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Distribution of Direct and Diffuse Radiation on Bawean Island, East Java Indonesia

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Abstract

A study of the availability of solar energy is an interesting topic. By knowing the amount of solar energy available at a location, it can be determined how much power can be generated by a solar energy equipment and what utilization system should be used (whether solar electric or solar thermal systems). Solar radiation that falls on the earth's surface is a total radiation consisting of direct radiation components and diffuse radiation components. In their use, direct radiation is more effective for photovoltaic solar cell applications to generate electricity and solar concentrators in high temperature thermal applications, whereas total radiation and diffuse radiation will be more effective for solar collector fittings for thermal applications with relatively low to moderate temperatures. This paper discusses the distribution of both radiation components, especially in Bawean Island. Based on observational data from Sangkapura Meteorology Station, Bawean for 15 years (1994-2010) obtained an illustration of direct radiation distribution is more dominant than the diffuse radiation. This indicates that Bawean Island is suitable for solar photovoltaic applications as well as solar concentrator for electricity generation purposes. This can help local people to overcome the problem of limited electricity supply from state owned electricity (PLN) on the island.

Keywords: Bawean Island, direct radiation, diffuse radiation, solar electric, solar thermal

1. Introduction

In the 2016 national energy mix, the new EBT portion is 7.7% or fails to reach the target of 10.4%. Though Indonesia can be said to be rich in EBT, such as sun, geothermal, water, until the wind. To achieve the 23% EBT target in the national energy mix by 2025, it is impossible to do with the usual things but it needs breakthrough and accelerated EBT development. The government needs to boost the installation of solar panels in buildings and factories so that renewable energy can be increased, as well as shifting sources of fossil energy such as petroleum, gas, coal. In addition, the mandatory 20% biodiesel program (B20) to reduce diesel oil consumption should also continue (finance.detik.com, 2017).

Basic data for the development of electricity in a region is the need for electricity. Electricity needs are two kinds of electricity needs for household and industrial electricity needs and public facilities. The needs of households and public facilities can be estimated based on population. Electricity can also be produced from Solar Power Systems. The corresponding solar radiation location data is needed to activate the Solar Power Plant. Solar radiation data are crucial to the active solar energy facilities (Li et al., 2012) and passive energy-efficient building design (Li et al., 2013). However, solar radiation readings vary with geographic latitude, season and time of day, due to the various positions of the sun under unpredictable weather conditions (Li et al., 2010). Long-term data measurement is the most effective and accurate way of setting up such databases. In many parts of the world, however, the basic solar radiation data for the surfaces of interest are not always readily available (Munner, 2004). Accurate prediction of solar energy resources over the potential location is very important for proper siting, sizing and life-cycle cost analysis of solar power plant (Charabi et al, 2016).

Bawean Island as one of the sub districts in Gresik Regency, East Java is a sub district with a very rapid growth.

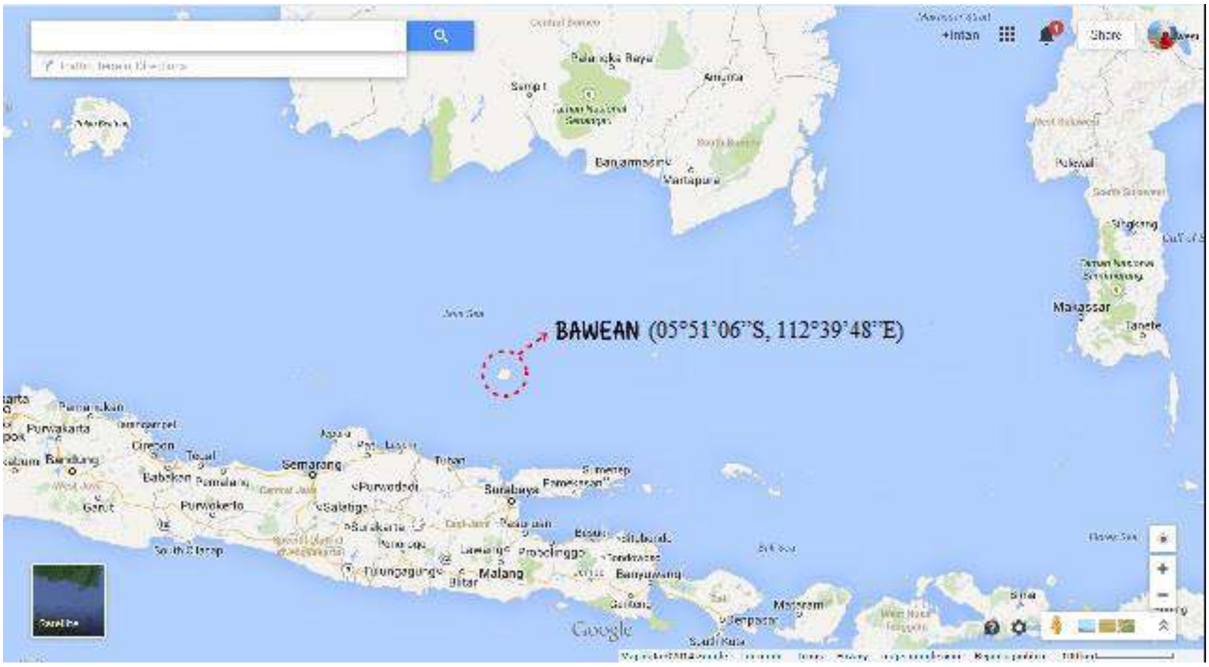


Fig. 1: Bawean Island Location

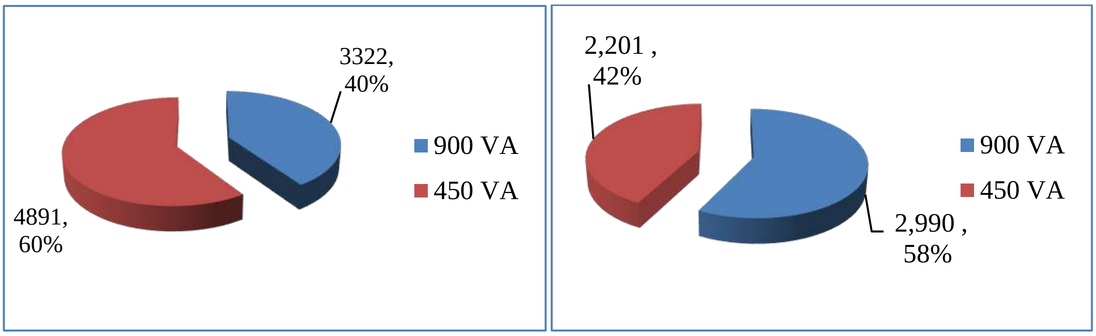
Figure 1 shows the location of Bawean Island located 150 km north of Gresik regency, East Java, with an area of 190 km^2. There are two sub districts on Bawean Island, namely Sangkapura and Tambak sub districts as shown in Figure 2. Based on the book Gresik in Figures 2010 the population in both sub districts can be detailed as can be seen in Table 1 (Statistics Gresik, 2010).

Table 1: Population Data on Bawean Island in 2009

Sub District	Population (person)
Sangkapura	70.372
Tambak	39.495
Jumlah	**109.867**

Fig. 2: Map of Bawean Island

The total population of 109,867 people consists of 18,436 households with details, number of families in Sangkapura sub district is 11,607 families and Tambak sub district 6.829 households. The electricity system in Bawean Island is currently supplied by PLTD through JTM (*Jaringan Tegangan Menengah*, JTM) Medium Voltage Network of 20 kV with 1750 kW power capacity and 5230 kW installed capacity. The highest peak load ever achieved is 2555 kW at the time of sufficient supply, and then dropped due to the decreased power capable of diesel. While the lowest load of 1893 kW. The load factor of the electricity system in Bawean Island is about 67%.



(a) **(b)**

Fig. 3: Number of Prospective Customers of Household & Business Sector (a)
Demand for Electricity Bawean Island Household & Business Sector (kVA) (b)

Bawean island residents have not all enjoyed electricity, because only about 10% (10,964 customers until September 2010) who have become State-owned Electricity Company (*Perusahaan Listrik Negara*, PLN) electricity customers. Meanwhile, in September 2010, about 8,213 potential customers were on the waiting list with 4,891 potential customers (60%) of R1 / 450 VA and 3,322 prospects (40%) R2 / 900 VA as presented in Figure 3. Thus, the total demand for power by the local community is 5,191 kVA. Taking into account the waiting list of 8,213 prospects, the projection of total peak load that will occur in the electricity system in Bawean Island is 6756 kW with the same load pattern assumption. Thus, the base load of Bawean Island's electrical system is 3 MW. The increasing electricity demand from year to year must be balanced with the increase of power capacity that can be generated by local PLN. To meet these needs can be met by utilizing the potential of local energy resources, such as solar energy. Nevertheless, it is necessary to study the potential of solar energy to ensure the fulfillment of local electrical energy needs. By knowing the amount of solar energy available at a location, it can be determined how much power can be generated by a solar energy equipment and what utilization system should be used (whether solar electric or solar thermal systems). Solar radiation that falls on the earth's surface is a total radiation consisting of direct radiation components and diffuse radiation components. In their use, direct radiation is more effective for solar photovoltaic applications to generate electricity and solar concentrators in high temperature thermal applications, whereas total radiation and diffuse radiation will be more effective for solar collector fittings for thermal applications with relatively low to moderate temperatures. This paper discusses the distribution of both radiation components, especially in Bawean Island.

2. Datasets and Methodology

In Bawean Island, the data used to analysis are sunshine duration measured in the meteorological stations of Sangkapura (05°51’06”S, 112°39’48”E, 3.3m asl). This sunshine duration data is used in the framework of Feasibility Study of Electricity Addition in Bawean Island using local energy resources by PLN East Java in 2011. Thus, in this paper sunshine data used is data collection for the last 15 years, 1994-2010 periods. Sunshine duration measurements were performed using Campbell Stokes belonging to the local Meteorological Station. The data collected is the duration of sun exposure in percent. In order to reflect the amount of energy, the data needs to be converted in units of energy power.

First, the sunshine duration data is converted into global radiation data using Angstrom correlation (Utomo et al, 2005a and Utomo et al, 2005b). Furthermore, global radiation data is broken down into two components, namely the diffuse radiation component and direct radiation components using a model that has been developed previously (Hoesin, 2005). Starting from the standard atmospheric model used to estimate the intensity of solar radiation, the mathematical model of standard atmospheric solar radiation (H_c), Hoesin (1983) and Utomo et al (2004) developed the form of mathematical model H_c as follows:

$$H_c = C_1 + C_2\, cos(t) + C_3\, cos(2t) + C_4 \cos(3t) + C_5 \sin(t) + C_6 \sin(2t) + C_7 \sin(3t) \quad (1)$$

$$t = \frac{365(h_n - 80)}{360} \quad (2)$$

The mathematical model is formulated based on standard atmospheric model, sunshine duration data, day length and global radiation data on the surface of the earth. The mathematical model which expresses the relation of global radiation (H_{g0k}) to sunshine duration (n_{0k}) is in the form of non-linear regression:

$$\frac{H_{gok}}{H_{cok}} = f\left(\frac{n_{0k}}{N_k}\right) \quad (3)$$

The sunshine duration data obtained from the meteorology / climatology station consists of two forms of Time Period, ie 1) 12 hours of sunshine duration, between 6:00 am to 6:00 pm or 2) 8 hours of sunshine duration, between 8:00 am to 4:00 pm. For the purposes of equation 1, sunshine duration (n) Meteorology/Climatology Station needs to be converted into sunshine duration based on length of day N. The sunshine duration relationship with the day length N is as follows:

$$n_{0k} = \left\{\frac{(W\ x\ n) + r}{N}\right\} \quad (4)$$

n_0 is sunshine duration after correction, W = 8 or 12, Time Period of sunshine period and should be determined in accordance with calculations performed by the climatological station. While n is sunshine duration (observer station), N is day length and r is correction factor for sunshine duration data. Value of r is in range $0 \leq r \leq 2.5$. The determination of r value is determined by sunshine duration data pattern. While the mathematical model which states the sunshine duration relationship between Meteorological Station (measuring sunsine duration only) with Climatology Station (measuring global radiation and sunsine duration) is in the form of linear regression:

$$\frac{n_{0k}}{N_k} = f\left(\frac{n_{0l}}{N_l}\right) \quad (5)$$

Both models (equations 3 and 5) are used to calculate solar radiation in locations where there is sunshine duration data. The day length (N) is calculated by the formula:

$$N = 0.133\ arc \cos\left(\frac{\omega_s}{360}\right) \quad (6)$$

$$\omega_s = -\tan\varphi\ \ x \tan\delta \quad (7)$$

Declination (δ) is calculated by the formula:

$$\delta = 23.45 \sin\left\{360\ \left[\frac{284 + h_n}{365}\right]\right\} \quad (8)$$

3. Result and Discussion

3.1. Global Radiation

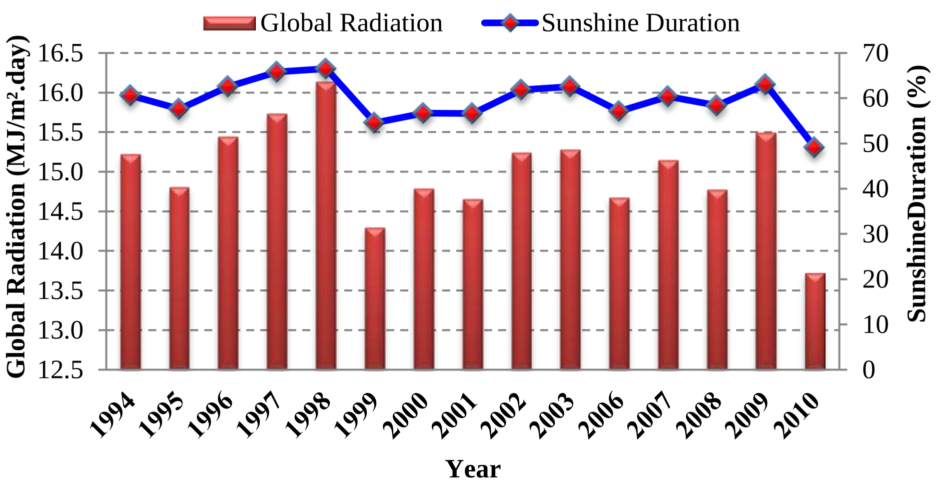


Fig. 4: Yearly Global Radiation and Sunshine Duration in Bawean Island.

Figure 4 shows the yearly-average-daily sunshine duration (%) data that has been converted to global radiation (MJ/m². day). It can be seen that Bawean Island receives quite a lot of solar energy, ranging from 13.72 MJ/m². day in 2010 to 16.14 MJ/m². day in 1998. Daily global radiation data are useful for evaluating the performance of solar electric or solar thermal systems. For further analysis purposes, global radiation is broken down into two components, namely the diffuse radiation component and direct radiation components.

3.2. Diffuse and Direct Radiations

Solar radiation that falls on the earth's surface is a total radiation consisting of direct radiation components and diffuse radiation components.

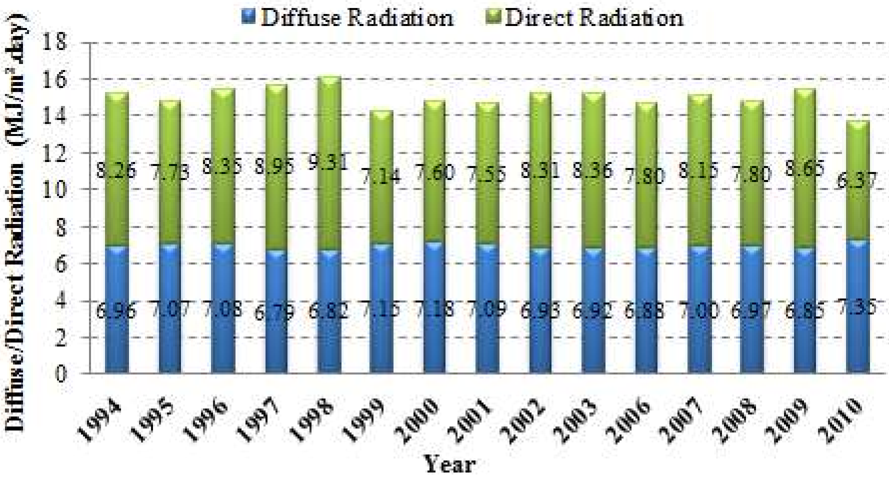


Fig. 5: Yearly Diffuse and Direct Radiation in Bawean Island

Figure 5 shows the global radiation after broken down into its two components, namely the diffuse and direct radiation. In their use, direct radiation is more effective for photovoltaic solar cell applications to generate electricity and solar concentrators in high temperature thermal applications, whereas total radiation and diffuse radiation will be more effective for solar collector fittings for thermal applications with relatively low to moderate temperatures.

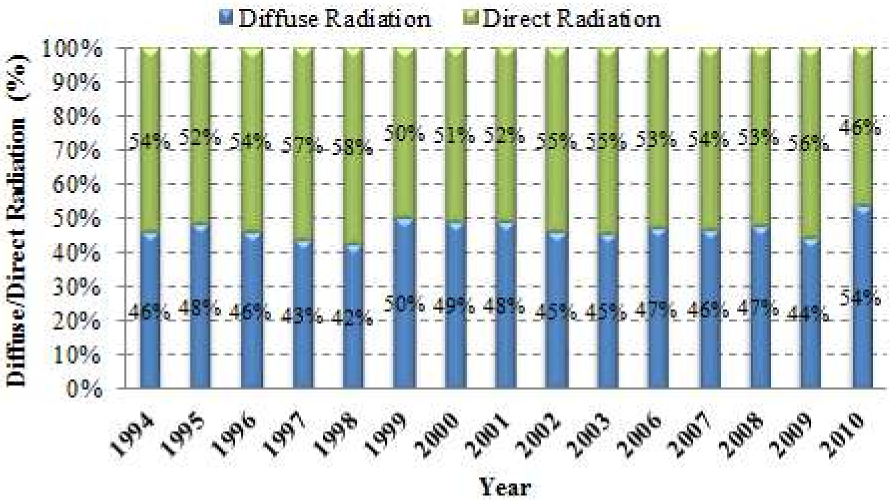


Fig. 6: Percentage Diffuse and Direct Radiation in Bawean Island

Figure 6 shows that the direct radiation distribution is more dominant than the diffuse radiation. It can be seen direct radiation dominates over 50%, except in 2010 only 46%. This indicates that Bawean Island is suitable for photovoltaic solar energy applications as well as solar concentrator for electricity generation purposes. It is expected to help local communities to overcome the problem of limited electricity supply from state owned electricity (PLN) on the island.

4. Conclusion

This paper assesses the distribution of diffuse radiation and direct radiation components in Bawean Island which growth very rapid and a lot of potential customers were on the waiting list. Based on observational data from Sangkapura Meteorology Station, Bawean for 15 years (1994-2010) obtained an illustration of direct radiation distribution is more dominant than the diffuse radiation. This indicates that Bawean Island is suitable for photovoltaic solar energy applications as well as solar concentrator for electricity generation purposes. This can help local people to overcome the problem of limited electricity supply from state owned electricity (PLN) on the island. Therefore, the availability of potential solar energy data in a potential location becomes very important, especially for proper siting, sizing and life-cycle cost analysis of solar power plant.

5. Nomenclature

$C_{1..}C_7$ harmonic constants

H_c	standard atmospheric solar radiation	$cal.cm^{-2}.day$
H_g	global radiation	$cal.cm^{-2}.day$
h_n	the n^{th} day in one year	1, January 1^{st} to 365
n_0	sunshine duration after correction	hour
n	sunshine duration	%
N	day length	hour
r	correction factor for sunshine duration data	in the range $0 \leq r \leq 2.5$
W	Time Period for sunshine duration data	8 or 12

Greek letters

δ	declination	^{o}
ϕ	Location latitude	^{o}
ω_s	sun hour angle	rad

Subscripts

k	climatology station
l	meteorological station
n	n^{th} day

6. Acknowledgements

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