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The potential overview of PV system installation at the quarry open Pit Mine PT. Bukit Asam, Tbk Tanjung Enim

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Abstract

South Sumatra has an established state-own enterprise exploring the Quarry Open Pit Mine. This mining process leaves some abondance open field that has a high potential to install a PV system. The Government has undertaken an initial analysis of 200 hectares of ex-mining land for this purpose. This paper analyzes the potential for PV panels to be installed at PTBA Tanjung Enim Quarry Open Pit Mine. The location of the PV panel in the open pit Quarry for this analysis is at an altitude of +140 m above sea level. Meanwhile, the PTBA Tanah Putih Township housing site where the PV comparison panel is installed is located on the altitude of +100 m above sea level, and within 2.97 km from the mine. PV panels installed in Open Pit mines generate better electricity and efficiency compared to PV panels installed outside the mine (in PTBA Township Housing). The difference of Isc between PV Panel installed in Quarry Open Pit Mine and Township is 0.0075 A. The Iload measured on the Quarry Open Pit Mine PV panel is 0.5478 A higher than the Township PV panel. Meanwhile, Voc measured on Quarry Open Pit Mine PV panel is smaller than Township PV panel, approximately 0.266 V and Vload of Quarry Open Pit Mine PV panel is 0.266 V larger than Township PV panel. The produced power of Quarry Open Pit Mine PV panel is 11.02 W larger than the Township PV panel. From the total value, the average efficiency produced by Quarry Open Pit Mine PV panels is 2.31 % higher than the efficiency produced by Township PV panels. This research shows the possibility and advantage of installing a PV system on a Quarry Open Pit Mine.

1. Introduction

The reduction of fossil energy supply, particularly petroleum, and the issue of global greenhouse gas emission reductions, has prompted the government to continue to increase its effort in ensuring the energy security and independence through renewable energy development. According to government regulation (GR), No. 79 of 2014 on the National Energy Policy, the target for utilizing the mix renewable energy in 2025 are at least 23% and 31% in 2050 [1]. Indonesia has high potential in renewable energies that are more than enough to meet the goal of a primary energy mix of 94.3 GW of water energy, 28.5 GW of geothermal energy, 32.6 GW of bioenergy. Bio and nuclear power plants have the potential of 200.000 Barrels per day. Solar energy is 207.8 GWp, and wind power is 60.6 GW [1]. Total potential renewable energy potentials, equal to 442 GW, are used for generating electricity, while 200 thousand Barrels per day of biofuel and biogas is used for transportation, residential, commercial, and industrial fuel. The use of New and Renewable Energy for power plants in 2018 amounted to 8.8 GW or 14 per cent of the total power generation capacity (fossil and non-fossil) of 64.5 GW [1].

Human demand for energy is rising every day; rapid technological advancements are directly proportional to the rise in energy demand [2][3][4]. The use of solar energy as new renewable energy is now commonly used in almost all parts of the world, including Indonesia [4][5][6][7][8][9][10][11][12], such as Dewi et al. in [4] discusses the increasing role of the solar cell in industry, Hanafiah et al. in [5] designed the IoT system for the automatic switch of a hybrid system, Edward et al. in [5], Hamdi et al. in [7], and Zhafarina et al. in [8] present the off-grid system analysis and how to improve PV system efficiency, Sasmanto et al . in [9] and Junianto et al. in [10] proposed the method to reduce the temperature effects by floating the PV panels in two different places, and Dewi et al. in [11] and Yudha et al. in [12] discuss the environmental effect on a PV system. Many of which have installed solar power generation applications for street lighting systems, offices, and even now have been integrated into motorcycle or vehicle driving applications [13][14][15][16]. However, the application of solar panel for residential needs are relatively few [17][18][19], due to the availability of the Government utility of electricity network and the common public's opinion of the expense required for solar panel technology is still prohibitive.

The intensity of solar radiation outside the earth' atmosphere is dependent on the distance between the earth and the sun. The distance between the sun and the earth varies throughout the year from 1.47×10^8 km to 1.52×10^8km. The irradiance E_0 fluctuates between $1.325\,\mathrm{W/m^2}$ and $1.412\,\mathrm{W/m^2}$. Therefore, the solar irradiance constant is $1.367\,\mathrm{W/m^2}$ and the average radiance value is referred to as the solar constant [20]. In Indonesia, which is a tropical area, has a vast potential for solar energy with average daily insolation of $4.5 - 4.8\,\mathrm{kWh/m^2}$/day. However, solar cells' electrical energy is strongly influenced by the intensity of sunlight received by the PV system. South Sumatra, which is on the equator, where the sun shines throughout the year, has the high potential to develop the solar power generator, as have been investigated by Sasmanto et al. in [9], Junianto et al. in [10], Dewi et al. in [11], and Yudha et al. in [12].

Even though the sunlight is free, installation costs are not inexpensive. Several environmental variables influence the production power and performance to be considered. Among other things, solar panels are prone to heat and shade [21][22][23][24][25][26][27] such as proven by Mustafa et al. in [21], shading investigation by Menoufi et al. in [22], Wang et al. in [23], Olivares in [24], and Sayyah et al. in [25], while the Setiawan et al. in [26] and Harahap et al. in [27] are experimenting in how to reduce the temperature effect. The temperature in South Sumatra can be up to 40ºC, and the solar panels' surface temperature can be up to 62ºC [26][27]. Through the Ministry of Energy and Mineral Resources (ESDM), the Government has encouraged state-owned and private companies to introduce and support the production of renewable energy. High priority is provided to remote areas where the Government can not provide power, such as the mountainous region and the islands. The mining site is the perfect location for installing solar panels, provided the open area where the potential of solar energy is enormous.

In several countries, ventures to install and operate renewable energy generation systems on abandoned mine sites to cultivate reuse and revitalize ex-mining land have increased in recent years [28][29]. Global mining companies and foreign environmental conservation organizations have recently established the use of solar energy as a solution for addressing all mining needs to reduce environmental impacts and to reform post-mining areas into green energy areas. As a result, PV systems are installed globally at both operating and abandoned mining sites. One of the top copper-producing countries, Chile, constructed a 1MW Calama 3 solar power plant project connected to a grid near the world's largest copper mine, the Chuquicamata Copper Mine, to meet the electricity needs of the mine. As a result, Chile experienced an annual reduction of 1,600 metric tons of GHG emissions. A 10.6 MW PV system was installed in Western Australia at the Degrussa copper-gold mine. Previous mining operations in this region relied on fossil fuels, and the installation of a PV system lowered Australia's overall emissions by 12,000 metric tons per year. Shanta Gold, an East African gold mining company in Tanzania, used a 63 kWp solar power plant on the New Luika gold mine in 2014. Following the success of the initial process, seven new PV power plant projects were built over the next three years, which amounted to an annual reduction of 660 tons of CO2 [28]. The largest PV power plant in Germany (166 MW) is situated in Meuro, an abandoned ex-mining area near Leipzig. In Korea, a small-scale (85 kW) photovoltaic (PV) system was installed at the passive acid mine drainage (AMD) treatment facility at the Hambaek coal mine (Jeongseon-gun, Gangwon-do) and another 80 kW PV system at the AMD physicochemical processing facility at the Hamtae Coal Mine (Taebaek-si, Gangwon-do) [29].

This paper discusses the possibilities of utilizing an Open Pit Mine through the construction of a PV system for power generation. This research is being conducted at Quarry Open Pit Mine PT. Bukit Asam, Tbk Tanjung Enim. This research analyzes the advantages and disadvantages of building solar panels in Open Pit Mine. The power and efficiency generated are compared to the PV system installed in the PTBA Tanah Putih Township housing, which is located in the same town but a little further away (2.97 km) from the mining site. The outcome of this project is a recommendation if PV panels are to be installed in an Open Pit Mine.

2. Research Method

This research is to investigate the potential of PV system installation at the Quarry Open Pit Mine PT. Bukit Asam, Tbk (PTBA) Tanjung Enim, South Sumatra. This study compares the output generated by PV panels installed at the Quarry Mine at an elevation of +140 meters above sea level and those installed in PTBA Tanah Putih Township housing at an elevation of +100 meters above sea level.

2.1 Environmental Effect of Solar Panel Output and Efficiency

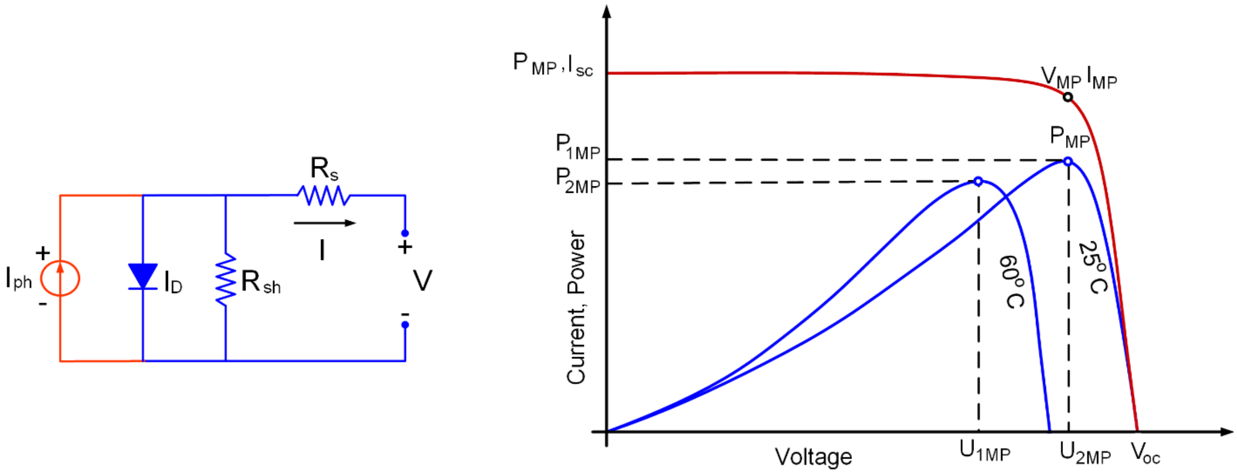
PV panel is modelled as an ideal diode, as shown in Figure 1(a). This model is achieved when PN Junction semiconductor is wired, and electricity applied, the electrons go to the positive side, and holes go to the negative side. During this motion, in the middle of the junction, the number of electrons and holes are the same creating a neutral barrier. The generated current (I) is given by Equation 1.

$$\mathrm{I} = \mathrm{I_{ph}} - \mathrm{I_0}\left(e^{q\left(\frac{V+IR_s}{AkT}\right)} - 1\right) - \frac{V + IR_s}{R_{sh}} \tag{1}$$

where I_{ph} is the photocurrent, R_s is series resistance, R_{sh} is shunt resistance, $I_D$is voltage-dependent current due to recombination, and V is voltage. The maximum power produced by a solar cell (P_{MP}) is given by the IV curve in Figure 1b, which is the function of short-circuit current (I_{sc}) and open-circuit voltage (V_{oc}). The efficiency of a solar panel is Equation 2.

$$\eta = \frac{\rho_{out}}{\rho_{in}} x100\%, = \frac{I_{mp} \cdot V_{mp}}{P_{in}} x\ 100\%, = \frac{I_{sc}V_{oc}FF}{P_{in}}\ x\ 100\%, \tag{2}$$

where I_{mp} and V_{mp} are the maximum current and volage, E is the solar energy, and is the fill factor



(a) *Ideal Diode* (b) *IV curve*

Figure 1. PV Panel Model of Output

Suppose PV panel's temperature increase over 45°C, the electrons in valence band gains more energy and breaks the bond to the nucleus and jumps to the conduction band. As the heat increase, the band gap is closer in semiconductor and makes it easier for the electrons to move to the valence band. Therefore, these two conditions increase the number of electrons in conduction bands, and the electrons move faster due to the heats. The quicker they move, the more likely they bump to each other. As the electrons hit one and another, recombination happens instantly. The more electrons move to the conduction band, and the more holes are left in the valence band; therefore, the more charge carrier both electrons and holes are available. This condition affects the open-circuit voltage (V_{oc}) in Equation 3, which is decreased due to its dependence on I_o (the saturation current A).

$$V_{oc} = \frac{nkT}{q} \ln\left(\frac{I_{ph}}{I_o} + 1\right) \tag{3}$$

Where k is the Boltzmann constant (1.380649×10^{-23} m^2 kg s^{-1} K^{-1}), n is diode ideality factor (the highest is 1), T is the absolute temperature (K), q is the electron charge ($1.60217646 \times 10^{-19}$C), and I_{ph} is the light generated current (A), where $I_{sc} \approx I_{ph}$. Figure 1(b) shows the difference of P_{MP} produced during normal condition ($P_{1\ MP}$) and overheated condition ($P_{2\ MP}$).

Soiling PV panel can cause shading or partial shading in which cause overheated to the shaded cell. The overheated shaded cell in time will be damaged and broken the entire circuit of the panel. This condition can be overcome by installing a bypass diode on the solar panel. However, although bypass diode can help in preventing the failure of all cells in a PV panel, one cell has failed and reduced the output and efficiency of that panel.

2.2 PV Panel installation in Quarry Open Pit Mine PT. Bukit Asam, Tbk Tanjung Enim

In Indonesia, there has so far been no mining or post-mining land used for the construction of the PV system. Therefore, the output of this study will be a recommendation of the advantage of installing a PV system in Quarry Open Pit Mine. The result of this study can be the contribution of this project. The Ministry of Energy and Mineral Resources, through the Director-General of New and Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources, announced that the Government had carried out a preliminary analysis of 200 hectares of ex-mining land ready for use in solar power plants [12].

Quarry Open Pit Mine PT. Bukit Asam, Tbk is located in the Bukit Tapuan Tanjung Enim, Muara Enim Regency, South Sumatra Province with a Mining license area of 26.2 hectares. The quarry open pit mine is situated at an altitude between +140 meters and +155 meters above sea level and right in the middle of the open pit coal mine shown in Figure 2. A mine site with an open area and a sufficiently high altitude have the capacity to be installed as a solar power plant by PV panels. At the end of the post-mining process, the Quarry Open Pit Mine will be at an altitude of +80 meters from sea level and is expected to be one of the locations for the construction of the first solar power plant on ex-mining land in PTBA in particular and Indonesia in general. The location of the PV panel in the open pit Quarry for this analysis is at an altitude of +140 meters above sea level. The data collected from PV panel installed in Quarry Open Pit Mine will be compared to the data achieved from PV panel installed the PTBA (Tanah Putih Township) housing site within 2.9 km from mining site as indicated in Figure 2.

Figure 2. PV Panel Installation Sites

3. Result and Discussion

This paper analyzes the characteristics of the PV panels to be mounted in the Quarry Open Pit Mine and the Tanah Putih housing estate of PTBA Township. The power generation and efficiency of the two PV panels installed will be compared to determine their different characteristics.

3.1 Experimental Setup

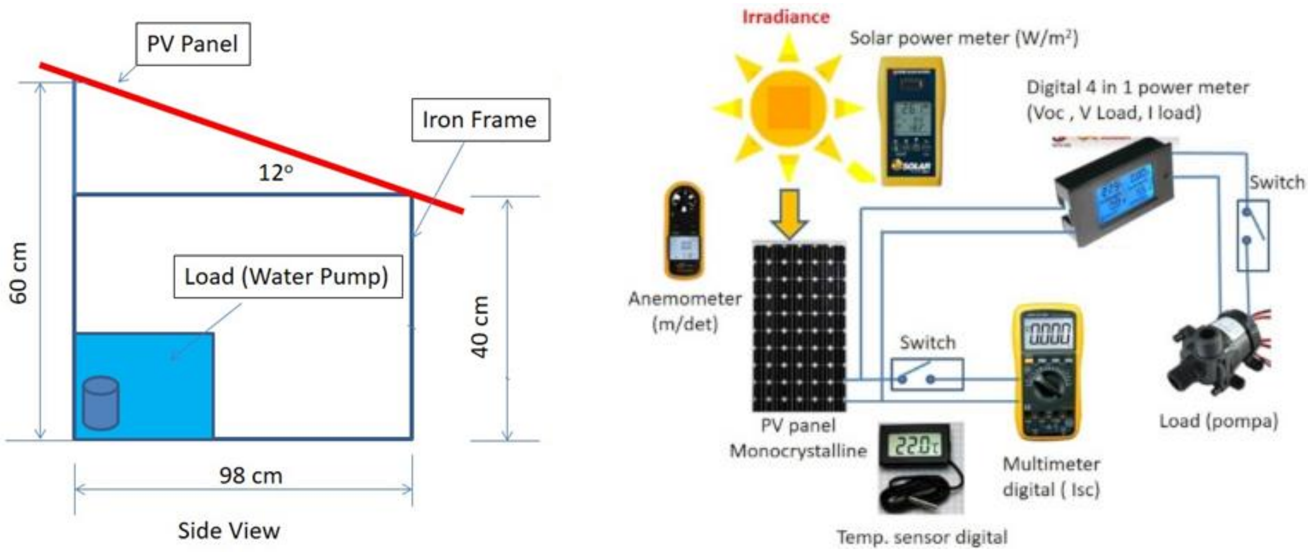
This study employs two monocrystalline panels (W-peak) of 120 WP installed in the Quarry PTBA Open Pit Mine, and another one installed in the Tanah Putih Township housing, as shown in Figures 3(a). Figure 3(b) shows the closed up experimental setup of both panels. The output of the PV panel is connected to a 17 Watt 12 VDC water pump. The circuit installation of the measuring instruments is shown in Figure 4.

(a) Installed PV systems *(b) The close-up circuit*

Figure 3. The Installed PV Systems Considered in this Study

The research is conducted for one month from 1 September 2020 in Tanjung Enim, Muara Enim Regency, South Sumatra. However, the DC pump installed in PV System at Quarry Open Pin Mine was not functioning from 15 to 20

September 2020. Therefore, the experiment was extended to 8 October 2020. The Quarry Open Pit mine is located at 3044'57"S, 103046'02"E, and the PTBA Tanah Putih Township is at 3046'20"S, 103046'49"E, about 190 km from Palembang, the capital of the province of South Sumatra. Measurement data is collected every hour from 07.00 AM to 05.00 PM per day. The highest PV panel surface temperature recorded in Quarry Open Pint Mine was 62.8ºC, and the highest PV panel surface temperature in the Tanah Putih Township housing was 62.2ºC, while the highest ambient temperature was 52.4ºC.



(a) *(b)*

Figure 4. The Experimental Setup

3.2 Environmental Results

This study took place for 32 days, with varying weather and often cloudy and rainy conditions during the research experiment. This varying weather allows the analysis of the environmental effect on the produced power and efficiency of both installed solar panels. The analysis of the effect of varying weather in a day is shown in Figure 5 and Figure 6, including the comparison of irradiance, ambient temperature, PV temperature and the power produced on September 5 and October 1, 2020, respectively. Figure 5 shows that the increase in irradiance follows an increase in the PV panel's surface temperature, and during the allowed temperature, the increment of irradiance produced higher power. The weather on September 5, 2020 was mostly sunny. The measured PV panel's surface temperature in Quarry Open Pit Mine is 0.45ºC higher than the one installed in Tanah Putih Township housing. The average PV panel's surface temperature is ±15ºC on September 5, 2020. The power produced by the PV system installed in the open pit mine is higher than the power produced by one installed in the residence area. The average difference is ± 6 Watts. The highest produced power is from 09.00 AM to 03.00 PM.

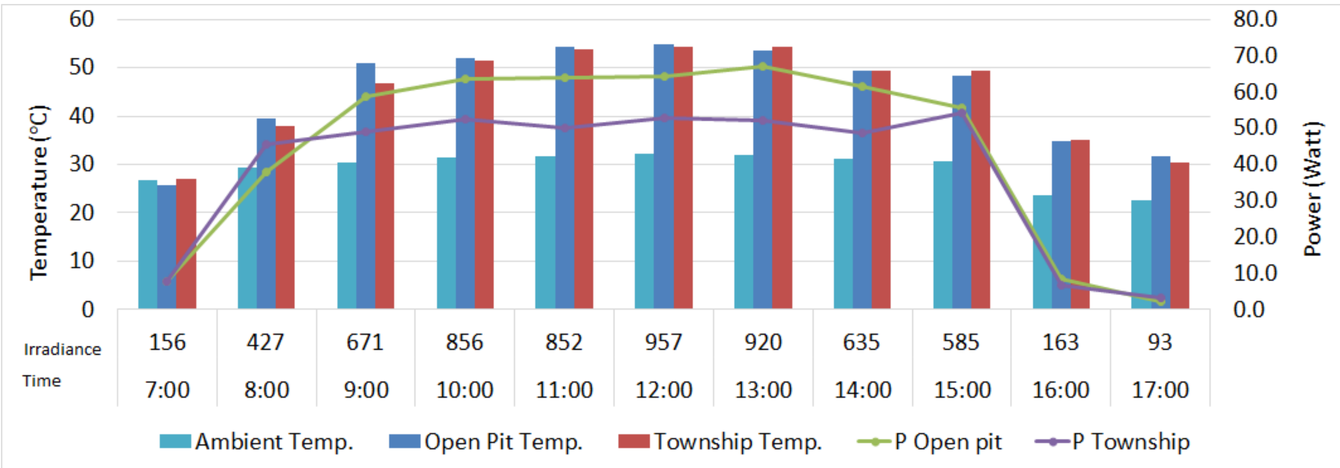


Figure 5. The Analysis of the Effect of Weather in a Day on September 5, 2020

The analysis of varying weather in a day is shown by the data from October 1, 2020, as illustrated in Figure 6. Figure 6 shows how the weather variation has a significant effect on the generation of electricity produced from both PV installations, where a decrease in Irradiance during cloudy weather is accompanied by a decrease in electricity generation and a decrease in PV temperature. The difference in average power generated between the PV installed in open pit mines and the PV installed in Tanah Putih Township is ± 10 Watt.

Furthermore, to illustrate the influence of weather on the generated power is shown in Figure 7, where the power produced during a sunny day on September 5, 2020, is compared with the gloomy and rainy day data on September 26, 2020, and cloudy day on October 8, 2020. When the weather is sunny throughout the day (September 5, 2020), solar radiation received by solar panels continues to increase every hour followed by an increase in electricity production until its peak at (09.00 AM to 03.00 PM), and electricity production continues to decline along with the decrease in sunlight radiation in the afternoon. The electric power generated on September 26, 2020, and October 8, 2020, was very inefficient due to cloudy weather and rain for most of the day.

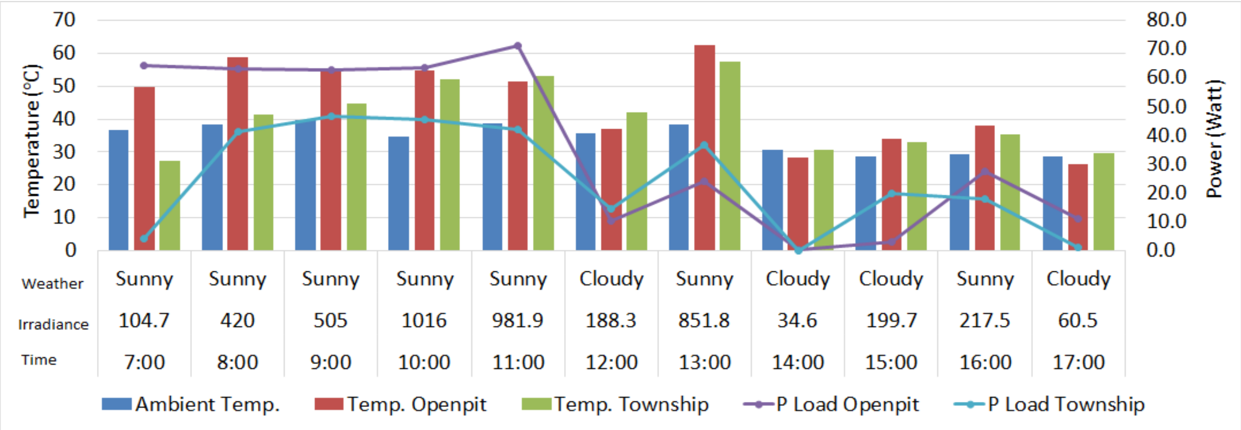


Figure 6. The Analysis of the Effect of Varying Weather in a Day on October 1, 2020

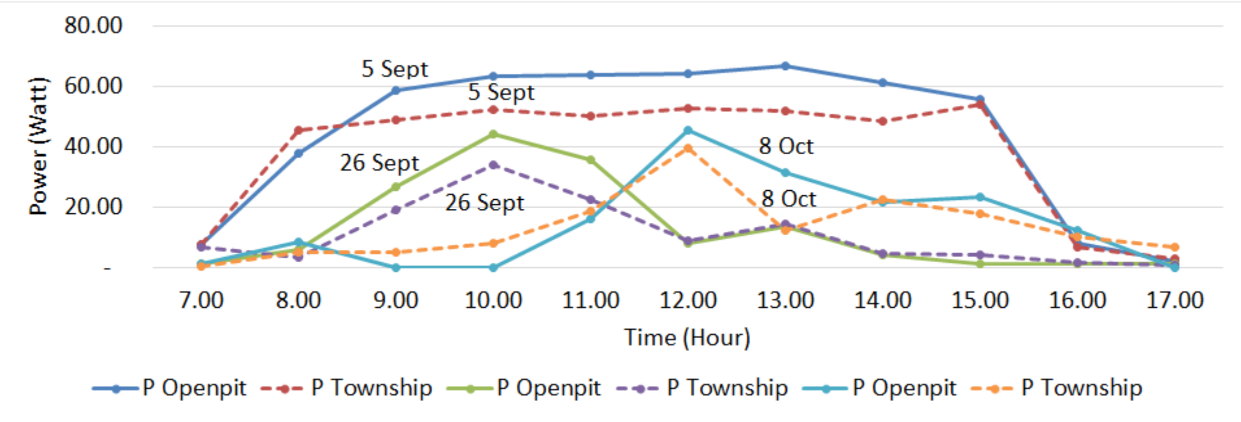


Figure 7. The Analysis of Power Produced on September 5 and 26, 2020, and October 8, 2020

Figure 8 shows the maximum I_{sc} value (short-circuit current) of the PV panels for open-pit mining and township housing, as well as the maximum load current for the two PV panels when connected to the DC water pump load. In addition, Figure 9 shows a contrast between the V_{oc} value of the two PV panels installed and the difference between the V_{load} calculated during the DC water pump load on the two PV panels. I_{sc} is the maximum current produced by the panel when the voltage is zero, and V_{oc} is the maximum voltage generated by the PV panel when the current is zero. These two parameters are the main components of the I-V curve.

The difference between maximum I_{sc} measured at the PV panel installed in Quarry Open Pit Mine and the PV panel installed in Township is 0.0075 A. The maximum I_{load} measured at the PV panel installed in mine is 0.5478 A higher than the current measured at the PV panel installed in Township residence. The average maximum V_{oc} measured at the PV installed in mine is 0.266 V lower than the V_{oc} of PV panels installed in residence. The average V_{load} measured at the PV panel installed in mine is 0.266 V higher than the one installed in residency.

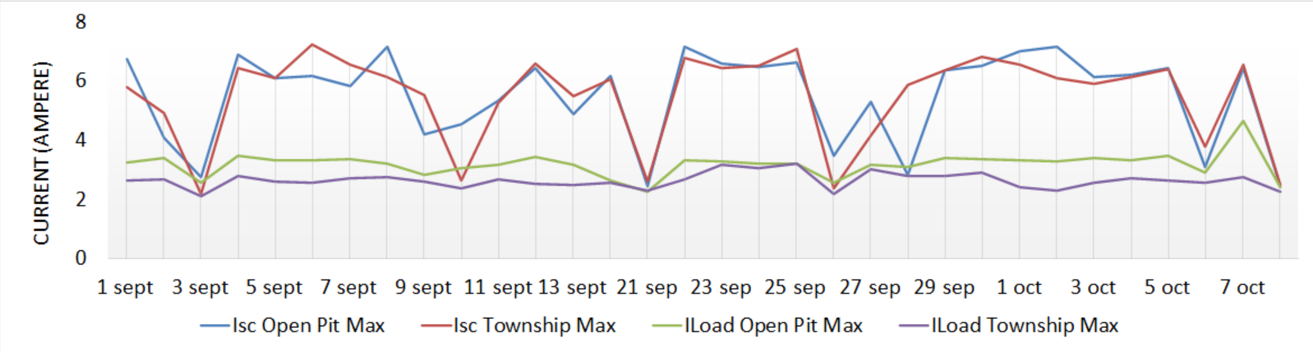


Figure 8. The Generated I_{sc} and I_{load} of Both Installed PV System

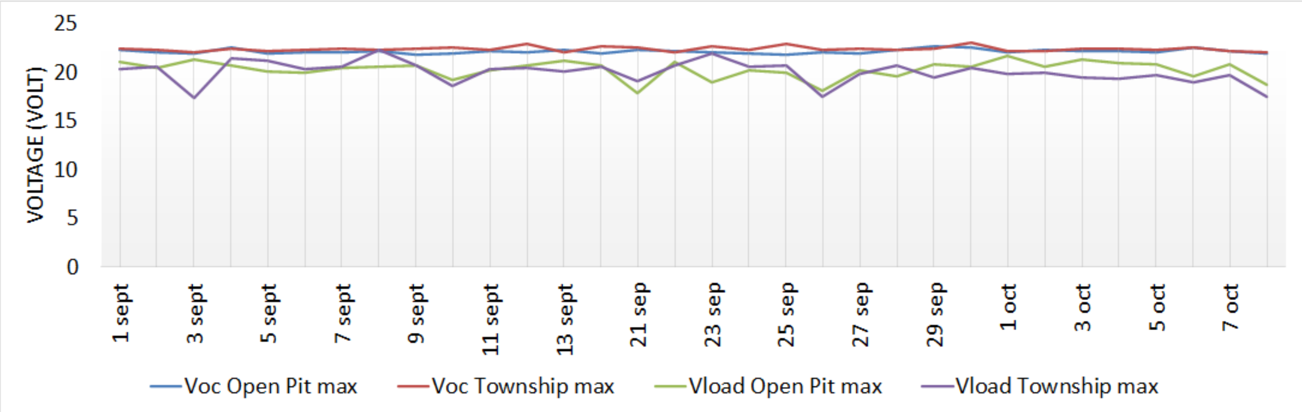


Figure 9. The Generated V_{oc} and V_{load} Comparison of Both Installed PV System

Figure 10 illustrates the ratio of power produced per day for each PV panel installed. The performance depends on the size of the solar radiation (irradiance) captured by the PV panels. Figure 10 shows that the higher the irradiance, the higher the power generated, and vice versa. Fairly sunny weather occurred on 5, 23, 24, 29 September 2020 and 5 October 2020, when the average irradiance was very high on those dates and was proportional to the power generated. The cumulative irradiance that occurs on 5 September 2020 is 957 W/m^2, 23 September 2020 is 1044 W/m^2, 24 September 2020 is 1070 W/m^2, 29 September 2020 is 991.4 W/m^2, 5 October 2020 is 1044 W/m^2. Of the five dates listed above, 490.82 Watt and 505.4 Watt were the highest total load power reported on 5 and 23 September 2020. Figure 11 shows the maximum measured day-to-day radiation in comparison to the maximum daily load power produced by the two installed PV panels. From the measurement results, the maximum load power produced by the Open Pit Mine PV panels is 11.02 Watt above the average maximum load power generated by the Township PV panels. The maximum load power registered on 7 October 2020 was 96.47 watts.

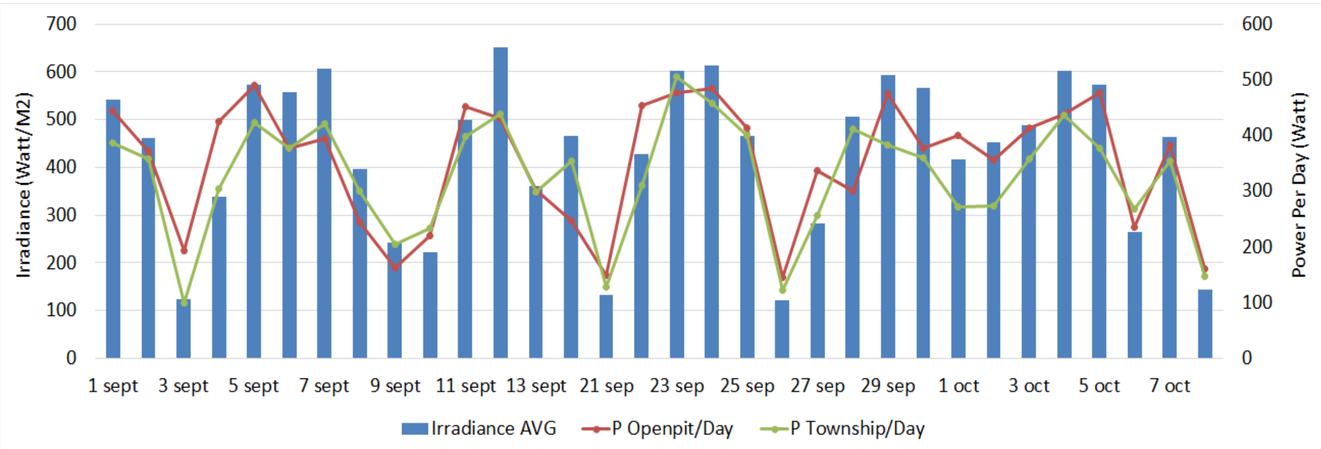


Figure 10. Comparison of Daily Power Generated by Both PV Panels

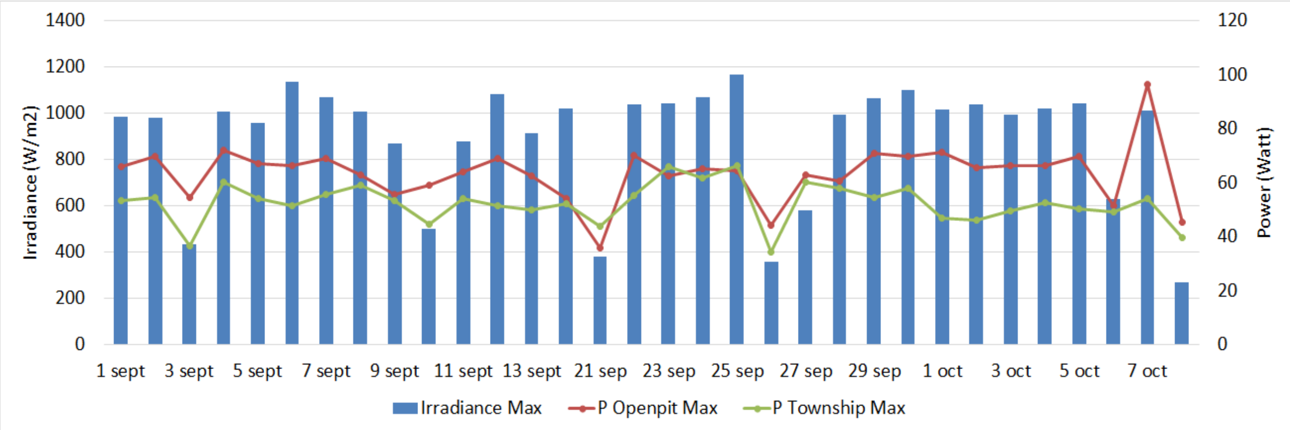


Figure 11. Effect of Maximum Irradiance on Maximum Power Generated by Both Installed PV System

The efficiency of generated electricity by the PV panel mounted in the Open Pit Mine and PV panels installed in the Township housing are shown in Figure 12. This efficiency is determined by the ratio from the input power (Pin) and the produced power (Pload). Pin is calculated based on the irradiance measured multiplied by the area/transversal portion of the PV panel. The mean efficiency of PV panel installed in Quarry Open Pit Mine is 2.31% higher than in the municipality's installed panels.

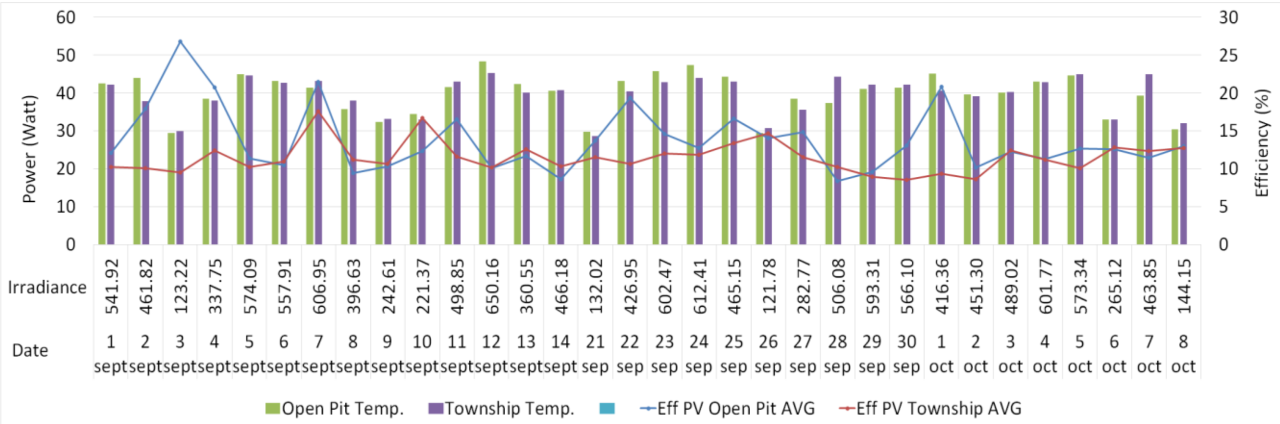


Figure 12. Effect of Maximum Irradiance on Maximum Power Generated by Both Installed PV System

This paper shows that PV panels installed in Quarry Open Pit Mine at the height of +140 from sea level are more effective than PV panels installed in Tanah Putih Township Housing (outside mines) at an altitude of +100 from sea level. The temperature differential that occurs in both locations does not greatly affect the electricity generation of the two PV panels installed, which is due to the temperature of the PV panels that occur is always below the working temperature based on the specification technique of the installed monocrystalline PV panels. Therefore, installing PV panels in Quarry Open Pit Mine is more profitable in the long run due to more power and efficiency resulted in Quarry Open Pit Mine PV system installation. However, the downside is the dust accumulation is more in Quarry Open Pit Mine than the resident site; this problem can be solved by installing a watercooling system that cools the panel and cleans it.

4. Conclusion

The results of the research show that it is possible and profitable to install PV panels at Quarry Open Pit Mine located on the PTBA Tanjung Enim, Muara Enim, South Sumatra. PV panel installed in Open Pit Mine generated better electricity and efficiency compared to PV panels installed outside the mine (in PTBA Tanah Putih Township Housing). The difference between the Isc Open Pit Mine PV panel and the Isc Township is 0.0075 A. The I_{load} on the Open Pit Mine PV panel is 0.5478 A higher than the Township PV panel. Meanwhile, Open Pit Mine PV panel Voc is smaller than Township PV panel, approximately 0.266 V. Meanwhile, the Open Pit Mine PV panel V_{load} is 0.266 V larger than Township PV panel. Meanwhile, for the resulting load or P_{load}, the Open Pit Mine PV panel is 11.02 Watt larger than the Township PV panel. From the total value, the average efficiency produced by the Open Pit Mine PV panels is 2.31% higher than the efficiency produced by Township PV panels.

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