# ON-GRID AND OFF-GRID RENEWABLE ENERGY DESIGN AS SWRO (SEAWATER REVERSE OSMOSIS) POWER FOR FRESHWATER NEEDS IN GILI TRAWANGAN (STUDI CASE: GILI TRAWANGAN)

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## Abstract

Indonesia has 17,504 islands and one of them is Gili Trawangan. Gili Trawangan is one of the favorite tourist destinations in Indonesia which has an area of approximately 6 km². In order to achieve the development of tourism islands, sufficient water and energy are needed in the area. The island's location in the middle of the sea makes it difficult to get freshwater and energy supplies.

In this study, on-grid and off-grid simulations of renewable energy (solar, wind, and biomass) were carried out to determine the potential of integration energy as seawater desalination power as the need for freshwater in the area by calculating NPC (Net Present Cost), COE (Cost of Energy), operational costs, energy, and $CO_2$ emissions. In the off-grid simulation, the lowest NPC and COE integration potentials were found at PV (Photovoltaic) capacities of 102 kW, 14 WT (Wind Turbine), 50 kW BG (Biogas Generator), and 50 kW DG (Diesel Generator) with a value of Rp 17,042,910,000 and Rp 1,587. The lowest operational costs and $CO_2$ emissions are at the PV capacity of 209 kW, 8 WT, 50 kW BG, and 50 kW DG with a value of Rp 292,308,100 and 163 kg/year. In energy production, there is excess production and electrical energy at the PV capacity of 188 kW, 25 WT, 50 kW BG, and 50 kW DG with values of 2,301,533 kWh/year and 1,821,626 kWh/year. On-grid simulation results obtained the lowest NPC and NOE at 30 kW PV, 5 WT, and 50 kW BG with a value 2,961,782,000 and Rp. 200. Lowest operating costs, lowest $CO_2$ emissions, largest electricity production, and best electricity trading at the PV capacity of 209 kW, 5 WT, and 50 BG with a value Rp 12,428,750, 84,000 kg/year, 882,455 kWh/year, 239,996 kWh, and 132,911 kWh.

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## 1. Introduction

The development of marine environment tourism is the present priority of the Indonesian government. Small islands are one of the main areas of coastal and marine tourism. The small island has become one of the most popular tourist destinations because of its destinations' splendour, exoticism, aesthetics, and variety of plant habitats, including warm, clear water, and attractive surroundings (Kurniawan, Adrianto, Bengen, & Prasetyo, 2016). In Lombok, West Nusa Tenggara, there is a small island called Gili Trawangan that is home to a variety of coral reefs. On this island, which has a surface area of less than 6 km$^2$, more than 2000 inhabitants live and up to 1 million tourists visit annually on average (Partelow & Nelson, 2020). The development of tourism islands is often associated with increasing natural resources to build supporting facilities for tourism activities in order to achieve sustainable island settlements where adequate water and energy are the two main problems for sustainable community development (Phong & Van Tien, 2021), (Zhang, Sivakumar, Yang, Enever, & Ramezanianpour, 2018). However, some of the inhabitants of the isolated island still depend on imported freshwater and fossil energy (Ye, Jiang, & Cang, 2019).

Desalination is a viable option and a necessary alternative for water-scarce communities, but it is also fraught with problems related to energy requirements, environmental effects, economic factors, and social and political ramifications (Kumar & Prakash, 2019). In light of these circumstances, studies were done to ascertain renewable energy's potential and develop on-grid and off-grid systems that may be used to run desalination equipment. The analysis is conducted by contrasting the economy, energy use, and environmental conditions (greenhouse gas emissions).

A seawater desalination system using the RO (Reverse Osmosis) technology can be utilized to create freshwater from seawater in order to meet the island's freshwater needs. This technique is ideal for usage in regions with brackish water wells or small islands surrounded by water from the ocean (Belessiotis, Kalogirou, & Delyannis, 2016). The estimate of the earth's hydrosphere containing 1.386 billion km$^3$ with a percentage of 96.54% seawater is a solution for small islands that lack freshwater (Gorjian, Ghobadian, Ebadi, Ketabchi, & Khanmohammadi, 2020).

The renewable energy potential on the island of Gili Trawangan is expected to be used to power desalination equipment, allowing it to meet the freshwater needs of tourists. This study provides a renewable energy integration option by optimizing the economic sector, energy, and $CO_2$ emissions of off-grid and on-grid systems as a power plant for seawater desalination for a 25-year project. The model accommodates a high penetration of renewable energy sources and introduces flexibility through Seawater Reverse Osmosis (SWRO) and power-water demand.

## 2. Methodology

a. Data Input

This study performs on-grid and off-grid system simulation of renewable energy with systems. The HOMER software is used as a tool in this simulation. HOMER (Hybrid Optimization of Multiple Electric Renewable) is a software program developed in 1993 by the National Renewable Energy Laboratory in the United States. HOMER is a tool for assessing the performance of on-grid and off-grid systems (Srivastava & Giri, 2016).

Primary and secondary data retrieval were carried out. Primary data includes desalination equipment and the amount of freshwater required based on the number of tourists visiting, while secondary data includes solar radiation, wind speed, biomass amount, and the price of renewable energy equipment components. The following are the data collected in this study; Table 1 shows the specifications of the seawater desalination equipment located on Gili Trawangan.

Table 1. RO desalination technology specification

| Type ($m^3$/hours) | 10 | 20 |
|---|---|---|
| Quantity | 3 | 4 |
| Feed Pump | 7.5 kW | 15 kW |
| Booster pump | 5.5 kW | 7.5 kW |
| HPP | 22 kW | 55 kW |
| Distribution Pump | 11 kW | |

The characteristics of the seawater desalination machinery on Gili Trawangan are shown in Table 1. The desalination tool is reviewed to determine how much power is required to create freshwater. Figure1 illustrates the per-person daily freshwater requirements for visitors to Gili Trawangan, which range from 120 to 150 litres (Suprihatin & Suparno, 2013).

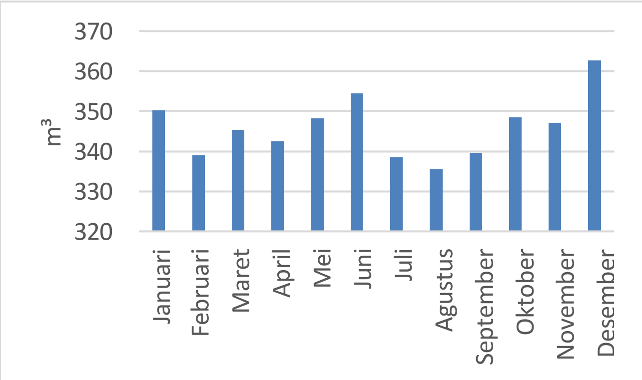


Figure 1. Water demand on 2021

As seen in Figure 1, the equipment used to desalinate seawater needs electrical energy to generate the freshwater it needs. The quantity of renewable energy components employed determines operational power, and the cost of all the components affects NPC and COE values. The cost of renewable energy components, replacement, operation, and maintenance are displayed in Table 2.

NASA secondary data linked to HOMER and journals are used to obtain the input data for the HOMER simulation, including solar radiation, clearness index, average wind speed, and the quantity of biomass present in the region for each month. Table 3 contains data on renewable energy sources.

Table 2. Technical and economic components (Mousavi, Zarchi, Astaraei, Ghasempour, & Khaninezhad, 2021)

| Component | Capital Cost (B Rp) | Replacement Cost (B Rp) | O&M Cost (Rp) |
|---|---|---|---|
| PV (25 years lifetime) | 4.725305 | 4.725305 | 145,394 per year |
| WT (20 years lifetime) | 72.697 | 65.4273 | 4,361,820 per year |
| Converter (10 years lifetime) | 261.7092 | 261.7092 | 145,394 per year |
| BT (12 years lifetime) | 18.305104 | 15.99334 | 145,394 per year |
| DG (15,000 hours lifetime) | 726.97 | 654.273 | 290,788 per hour |
| BG (20,000 hours lifetime) | 1,090.455 | 1,090.455 | 145,394 per hour |

Table 3. Input data for HOMER simulation *(Sekito, Dote, & Hindarman, 2019)

| | Energy demand (kWh) | Index clear-ness | Daily radiation (kWh/$m^2$/day) | Wind average (m/s) | Biomass* (tons/day) |
|---|---|---|---|---|---|
| Jan | 1,266 | 0.453 | 4.910 | 3.460 | 0.739 |
| Feb | 1,227 | 0.454 | 4.920 | 3.540 | 0.739 |
| Mar | 1,250 | 0.509 | 5.340 | 2.790 | 0.739 |
| Apr | 1,240 | 0.568 | 5.520 | 2.640 | 0.739 |
| Mei | 1,260 | 0.607 | 5.350 | 3.200 | 0.739 |
| Jun | 1,282 | 0.591 | 4.920 | 3.570 | 0.739 |
| Jul | 1,225 | 0.582 | 4.960 | 3.810 | 0.739 |
| Aug | 1,216 | 0.589 | 5.470 | 3.720 | 0.739 |
| Sep | 1,230 | 0.598 | 6.060 | 3.500 | 0.739 |
| Oct | 1,261 | 0.588 | 6.270 | 3.180 | 0.739 |
| Nov | 1,256 | 0.534 | 5.760 | 2.790 | 0.739 |
| Dec | 1,310 | 0.494 | 5.330 | 2.990 | 0.739 |

The data is entered into the HOMER software so that the software operates to produce data output as shown in Figure 2.

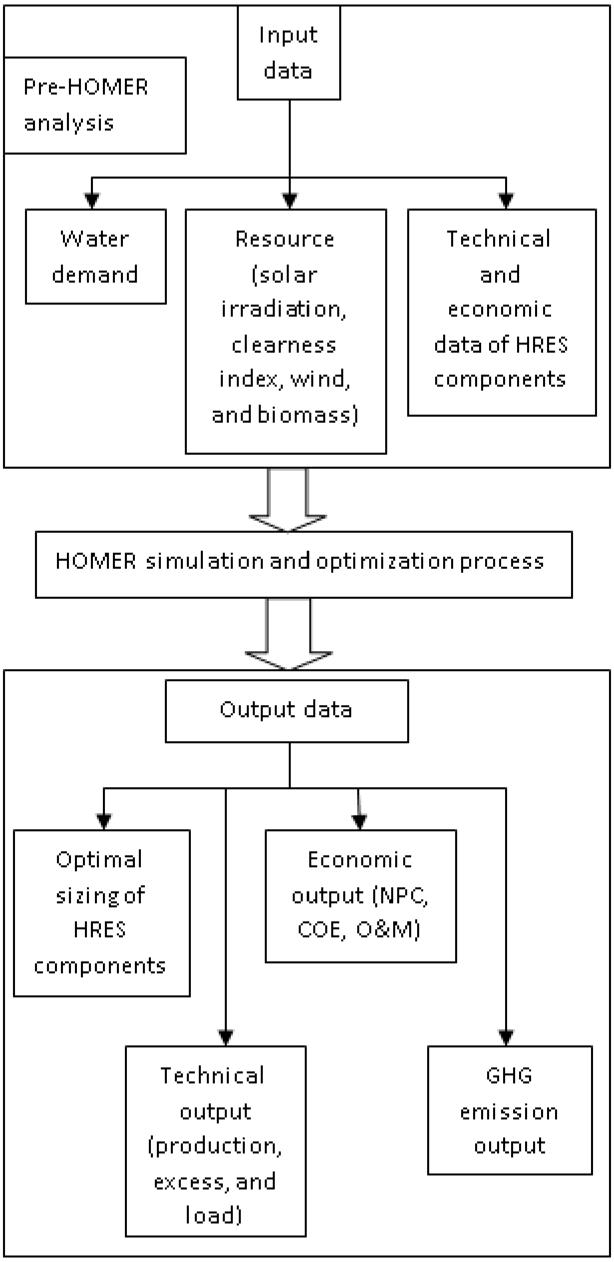


Figure 2. HOMER simulation procedure (Das, Ray, & De, 2022)

a. Economic Aspect

NPC and COE are the economic factors that this study has identified. However, HOMER's output also accounts for maintenance and operation expenditures.

I. NPC

NPC (Net Present Cost) is the combination of investment cost, O&M cost, and other energy revenues over the project lifetime (Das et al., 2022).

$$NPC = \frac{C_{ta}}{CRF(i,n)}$$

NPC = Net Present Cost over the project lifetime (Rp)
$C_{ta}$ = Total annualized cost (Rp/year)
i = Interest rate (0.49%)
n = Project period in years (25)
CRF = a function returning the capital recovery factor

II. COE

HOMER defines the Levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served, using the following equation (Homer Energy, 2019):

$$COE = \frac{C_{ta}}{E_{served}}$$

$COE$ = Cost of Energy (Rp/kWh)
$Cta$= Total annualized cost (Rp/year)
$Eserved$ = Total electrical load served (kWh/year)

III. Energy Aspect

The energy aspect that is seen in this study is the amount of production and the excess energy produced. In the on-grid system, the energy aspect is the amount of buying and selling electrical energy. These are the equation for the power output produced by renewable energy sources PV, Wind, and Biomass (Homer Energy, 2019):

$$P_{pv} = Y_{pv} \cdot f_{pv} \left(\frac{\bar{\bar{G}}_r}{\bar{\bar{G}}_{rstc}}\right) [1 + \alpha_p \,(T \;-\; T)]$$

$P_{PV}$ = Solar power output (kW)
$Y_{PV}$ = The rated capacity of the PV array under standard test conditions (kW)
$f_{PV}$ = The PV derating factor (%)
$\bar{G}_{\bar{r}}$ = The solar radiation incident on the PV array in the current time step (kW/m$^2$)
$G_{r,stc}$ = The incident radiation at standard test conditions (1 kW/m$^2$)
$\alpha_p$= The temperature coefficient of power (%/°C)
$T_c$ = The PV cell temperature in the current time step (°C)
$T_{c,stc}$ = The PV cell temperature under standard test conditions (25 °C)

$$P_{wind} = \frac{1}{Z}\,\bar{\rho}(\bar{v}^3)$$

$$V_{hub} = V_{anem} \cdot \frac{\ln\,(Z_{hub}/Z_0)}{\ln\,(Z_{anem}/Z_0)}$$

$$NPC = CRF\ (i, n)$$

$P_{wind}$ = Wind power output (W/m$^2$)
ρ = Air density (kg/m$^3$)
$v_{hub}$ = The wind speed at the hub height of the wind turbine (m/s)
$v_{anem}$ = The wind speed at anemometer height (m/s)
$Z_{hub}$ = The hub height of the wind turbine (m)
$Z_{anem}$ = The anemometer height (m)
$Z_0$ = The surface roughness length (m)
ln = The natural logarithm

$$F = F_0 Y_{gen} + F_1 P_{gen}$$

$P_{gen}$ = Biomass generator output (kW)
F = Biomass fuel (kg/hour)

$F_0$ = The fuel curve intercept coefficient (0.0330 kg·kW/h)
$F_1$ = The fuel curve slope (0.2730 kg·kW/h)
$Y_{gen}$ = The rated capacity of the generator (kW)

IV. Environment Aspect

The environmental aspect is viewed from the resulting $CO_2$ emissions. $CO_2$ emissions are produced from the process of forming biogas from biomass, diesel generator, and electricity generated by fossil fuels. However, carbon emissions depend on the duration of the generator and the electrical energy generated.

The HOMER software's emission values produced by biogas, diesel, and grid are 30.8 $gCO_2$/kWh of biomass, 31.7 $gCO_2$/kWh diesel, and 632 $gCO_2$/kWh grid.

## 3. Results & Discussion

a. Renewable Energy Operating Hours

The HOMER simulation results show many renewable energy integration options. HOMER calculates the possible number of renewable energy components that can operate SWRO desalination. The weakness of renewable energy is the inability to produce electrical energy continuously. The monthly energy output of off-grid and on-grid energy sources can be seen in Figure 3. The graphic illustrates the varied operational timeframes each month for PV, WT, BG, and DG taken at the lowest NPC value. Monthly graph shows overall maximum (top line correspond), overall minimum (bottom line), daily maximum (top of the blue box), daily minimum (bottom of the blue box), and the middle line is the overall average. That is because each renewable energy's operational duration fluctuates with the weather and climate. The optimal time for PV is around 6 am to 6 pm because the sun rises to sunset. The maximum peak power generated in PV operation lies in the vicinity of 11 to 13 with a value of 88.6 kW, the minimum output is 0 kW, and the average output produced is 474 kWh/day on an off-grid system. The maximum peak power generated in the on-grid system is 26.2 kW with an average output of 140 kWh/day.

WT uptime appears to be more distributed than PV. The maximum power produced by the WT is 413 kW with an operating time of 6,757 hours/year and an average output of 126 kW for the off-grid system. In the on-grid system, the maximum power generated is 147 kW with an operating time of 6,757 hours/year and an average output is 44.9 kW.

The biogas generator output is rarely used in an off-grid system because the energy produced by the PV, WT, and BT is sufficient to power the desalination equipment. Because its flexibility is dependent on the amount of biomass fuel used as feed, biogas energy can be used to compensate for the shortcomings of PV and WT. When renewable energy and batteries cannot meet the electricity demand, biogas will be used as a power plant. Biogas is not used in the on-grid system due to the high maintenance cost. In addition to biogas, diesel is used when renewable energy cannot meet diesel as renewable energy sources in an off-grid system is 1,101,089 kWh, 173,144 kWh, 24,898 kWh, and 3,142 kWh. Wind energy has the largest production of energy, followed by diesel, biogas, and diesel. With wind, grid, and diesel producing the most energy, respectively, the on-grid system's renewable energy to wind, solar, and grid amounts to 393,246 kWh/yr, 51,143 kWh/yr, and 188,070 kWh/yr. The installed wind energy capacity is higher than the other capacities, which results in higher energy production. Off-grid and on-grid systems are different in that on-grid systems can purchase and sell electrical energy from the existing PLN connections.

The power output from the generator set is less than other renewable energies. It happens because the capacity of the biomass and diesel generator sets which are only installed at 50 kW, differs from the installed PV and larger WT capacities. Wind energy is produced more than other renewable energies due to the large capacity of the wind turbine and the location near the coast, which gives the length of surface roughness factor ($Z_0$) low. In the off-grid system, the excess energy produced by the wind turbine is stored in the battery for use when other renewable energy cannot meet the load requirements, while for the on-grid system, the excess energy will be sold to PLN when the renewable energy produces electrical energy that is more than the load, the installed battery will store the energy. Likewise, when the energy produced by renewable energy is insufficient, the battery will be used to meet the needs of the load.

b. Off-Grid and On-Grid Simulation

The off-grid design is carried out by integrating solar, wind, biogas, and diesel renewable energy as reserves. The simulation results will issue NPC, COE, annual operating costs, $CO_2$ emissions, and electrical energy produced along with the excess energy. A CC (Cycle Charging) scenario is carried out in the off-grid simulation. This scenario is carried out because, on the off-grid, renewable energy does not continuously generate electricity and depends on the source. While the off-grid scenario is CC, in this on-grid simulation, the LF (Load Following) process is carried out in which the results of renewable energy that meet the load are directly used. Table 4 and 5 shows the result of the off-grid and on-grid simulation.

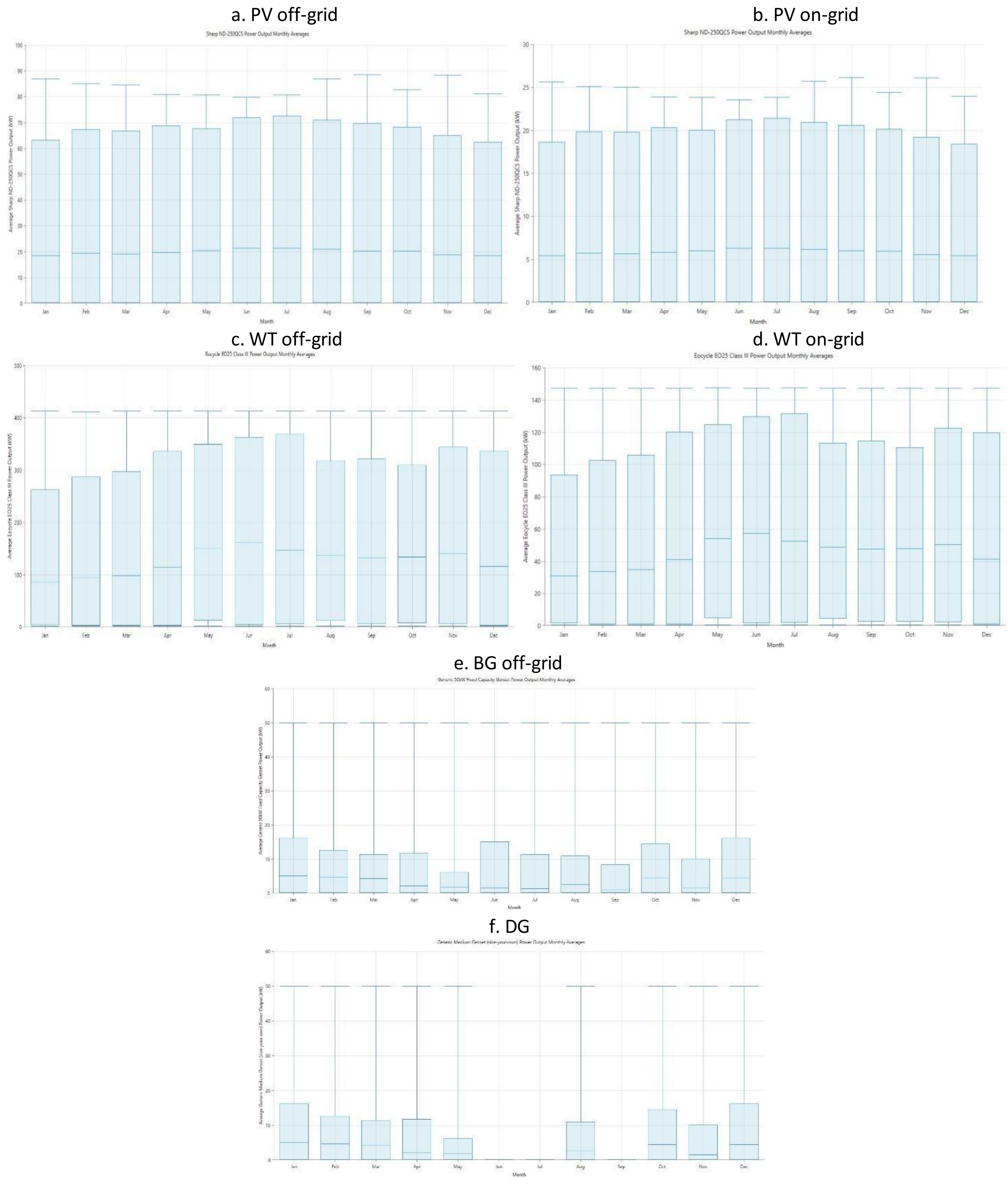


Figure 3. Monthly averages power output

I. NPC (*Net Present Cost*), COE (*Cost of Energy*), and Operating Cost

On the off-grid, the results of this simulation show that the lowest NPC (Net Present Cost) and COE (Cost of Energy) output values are Rp. 17,042,910,000 and Rp. 1,587 with a capacity of PV 102 kW, 14 WT, 50 kW biogas, and 50 kW diesel. The NPC value depends on the capital recovery factor, while this factor depends on the interest rate and the length of the project. The value of a small recovery factor capital will result in a small annual fee. The annual cost (Cta) determines the average electricity price. A large annual cost will result in a high average price of electrical energy and vice versa. The operating duration of biogas and diesel affects the resulting $CO_2$ emissions. This simulation shows that the resulting $CO_2$ emission is 2,335 kg/yr with biogas and diesel operating times 563 and 65 hours. The annual operating cost in this scenario is Rp. 335,846,900. These costs are generated from the total system costs on an annual basis: component replacement, operation and repair, fuel, and salvage minus the annual component system cost.

Table 4. Off-grid Simulation Result

| PV (kW) | WT (kW) | BG (kW) | DG (kW) | BT | Converter (kW) | NPC (B Rp) | COE (Rp) | Operational cost (B Rp/yr) | Electricity yield (kWh/yr) | Excess electricity (kWh/yr) | $CO_2$ (kg/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 102 | 350 | 50 | 50 | 187 | 112 | 17,042.91 | 1,587 | 335.8469 | 1,302,273 | 815,814 | 2,335 |
| 188 | 625 | 50 | 50 | 139 | 117 | 19,516.06 | 1,818 | 373.0963 | 2,301,533 | 1,821,626 | 614 |
| 209 | 200 | 50 | 50 | 277 | 156 | 19,643.63 | 1,830 | 292.3081 | 990,478 | 500,410 | 163 |

Table 5. On-grid simulation result

| PV (kW) | WT (kW) | BG (kW) | Converter (kW) | NPC (B Rp) | COE (Rp) | Operational cost (B Rp/yr) | $CO_2$ (kg/yr) | Energy purchased (kWh) | Energy sold (kWh) |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 125 | 50 | 23 | 2,961.782 | 200 | 31.36244 | 118,861 | 188,070 | 173,332 |
| 90 | 125 | 50 | 23 | 4,022.174 | 265 | 28.49387 | 107,518 | 170,123 | 189,170 |
| 149 | 125 | 50 | 23 | 5,767.869 | 378 | 54.80075 | 104,956 | 166,069 | 192,664 |
| 209 | 125 | 50 | 47 | 6,104.5 | 373 | 12.42875 | 84,000 | 132,911 | 239,996 |

In contrast to the NPC scheme, the PV integration energy capacity of 209 kW, 8 WT, 50 kW biogas, and 50 kW diesel has the lowest operational costs in this simulation. This operational cost is IDR 292,308,100, with 116 and 5 operating hours for biogas and diesel. The significant difference between the lowest NPC and the lowest operating costs is Rp. 70,916 million in component replacement.

The results of the on-grid simulation are obtained lowest NPC and COE are Rp 2,961,782,000 and Rp 200. These values are lower than the lowest NPC and COE off-grid. It is because the price of electricity at PLN is cheaper and the amount of renewable energy used is less. On-grid systems with fewer renewable energy components have reduced maintenance and operating costs.

The lowest operational at on-grid is Rp 12,428,750. Adding PV to grid system effected the price of operational cost. Energy excess produced by renewable energy source is sold to PLN. The higher energy excess produced reduce the operational of the on-grid system.

II. $CO_2$ Emission

$CO_2$ emissions in off-grid systems are only produced in biogas and diesel. The lowest $CO_2$ emission scenarios are the PV capacity of 209 kW, 8 WT, 50 kW biogas, and 50 kW diesel. The lowest emission in this integration is caused by the lack of biogas and diesel generators used during operating hours. The operating hours of biogas and diesel in this scenario are 116 hours of biogas and 5 hours of diesel, so the $CO_2$ emission value is 163 kg/year. The annual NPC, COE, and operational costs in the scenarios are Rp 19,643,630,000, Rp 1,830, and Rp 292,308,100.

In the on-grid scenario, adding PV increases electrical energy production and decreases $CO_2$ emissions. The increase in electrical energy and the reduction in $CO_2$ emissions occur due to the increased power installed by renewable energy, thereby increasing electricity production. The $CO_2$ emissions are decreasing due to the increase in renewable energy capacity because $CO_2$ emissions are only produced by coal fuel from PLN.

III. Electricity Production

At off-grid system, renewable energy sources such as wind and solar energy have limitations in terms of continuously producing electrical energy, so auxiliary components such as batteries that can store energy must be utilized. The excess electrical energy generated by renewable energy will be stored in batteries and used when renewable energy results in a lack of electrical energy required by the load. Excess electricity means there is no room for the battery to store the energy, so that energy must be discarded. The positive impact of this excess electricity is that it can be used in addition to turning on desalination equipment, such as lighting lamps and others. Excessive electricity and electricity production in this simulation are 2,301,532 kWh/yr and 1,821,626 kWh/yr.

In the on-grid system, the amount of electrical energy produced can be resold if the electricity generated by the renewable energy integration exceeds the load requirement and purchase electrical energy from PLN if there is a shortage of energy to operate seawater desalination equipment. It can affect the operational costs that HOMER simulates. The more electrical energy sold, the less operational costs are generated because HOMER simulates the operational costs of the grid as the sum of the energy costs purchased minus the energy sold. It can be seen in the on-grid simulation results, operational costs, lowest emissions, lowest electricity purchase, and highest electricity sales on the integration of 209 kW PV, 5 WT, and 50 BG with successive results of Rp 12,428,750, 84,000 kg/year, 132,911 kWh, and 239,996 kWh of energy were sold with the integration of renewable energy as shown in the simulation results table.

## 4. Conclusion

1. Renewable energy that has the potential to be used as a means of seawater desalination in Gili Trawangan is solar, wind, and biomass, with a choice of renewable energy with off-grid and on-grid systems.
2. Renewable energy with off-grid and on-grid systems can meet the electricity needs for seawater desalination by integrating the following renewable energy options:

SWRO powered by off-grid renewable energy integration

| PV-Shar 250 (kW) | WT-EO25 III (kW) | BG (kW) | DG (kW) | BT-S4KS 25P | Converter - Ideal 30kW (kW) |
|---|---|---|---|---|---|
| 102 | 350 | 50 | 50 | 187 | 112 |
| 188 | 625 | 50 | 50 | 139 | 117 |
| 209 | 200 | 50 | 50 | 277 | 156 |

SWRO powered by on-grid renewable energy integration

| PV-Shar250 (kW) | WT-EO25III (kW) | BG (kW) | Converter-Ideal30kW (kW) |
|---|---|---|---|
| 30 | 125 | 50 | 23 |
| 209 | 125 | 50 | 47 |

3. In off-grid and on-grid systems, the lowest economic value based on NPC Rp 17,042,910,000 and COE Rp 1,587 is found in the integration of renewable energy PV 102 kW, 350 kW WT, 50 kW BG, and 50 kW DG for off-grid and NPC Rp 2,961,782,000 and COE Rp 200 with PV 30 kW, 125 kW WT, and 50 BG for On-grid while the lowest operational costs Rp 292,308,100 per year at PV 209 kW, 200 kW WT, 50 BG, and 50 DG for off-grid and Rp 12,428,750 PV 209 kW, 125 kW WT, 50 BG for on-grid.
4. The lowest CO2 emissions are found at PV capacities of 208 kW, 200 kW WT, 50 BG and 50 DG with a value of 163 kg/year for the off-grid system and 209 kW PV, 125 kW WT, and 50 kW BG with a value of 84,000 kg/year for the on-grid system.
5. The highest and excess production of electrical energy in the off-grid system occurs at PV capacities of 188 kW, 625 kW WT, 50 BG, and 50 DG, with a value of excess electricity and electricity production of 2,301,533 kWh/year and 1,821,626 kWh/year. The amount of power purchased and sold measures the on-grid system's energy. According to the simulation, 132,911 kWh and 239,996 kWh of electrical energy were sold and bought.

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