Hybrid solar-wind-diesel power plant for small islands in Maluku Province

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Abstract. Maluku Province is an archipelagic province consist of 1,340 islands mostly classified as small island and has the total area of 712,479.69 km² of which 658,331.52 km² (92.4%) are marine and only 54.15 km² (7.6%) are terrestrial. This geographic condition causes high insularity and approximately 34% of villages in Maluku are without electricity and it is highly impossible to provide every remote small island with the power supply. Solar and wind penetration into existing diesel systems can be considered as a breakthrough to meet the need for power supply for these remote islands. A techno-economic analysis is applied to perform a design of an optimal hybrid solar-wind-diesel power plant to serve the load of the villages at these remote islands. The hybrid plant can reduce cost about 20% as well decrease of greenhouse gas emissions of diesel generator alone. Based on the result obtained, the villages in Maluku Province particularly those at the remote area are the potential candidate for deployment of the proposed hybrid solar wind-diesel power plant for electricity generation.

1. Introduction
Maluku province is located at the eastern part of Indonesia at -3°14’18.46” S 130°08’42.97” E is commonly called as the Thousand Island’s Province since there are 1,340 islands compose this province. As an archipelago Province that comprises approximately 92.4% of ocean area (658,311,52 Km²) and only 7.6% of the land-dwelling area (54,168.14 km²) makes Maluku Province as one of the provinces having the longest coastal line in Indonesia [1].

This province consists of nine regencies i.e. Central Maluku regency, Southeast Maluku regency, West Seram regency, East Seram regency, Buru regency, South Buru Regency, Western South East Maluku regency, South West Maluku regency, and Aru regency. Majority of islands in Maluku consist of small island and only four islands out of 1,340 islands classified as the big island (Figure 1).

Some characteristics of being a small island include extreme dependence on the external sector – trade with other states or mainland [2], remoteness, isolation, reliance on remittances, vulnerability to natural disasters [2, 3], small population, limited market size, consumption center [2, 4]. Major disadvantages of small islands include lack of terrestrial natural resources, a limited labor supply, remoteness, limited manufacturing industry, inadequate access to technology, high cost in economic development, and a very small private sector [2, 4]. One example of the disadvantage of a small island in Maluku Province is the ratio of electrification which was 66% in 2017. From 1,233 villages, 419 villages (34%) still has no electric facility [5], in the meantime the supply of electricity is also important for the community in this area.

After 1998, the Indonesian energy consumption growth rate increased by 7% per year and was not balance with adequate fossil fuel reserve [6] whilst dependency towards fossils fuel is still high. Alternate energy resources, therefore, become an important factor and two of them are solar energy...
and wind energy which have unique characteristics of being clean, inexhaustible, unlimited and environmentally friendly. These energy sources have proven to be advantageous for decreasing the depletion rate of fossil fuel as well as supplying energy to remote rural areas [6, 7], like many small islands in Maluku province, without harming the environment.

![Figure 1. Map of Maluku province](image)

### 2. Renewable Energy Resources in Maluku

#### 2.1. Solar energy

Solar energy is one of the most promising sources of clean, renewable energy and it has the greatest potential than any other power resource to solve the world’s energy problems and has become more popular as an energy supply in the world [6, 8]. Maluku province is in the tropical region and has free solar energy that can be utilized to produce electricity [9]. Table 1 shows the monthly average of solar irradiation in five cities in Indonesia used in testing irradiation intensity [10]. This table shows that in average Ambon city as a representative of Maluku province has the second highest irradiation intensity in Indonesia, hence become potential for solar energy sources. Figure 2 shows climate map of Maluku and North Maluku which explain variation climate in these two provinces, whilst Figure 3 shows monthly average percentage of solar irradiation during day time.

| City      | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Bengkulu  | 4.54| 4.69| 4.69| 4.71| 4.70| 4.73| 4.83| 5.24| 5.13| 4.84| 4.47| 4.52| 4.76 |
| Jakarta   | 4.57| 4.64| 4.85| 4.95| 4.96| 5.00| 5.07| 5.21| 5.42| 5.40| 4.84| 4.74| 4.97 |
| Samarinda | 4.66| 4.88| 4.99| 4.98| 4.80| 4.76| 4.76| 4.87| 6.92| 5.04| 4.80| 4.42| 4.82 |
| Manado    | 5.61| 5.77| 6.04| 6.24| 6.00| 5.65| 5.87| 6.30| 6.61| 6.19| 5.69| 5.59| 5.96 |
| Ambon     | 5.52| 5.57| 5.49| 5.37| 5.17| 5.16| 5.35| 6.00| 6.02| 6.25| 6.20| 6.04| 5.68 |
Figure 2. Climate Map of Maluku and North Maluku

Figure 3. Monthly Average percentage of solar irradiation during day time

2.2 Wind Energy
Like solar energy, the kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world [11, 12]. The worldwide demand for wind turbines has been growing rapidly over the last 15 years. During 2001 alone the wind energy industry installed
close to 5,500 MW of new generating capacity. More than 24,000 MW of wind energy capacity is now estimated to be in operation around the world [11]. The implementation of wind energy technology in Indonesia is still low it is around 1.6 MW installed capacity [13].

The energy that can be captured by wind turbines is highly dependent on the local average wind speed [11]. The Indonesia Ministry of Energy and Mineral Resources has estimated total potential for onshore wind energy was estimated at 9.3 GW in Indonesia. Of this, about 960 MW has been identified as ready for development immediately, with half of this finding to be on Java-Bali and another 25% on Sulawesi [14]. Summary data from research conducted to estimate potential site for wind energy development has identified Maluku as one of the potential site with marginal category (3-4 m s$^{-1}$ at 50 m) and good category ($>5$ m s$^{-1}$ at 50 m) [13]. This opens the opportunity to establish renewable energy resources for the remote area with limited electricity supply.

3. Materials and Method

Data in this study was secondary data which was collected from various literatures [10, 13]. A techno-economic analysis was used in order to design hybrid power system as electricity power plant to deploy at remote area in Maluku Province.

4. Results and Discussion

4.1. Power Energy

Power energy in this paper consist of diesel generator, wind turbine and solar panel photovoltaic (solar-PV).

4.1.1. Diesel generator. If the power plant uses only a diesel generator to produce electricity, so it needs two diesel generators of 15 kVA each. This can produce 262,800 kWh yearly with total fuel consumption of 65,700 liters, hence the total fuel cost is IDR. 459,900,000. Figure 4 and Table 2 show an example of the diesel generator and its specification.

| Table 2. Yanmar diesel generator specification |
|-----------------------------------------------|
| Model                                        | ATL-10 YMR |
| Engine brand                                 | Yanmar     |
| Engine type                                  | 3TNV82A    |
| Prime power (kVA)                            | 10         |
| Prime power (kW)                             | 8          |
| Rated speed                                  | 1500 RPM   |
| Standard voltage                             | 400/230 V  |
| Output frequency                             | 50 hz      |
| Bore (mm)                                    | 111        |
| Stroke (mm)                                  | 139        |
| Displacement (L)                             | 8.071      |
| Fuel consumption 100% Prime power            | 35.4       |
| Fuel consumption 75% Prime power             | 26.7       |
| Fuel consumption 50% Prime power             | 18.7       |
| Price genset Yanmar 10 KVA open type         | IDR 147000000 |

According to GTI (Gas Technology Institute), standard maintenance cost for a diesel engine that propelled the generator is $0.005-$0.010 (IDR. 70 – IDR. 140) per kWh. Year average maintenance cost, therefore, amounted to IDR. 27,594,000. In 6 years total Investment, operational and maintenance cost by using diesel generator is IDR. 2,710,181,440.
With a good approximation, we can say that burning a liter of diesel fuel oil produces 2.63 kg CO$_2$, the value depends on the mixture of hydrocarbons and the engine, but does not differ much. The weight gains due to the fact that we have considered only the combustible, but we need to add oxygen in the combustion. The diesel engine exhausts 173 tonnes CO$_2$ yearly. Formula for carbon emission is: $\text{CO}_2$ emission = Fuel Combusted (fuel units) * EF$_{\text{CO}_2}$ (kg CO$_2$/fuel units), where EF$_{\text{CO}_2}$ is emission factor of diesel fuel oil the magnitude is 10.14 kg/gallon [15].

4.1.2. Wind turbine. In the recent years, wind turbine technology has developed rapidly and is becoming more powerful, with the latest turbine models having larger blade lengths which can utilize more wind and therefore produce more electricity, bringing down the cost of renewable energy generation [16]. Figure 5 and Table 3 shows windmill type and its general specification. Proposed full capacity of two wind turbines yearly is 210,240 kWh (see section 4.2).

Table 3. General specification for wind power unit

| Specification                          | Value     |
|----------------------------------------|-----------|
| Power output (kW)                      | 5         |
| Generator output (kW)                  | 2         |
| Voltage (V)                            | 220 – 120 |
| Frequency (Hz)                         | 50 or 60  |
| Rated wind speed (ms$^{-1}$)           | 9.1       |
| Operating wind speed minimum (ms$^{-1}$)| 3         |
| Operating wind speed maximum (ms$^{-1}$)| 25        |
| Storm wind speed (ms$^{-1}$)           | 60        |
| Propeller diameter (m)                 | 4.5       |
| RPM                                    | 100 … 160 |
| Tower height (m)                       | 12        |
| Number of Block                        | 3         |
| Operational temperature range (°C)     | -0.8      |
| Noise level (decibel)                  | 45        |
| Expected life cycle (year)             | 25        |
| Average annual energy output (kWh) at 4 ms$^{-1}$ | 2581 |
| annual average wind speed (wind repetition according to Weibul) | |
| 5 ms$^{-1}$                            | 4664      |
| 6 ms$^{-1}$                            | 6747      |
| 7 ms$^{-1}$                            | 8554      |
| 8 ms$^{-1}$                            | 9990      |
| Total weight (kg)                      | 270       |
| Tower include                          | 95        |
| Tower exclude                          |           |
One important advantage of solar PV is that it utilizes the most abundant renewable energy resource on the planet, the sun. The power of solar energy PV is generally employed on a panel which is consisted of many cells of semiconductor mostly made from silicon. By using these semiconductors, solar radiation is converted into direct electricity current.

Despite naturally high insolation across most parts of Indonesia, current solar PV deployment remains limited, totally 108 MWp, although its potential is estimated to be around 206.7 GWp [17, 18].

By using Ambon as representative of Maluku Province, the annual average solar radiation in this province is 5.68 kWh m$^{-2}$ day$^{-1}$, maximum solar radiation (6.26 kWh m$^{-2}$ day$^{-1}$) is recorded in October, and the minimum solar radiation (5.16 kWh m$^{-2}$ day$^{-1}$) is recorded in June. In this study, proposed amount of PVs used by the power plant is 200 sq. m 12V which has the annual capacity is 43,800 kWh (see section 4.2. below)

4.1.3. Solar Panels- PV. One important advantage of solar PV is that utilizes the most abundant renewable energy resource on the planet, the sun. The power of solar energy PV is generally employed on a panel which is consisted of many cells of semiconductor mostly made from silicon. By using these semiconductors, solar radiation is converted into direct electricity current.

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4.2. Design of the hybrid power plant

The hybrid energy system is the combination of two or more energy sources for giving power to the load. In other words, it can be defined as “Energy system which is fabricated or designed to extract power by using at least two energy sources”. Hybrid energy system has good reliability, efficiency, less emission, and lower cost [7, 19, 20].

The design of the hybrid power plant is to supply electricity to the villages at the remote area of Western East Maluku and South West Maluku regencies which are the area with an average yearly wind speed of more than 5m s$^{-1}$ and average solar intensity irradiation of about 5.16 – 6.25 kW m$^2$. This study uses three sources of hybrid energy system i.e. diesel generator, solar and wind energy. Figure 6 displays a schematic of the hybrid power plant proposed in this study while Table 4 shows equipment and capacity for the hybrid power plant.

Figure 5. Windmill SW2-5
The power plant should supply electricity for 100 houses and the equipment required for this consist of two diesel generator capacity 10 kVA each, two wind turbines capacity 5 kW each and PV 12V with area 40 sq. m, 130 batteries of 12V 200 Ah each and 5 Inverter DC to AC capacity 50 kVA each.

**Table 4. Equipment for the hybrid power plant**

| Equipment               | Total | Power | Capacity/year | Total Capacity/year | Total Houses | Available Capacity/house/month | Available Capacity/house/day |
|-------------------------|-------|-------|---------------|---------------------|--------------|-------------------------------|-------------------------------|
| Diesel-Generator, pc    | 2     | 10    | 0             | 210,240             | 100          | 212                           | 7.06                          |
| Wind Turbine, pc        | 2     | 5     | 43,800        | 254,040             | 100          | 212                           |                               |
| Solar panel, m²         | 40    | 5     |               |                     |              |                               |                               |
| Battery 12V 200Ah       | 130   | 312   |               |                     |              |                               |                               |
| Inverter, 50 KVA        | 5     | 50    |               |                     |              |                               |                               |

Totally producing energy wind turbine and PVs is 254,040 kWh yearly which is almost equal to annual production of diesel generator alone. Investment for two diesel engines each 15 kVA, two wind turbines, PVs, 130 batteries & 5 inverters is IDR. 2,154,000,000. Where yearly operational and maintenance cost is almost zero. Compare with full diesel generator is IDR. 2,710,181,440. Thus, total investment of hybrid energy system for more than six years investment is about 20% lower than diesel generator alone. In addition, this hybrid energy system will reduce greenhouse gas emission which is produced by power plant of diesel generator.
5. Conclusion

- Hybrid system power plant generates 254,040 kWh yearly, hence each house receives 212 kWh monthly. Full diesel generator system generates almost the same capacity.
- Diesel system exhausts 173 tonnes CO₂ yearly into the atmosphere.
- Within a period of more than 6 years the investment plus maintenance and operational cost of diesel system is about 20% higher than hybrid system.

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