

Decarbonizing Electricity in Indonesia: Opportunity in the Implementation of Rooftop Solar PV

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Abstract - Efforts to decarbonize the electricity generation system to mitigate the environmental impacts including climate change are done around the world. The world is in an act of transfer from fossil fuel to new and renewable energy. Indonesia is trying to achieve future energy mix target through penetration in technology and policies emphasize. Indonesia through its state-owned company, PT Pembangkitan Jawa Bali (PT PJB) has a huge potential for new and renewable energy, particularly rooftop solar photovoltaic. Indonesia solar PV capacity installation was only 0.04% on 2017 whilst theoretical solar potential production is around 207.9 GW (4.8 kWh/m2/day). This article results that utilization rooftop asset from PT PJB can produce 8.09 GWh/year of electricity and reduce carbon dioxide which parameter greenhouse gas emission from electricity around 8.81 tonCO₂eq in accordance with comparisons from coal power plant. Keywords Indonesia, electricity, policy, rooftop solar PV, greenhouse gas

1. Introduction
The period of industrialization which happen now is relates linearly with humanity welfare. The grownups industrialization requires significant amount of electricity consumption. However, humanity welfare facing constraints on climate change problem as well due to usage of fossil fuel base energy source to produce electricity. Energy consumption are responsible for two-third of greenhouse gas (GHG) emissions worldwide. United nation framework convention on climate change (UNFCCC) ratify world action to control maximum limit of world temperature trajectory to control world GHG emissions. According to United Nation (UN) environment emission gap report in 2019, it shall require an active CO₂ reduction to reach allowable limit at 40 GtCO₂e and 24 GtCO₂e of global emission to achieve 2.0 and 1.5 degree Celsius world increasing temperature threshold, respectively.

Republic of Indonesia is an archipelago country which located around the earth equator line with solar radiation as much as 4.80 kWh/m²/day and the fourth most populated country in the world. Indonesia Ministry of Energy and Mineral Resources (MEMR) through Electric Directorate General Performance Report (LAKIN DJK), report that consumption of electricity as much as 1,084 kWh/capita in 2019. This growth value is increased around 5.37% compare to previous year. Like most of the other countries around the globe, electricity that generated in Indonesia were mainly comes from fossil fuel burned, especially coal. In 2019, around 87.99% of total power plant in Indonesia was generate from fossil fuel base energy: 62.71% from coal, 21.24% from natural gas,
4.00% from oil and diesel. The remainders were generated from new and renewable energy (NRE) sources, including 6.10% from hydro power plant, 5.00% of geothermal, 0.64% from import, and 0.27% of NRE sources as mentioned in PT Perusahaan Listrik Negara Electricity General Business Plan 2019-2028 (RUPTL PT PLN). Aside from hydro and geothermal sources to produce electricity, Indonesia acknowledge NRE such as solar PV, wind power, biomass, biogas, waste, and tidal energy.

Policy in Indonesia related significantly to electric power plant energy mix plan in Indonesia specially to accelerate NRE installation higher. Indonesia’s national energy policy, regulation No. 79 of 2014, specifies the aim of increasing the share of renewables. By 2025, it targets to achieve more than 23% of the electricity should come from NRE. By 2050, it further envisioned to have more than 31% of energy is from NRE sources. To fulfill these shares from NRE, presidential regulation No 22 of 2017 on national energy plan further specified future electric power plant installed capacity plan which are 45.2 GW of total 135 GW in 2025 and 167.7 GW of total 443 GW in 2050 respectively shall come from NRE sources.

![Indonesia energy mix target](image)

**Figure 1.** Indonesia energy mix target

In August 2017, MEMR adopted a flat rate buy scheme for NRE sources through MEMR Regulation No. 50 of 2017. This policy ratifies a ceiling price based on the power generation cost (Biaya Pokok Produksi/BPP), a reference price determined by PLN every year which distinguished by province as a guidance for the electricity tariff in purchasing electric power from renewable energy sources. In terms of solar PV penetration, the most constraint that occurred in every solar PV installation is usage of land. Land are always become premium commodity worldwide, therefore one of mitigation result are usage of rooftop solar PV. This solution supported by the Government of Indonesia (GoI) through ratification of MEMR regulation No 49 of 2018 on usage of rooftop solar PV to Indonesia electric state-owned company, PT PLN, to accelerate solar PV penetration in Indonesia. Utilization of rooftop solar PV were included in PT PLN annual general plan for electricity supply as well.

PT PJB is one of subsidiary from PT PLN which main business core is power generation in Indonesia. Established in 1995 PT PJB own and control many power plants in Indonesia. In power plant electrical system, self-consumption energy for power plant is an electrical energy that used by the power to initiate the power plant on-line and for other purposes such as office and warehouse facilities electric consumption. However new regulation on self-consumption energy power plant multiplier tariff, PT PLN director regulation No 0283.P/Dir/2016 on self-consumption electric energy by electric power producer non-PT PLN force high efficiency activities on self-consumption matter. One of the solutions to reduce self-consumption is usage of NRE source inside existing power plant. This article will utilize opportunity from PT PJB asset to develop rooftop solar PV installations and contribute in decarbonizing electricity from coal-based power plant and advantage through self-consumption reduction as well.
2. Literature Review

Solar PV is an existing technology especially electric energy supply which can play a significant role to develop environmentally friendly electric supply. Solar PV works through converting sunlight energy into electricity [1]. NRE technology is realized to be one of solutions for world dependence on fossil fuel-based energy. Solar PV system, wind energy system, energy storage, and electric vehicle are four major clean energy technologies which are mature, commercially competitive and develop well [2]. Solar PV global increasing capacity in 2017 was approximately 402 GW [3]. Simultaneously with world awareness in solar PV beneficiaries, it is predicted that solar PV market will keep develop in future days to come. Thi, et al. 2017 and Sah, et al. 2016 define installations of solar PV worldwide. Installations are divided into 5 categories which are ground-mounted, floating, canal-top, offshore, and rooftop system [4, 5]. Ground mounted solar PV is the most common solar PV installations. It mounted directly to any kind of ground base through common system structure foundation. Floating PV system install solar PV above a floated module. This method mitigates land-use constraint issue, however high cost of floater, mooring, and anchoring system generate issues in this installation method. One of the efforts to reduce land use and to reduce deforestation due to solar PV implementation is canal top solar system. Although the construction systems are still lying on ground mounted system, however it shall cover the unused canal area. Offshore solar PV is also a solution for scarcity of land onshore considering that 70% of earth surface are covered by ocean. The ocean also actually receives huge amount of solar PV which can be used as an energy source. It is fit for archipelago countries that formed from islands and oceans territory like Maltese islands and others. Rooftop solar PV system usually using rooftop of a residential or commercial building or structure. It can be on-grid or off-grid system. Rooftop solar PV system is the second most popular type of solar PV installation method, therefore many countries ratified policies and tariff regarding utilization of energy that produced through rooftop system. European countries are likely more focus on this rooftop system since in 2018, 19% of total European solar PV capacity was generated through rooftop [6].
Table 1 Solar PV Installation Method Comparison

| Parameter/Type                  | Ground Mounted solar PV | Rooftop solar PV | Canal top solar PV | Offshore solar PV | Floating solar PV (FPS) |
|--------------------------------|-------------------------|------------------|--------------------|-------------------|------------------------|
| **Advantages**                 | Lower installation cost | Aesthetic appearance | Land saves | Minimum usage of land | Land saves |
|                                | Convenience of tilt adjustment | Space optimization | Canal evaporation avoidance | Less shading issues | Panel natural cooling effect |
|                                | Conveniences for maintenance | Utilization of roof free space | Panel natural cooling effect | Panel natural cooling effect | Panel natural cooling effect |
|                                | Larger system availability | Installation convenience | Household participation | Household participation | Household participation |
| **Disadvantages**              | Land cost | Rooftop of roof house need to be accurate for optimal energy | Free canal is quite rare | Natural disaster like typhoon and high tide | Natural disaster like high wind and tide |
|                                | Deforestation possibility | Shading factor | Require ground base concrete foundation | Corrosion issue | Fishing and lake activities |
|                                | Heavy construction process | Difficult to clean | Difficult to maintenance | All material needs to be waterproof | Partially affects |
|                                | Time and cost consume for civil works construction | Material consume higher due to “long shape” of canal | Natural disaster like high tide | Block sunlight may affect | Block sunlight may affect |
|                                | Permit access requirements | | | Need a strong anchor | Growth of water ecosystem |
|                                |                        |                   |                   | Expensive floater | Expensive floater |

GHG emissions are consist of several gasses such as carbon dioxide (CO$_2$), methane (CH$_4$), nitrous oxide (N$_2$O), sulfur oxide (SF$_6$), etc. Burned fossil fuel from coal electric power plant produce almost all greenhouse gas mentioned above with high focus on CO$_2$ parameter. CO$_2$ is linearly related to global warming parameter (GWP), therefore reduction on CO$_2$ is important to be addressed. Life cycle analysis (LCA) on coal power plant has been done from several researcher to estimate LCA of generating per kWh of electricity from coal. This article will assume that NRE source will produce zero gCO$_2$eq/kWh.

Table 2 CO$_2$ Production from Coal Per KWh

| References         | GWP of Coal (gCO$_2$eq/kWh) |
|--------------------|-----------------------------|
| Agrawal, et al. 2014 [7] | 1,127                      |
| Weisser, et al. 2007 [8]   | 950 – 1,250                |
| Jaramilo et al, 2007 [9]  | 910 – 1,170                |

In the world of solar PV plant energy production prediction, researchers are commonly using software tools to develop a design from specific solar PV project. One of the software is system advisor model (SAM) which developed by national renewable energy laboratory (NREL), USA. SAM is a techno-economic computer model that support people who interest in NRE industry. According to Blair, et al. 2014, SAM is suitable to simulating NRE on-grid performance systems with financial model of NRE project [10]. Meteorological data such as irradiation (kWh/m$^2$/day), wind speed (m/s), and ambient temperature (°C) value also a significant parameter in determining energy production NRE. SAM provides several sources to obtain free meteorological data such as the national solar radiation database (NSRDB) and European commission’s photovoltaic geographical information system (PVGIS) [11].

To determine Rooftop of rooftop solar PV installations, a remote desk job measurement through map software has been done for this article. Google Earth is a geospatial software application that displays a virtual globe, which offers the ability to analyze and capture geographical data as explained in Forbes article by Chowdhry in 2015 [12]. Taylor, et al. 2011 ensure that Google earth pro has tools for remote measurement to measure object, open space, and others [13].

Design of solar PV plant is following mathematical equation which formulated by Song, et al. 2016 and Sukarso, et al. 2020 [14, 15] with PV installation in Korea and Indonesia respectively. Design of solar PV calculates usage of optimal combination between selected solar PV module and inverter electrical parameter. Therefore, usage of area will be resulted as linear result from solar PV module quantity of use. This article assume that inverter shall be replace not at the rooftop nevertheless other locations.
Author realize that this article is original and triggered for the first time since there are no other from previous article discuss on this topic earlier. This article is pioneer to acquire data from Google earth pro and usage of NRE technology software at PT PJB location for rooftop PV installation

3. Data and Methodology

3.1 Schematic workflow
This article will use schematic workflow as follow

![Schematic workflow](image)

**Figure 3** Schematic workflow

3.2 Determining location of rooftop solar PV
Google earth pro is used by the author to identify available and potential rooftop of 12 PT PJB asset as in figure 2 above. Detail locations of PT PJB businesses was obtained through PT PJB website (www.ptpjb.com). Lists of potential PT PJB rooftop and predicted area for rooftop solar PV installation described in table 3 and table 7 on Appendix below.

![Example rooftops at PT PJB UP Muara Karang (red line)](image)

**Figure 4** Example rooftops at PT PJB UP Muara Karang (red line)

| No | Rooftop location | Coordinate | Total Area (m²) |
|----|-----------------|------------|----------------|
| 1  | UP Paiton       | 7°42'58.08"S 113°35'4.40"E | 1,671 |
| 2  | UP Brantas      | 8° 9'28.22"S 112°26'36.00"E | 2,890 |
| 3  | UP Cirata       | 6°40'25.48"S 107°21'9.03"E | 5,373 |
| 4  | UP Muara Karang | 6° 6'40.08"S 106°46'57.90"E | 3,384 |
| 5  | UP Muara Tawar  | 6° 5'23.36"S 106°59'49.28"E | 3,670 |
| 6  | UP Gresik       | 7°10'1.47"S 112°39'48.73"E | 2,900 |
| 7  | UBJOM Arun      | 5°12'58.82"N 97° 5'23.95"E | 1,320 |
| 8  | UBJOM Tenayan   | 0°33'47.68"N 101°31'24.14"E | 1,603 |
| 9  | UBJOM Indramayu | 6°16'29.39"S 107°58'13.00"E | 1,932 |
| 10 | UBJOM Pulang Pisau | 2°49'20.40"S 114°12'32.00"E | 1,985 |
| 11 | UBJOM Rembang   | 6°38'9.01"S 111°28'30.08"E | 2,879 |
| 12 | UBJOM Pacitan   | 8°15'29.34"S 111°22'25.94"E | 4,284 |
3.3 Meteorological data
Based on coordinate on every potential rooftop location above, meteorological data was downloaded through European PVGIS data source. Data format is downloaded in typical meteorological year (TMY) format (.epw). The meteorological file downloaded within most updated from the website which are 10 years of data collection (2007 – 2016). The meteorological parameter result shown below

| No | Location       | Global Horizontal Irradiation (kWh/m²/day) | Average wind speed (m/s) | Average ambient temperature (°C) |
|----|----------------|-------------------------------------------|--------------------------|---------------------------------|
| 1  | UP Paiton      | 5.57                                      | 1.9                      | 25.2                            |
| 2  | UP Brantas     | 5.25                                      | 2.3                      | 25.0                            |
| 3  | UP Cirata      | 5.07                                      | 1.6                      | 26.0                            |
| 4  | UP Muara Karang| 5.25                                      | 2.0                      | 26.9                            |
| 5  | UP Muara Tawar | 5.42                                      | 2.1                      | 26.9                            |
| 6  | UP Gresik      | 5.57                                      | 2.8                      | 27.1                            |
| 7  | UBJOM Arun     | 5.21                                      | 1.4                      | 26.6                            |
| 8  | UBJOM Tenayan  | 4.77                                      | 1.3                      | 26.0                            |
| 9  | UBJOM Indramayu| 5.44                                      | 2.3                      | 27.0                            |
| 10 | UBJOM Pulang Pisau | 4.85                                      | 1.6                      | 26.6                            |
| 11 | UBJOM Rembang  | 5.49                                      | 3.1                      | 27.0                            |
| 12 | UBJOM Pacitan  | 5.16                                      | 4.5                      | 26.4                            |

3.4 System Advisor Model (SAM)
Inside SAM calculation of energy yield production will obtained based on proposed location. Author will design of rooftop solar PV with above limitation of total available rooftop area which stated on table 3 above. SAM require location and meteorological data, type of solar PV module, type of installation, system design, shading, losses, and degradation factor. Fixed type of solar PV with commonly use 5 degree of fix tilting degree was chosen consider Indonesia location is around the equator line of the earth. The design was calculated based on usage of PV module and land availability at each location. For the simplicity of research, this article will use data from SAM repository in table 5 below and several assumptions based on literature review.

| Solar Module: | Inverter type: | |
|---------------|----------------|------------------|
| SunPower SPR-220-BLK | Schneider Conext TX5000 NA [240 V] | |
| Rated Power: 221,443 Watt | Rated Power: AC: 5 kW | |
| Nominal efficiency (ƞ): 17.8% | Vmax_mppt: 480 V | |
| Voltage module: 40,8 V | Vmin_mppt: 100 V | |
| βreff: -0.0041/°C | Inverter DC to AC ratio: 0.99 | |
| Length x Width: 1.244m x 1m | Efficiency: 95.9% | |
| Lifetime expectancy: 25 years | Solar module NOCT condition; Irradiation: 1000W/m²; Ambient temp (Ta): 25°C; Module temp (Tc): 49.2°C | |

4. Result
4.1 Solar PV energy yield
Calculation resulted through SAM output software. Recommended installed capacity design (Watt) was created on diverse considering rooftop availability and the actual design area size was controlled as near as limitation of rooftop area to obtain maximum energy yield. Energy production (kWh/year)
and capacity factor (%) from the rooftop PV design were obtained considering locations from each rooftop. The result shown in Table below

| No | Rooftop Location       | Recommended Installed Capacity (Watt) | Energy Yield (kWh/year) | Capacity factor (%) | Total Area (m²) |
|----|------------------------|--------------------------------------|-------------------------|---------------------|----------------|
| 1  | UP Paiton              | 295,000                              | 431,639                 | 16.8                | 1654.5         |
| 2  | UP Brantas             | 500,000                              | 685,306                 | 15.7                | 2812.6         |
| 3  | UP Cirata              | 950,000                              | 1,237,864               | 15.0                | 5338.0         |
| 4  | UP Muara Karang        | 600,000                              | 812,922                 | 15.6                | 3369.9         |
| 5  | UP Muara Tawar         | 640,000                              | 896,412                 | 16.1                | 3596.4         |
| 6  | UP Gresik              | 500,000                              | 720,289                 | 16.5                | 2812.6         |
| 7  | UBJOM Arun             | 225,000                              | 300,775                 | 15.4                | 1,262.7        |
| 8  | UBJOM Tenayan          | 280,000                              | 342,451                 | 14.4                | 1567.4         |
| 9  | UBJOM Indramayu        | 340,000                              | 479,008                 | 16.1                | 1,915.1        |
| 10 | UBJOM Pulang Pisau     | 350,000                              | 434,199                 | 14.3                | 1959.3         |
| 11 | UBJOM Rembang          | 500,000                              | 714,809                 | 16.4                | 2812.6         |
| 12 | UBJOM Pacitan          | 750,000                              | 1,034,401               | 15.8                | 4223.4         |
| Total |                      |                                      | 5,950,000               |                     | 33,324.5       |

**Figure 5** Rooftop PV result analysis

4.2 Greenhouse gas potential reduction
Substitution of energy yield production from each type from power plant are done in this article to estimate GHG emission through comparison among fossil fuel (coal) base energy and NRE (rooftop PV) base energy. Through literature review stated on section 2 above average value of GHG emissions production from coal base power plant are 1,089 gCO₂eq/kWh. Therefore, GHG reduction calculated from substituting production from coal power plant with rooftop PV production. The installation rooftop PV will reduce around 8,810,091.675 gCO₂eq.

5. Discussion and Conclusion
Study and analysis of implementation of rooftop solar PV at PT PJB asset to encourage energy mix and reduction of GHG emission has been done in this article. PT PJB as a PT PLN subsidiary can shift the base paradigm of electricity production from fossil fuel oriented to high priority NRE penetration.
This act will in line with Government of Indonesia future energy mix target which stated in policies ratification and strategies. One of the ways to decarbonize electricity in the world is substituting fossil fuel-based power with power from new and renewable energy source. Indonesia, with huge potential of solar PV and other renewable energy in general, can use this as an opportunity to develop solar PV industry to reduce greenhouse gas emissions and to achieve ideal 100% of the electrification rate. Penetration of NRE is very important to have a better sustainability energy life in the future come and support Indonesia future target as well.

PT PJB assets locations has significant source for solar PV installation. UP Paiton and UP Gresik has irradiation of 5.57 kWh/m²/day whilst UBJOM Tenayan receive 4.77 kWh/m²/day. Indonesia average value stated in RUPTL was only 4.8 kWh/m²/day. Through analysis of rooftop solar PV installation at PT PJB asset, PT PJB estimated to have a minimum total 5.9 MW of rooftop solar PV installation with electricity production around 8.090 GWH/year. This installation will occupy 33,324.5 m² area of rooftop which already available at PJ PJB.

GHG reduction calculated from substituting production from coal power plant with rooftop PV production. The installation rooftop PV will reduce around 8.81 tonCO₂eq. In rooftop PV analysis UP Paiton at East Java province has the highest capacity factor with 16.8% whilst UBJOM Pulang Pisau at Central Kalimantan province obtained the lowest capacity factor with 14.1%. This analysis also can be used by PT PJB to develop a new business parameter on NRE projects.

Author realize in this article has uncertainty parameter due to data was acquire remotely and not direct measurement and it shall be improved. Improvement in the future can optimize this study with direct measurement on-site and ensure multi environment parameter to have a preferable result.

**Appendix**

**Table 7 Potential Rooftop PT PJB details**

| No | Rooftop location | Coordinate | Predicted Area (m²) |
|----|------------------|------------|---------------------|
| 1  | UP Paiton        |            |                     |
|    | Rooftop 1        | 7°42'59.19"S 113°35'8.42"E | 1,283               |
|    | Rooftop 2        | 7°43'1.02"S 113°35'7.56"E | 215                 |
|    | Rooftop 3        | 7°43'0.25"S 113°35'6.80"E | 173                 |
| 2  | UP Brantas       |            |                     |
|    | Rooftop 1        | 8° 9'29.09"S 112°26'35.89"E | 1,396               |
|    | Rooftop 2        | 8° 9'27.67"S 112°26'35.03"E | 1,218               |
|    | Rooftop 3        | 8° 9'28.87"S 112°26'34.27"E | 119                 |
|    | Rooftop 4        | 8° 9'28.43"S 112°26'34.40"E | 157                 |
| 3  | UP Cirata        |            |                     |
|    | Rooftop 1        | 6°40'25.23"S 107°21'16.82"E | 229                 |
|    | Rooftop 2        | 6°40'25.47"S 107°21'13.43"E | 137                 |
|    | Rooftop 3        | 6°40'24.90"S 107°21'12.57"E | 386                 |
|    | Rooftop 4        | 6°40'24.88"S 107°21'11.76"E | 393                 |
|    | Rooftop 5        | 6°40'24.94"S 107°21'1.15"E  | 1,683               |
|    | Rooftop 6        | 6°40'26.90"S 107°21'1.91"E  | 880                 |
|    | Rooftop 7        | 6°40'26.55"S 107°21'3.43"E  | 635                 |
|    | Rooftop 8        | 6°40'23.99"S 107°21'3.55"E  | 677                 |
|    | Rooftop 9        | 6°40'25.55"S 107°21'3.51"E  | 353                 |
| 4  | UP Muara Karang  |            |                     |
|    | Rooftop 1        | 6° 6'39.06"S 106°46'58.34"E | 826                 |
|    | Rooftop 2        | 6° 6'38.58"S 106°46'56.51"E | 1,103               |
|    | Rooftop 3        | 6° 6'41.13"S 106°46'57.53"E | 249                 |
|    | Rooftop 4        | 6° 6'33.06"S 106°46'58.26"E | 565                 |
|    | Rooftop 5        | 6° 6'37.89"S 106°47'16.23"E | 395                 |
|    | Rooftop 6        | 6° 6'41.04"S 106°46'58.09"E | 135                 |
|    | Rooftop 7        | 6° 6'39.64"S 106°46'59.51"E | 111                 |
| 5  | UP Muara Tawar   |            |                     |
|    | Rooftop 1        | 6° 5'24.17"S 106°59'47.94"E | 329                 |
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