A Study of Global Solar Radiations Measurement in Java Island, Indonesia

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A Study of Global Solar Radiations Measurement in Java Island, Indonesia

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Abstract: Solar energy is well-known renewable energy that has been widely used nowadays. Given that Solar energy is green, inexhaustible, pollution-free and simple to use, it has received significant interest all over the world including in Indonesia. Therefore, the main purpose of the present study is to evaluate and compare the potential of solar energy in six stations on Java Island in Indonesia. The methodology has used the renowned Angstrom-Prescott mathematical method while estimating the global solar radiation in the six stations on java island as a potential to utilize solar energy to be a source of electricity generation. The meteorological data used in this assessment is recorded in daily format for five consecutive years starting from 2015 until 2019. The results show that the area that has the highest global solar radiation potential is Banten city with an average value of 5.43 kWh/m^2 while the city with the lowest global solar radiation potential is Yogya city with an average value of only 5.40 kWh/m^2. The highest clearness index value among the six provinces is in Jeteng with a value of 0.52 and the lowest is in the province of Jabar with a value of 0.50. Whereas the difference in the daily ratio of the duration of sunlight between one province and another province is very small. Moreover, each province has extraterrestrial solar radiation values increasing from January until June and then decreasing from July until December. Thus, in this study, it is expected that it can raise awareness to reduce conventional energy by utilizing domestic renewable energy.

Keywords: Solar energy; Solar Conversion Energy System; Angstrom, Java Island, Indonesia

1. Introduction

Rising concerns over the air pollution generated by burning conventional fuel have sped up the search for cleaner energy resources. In order to reduce the results of global warming, relevant stakeholders have been working broadly on the development of effective technologies to produce clean power from renewable resources[1–5]. Based on the International Energy Agency report in 2020, alternative green renewable energies will remain the main source of electrical energy generation in the coming decades because of costs falling and the fast growth of emerging technologies[6–9]. In 2019, renewable energy dominated more than 200 GW of the gross electric capacity the largest increase ever[10,11]. Sun is considered the main source of renewable energy either in direct form or indirectly. However, among all the renewables, solar energy is considered a promising energy source, both in terms of reliability and harvesting potentials[12–14].

Today, solar energy is recognized as one of the most promising clean energies in the sector due to its lower costs[15,16]. Renewable energy sources are gradually becoming more competitive with the existing conventional fossil fuels as they are contributing significantly in a positive way towards the urgent need to save the environment[17,18]. Furthermore, solar energy technologies are extensively utilized for numerous purposes including power generation, space heating, and providing hot water. A total of 115 GW of solar power using photovoltaic panels were generated in 2019 which accounted for about 57% of renewable energy capacities in the world[10]. Indonesia's daily solar radiation intensities are about 4.8 kWh/m^2 per day and the total annual sunshine duration is about 2500 hours/year[19,20].

Recently, numerous studies pertaining to the assessment of solar energy resources were performed in various regions of the world. Nassar and Alsadi 2019[21], evaluated the potential of solar power in Palestine. The study showed that a load of 552 GWh/year can be generated using a PV solar system. Dasari et al., 2019[22], presented a study on solar power assessment in the Arabian Peninsula using data from late 1980 until 2017. The study demonstrated that the annual global horizontal irradiance ranges between 6000 and 8500 Wh/m^2. Enongene et al., 2019[23] estimated the solar photovoltaic panel's system potential in domestic houses in Lagos, Nigeria by employing a survey of about 150 residential buildings in the area. Results were determined using HOMER software and it illustrated that the quantity of power that could be produced using the PV systems ranges between 0.3 – 76 kW. El Ouderni et al., 2013[24] estimated the existence of solar radiations per hour, day, month, and season in Borj-Cedria, Tunisia. A traditional method was used to determine the horizontal solar radiations per hour. Results illustrated the closer agreement between the traditional method and the data from the measurement using the clear-sky condition.

The measure of solar irradiation in any area is the main required boundary for estimating and introducing solar systems. The inaccessibility of this information has prompted the introduction of various models for assessing its worth. Utilizing temperature-based models is perhaps the most considered technique because of its straightforwardness and legitimacy. Presenting different temperature-based strategies. Hargreaves and Samdani's models have been chosen to assess solar-based radiation potential in four distinct urban areas with different environmental conditions and scopes in Iran. Solar-oriented radiation has been assessed in every city[25]. This examination shows the high solar-oriented radiation capability of Iran uncommonly in Shiraz city. The amount of assessed solar energy potential for the four explored urban communities winds up to 8.43 MWh every year which is a high solar-based energy potential to utilize in Iran.

In Malawi, utilizing daylight hours information recorded at six chosen meteorological stations in Salima, Makoka, Karonga, Bolero, Chileka and Mzimba over the time frame 1991-1995. of The Angstrom constants were gotten at the midpoint to build up the direct relapse model. This model has the potential for generating ground perception information of sun-powered radiation at some random area in the nation utilizing daylight hours as the lone required information. The outcomes in general show a serious level of arrangement between the two factors, with relationship coefficients going from 0.63 to 0.90. Sunlight-based radiation esteems acquired utilizing this model were noted to be in acceptable concurrence with those produced for every one of the six meteorological stations[26,27].

Worldwide solar radiation and air temperature information were estimated to improve the perspective on the solar-based energy potential in Kuala Terengganu. Day by day normal solar-oriented radiation information shows that normal qualities are lower in the upper east rainstorm from November to January and are higher in different periods. The greatest worldwide radiation of 1139 W/$m2$ was recorded in April, and the most elevated 24 hours premise daily normal sunlight-based radiation of 314.9 W/$m2$ was recorded likewise in April. Normal daily energy contribution for the entire year was 18.93 MJ/$m2$/day. The most noteworthy day-by-day greatest and month-to-month normal temperatures were 34.5 C and 29.4 C in August and April, separately[28]. This examination shows that the Terengganu state has solid sunlight-based energy potential.

The location of Indonesia around the equator creates a tropical climate that is generally hot. Due to this condition, Indonesia has a high temperature around the year Indonesia experiences a famine season or what is called a prolonged summer. Because the country of Indonesia has a tropical climate, the season in Indonesia is divided into two kinds, namely the rainy season and the dry season. As the country is one of the countries crossed by the equator where in the summer the sun shines for a bright and long duration, the capability of sun-oriented energy in Indonesia is very high. Since the sun keeps on existing consistently, with an average of 6 to 8 hours a day. While the average irradiation length that can produce electricity on solar panels is 4 to 5 hours per day. This can be used to reduce electricity consumption in the urban area and applied to remote areas that are hard to affordable by electricity companies in Indonesia. Unfortunately, the abundant resources are still considered to be underutilized by human resources in Indonesia[29].

The utilization of solar energy relays on its resources availability as they are required to be assessed. In the region near the equator, the solar irradiance fluctuates considerably and the radiance rarely stays at the same value for more than 1 minute. Given that the solar irradiance fluctuates faster than the thermal response time of parabolic trough collectors, a transient thermal model is needed to evaluate the performance of parabolic through collectors under fluctuating solar irradiance conditions. Solar radiation data can be obtained directly from the NASA Surface Weather and Solar website by entering the location coordinates[30,31]. Thus, among the renown and reliable methods of estimating solar radiation in a particular site is the Angstrom-Prescott technique which has been used worldwide due to its due to its simplicity and validity[32,33]. This method calculate the average monthly radiation, maximum monthly radiation, constant coefficients and insolation over flat areas of all sites[34,35].

Thus, the present study seeks to evaluate the potentiality of solar power on Java Island including six provinces which are West Java (Jabar), Central Java (Jateng), East Java (Jatim), Banten, Jakarta and Yogyakarta. Based on that, the potentiality and characterization of solar energy are investigated using the Angstrom-Prescott model for five-year long-term (2015 – 2019) data for the six major meteorological stations on the island.

2. Materials and methods

2.1 Geographical description

Indonesia mainly comprises five main islands which are Sumatra, Java, Kalimantan, Sulawesi, and Papua and others about 17508 islands stretching 5150 km east to west. The country is abundant with volcano mountains and tropical rainforests. The average temperature ranges between 22°C and 29°C and the humidity of about 75%. The rainy season starts from November up to April. More than half of the population in the country lives on Java Island which is 145 million. The total area of the island is about 138,800 km^2. The Java Island, as shown in Figure 1 has four provinces which are Banten, West Java, Central Java, and East Java and two special provinces Jakarta and Yogyakarta. The details of each meteorological station in each province on Java Island are illustrated in Table 1.

Fig. 1: Java Island.

Table 1. Geographic details for each station.

Meteorological station	Latitude (N)	Longitude (E)	Elevation (m)
Jakarta	-6.15559	106.84000	4
West Java	-6.88356	107.59733	791
Central Java	-6.98470	110.38120	6
Yogyakarta	-7.82000	110.30000	153
East Java	-7.22360	112.72390	3
Banten	-6.11185	106.11000	100

2.2 Analysis methodology and formulation

In this section, the method to assess solar radiation and the evaluation of the solar energy potentials of some capital cities on the Javanese island in Indonesia is discussed. The necessary data for the evaluation include sunshine duration, relative humidity, maximum and average temperatures, latitude, longitude, declination angle, sunset hour angle, sunshine duration, were obtained from the meteorological company in Indonesia and assessed using the renown Angstrom-Prescott method.

This assessment uses Angstrom-Prescott as a statistical approach to assess global solar radiation. This method is often used to estimate the solar radiation at the surface of the earth, H the extraterrestrial radiation, H_0 the Clearness Index, etc. To find the ratio of solar radiation it is necessary to know the parameters such as sunset hour angle, ω declination angle, δ monthly average daily bright sunshine duration, n monthly average maximum possible daily sunshine duration, N and the empirical coefficients a and b.

However, although some studies including Ismail, (2022)[36] used regression functions such as the root mean square error (RMSE) and mean bias error (MBE) to evaluate the statistical Angstrom-Prescott model, it is beyond the scope of the present study to conduct such studies as the Angstrom-Prescott could be able to show reasonable results when compared to measured data from NASA as well as the regression functions as shown respectively in Hassane, et al. (2018)[12] and Ismail, (2022)[36].

2.2.1 Sunset Hour angle

The sunset hour angle (ω) maximum possible sunshine hours can be obtained by using Equation 1[35]:

$$\omega = cos^{-1}(-\tan \emptyset \tan \delta) \tag{1}$$

Where:

ϕ = latitude of the location

δ = declination angle

2.2.2 Declination angle

The declination angle (δ) can be gained by using Equation 2[37].

$$\delta = 23.45\, sin\left[360\left(\frac{284+d}{365}\right)\right] \tag{2}$$

Where:

d = signifies the day number in a year starting from the first of January.

2.2.3 Average sunshine duration

The daily bright sunshine duration can be got from Equation 3[38]:

$$n = \frac{24}{\pi}\omega \tag{3}$$

where ω is the sunset hour angle.

2.2.4 Empirical Coefficient

The empirical coefficient (a & b) can be got by using Equation 4 and Equation 5[39]:

$$a = -0.110 + 0.235\cos L + 0.323\left(\frac{s}{s_0}\right) \tag{4}$$

$$b = 1.449 - 0.533\cos L - 0.694\left(\frac{s}{s_0}\right) \tag{5}$$

Where:
L = represents the latitude
s = represents the monthly average daily bright sunshine duration in hours (h)
So= represents the monthly average maximum possible daily sunshine duration in hours (h)

After knowing those parameters, we can directly find the value of H_0 is the monthly average daily extraterrestrial radiation by using Equation 6[40–42]:

$$H_0 = \frac{24}{\pi} I_{sc}\left[1+0.33\cos\left(\frac{360D_n}{365}\right)\right] * \left[\cos L\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin L\sin\delta\right] \tag{6}$$

Where:
I_{sc} = represents the solar constant (1367 W/m^2),
d = represents the day of the year starting from the day of January to the last day of December,
ϕ = represents the latitude of the location,
δ = declination angle,
ω = sunset hour angle

After calculating the value of H_0 then the next step is to find H by utilizing the following Equation 7[43]:

$$\frac{H}{H_0} = a + b\frac{n}{N} \tag{7}$$

3. Results and discussion

3.1 Global solar radiation, H

Figure 2 presents the results of radiation from six cities on the island of Java obtained from the results of calculations using the Angstrom Prescott method based on climatological and measured data obtained from the Meteorological, Climatology, Geophysics Agency in Indonesia. Each region is distinguished by a different colour line to be clear in terms of flow differences. It aims to beautify the graph and is very easy to be able to directly compare and find information on the graph.

The results in Figure 2 show that from April until September there is significant solar radiation in all stations on java island. The highest global solar radiation is observed in Jun at Jateng with 5.58 kWh/m2, while the lowest was observed at Jabar with 5.06 kWh/m^2 in December. However, as can be seen in Figure 2, the variation of global solar radiation in all different stations on the island is trivial. In addition, it is observed that no station has shown lower than 5.06 kWh/m^2 of annual global solar radiation, which indicates that each station has immense potential for solar PV applications. Thus, the analysis result shows that solar radiation in each station on java island gives the potential for PV power generation.

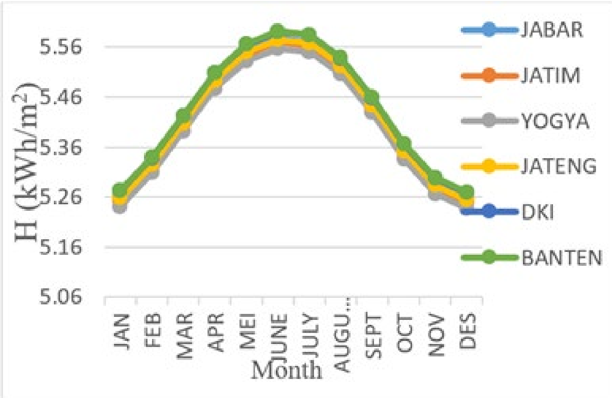

Fig. 2: Global solar radiation on Java Island.

3.2 Extraterrestrial solar radiation, H$_0$

In this section, the extraterrestrial solar radiation of six stations on Java Island in Indonesia is presented. From Figure 3 below it can be shown that each province has extraterrestrial solar radiation values increasing between January and June and then decreasing between July and December. A similar trend happens in every province on the island of Java. However, the variations of extraterrestrial solar radiation among the stations are significant. The highest extraterrestrial solar radiation value was in June and the lowest occur around December and January. Comparing all the stations on Java Island it is observed that Bantin station possesses the highest extraterrestrial solar radiation with 10.72 kWh/m^2 while Jabar station exhibit the lowest with 10.11 kWh/m^2. Higher values of the extraterrestrial solar radiation indicate the existence of better potentials of solar power harvesting.

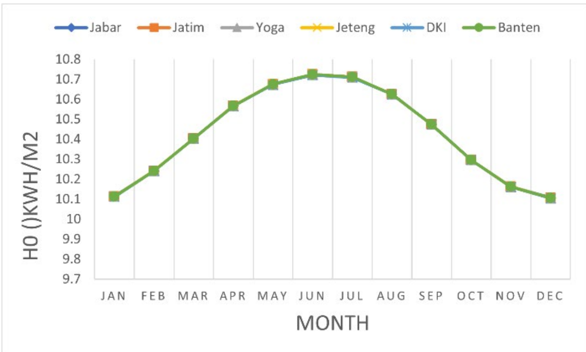

Fig. 3: Extraterrestrial solar radiation for the six provinces on Java Island.

3.3 Sunshine duration, S

The sunshine duration for all sites is presented as shown in Figure 4. It is apparent that the average daily bright sunshine on Java Island is in the range of 11 to 12 hours among all stations throughout the year. However, the highest sunshine is observed between October to February and the lowest is observed in the period between April to August. This is true for all stations considered in the java island of Indonesia since the stations are in close proximity to each other. As a result, the global solar radiation on a horizontal surface increase in those months as sunshine duration increases. It is also observed that the maximum sunshine duration hours of a day at each station occurs in December and the lowest occurs in June, as shown in Figure 4.

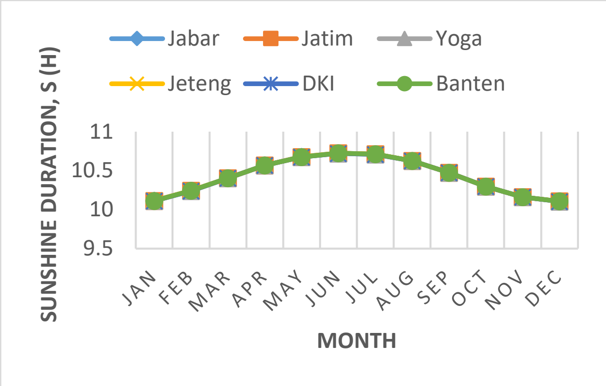

Fig. 4: Average daily sunshine duration per day for the six provinces on Java Island.

3.4 Clearness index, H/H_0

The clearness index is defined as the ratio between the monthly average solar radiation on a horizontal surface, H and the monthly average extraterrestrial radiation, H0. It can be seen from the calculation graph in Figure 5 that all provinces have a clearness index that is almost constant from January to December, with the exception of Jeteng station where the clearance index is constant at 0.52 throughout the year. It is also apparent that all other stations exhibit a constant clearance index from February to December and increases in January, as there were no significant variations between the monthly average solar radiation on a horizontal surface and the monthly average extraterrestrial radiation. However, in general, the variations of the clearance index between the stations under study is not significant. This is due to the fact that the location of all sites is close to each other and their proximity to the equator. Thus, the seasonal variation is not substantial and thus it is almost hot and rainy throughout the year. The only difference is in the clearness index value from one province to another. Therefore, comparing all stations, the highest clearness index among the six provinces is in Jeteng province which was about 0.52 and the lowest is the clearness index in Jabar province with a value of 0.50. The clearness index sequence for the six provinces from high to low is Jateng DKI, Banten, Jatim, and Jabar, respectively. However, it appears from Figure 5 that all stations in Java Island could be suitable for solar energy application since all stations have exhibited a reasonable clearance index which greater than 0.5.

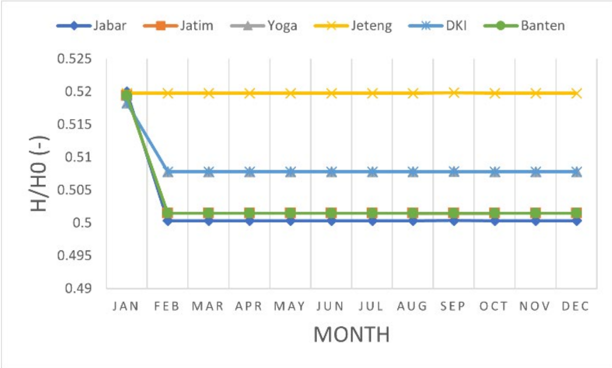

Fig. 5: Clearness index for six cities on Java Island.

4 Conclusion

In the present study, five-year long-term data for six major meteorological stations on the island of Java have been studied. This assessment technique involved the potentiality of solar energy on the island of Java in Indonesia. The statistical Angstrom-Prescott method has been used to determine the potential of solar energy.

Based on the explanation from the previous chapters, it can be concluded that the area that has the highest global solar radiation potential is Banten city with an average value of 5.43 kWh/m^2 while the city with the lowest global solar radiation potential is Yogya city with an average value of only 5.40 kWh/m^2 only. The highest clearness index value among the six provinces is in Banten with a value of 0.145 and the lowest is in the province of Yogyakarta with a value of 0.144. The clearness index sequence for the 6 provinces from high to low is Banten, DKI, Jabar, Jateng, Jatim and last is in Yogyakarta. Whereas, the difference in the daily ratio of the duration of sunlight between one province and another province is actually very small. Each province has extraterrestrial solar radiation values increasing from January until June and then decreasing from July until December. The highest extraterrestrial solar radiation value was in June with each value in each region being 38,612 kWh/m^2 in West Java province, 38,606 kWh/m^2 in East Java province, 38,610 kWh/m^2 in Central Java province, 38,622 kWh/m^2 in DKI province, 38,597 kWh/m^2 Yogyakarta province and the last one is in Banten province with the value 38,623 kWh/m^2. Thus, it is concluded that all stations in Java Island could be suitable for solar energy application since all stations have exhibited a reasonable clearance index.

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