking systems, either E–W or N–S alignment depends on the needs.

2.3. Model of The Sun
To estimate solar radiation in a specific location, it can estimate using Parabolic Trough Concentrator (PTC) calculation to collect solar radiation. First, it needs an angle of the day (B) [12] in degrees as follow.

$$B = \frac{360}{365}(n - 1)$$  \hspace{1cm} (1)

Where \( n \) is a selected day, and \( n = 1 \) is 1\textsuperscript{st} January. Then, it needs an equation of time [12] defined by the correction time factor (\( E \)) in minutes as follow.

$$E = 229.2 \left(0.000075 + 0.001868 \cos B + 0.032077 \sin B - 0.014615 \cos 2B - 0.04089 \sin 2B\right)$$  \hspace{1cm} (2)

Then, it needs to find the reference median (LSTM) in degrees in terms of a different time with coordinated universal time (UTC) as follows.

$$LSTM = 15^\circ \Delta T utc$$  \hspace{1cm} (3)

Where \( \Delta T utc \) is the difference between local time and UTC.
After the reference median, it needs a time correction factor \( (TC) \) in minutes. The value will negative for eastern longitude and positive for western longitude.

\[
TC = \pm 4 (L_{st} - L_{loc})
\]

(4)

Where \( L_{st} \) and \( L_{loc} \) are standard meridian for the local time zone and local longitude both in degrees.

To obtain solar time \( (LST) \) in hours, local time has to correct by time correction as equation below.

\[
LST = LT + \frac{TC}{60}
\]

(5)

The local solar time had been found, it needs to convert into hour angle \( (\omega) \) in degree.

\[
\omega = 15\degree (LST - 12)
\]

(6)

To track the sun, it needs a declination angle \( (\delta) \) in degree based on selected day \( (n) \) [16] as the equation below.

\[
\delta = 23.45 \sin(360\degree \frac{284 + n}{365})
\]

(7)

To obtain a minimum incident angle at \( N-S \) alignment as equation below.

\[
\cos \theta = \left( \cos^2 \theta_z + \cos^2 \delta \sin^2 \omega \right)^{1/2}
\]

(8)

Where zenith angle \( (\theta_z) \) can find using the equation below.

\[
\cos \theta_z = \sin \delta \sin \phi + \cos \delta \cos \phi \cos \omega
\]

(9)

To obtain a minimum incident angle at \( E-W \) alignment as equation below.

\[
\cos \theta = \left( 1 - \cos^2 \delta \sin^2 \omega \right)^{1/2}
\]

(10)

To get beam radiation in clear sky models, it needs to calculate the extraterrestrial radiation incident \( (G_{on}) \) in W/m\(^2\) [13] as the equation below.

\[
G_{on} = G_{sc} \left( 1 + 0.033 \cos \frac{360n}{365} \right)
\]

(11)

The value of solar constant \( (G_{sc}) \) of 1,367 W/m\(^2\).

Previous research has presented a method to estimate the beam radiation transmitted through clear atmospheres [14]. The atmospheric transmittance for beam radiation \( (\tau_b) \) is given in the form.

\[
\tau_b = a_0 + a_1 \exp \left( - \frac{k}{\cos \theta_z} \right)
\]

(12)

\[
a_0^* = 0.4237 - 0.00821 (6 - A)^2
\]

(13)

\[
a_1^* = 0.5055 + 0.00595 (6.5 - A)^2
\]

(14)

\[
k^* = 0.2711 + 0.01858 (2.5 - A)^2
\]

(15)

For the tropical climate factor the following \( a_0^*, a_1^*, k^* \) are 0.95, 0.98, and 1.02 [14].

Clear-sky horizontal beam \( (G_{cb}) \) in W/m\(^2\) is given as equation below.

\[
G_{cb} = G_{on} \tau_b \cos \theta
\]

(16)

It can also estimate the clear-sky diffuse radiation on a horizontal surface to get the total radiation [15]. Clear-sky horizontal diffuse \( (G_{cd}) \) in W/m\(^2\) is given as the equation below.

\[
G_{cd} = G_{on} \cos \theta (0.271 - 0.294 \times \tau_b)
\]

(17)
To obtain the total radiation (\(G_{ct}\)) in W/m\(^2\) using the equation below.

\[
G_{ct} = G_{cb} + G_{cd}
\]  
(18)

2.4. Geothermal Power Plant

There are four basics geothermal energy conversion with process diagrams shown in (Figure 2). In Flores, exploration study and well drillings have been done in Ulumbu and Mataloko, and the existence of geothermal reservoir was confirmed in 9 fields, Huu Daha, Wai Sano, Ulumbu, Bena-Mataloko, Sokoria-Mutubusa, Oka-Larantuka, Atadei, Tulehu, and Jailolo, some geoscientific data of feasibility studies are published [16]. Ulumbu field is one of several geothermal prospects on the island of Flores in Indonesia. The value of wellhead pressure (WHP), quality of steam, and enthalpy are 15 bar, 0.56, and 1944 kJ/kg [17].

![Figure 2. Basics geothermal energy conversion system [18].](image)

To obtain work produced by the turbine (\(\dot{W}\)) in kW, it is given the equation below.

\[
\dot{W} = \dot{m} \eta (h_i - h_o)
\]  
(19)

Where \(\dot{W}\), \(\eta\), \(\dot{m}\), \(h\) are work produced by a turbine (kW), turbine efficiency, the mass of steam (kg/s), and enthalpy (kJ/kg).

The equation above shows the way to find the mass of steam (\(\dot{m}\)) in kg/s as the equation below.

\[
\dot{m} = \frac{\dot{W}}{\eta (h_i - h_o)}
\]  
(20)

To obtain the specific steam consumption (SSC) in ton/MWh, it is given as equation below.

\[
SSC = \frac{\dot{m}}{\text{Power Generation}}
\]  
(21)

For the conversion efficiency as a function of enthalpy (\(\eta_{act}\)) [19] as the equation below.

\[
\eta_{act} = 7.8795 \ln(h) - 45.651
\]  
(22)

2.5. Thermal System

The solar geothermal hybrid system needs a heat exchanger to increase steam quality from the geothermal working fluid. To obtain the power needed (\(\dot{Q}\)) in kW, as shown in the equation below.

\[
\dot{Q} = UA \cdot LMTD = \dot{m}c_p(T_h - T_c)
\]  
(23)

Where \(\dot{m}\), \(c_p\), \(UA\), LMTD, \(T_h\), \(T_c\) are mass flow rate (kg/s), specific heat (kJ/kgK), logarithmic mean temperature difference (°C), higher temperature (°C), and lower temperature (°C).

To find the collector area (\(A_c\)) in m\(^2\) that is needed, it can use the equation below.

\[
A_c = \frac{\dot{Q}}{\eta_{act} \cdot G}
\]  
(24)
The $\eta_c$ is the collector efficiency 0.6, for ET-150 the efficiency of 0.6, and $G$ is beam irradiance (W/m$^2$).

To find the volume of storage ($V_{TES}$) in m$^3$ equation below [19].

$$V_{TES} = \frac{Q_{avg\text{-}day}}{h_{pc} \cdot \rho}$$

(25)

Where $h_{pc}$, $Q_{avg\text{-}day}$, $\rho$ are specific enthalpy (J/kg), collector thermal energy (J), density (kg/m$^3$).

2.6. Estimation of Carbon Dioxide Emission

To obtain an estimation of carbon dioxide emission using LCAs as the equation below.

$$\text{Annual CO}_2\text{ emission} \left(\text{tonCO}_2\text{eq year}^{-1}\right) = \text{emission factor} \left(\text{tonCO}_2\text{eq MWh}^{-1}\right) \times \text{annual production} \left(\text{MWh year}^{-1}\right)$$

(26)

3. Methodology

3.1. Thinking Framework

Parabolic trough concentrator collects solar radiation with E–S or N–S alignment based on the highest daily radiation. Heat transfer fluid (HTF) that will be chosen based on technology and thermal characteristic will be used as a solar energy absorber. Then, HTF’s energy will flow to TES, that the storage medium will be chosen based on thermal characteristics and technology. During the baseload, geothermal working fluid will directly to the power plant system with the mains system. The single-flash will be chosen as the primary system according to Ulumbu characteristics using graphic chart enthalpy and efficiency from each type of system [19]. While peak load, geothermal working fluid will flow to the heat exchanger before entering the power plant system.

Figure 3. Thinking framework.

3.2. Solar Radiation Potential

To estimate the solar radiation potential in Ulumbu, the idea is combining empirical formula with LPM from BMKG Frans Sales Lega Station in the last three-year. The first step is to select the day with seven-day in a row for the last three-year, as shown in Table 2.

Table 2. Sample of Days.

| Month | Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|-------|-----|---|---|---|---|---|---|---|---|---|----|----|----|
|       |     | n | n | n | n | n | n | n | n | n | n  | n  | n  |
| 17    | 49  | 78 | 93 | 122| 175| 196| 231| 254| 278| 315| 350|
| 18    | 50  | 79 | 94 | 123| 176| 197| 232| 255| 279| 316| 351|
| 19    | 51  | 80 | 95 | 124| 177| 198| 233| 256| 280| 317| 352|
| 20    | 52  | 81 | 96 | 125| 178| 199| 234| 257| 281| 318| 353|
| 21    | 53  | 82 | 97 | 126| 179| 200| 235| 258| 282| 319| 354|
| 22    | 54  | 83 | 98 | 127| 180| 201| 236| 259| 283| 320| 355|
Solar energy will divide into irradiance (W/m$^2$) and irradiation (Wh/m$^2$) to design a hybrid system. For the irradiance, this work uses model empirical that describes in the previous section to get irradiance from 07.00–17.00 from seven days each month. Then, calculate the average irradiance from seven days to be representative for that month. Lastly, select the lower quartile from the Boxplot feature in Microsoft Excel to be selected annually from 07.00–17.00.

Alternatively, the irradiation has to input the LPM and set symmetry duration in solar noon. The irradiance equation is acquired from regression in Microsoft Excel, to convert irradiance to irradiation, use integral and set the low and top boundary from LPM. Then calculate the average irradiation from seven days to be representative for that month. Last, validate the result with data from RETScreenExpert.

3.3. Mass and Energy Balance
To create a model of this system using Aspen HYSYS, it must choose the power plant's equipment. In a single-flash system, the essential equipment are separator, turbine, and condenser. Then, it has to input the information for each condition. The difference between geothermal standalone and hybrid system is the heat exchanger, in a hybrid system, there is an additional heat exchanger to increase steam quality. This work will evaluate the increases from 0.56 to 0.71, then select the suitable increases of the steam quality based on the available area.

3.4. Thermal Systems
After the power that needed to heat exchanger is acquired from Aspen HYSYS, it has to calculate the PTC's power. The first step is to set the inlet and outlet temperature for each condition. This system chooses the counterflow heat exchanger, and there will be two heat exchangers. The first one is the heat exchanger for the steam power plant (HE1), and the other is a heat exchanger for TES (HE2).

![Figure 4. Thermal system model.](image)

It needs to calculate the mass flow rate of synthetic oil before calculating the power needed for HE2, then calculates the power needed for HE2 to obtain the flow rate for nitrate salt to stored energy in TES. Furthermore, calculate the power needed for PTC and calculate the collector area. Last, obtain the TES volume for a 2-tank system and oversized by 30% to add some nanoparticle solid for increasing HTF performance.

3.5. Carbon Dioxide Emission
To calculate the CO$_2$ emission between the PLTD, PLTP standalone, and the solar-geothermal hybrid system it needs CO$_2$ emission factors where the emission are 0.33 ton CO$_2$eq/MWh [21], 0.047 ton
CO₂eq/MWh [22], and 0.023 ton CO₂eq/MWh [23]. Then, multiple each factor with annual year production for the hybrid system.

4. Results and Discussions

4.1. Model of Hybrid System

This system will operate a geothermal standalone to supply baseload and will operate hybrid to supply peak load. In a day, energy from solar radiation will be stored in TES. Based on LPM from BMKG, the range of LPM in Ulumbu is 4–8 hours. This system will set the average LPM or 6 hours with 202 days in a year to operate the hybrid system from 18.00–24.00.

![Figure 5. Schematic of a solar, geothermal hybrid system.](image)

The difference between the two-condition is the steam quality before entering the separator. While operating in a hybrid system, the steam quality is higher than the geothermal stand alone. It is shown in (Figure 6).

![Figure 6. Diagram process of a design system.](image)
4.2. Solar Thermal Energy Potential

To obtain the solar energy from the collector, the thing that has to know is the location of Ulumbu site, according to Google Maps the latitude, longitude, and elevation are -8° 72′, 120° 43′, 0.661 km, and located in Satarmase, Manggarai, NTT. Day of samples is provided in Table 2 taken from BMKG Frans Sales Lega within seven days in a row by the last three-year. Figure 7 results from an average irradiance of seven days to represent each month from 07.00 – 17.00. The insight that E–W and N–S alignment have a similar characteristic in terms of the highest irradiance at the end of the year and the lowest at the middle of the year. E–W alignment has a daily peak higher than N–S alignment, but in daily irradiance, N–S alignment has a higher value than E–W. Thus, the N–S alignment suitable to implement based on daily irradiance.

![Figure 7. Daily beam irradiance (a) E–W alignment; (b) N–S alignment.](image)

Besides the irradiance, this work calculated the irradiation from two-alignment. As shown in (Figure 8), an average of seven days in a row represents each month in terms of mean and peak irradiation for E–W alignment.

![Figure 8. Beam irradiation E–W alignment (a) mean; (b) peak.](image)

Figure 9 below shows the behavior N–S alignment obtains more energy than E–W.
The additional information, diffuse radiation is lower than total radiation, as shown in (Figure 10). The concentrated solar collector only calculated the beam radiation, but the total component needed for calculated solar PV, and it also needs the diffuse component [24].

The result is closed enough by 0.1 kWh/m²/day compared with value from RETScreenExpert. Table 3 shows the irradiation based on LPM in Ulumbu from two-alignment.

| LPM [hours] | Beam Irradiation E-W [kWh/m²] | Beam Irradiation N-S [kWh/m²] |
|-------------|-------------------------------|-------------------------------|
| 4           | 2.3 ± 0.3                     | 3.0 ± 0.5                     |
| 6           | 3.5 ± 0.5                     | 4.5 ± 0.7                     |
| 8           | 4.6 ± 0.6                     | 6.0 ± 0.6                     |

As described before, this design will choose PTC with N–S alignment based on higher daily irradiation. The average beam irradiance for E–W and N–S alignment are 581 W/m²/day and 758 W/m²/day. For E–W and N–S alignment, average beam irradiations are 5.0 kWh/m²/day and 5.5 kWh/m²/day. This value will be used to calculate the collector area of hybrid design.

4.3. Steam Power Plant

This simulation will be evaluated with wellhead pressure and enthalpy in the amount of 15 bar and 1944 kJ/kg, the pressure of separator is 10.5 bar, and non-condensable gas (NCG) consist of CO₂ are 1 w.t% and 0.6 w.t%. The least steam flow rate can be found by simulation in various values of Pt (i.e.,
turbine inlet pressure) between 8 bar to 10 bar and Pc (i.e., condenser pressure) between 0.06 bar to 0.12 bar. This design will choose the turbine inlet pressure and condenser pressure in 10 bar and 0.08 bar.

In the hybrid system of this work, use 10 bar and 0.08 bar for the turbine and condenser. The hybrid system with 20 MWe with 95% generator efficiency and evaluated in various steam quality.

![Figure 11](image_url)

**Figure 11.** (a) solar energy needed to supply heat exchanger; (b) power increases; (c) area of collector; (d) brine from the separator.

Figure 11 shows no significant difference between NCG fractions, for selecting the type of PTC, the fact that efficiency definition used by Sandia for LS-2 collector evaluation shows the performance Eurotrough higher than LS-2 [25]. This work will choose the Eurotrough-150 (ET-150) with 94% mirror reflectivity [26], 0.6 collector efficiency [25], aperture area in the amount of 817.5 m² [27]. It needs at least 14 MW to heat the geothermal fluid from a level of 0.56 steam to 0.66 steam quality. Then, to heat the geothermal fluid for constant heating for up to 6 hours, it needs 84 MWh.

### Table 4. Characteristics of steam power plant.

| Parameters                        | Turbine (NCR) | Turbine (MCR) |
|-----------------------------------|---------------|---------------|
| Capacity                          | 22 MW         | 26 MW         |
| Geothermal mass flow rate         | 243 ton/hour  | 243 ton/hour  |
| Turbine efficiency                | 78%           | 80%           |
| Conversion efficiency             | 14%           | 15%           |
| Steam quality                     | 0.56          | 0.66          |
| 24 hours of duration              | 18 hours      | 6 hours       |
| Thermal energy from TES           | 0 MWh         | 80 MWh        |
| Thermal energy from PTC           | 0 MWh         | 84 MWh        |
4.4. Thermal System

The result of the thermal system for this design as shown in Table 5 and Table 6. Where Table 5 shows a characteristic of the collector system from two-alignment, and Table 6 shows a characteristic of the storage system from two-alignment.

Table 5. Characteristics of the collector system.

| Parameter | 4 hours | 6 hours |
|-----------|---------|---------|
| Aperture area PTC N–S [ha] | 4.5 ~ 5.5 | 3.0 ~ 3.6 |
| Aperture area PTC E–W [ha] | 5.9 ~ 7.0 | 4.0 ~ 4.5 |
| Parameter | 4 hours | 6 hours |

This design chooses the average LPM or 6 hours from N–S alignment in the amount of 3.0 ha of collector area to fulfilled thermal energy from PTC required in the amount of 84 MWh. This area will use to calculate the storage system.

Table 6. Characteristics of a storage system.

| Parameter | 4 hours | 6 hours | 8 hours |
|-----------|---------|---------|---------|
| PTC N–S  |         |         |         |
| Mass of HTF in PTC [ton] | 3,350 ~ 3,900 | 5,000 ~ 5,800 | 6,700 ~ 7,800 |
| Mass of HTF in TES [ton] | 2,800 ~ 3,300 | 4,250 ~ 5,000 | 5,600 ~ 6,600 |
| Volume of TES [m³] | 2,000 ~ 2,300 | 3,000 ~ 3,400 | 4,000 ~ 4,600 |
| PTC E–W  |         |         |         |
| Mass of HTF in PTC [ton] | 2,500 ~ 3,000 | 3,900 ~ 4,400 | 5,200 ~ 5,800 |
| Mass of HTF in TES [ton] | 2,200 ~ 2,400 | 3,300 ~ 3,700 | 4,300 ~ 5,000 |
| Volume of TES [m³] | 1,500 ~ 1,700 | 2,300 ~ 2,500 | 3,000 ~ 3,500 |

HTF for PTC and TES are synthetic oil and nitrate salt. The TES uses a 2-tank system with hot storage tank (HST) for higher temperatures and cold storage tank (CST) for lower temperatures. The TES volume is $2 \times 3,000 \text{ m}^3$ with another nanoparticle solid.

4.5. Carbon Dioxide Emission

The estimation of CO$_2$ emission each power plant in the amount of 5,450 MWh/year increases production, as shown in Figure 12. CO$_2$ emission of a PLTD, PLTP standalone, and solar-geothermal is 1,800 tons CO$_2$eq/year, 260 ton CO$_2$eq/year, dan 125 ton CO$_2$eq/year. The reduction from geothermal standalone and the hybrid system are 86% and 93%.

Figure 12. Carbon dioxide emission each power plant.
5. Conclusions
The design of the solar-geothermal hybrid system will use N–S alignment with ET-150. It needs a collector area in the amount of 3.0 ha with 0.6 efficiencies. The average of beam irradiance and LPM are 758 W/m²/day and 6 hours. ET-150 will generate power in the amount of 14 MW and total daily energy 84 MWh/day. It can be used for increasing the steam quality to 0.66 and increase electricity production in the amount of 4 MWe from 26 MW turbine power.
Thus, with 6 hours duration, this hybrid system will operate 1,215 hours per year and generate increases production in the amount of 5,450 MWh/year. If the duration only 4 hours, the hybrid system will operate only 18.00–22.00 WITA.

6. Recommendations
Further research for this topic, since the limited data of daily sunshine (LPM) from BMKG only available in time duration, we suggest calculating LPM in detail to get the range each day. Then expand the scope of research in thermal energy storage (TES) to get better results to store the energy and conduct economical aspect.

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