Contribution of Solar Photovoltaic on the Reduction of Greenhouse Gas Emission in the Indonesia Power Sector

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Abstract. Indonesia has released the target of reducing Greenhouse gas (GHG) emissions. The strategy includes enhancement renewable energy utilization. One of the most potential renewable energy resources in Indonesia is solar energy. State Electricity Company of Indonesia has planned to develop solar Photo voltaic (PV) power plan in the document planning 2019-2028. The objective of this study is to explore the contribution of solar PV to the reduction GHG of Indonesia. The potency of solar irradiance and solar PV output in several big cities in Indonesia are discussed. The results show that by using the PV technology of Crystalline silicon with mounting position building integrated and the slope and azimuth is 0°, the average solar PV output in Indonesia is 1361.2 kWh/kWp. The planned solar PV installed capacity by the end of 2028 is 985.5 MW. The electricity resulted by the system in a year will be 1341.47 GWh or it is only 0.31% of national electricity consumption. The contribution of solar PV to the GHG emission reduction is 1.341 million tons CO₂eq in the year 2028.

1. Introduction

Indonesia has released its pledge on climate change mitigation by submitting the Intended National Determined Contribution (INDC) to the UNFCC [1]. In the INDC document it is stated that Indonesia is committed to reducing greenhouse gas (GHG) emissions by 29% compared to the business as usual (BAU) scenario by 2030. The target can be up to 41% by using international support. The target of reduction divided into five source categories, they are (i) Industrial Process and Product Use, (ii) Agriculture, (iii) Land-use, Land-use Change and Forestry, (iv) Energy, and (v) Waste. For Indonesia case, several studies on the GHG emission reduction have been found in literature [2,3,4].

In energy sector, the source of GHG emissions is all activities that burn fossil fuel. The activities include transportation, electricity production, and machineries. The strategy of reduction GHG emission is sustainable energy policy. The sustainable energy policy has two pillars, energy efficiency and renewable energy utilization. Renewable energy sources include wind energy, solar energy, hydropower, geothermal, etc. This work focus on the utilization of solar energy to producing electricity
by using solar cells (Photovoltaic or PV). Mousa et al. [5] reported a comparative energy and GHG assessment of industrial rooftop-integrated PV and solar thermal collector. Kirshner et al. [6] examined the emergence and adoption of solar PV in the Mozambique and South Africa. Duan et al. [7] explored the potential of GHG mitigation and temperature benefits by substituting PV-generated power for coal fired electricity. The results showed that PV solar promises to dominate GHG mitigation, with the highest contribution reaching 64.67% in the year 2050. Pillot et al. [8] investigated the historical interactions between energy and society in both global and Sub-Saharan contexts and how renewable energy power has ended up being considered accordingly. Zurita et al. [9] reported their review on the solar PV development in Chile. In the year 2017, the net PV installed capacity has reached 1802 MW. This result in 3% of electricity. Moldal and Islam [10] reported the impacts of CO₂ emission constraints on the penetration of solar PV in the Bangladesh power sector. It was stated that the total primary energy requirement would be reduced in the range of 4.5 – 22.37% and the primary energy supply system would be diversified. Solar PV plays an important role in achieving reasonable energy security. The above reviewed studies show that solar PV has a great contribution in reducing GHG emissions. However, many barriers do exist and different for every country.

In order to meet the climate change pledge, Indonesia has released several targets on utilization of renewable energy to produce electricity. In the power sector the target is announced in the Electricity Supply Business Plan (known as RUPTL). The objective of this study is to investigate the future contribution of solar PV development in the Indonesia power sector. The results are expected to supply the necessary information to meet Indonesia INDC targets.

2. Method and Theoretical approach
In the first section of this study global solar irradiation will be discussed. The development of renewable energy, include solar energy, in the Indonesia power sector will be discussed. Solar irradiation of clear sky condition on a horizontal surface on the earth can be calculated using the below equation.

\[ G = G_{on} \cos \theta \left[ \tau_b + 0.271 - 0.294 \right] \]  

(1)

where \( G_{on} \) is extraterrestrial irradiation, \( \theta \) is zenith angle, and \( \tau_b \) is the atmospheric transmittance for beam radiation. All of these parameters and the methodology to calculate the clear sky radiation can be found elsewhere [11]. The solar irradiation that reaches the surface of solar cell is the converted into electricity.

The conversion of solar irradiation into electricity is estimated using method proposed by Huld et al. [12]. The method is explained in the followings. The instantaneous power (Watt) of the solar PV can be calculated by the below equation.

\[ P(G',T') = G' \left( P_{STC,m} + k_1 \ln(G') + k_2 \ln(G')^2 + k_3 T' + k_4 T' \ln(G') + k_5 T' \ln(G')^2 + k_6 T'^2 \right) \]  

(2)

where \( G' \) is the normalized in-plane irradiation and \( T' \) is module temperature relative to standard test condition, they are defined in equation (3) and equation (4), respectively.

\[ G' = \frac{G}{G_{STC}} \]  

(3)

\[ T' = T_{mod} - T_{STC} \]  

(4)

here, \( STC \) is standard test condition and \( mod \) stands for module. By using the above equations, the energy resulted from the solar PV can be estimated. In this study, an online software named as Photovoltaic Geographical Information System (PV-GIS) [13] is employed to estimate energy resulted by the solar PV system.

3. Results and Discussions
The results will be presented in four sub sections. In the first section Global Solar irradiation will be discussed and followed by solar energy development in Indonesia in the second section. In the last two sections the solar electricity produced and emission reductions are discussed.
3.1. Global Solar Irradiance
The solar irradiance on the horizontal surface in Indonesia islands is shown in Fig 1. The solar resource data obtained from the Global Solar Atlas, owned by the World Bank Group and provided by SOLARGIS [14]. The figure shows that daily solar irradiation in Indonesia varies from 3.2 kWh/m² to 6.2 kWh/m². In a year it can be 1300 kWh/m² to 2200 kWh/m². The lowest of solar irradiation captured in the middle part of Irian Jaya (eastern part of Indonesia). On the other hand, the highest is shown by the West Timur and Sumbawa islands (in the figure shown by red areas). The solar irradiation in Indonesia islands, in comparison with Middle East and North Africa, can be categorized as medium. In the Middle East countries, the solar irradiance can be up to 7 kWh/m² per day or yearly total up to 2500 kWh/m².

![Figure 1. Global Horizontal Irradiance in Indonesia [14]](image)

3.2. Solar energy development in Indonesia
The planned renewable energy development in Indonesia during 2019-2028 are shown in Table 1. In the table the development is shown in capacity [MW].

| Year | Technology       | Total |
|------|------------------|-------|
|      | Geothermal [MW]  |       |
| 2019 | 190              | 559   |
| 2020 | 151              | 932   |
| 2021 | 147              | 1697  |
| 2022 | 455              | 1501  |
| 2023 | 245              | 1065  |
| 2024 | 415              | 2288  |
| 2025 | 2759             | 6252  |
| 2026 | 45               | 199   |
| 2027 | 145              | 648   |
| 2028 | 55               | 2416  |
| Total| 4607             | 16715 |
In Indonesia the electricity distribution is monopolized by State Electricity Company (named as PLN). The PLN generates the majority of the Indonesia electric power. Even though, the solar irradiance in Indonesia is categorized medium it is sufficient to be converted into electricity power. In the year 2019, PLN released the Electricity Supply Business Plan 2019-2028. In the document the list of renewable energy development capacities is mentioned and showed in the Table 1. In the table of the renewable developments are planned based on the potency of the renewable. In total during 2019 to 2028, a total of 16.7 GW renewable energy power plant will be developed. The highest capacity development is Hydropower. The total capacity, together with Mini Hydro, is 9.544 GW. The second is Geothermal power plant with a total capacity development of 4.6 GW. The third is solar power plant with a capacity of 907 MW. It is bigger than Wind power and Biomass. In addition, a small portion of ocean power is also planned. In term of capacity, the solar power has a portion of 5.4% from all renewables.

3.3. PV electricity potency

The renewable energy development shown in Table 1 is only capacity. The emissions reduction can be estimated by using electric energy resulted by the system. In order to estimate the electricity produced from the solar PV, the PV-GIS software is employed. As shown in Fig 1, the solar irradiance in Indonesia varied in every location. For instance, the potency of electricity resulted by solar PV 1 kWp in Medan city is shown in Table 2. The table shows average daily and monthly energies produced by the system. It can be seen that the maximum and minimum average monthly electricity is 120 kWh (March) and 91.7 (December), respectively.

| Month | Ave. daily energy produced [kWh] | Ave. daily Irradiation received [kWh/m²] | Ave. monthly energy produced [kWh] | Ave. monthly Irradiation received [kWh/m²] | Standard deviation of monthly energy [kWh] |
|-------|----------------------------------|------------------------------------------|-----------------------------------|-----------------------------------------------|------------------------------------------|
| Jan   | 3.39                             | 4.68                                     | 105                               | 145                                           | 9.84                                     |
| Feb   | 3.70                             | 5.15                                     | 104                               | 144                                           | 7.02                                     |
| Mar   | 3.88                             | 5.48                                     | 120                               | 170                                           | 10.3                                     |
| Apr   | 3.71                             | 5.24                                     | 111                               | 157                                           | 9.1                                      |
| May   | 3.49                             | 4.96                                     | 108                               | 154                                           | 4.41                                     |
| Jun   | 3.52                             | 5.02                                     | 106                               | 151                                           | 7.8                                      |
| Jul   | 3.54                             | 5.04                                     | 110                               | 156                                           | 7.31                                     |
| Aug   | 3.56                             | 5.03                                     | 110                               | 156                                           | 8.08                                     |
| Sep   | 3.45                             | 4.86                                     | 103                               | 146                                           | 6.84                                     |
| Oct   | 3.32                             | 4.64                                     | 103                               | 144                                           | 6.81                                     |
| Nov   | 3.11                             | 4.32                                     | 93.2                              | 130                                           | 5.1                                      |
| Dec   | 2.96                             | 4.07                                     | 91.7                              | 126                                           | 5.41                                     |
| Year  | 3.47                             | 4.87                                     | 105                               | 148                                           | 3.5                                      |

The different results are shown by the solar PV if it is installed in Jakarta. The typical average monthly solar electricity resulted by the system at several cities in Indonesia are shown in Fig 2. The cities are Medan, Jakarta, Surabaya, Samarinda, and Sumbawa. The figure shows that the characteristics of each city is different. The total produced electricity if the solar PV installed in Medan is 1264.9 kWh/kWp and in Jakarta is 1314.4 kWh/kWp. The energy in Surabaya, Samarinda and in Sumbawa is 1439.9 kWh/kWp, 1216.2 kWh/kWp and 1523 kWh/kWp, respectively. In order to estimate the energy produced by the solar power plant capacity planned in Table 1, an average electricity produced must be estimated. The total produced electricity in a year from all cities will be averaged by considering the total energy consumed in every city in comparison to Indonesia. By using this definition, the average number is 1361.2 kWh/kWp. This number will be used to estimate electricity production from solar PV.
Figure 2. Average monthly energy produced from the PV system in several cities

3.4. Solar Electricity and Emission Reduction

By using average electric energy produced by PV in Indonesia, the solar electricity produced from the planned solar PV is calculated and presented in Table 3.

| Year | Installed Capacity per Year [MW] | Total Installed Capacity [MW] | Solar Electricity Produced [GWh] | National Electricity Consumption [GWh] | Solar Energy Share |
|------|---------------------------------|-------------------------------|---------------------------------|---------------------------------------|-------------------|
| Baseline | 78.5 | 78.5 | 106.86 | 232,296 | 0.05% |
| 2019 | 63 | 141.5 | 192.61 | 245,397 | 0.08% |
| 2020 | 78 | 219.5 | 298.79 | 261,450 | 0.11% |
| 2021 | 219 | 438.5 | 596.89 | 279,353 | 0.21% |
| 2022 | 129 | 567.5 | 772.49 | 299,510 | 0.26% |
| 2023 | 160 | 727.5 | 990.28 | 320,004 | 0.31% |
| 2024 | 4 | 731.5 | 995.73 | 339,923 | 0.29% |
| 2025 | 250 | 981.5 | 1336.03 | 360,939 | 0.37% |
| 2026 | 0 | 981.5 | 1336.03 | 383,310 | 0.35% |
| 2027 | 2 | 983.5 | 1338.75 | 407,239 | 0.33% |
| 2028 | 2 | 985.5 | 1341.47 | 432,713 | 0.31% |

In the calculation several estimations have been made. The PV technology is Crystalline silicon, the mounting position is building integrated, and the slope and azimuth is 0°, respectively. The system loss is 14% and it includes losses in cables, power inverters, dirt on the modules, etc. The baseline of the installed solar capacity is 78.5 MW. In the year 2019, the electricity produced by the solar PV is 192.61 GWh. In the same year, the total electricity consumption in Indonesia is 245,397 GWh. This means, there only 0.08% of the energy produced from solar PV. In the year 2020, the energy produced by solar...
PV, total energy consumed, and percent of the solar PV is 298.79 GWh, 261,450 GWh, and 0.11%, respectively. The data shown in Table 3 shows that the maximum contribution of the solar PV is only 0.37%, it is reached in the year 2025. As a note, the Government of Indonesia has a target of energy share of 23% renewables by 2025. The renewables include solar PV. Solar PV is expected to support this target. However, the contribution of the planned solar PV is still very low or less than 1%.

The emission factor in Indonesia power sector in the year 2019 is 0.817 ton CO$_2$/MWh. This emission factor will increase to 0.945 CO$_2$/MWh in the year 2028. By using these factors the contribution of solar PV to Indonesia emission reduction is 106.85 kilo tons CO$_{2\text{eq}}$ in the year 2019. The contribution will be 1.341 million tons CO$_{2\text{eq}}$ in the year 2028.

4. Conclusions

In this study, the contribution of solar PV development in the power sector to the reduction of GHG emission has been examined. The conclusions are as follows. The development of solar PV shows a significant in the capacity number. However, in term of energy resulted the contribution is very low. During the year 2019 to 2028, the highest contribution of electricity resulted by solar PV system is only 0.37% in comparison with national electricity consumption.

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Acknowledgement

This work is a part of research project funded by Ministry of Research and Higher Education of Republic of Indonesia. The scheme of the research project is “Hibah Kompetensi DRPM” Year of 2019.