Solar energy potential in Bangka belitung islands, Indonesia

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Abstract. Bangka Belitung Islands is one of the provinces in Indonesia which has hundreds of small islands. Because the islands are separated from each other it is almost impossible to distribute electricity from the main electricity source in the Bangka Island to all the islands. Because it is located in the tropic country, solar cells can provide an alternative solution to the fulfillment of electricity rather than create a distribution cable across the sea. The solar energy potential in Bangka Belitung Islands can be calculated based on climatological, meteorological, and geographical data. Various solar radiation transmittance coefficients have a higher value in the dry season. This condition indicates that in the dry season the total solar radiation is higher than in the rainy season. Due to the high value of total solar irradiance in the Bangka Belitung Islands, it reaches 4.95 kWh/m$^2$ day, it is interesting to utilize this potential to provide electrical energy in the Bangka Belitung Islands.

1. Introduction
In a modern civilization the need for electrical energy has become a basic necessity. Electricity will support people in various activities: social, economic, technology, and others. Most traditional electric power generation use oil and its derivatives to produce energy. But the issue of limited sources of fossil energy and the impact of pollution has led many countries around the world develop electricity conversion technologies from a renewable energy [1, 2]. The photovoltaic panel has been widely used because it provides various advantages in terms of both economy and environment [3]. Additionally, because the installation process is easy and has good durability, the solar cells can support electricity supply for people who do not have access to the main electricity source [4]. Solar cells have been widely applied in various geographical areas such as cities, countryside, and deserts [5]. Generally, tropical countries have abundant solar energy. Even tropical countries can receive about 300 sunny days with 8 hours sunshine in a year [6]. Therefore, the use of solar energy as a source of electrical energy in the tropics has a promising prospect.
Bangka Belitung Islands is a province in Indonesia that has many small islands. There are about 1015 islands in the province [7]. Therefore, the effort to distribute electricity from the main electricity source in Bangka Island will have economic difficulties. Alternatively, the use of solar cells to provide electrical energy in small islands in the Bangka Belitung Islands is interesting to be developed because the province is located in the tropics.
In this paper we analyze the potential of solar radiation energy in Bangka Belitung Islands based on climatology, meteorology, and geographical data. The model of solar irradiance potential is
constructed based on Bird-Hulstrom [8] and Villicana-Ortiz [9] model. It is expected that the calculations in this paper will be taken into consideration in the effort of electrification of small islands in Bangka Belitung Islands.

2. Solar Irradiance Physical Model

The solar energy that reaches the earth is partly of a electromagnetic radiation emitted by the sun. The radiation travels from the solar core and is distributed uniformly and isotropically throughout the universe. When it reaches the Earth's atmosphere the radiation undergoes several interactions such as scattering, absorption, and reflection. The various interactions occurs because the atmosphere composed by various molecules such as water vapor, CO$_2$ and O$_2$, ozone, and various types of aerosols [9]. In the model of Bird-Hulstrom, total radiation ($I_T$) is the amount of direct radiation ($I_d$) with diffuse radiance ($I_{sd}$) and it corrected with albedo parameters: ground ($r_g$) and sky/atmospheric ($r_s$) [8],

$$I_T = \frac{(I_d + I_{sd})}{1 - r_g r_s}$$  \hspace{1cm} (1)

Since it is difficult to obtain an explicit value of $r_s$ then in the model the parameter $r_s$ is proposed as [8]

$$r_s = 0.0685 + (1 - B_a)(1 - r_{as})$$  \hspace{1cm} (2)

where $B_a$ is a forward-scattering factor ratio and it is related to asymmetry factor in Mie theory. But by looking at the asymmetry factor data for different types of aerosols, Bird-Hulstrom suggested the value of $B_a=0.84$. The $r_{as}$ is the transmittance coefficient due to absorbance and scattering by dry air in the Watt model [8],

$$r_{as} = 10^{0.045(\frac{P}{101325})^{0.7}}$$  \hspace{1cm} (3)

where $P$ is atmospheric pressure whose value depends on altitude, $z$, \( P = 101325 \exp(-0.0001184z) \) and $m_{rel}$ is relative air mass. Solar direct irradiance is determined through the relationship [9],

$$I_d = 0.9662C_r \tau_r \tau_o \tau_g \tau_a \tau_o \cos \theta$$  \hspace{1cm} (4)

where $C_r$ is daily solar constant, $\tau_r$ is transmission coefficient by scattering due to air molecules, $\tau_o$ is transmission coefficient due to ozone absorption, $\tau_g$ is transmission coefficient due to absorption by uniform gases mixture, $\tau_a$ is transmission coefficient due to absorption of water vapor, $\tau_{as}$ is transmission coefficient due to absorption and scattering by the presence of aerosols, and $\theta$ is solar zenith angle. Explicitly, the parameters in solar direct irradiance defined as in Table 1. In Table 1, $C$ is normalized solar constant ($C = 1367 \text{ W/m}^2$), $n$ is the Julian day, $m_o$ is optical air mass, $L_o$ is thickness of ozone layer, $Ww$ is amount of water capable of precipitate in the vertical direction over the place, $H$ is relative humidity, $T$ is absolute temperature, $\alpha$ and $\beta$ is parameter that related to aerosol particle size and turbidity level, respectively.

In the other hand, the model of diffuse solar irradiance is defined as [8],

$$I_{sd} = 0.79C_r \tau_r \tau_g \tau_w \tau_{as} \frac{0.5 - \tau_r + B_a (1 - \tau_{as})}{1 - m_o + m_o^{0.02}} \cos \theta$$  \hspace{1cm} (5)

where $\tau_{as}$ is transmission coefficient due to aerosols scattering and $\tau_{as}$ is transmission coefficient due to absorption by aerosols. Mathematically, the both coefficient defined as (15) and (16). While $\omega_0$ is a parameter called as single scattering albedo [8],

$$\tau_{as} = 1 - (1 - \omega_0)(1 - m_o + m_o^{1.06})(1 - \tau_o)$$  \hspace{1cm} (6)

$$\tau_{as} = \frac{\tau_a}{\tau_{as}}$$  \hspace{1cm} (7)
Table 1. Explicitly definition of parameters in the direct solar irradiance [8,9].

| Parameters | Eq. no. |
|------------|---------|
| $C_r = C \left(1 + 0.33 \cos \frac{360n}{360}\right)$ | (8) |
| $\tau_s = \exp\left(-0.0903m_{10.84}^{(1)}(1 + m_a - m_{10.01})\right)$ | (9) |
| $m_a = \exp\left(-0.0001184z\right)m_{rel}$ | (10) |
| $m_{rel} = \frac{1}{\cos \theta + 0.15(93.85 - \theta)^{-1.253}}$ | (11) |
| $\tau_a = 1 - \left(0.1611(L_a m_{rel}^{(1)} + 139.48L_a m_{rel}^{(0.035)}) + \frac{0.002715L_a m_{rel}}{1 + 0.044L_a m_{rel} + 0.003(L_a m_{rel})^2}\right)$ | (12) |
| $\tau_w = \exp\left(-0.0127m_{w^{0.26}}\right)$ | (13) |
| $\tau_w = 1 - \frac{2.4959(W_w m_{rel})^{0.068}}{1 + 79.034(W_w m_{rel})^{0.628} + 6.385(W_w m_{rel})}$ | (14) |
| $W_w = 0.493 \left(\frac{H}{T}\right) \exp(26.23 - 5416/T)$ | (15) |
| $r_a = 0.12445\alpha - 0.0162 + (1.003 - 1.125\alpha)\exp(-\beta m_a(1.089\alpha - 0.1523))$ | (16) |

3. Results and Discussion

The solar energy availability model proposed by Bird-Hulstorm requires several geographical, climatological, and meteorological parameters. To evaluate the solar irradiance it is necessary to use climate data available in existing weather stations, i.e. Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) - Depati Amir Meteorology Station, Pangkalpinang from January 1, 2016 to January 1, 2018. In Fig. 1, the temperature and humidity patterns for this time period are presented. Through temperature and humidity patterns it appears that the values of temperature and humidity in Bangka Belitung Islands have a relationship that is inversely proportional. The temperature range is 24°C to 30°C. While the moisture range is 69% to 99%. The Bangka Belitung Islands has two seasons: the rainy season that occurs in October - May and the dry season that occurs in June - September [10].

![Figure 1](image_url)

Figure 1. Temperature and humidity patterns in Bangka Belitung Island since 2016 to 2018.

To analyze solar direct irradiance then required coefficients as stated in eq. (4). The first coefficient is the transmission coefficient by scattering due to air molecules, $\tau_s$. Based on eqs. (6)-(8), the transmission coefficient is influenced by altitude and solar zenith angle. According to ref. [11] it is
stated that some areas of the Bangka Belitung Islands lies in altitude 0-699 masl. Although for the Pangkalpinang area itself is only in altitude 0-70 masl. Based on the pattern of relationship between transmission coefficient by scattering due to air molecules with altitude and solar zenith angle as shown in Fig. 2(a) it appears that the dominant factor that changes the value of $\tau_s$ is solar zenith angle. Above 1 rad the value of $\tau_s$ decreases significantly. This condition can be understood as a result of the dependence of $\tau_s$ to the relative air mass which also changes rapidly above 1 rad.

The second transmission coefficient is the transmission coefficient due to ozone absorption, $\tau_o$. Based on eq. (9), $\tau_o$ is influenced by solar zenith angle and the ozone layer thickness. However, the thickness of ozone layer in Indonesia in the recent decades is relatively stable. Since 2003, the thickness is in the range 246.26 DU to 249.46 DU [12]. Thus, it is safe to say that the average ozone thickness in Indonesia is 247.82 DU or about 0.11 mol/m$^2$. By using eq. (9) can be obtained the relationship between $\tau_o$ with solar zenith angle as shown in Fig. 2(b). It appears that the value of $\tau_o$ changes rapidly for solar zenith angle above 1 rad.

According to eq. (10) transmission coefficient due to absorption of gas mixtures, $\tau_g$, influenced by altitude and solar zenith angle. In Fig. 3 it appears that $\tau_g$ is also changing rapidly due to changes in solar zenith angle above 1 rad. However, the change in $\tau_g$ is not significant and the value remains at around 0.98.

To calculate the transmission coefficient due to the absorption of water vapor, $\tau_w$, then the required amount of $W_w$ as indicated in eq. (12). Based on the temperature (absolute) and humidity data as expressed in Fig. 2 then the daily $W_w$ within the period 2016 to 2018 can be calculated as in Fig. 4(a). The pattern of fluctuations in $W_w$ almost related with the season that occurred Bangka Belitung Islands. According to the type of season it can be calculated the average value of $W_w$ for the dry season is 508.7 while in the rainy season its value is 515.4. The high value of $W_w$ in the rainy season because the amount of water vapor that may become water has a greater probability than when the dry
season. Thus by using the result it can be analyzed the value of $\tau_w$ for both seasons as shown in Fig. 4(b). It appears that the transmission coefficient $\tau_w$ in the dry season is higher than the rainy season because in the dry season the amount of water vapor that absorbs solar radiation is more slight. However, the differences in both conditions are not so significant.

\textbf{Figure 4.} (a) The value of $W_w$ since 2016 until 2018, (b) the relationship between $\tau_w$ for dry season and rainy season with the solar zenith angle.

The last transmission coefficient on direct solar irradiance is the transmission coefficient due to absorption and scattering by aerosols. In eq. (13) it has been stated that the transmission coefficient is affected by the size of the aerosol particles ($a$) with the mean size being 1.3 $\mu$m and the level of atmospheric turbidity ($\beta$). In this article it is assumed that there are only two conditions of atmospheric turbidity: (i) $\beta=0.1$ for conditions with cloud-free sky that occur during the dry season and (ii) $\beta=0.4$ for cloudy sky conditions that occur in the rainy season. According to the assumption the value of coefficient $\tau_a$ shows in Fig. 5. Based on the calculation it appears that the value of $\tau_a$ for the dry season is greater than the value of $\tau_a$ for the rainy season.

\textbf{Figure 5.} The relationship between $\tau_a$ with the altitude and solar zenith angle for dry season and rainy season.

In addition to direct solar irradiance, total solar irradiance is also contributed by diffuse solar irradiance on horizontal surfaces from atmospheric scattering. In the Bird-Hulstrom model, the ratio of $B_a$ for aerosols in atmospheres is 0.84 whereas for albedo single scattering, $\omega_0$, is 0.9. But before calculate the solar irradiance we require information related to transmission coefficient due to aerosol absorption as in eq. (15). By substituting the related parameters, we obtain the transmission coefficient $\tau_a$ and $\tau_{AS}$ for the rainy and dry seasons as shown in Fig. 6(a) and (b). It appears that the both $\tau_{aa}$ and $\tau_{AS}$ transmission coefficients for the dry season are higher than the rainy season.
Figure 6. The relationship between solar zenith angle and altitude with: (a) $\tau_{aa}$ and (b) $\tau_{AS}$ for dry season and rainy season.

Through the results obtained above, we can calculate the total solar irradiance in Bangka Belitung Islands. The total solar irradiance in one day can be determined through multiplication of solar irradiance power with the average daylight hours for 2016 to 2018 (solar power above 120 W/m$^2$; Depati Amir Station). To simplify the conditions then the analysis will be divided based on the seasons: the dry season and the rainy season and it assumed the solar zenith angle in 0° and the altitude, $z=33$ masl. The average duration of daylight hours for the dry season is 6.19 hours/day while for the rainy season is 4.14 hours/day. The albedo ground conditions are assumed as bare soil ($r_g=0.17$), green grass ($r_g=0.25$), and concrete ($r_g=0.55$) [13]. The calculations are presented in Table 2. Generally, total daily solar radiance in the dry season is higher than in the rainy season. In addition, based on the results it can be stated that the Bangka Belitung Island has the high potential of solar energy for the development of renewable energy technology.

Table 2. Total, direct, and diffuse irradiance for rainy season and dry season

|                      | Dry season (kWh/m$^2$ day) | Rainy season (kWh/m$^2$ day) |
|----------------------|-----------------------------|-----------------------------|
| Solar direct irradiance | 4.26                        | 1.81                        |
| Solar Diffuse irradiance | 0.47                        | 0.66                        |
| Total (bare soil)     | 4.79                        | 2.51                        |
| Total (green grass)   | 4.82                        | 2.52                        |
| Total (concrete)      | 4.95                        | 2.59                        |

4. Conclusions
Climatological, meteorological, and geographical factors determine the level of attenuation of solar irradiance and the amount of solar energy abundance. In addition to the zenith solar angle, an important factor that significantly changes the value of the transmission coefficient is the type of season. Various transmittance coefficients such as $\tau_\omega$, $\tau_\alpha$, $\tau_{aa}$, and $\tau_{AS}$ have a greater value when the dry season. This condition also has implications on the total solar irradiance. In the dry season the solar potential in Bangka Belitung Islands tends to be higher than in the rainy season. In the dry season the total solar irradiance can reach 4.95 kWh/m$^2$ day so it can be utilized as a source of electrical energy.

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6. References
[1] Tobnaghi D, Madatov R and Farhadi P 2013 Electric Power Engineering & Control Systems, . November 90
[2] Razykov T, Ferekides C, Morel M, Stefanakos E and Ullal H 2011 Solar Energy 85 1580
[3] Kazem H 2015 International Journal of Applied Engineering Research 10 43572
[4] Khemariya M, Mittal A, Baredar P, and Singh A 2017 *Journal of Energy Storage*, 14 62.
[5] Al-Shafeey M and Harb A 2018 *9th International Renewable Energy Congress (IREC)* Hammamet 1
[6] Mahtta R, Joshi P and Jindal A 2014 *Renewable Energy* 71 255
[7] Soyusiiawaty D, Umar R and Mantofani R 2007 *Seminar Nasional Aplikasi Teknologi Informasi 2007 (SNATI 2007)* Yogyakarta K-17.
[8] Bird R and Hulstrom R 1981 *A simplified clear sky model for direct and diffuse insolation on horizontal surface* (USA: U.S. Department of Energy)
[9] Villicana-Ortiz E, Gutierrez-Trashorras A, Paredes-Sanchez J and Xiberta-Bernat J 2015 *Renewable Energy* 81 534
[10] Fadholi A 2013 *Jurnal Geografi* 10 112
[11] Ngadenin, Syaeful H, Widana K and Nurdin M 2014 *Eksplorium* 35 69
[12] Fajar M 2011 *Pengukuran Ketebalan Lapisan Ozon Menggunakan Data MODIS sebagai Bagian dari Sistem Pemantauan Bencana* (Depok: Universitas Indonesia)
[13] Markvart T and Castaner L 2003 *Practical Handbook of Photovoltaics: Fundamentals and Applications* (UK: Elsevier)