PV Rooftop Repowering Potential In Indonesia: Study Case

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Abstract. Indonesia is intensively building solar energy, which divided into three types, namely rooftop, solar farm, and floating solar with a target-installed capacity of 37.15 GW. A lot of land area is required for the development of solar energy for the next 20-25 years. The average land area required for 1 PV module is approximately 2 m², so it is predicted that the new land area needed will be difficult to obtain in the future. Repowering is a solution to deal with these potential problems, repowering is an interesting new business in Europe when we have to face power plants that have entered the end-of-life. The study aims to analyze if repowering is implemented, we can reduce the Levelized Cost of Electricity. A plant with a capacity of 1.4 MWp will be used as the basis for the simulation. Using a monitoring system to see energy production, temperature, irradiance, and performance ratio is used as the methodology for collecting data. After that, it will analyze from a technical and economic point of view. The result shows that energy production increased by 24% or by 10,645,786 kWh and the Levelized Cost of Electricity decreased by 0.02 USD/kWh with an IRR of 5.67% and a payback period of 14.5 years. This study finds that repowering can reduce electricity tariffs and increase energy production.

Key Words: PV Rooftop, Levelized Cost of Electricity (LCOE), Repowering

1. Introduction
Indonesia is a tropical country that has renewable energy sources. According to the Ministry of Energy and Mineral Resources of Indonesia (MEMR), the potential of solar energy reaches 208 GW, where until now Indonesia has only utilized about 0.07%. Indonesia has energy mix target of 23% in 2025 and 31% in 2030 are still a long way to achieve [1]. The stakeholders such as Government, entrepreneur, and academic institutions have to work together well. One of the fastest ways to pursue the renewable energy mix target is the use of solar energy. Currently, Indonesia is intensively build PV rooftop. At this time, we have 3.472 PV rooftop customers with total installed capacity around 26.51 MWp. The additional PV rooftop installation will continue increase in the following years and MEMR targeted that PV rooftop capacity will reach 3.61 GW [2].

PV rooftop development in Indonesia, sooner or later will face the shortage of land area like European countries [3]. The land area required is around 2 square meters for one unit PV with a various capacity up to 500 Wp for PV rooftop installation. Land area required for PV rooftop is not as big as for solar farm, In Indonesia usually the various capacity installed around 1 kWp – up to more than 1 MWp where those capacity divided into three sectors (commercial, industrial, and household). One of the solutions to overcome the problem of a shortage of land area to build new PV rooftop is by repowering. Currently,
Indonesia will continue aggressively to build solar PV rooftop. However, at the same time, PV rooftop that have started operating since 2020 and below will face a decrease on performance in the future (usually the lifetime of solar PV for 25 years). During the operation period of PV rooftop continue, PV technology will also continue to develop. Therefore, repowering will be a solution for renewable energy businesses in Indonesia in the next 20 to 25 years. Repowering stands for old PV and inverter replacement with more advance and modern technology. It means being able to generate more energy from before, and still using the same area where PV and inverter was installed [4].

This study aims to see the effect of repowering PV rooftop installed in Indonesia against the Levelized Cost of Electricity (LCOE) value. In addition to measuring the value of LCOE, this study could also be useful for renewable energy sector in Indonesia, since in the next 20 – 25 years there will be many PV rooftop entering end-of-lifetime and this study can help stakeholders or decision maker make a comprehensive regulation. A case study will be conducted in this study. Repowering simulation will be carried out on PV rooftop with a capacity of 1.4 MWp (on grid system) to see the technical and economic aspects.

2. Methodology
The methodological process is organized in three main steps: collecting data, case studies for technical analysis and economic analysis

2.1. Collecting data
Evaluation of the site location, annual energy production, average of solar irradiance at site location, performance ratio of PV rooftop, and detail technical specification of PV module and inverter. All data obtained based on the actual data operational from the monitoring. We do plant layout assessment too, to show that the actual condition of area divided into two parts or two utilities.

2.1.1. Data of plant. This PV rooftop with a capacity of 1.4 MWp is used as a basis for conducting repowering simulations and it has only been operating for 1.5 years. The PV rooftop system is an asset of SUN Energy, where SUN Energy is a company that develops the use of PV in Indonesia and overseas. The following information is a description of PV Rooftop located in Indonesia, especially in the West Java area.
Figure 2. Plant Layout (source: earth.google.com and owner). The figure is a top view of the plant, which divided into two utilities. The blue colour is utility-1 and yellow is utility-3.
As an important parameter to perform repowering simulation, here is main features of plant:

| Description                      | Utility-1 | Utility-3 |
|----------------------------------|-----------|-----------|
| Operation year                   | 2019      | 2019      |
| Capacity (kWp)                   | 183.6     | 1227.4    |
| Number of PV (pcs)               | 540       | 3610      |
| Average solar irradiance (kWh/m²)| 4.82      | 4.76      |
| Land area (m²)                   | 1570.5    | 2415.9    |
| Number of Inverter (unit)        | 3         | 20        |
| Model of Inverter                | Solid-Q 50| Solid-Q 50|
| Capacity of Inverter (kW_{AC})   | 3 x 50    | 20 x 50   |

Based on information from owner, this plant has just finished construction at the end of 2019 and has been operating since early January until now. This plant will operate for 25 years and will supply electricity up to 30% of the total load. The PV rooftop system is on grid where the power source coming from the main power incoming. For information, Indonesia has Perusahaan Listrik Negara (PT PLN) which is the only company to distribute electricity to customers. But, in the special region like Cikarang where plant was located, the main power source from Cikarang Listrindo. PLN and Cikarang Listrindo have a long-term contract to supply electricity in the Cikarang area and commonly known as Independent Power Producer (IPP).

2.1.2. Data of solar irradiance and temperature

Data of solar radiation always different for each month. So, assumption is made of the average daily solar radiation (kWh/m². day). For the details, this is the following data of solar radiance at the location and data of temperature for each month:

| Month      | Utility-1 | Irradiance (kWh/m²) | Temperature (°C) | Utility-3 | Irradiance (kWh/m²) |
|------------|-----------|---------------------|------------------|-----------|---------------------|
| January    | 26.30     | 110.1               | 26.30            | 121.5     |
| February   | 25.80     | 101.3               | 25.80            | 110.5     |
| March      | 26.30     | 136.5               | 26.30            | 146.5     |
| April      | 26.90     | 136.4               | 26.90            | 142.6     |
| May        | 27.20     | 142.4               | 27.20            | 145.6     |
| June       | 27.00     | 133.8               | 27.00            | 136.6     |
| July       | 26.60     | 147.8               | 26.60            | 150.6     |
| August     | 27.00     | 167.4               | 27.00            | 172.6     |
| September  | 27.80     | 167.2               | 27.80            | 175.6     |
| October    | 28.30     | 158.1               | 28.30            | 170.5     |
| November   | 28.10     | 126.9               | 28.10            | 139.4     |
| December   | 27.19     | 114.6               | 27.19            | 126.4     |

From the data above, we can conclude that the average of ambient temperature is 27.05 °C for both locations and the total annual radiation is 1761.6 kWh/m². year for the utility-1 and 1738.3 kWh/m². year for the utility-3.
2.1.3. Data of performance ratio
The performance ratio value obtained from the actual condition, which figured out in the monitoring system and starting from January 2020 to July 2021. It will be used as a reference to conduct technical analysis whether the performance of plant for a period of 1.5 years meets the expected performance or not.

| Month       | Utility-1 Forecast | Utility-1 Actual | Utility-3 Forecast | Utility-3 Actual |
|-------------|--------------------|------------------|--------------------|------------------|
| 2020        |                    |                  |                    |                  |
| January     | 77,97%             | 83,60%           | 78,79%             | 84,90%           |
| February    | 77,69%             | 85,70%           | 78,55%             | 84,83%           |
| March       | 77,84%             | 83,31%           | 78,80%             | 79,32%           |
| April       | 77,65%             | 81,42%           | 78,64%             | 79,03%           |
| May         | 77,24%             | 78,25%           | 78,25%             | 66,97%           |
| June        | 77,35%             | 77,96%           | 78,49%             | 75,10%           |
| July        | 77,26%             | 78,72%           | 78,39%             | 74,00%           |
| August      | 76,48%             | 78,47%           | 77,59%             | 74,94%           |
| September   | 76,22%             | 78,67%           | 77,14%             | 76,37%           |
| October     | 76,05%             | 80,13%           | 76,88%             | 75,55%           |
| November    | 76,91%             | 79,69%           | 77,61%             | 75,33%           |
| December    | 77,45%             | 77,24%           | 78,23%             | 82,13%           |
| 2021        |                    |                  |                    |                  |
| January     | 77,44%             | 84,56%           | 78,26%             | 85,42%           |
| February    | 77,16%             | 83,57%           | 77,99%             | 81,91%           |
| March       | 77,31%             | 81,03%           | 78,27%             | 77,32%           |
| April       | 76,60%             | 78,73%           | 77,55%             | 71,06%           |
| May         | 76,72%             | 79,21%           | 77,72%             | 67,13%           |
| June        | 76,82%             | 79,90%           | 77,95%             | 81,06%           |

The design of a PV system, engineers usually use several software such as Homer or PVsyst. The forecasting data above obtained from the PVsyst which provided by the owner.

2.1.4. Data of PV module
The types of modules used in both utilities are the same and come from Trinasolar manufacturers. Trinasolar is one of the largest PV module manufacturers in the world where they managed to sell PV modules with a total capacity of 70 GW spread throughout the world. [5]. The following are the specifications for the Trinasolar PV Module used in 1.4 MWp PV rooftop.
Table 4. Specification of PV Module

| Specification                        | Value |
|--------------------------------------|-------|
| PV capacity (Wp)                     | 340   |
| Efficiency (%)                       | 17.5  |
| Annual degradation rate (%)          | 0.71  |
| Material                             | Multicrystalline |
| Maximum power voltage-\(V_{MPP}\)   | 38.2  |
| Maximum power current-\(I_{MPP}\)   | 8.90  |
| Open circuit voltage-\(V_{OC}\)     | 46.2  |
| Short circuit current-\(I_{SC}\)    | 9.50  |
| Module dimensions (mm)               | 1960 × 992 × 40 |
| Operational temperature             | 40~+85°C |

The data above is assumed under standard conditions (STC) where the solar radiation value is 1 kWh/m², temperature is 25°C, and the air mass is 1.5 with tolerance ±3%.

2.2. Case studies: technical analysis

We will conduct analysis of the plant layout and energy production. After that, we will validate all data such as the annual energy production, solar irradiance, performance ratio based on the actual condition (Current Status) and compare with the forecast. Data forecast usually provide solar monthly solar irradiance, average of temperature, total losses, and annual energy production. After we thought the actual data, we will validate the amount between current status and manual calculation. There are some equations used to calculate the main parameters, such as (1)-(4):

\[
Y_F = PV \text{ capacity (Wp)} \times PSH (h) \times 365
\]  
\[
PR = \frac{Y_F (kWh)}{PSH (h) \times P_{rated} (kWp)}
\]  
\[
CF = \frac{Y_F (kWh)}{PSH (h) \times P_{rated} (kWp)}
\]  
\[
\eta = \frac{Y_F (kWh)}{Irradiance (kWh/m²) \times A_{PV} (m²)}
\]

The Peak Sun Hours (PSH) value used in the study is 3.73 hours where it is taken from the actual average value of the monitoring system, the annual energy production value (\(Y_F\)) which is useful for calculating economic analysis, performance ratio (PR) is useful for knowing the performance of PV rooftop, capacity factor (CF) where usually the value is in the range 15% ~ 20% and yearly electric conversion (\(\eta\)).

After we got the result from data actual, we will analyse the implementation of. In this section we will carry out the simulation to use PV and inverters with a larger capacity and more advanced technology. After that, we can see the benefit of repowering from a technical point of view.

2.3. Case studies: technical analysis

In addition to the technical calculations above, we also calculate the Levelized Cost of Electricity (LCOE) if the repowering is implemented. In accordance with the objectives of this study which have been mentioned in the introduction, we will see how big the effect of the repowering on the value of LCOE and the economic sustainability. In addition, we also calculate the Net Present Value (NPV) and
Internal Rate of Return (IRR) to provide future business views for renewable energy business players in Indonesia. Here are the equations used to get LCOE, NPV, and IRR values (5)-(7):

\[
LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}
\]  

(5)

\[
NPV = \sum_{t=1}^{n} \frac{C_t}{(1+i)^t}
\]  

(6)

\[
0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} = C_0
\]  

(7)

Where \( I_t \) is the value of investation, \( M_t \) is the value of O&M and \( F_t \) is the value of fuel. However, for PV rooftop the \( F_t \) component is not taken into account because there is no fuel component. The \( C_t \) value is a cash flow of project, \( C_0 \) is the initial investment cost and \( t \) describes the function of time in a certain period. In this economic analysis, there are also several assumptions that will be used in the calculations such as Weighted Average Cost of Capital (WACC), discout factor, and the ratio between share of equity and loan.

Details of the analysis and results regarding the three steps mentioned above are reported in the following three sections respectively.

3. Result and discussion

3.1. Definition of repowering

Repowering is intended as an intervention finalized to the complete replacement of the old PV module with new ones equipped with the latest advanced technologies and consequently capable to provide improved performance (e.g. efficiency, small loses) and probably higher installed capacity[6]. Some of the benefits of repowering include:

- increase of the specific energy production due to the higher PV capacity
- no need a new land area, since we use old before
- lower number or PV module and inverter
- prevention of further “virgin” land area consumption for solar energy (e.g. solar farm, PV rooftop)
- improvement of the electric grid integration because of the new inverter up-to-date connection systems
- reduction of the overall capital costs for the installation of PV rooftop in comparison to a new plant (some of existing infrastructures could be re-used)
- reduction of the operation and maintenance costs in comparison to an old plant due to lesser maintenance interventions
- open new business opportunities and create jobs

This study is certainly very useful for entrepreneur in Indonesia and also be used as material in making policies for the future. Since we know that Indonesia is still in the process for developing solar energy so that it can be a solution for the future.
3.2. Case studies: technical analysis

3.2.1. Plant analysis

The total area of PV installation in utility-1 is 1570.5 m² and for utility-3 is 2415.9 m². However, not all areas are installed with PV modules due to structural constraints and the potential of shading. The following figure is the condition of the roof that has been installed with PV along with the potential of shading that caused the PV placement cannot maximized.

![Figure 3. Potential of Shading at Plant (source: owner).](image)

The figure above explains that if PV is installed in the red circle area, performance of PV will not be optimal due to shading impact caused by height differences between one building and others. Conducting an assessment of the location where PV will be installed is very important so that we can optimize the existing land area with optimal capacity.

3.2.2. Energy production analysis (current status)

Energy production analysis is carried out to validate whether the data obtained are the same or close if the calculations are carried out using a mathematical approach according to the equations described in the methodology section.
From the figure above, we can analyse that there is a slight deviation of annual energy production between utility-1 and utility-3 with the amount of 0.43% and 1.75%. In the forecasting, the value of energy production in the first year is 256.1 MWh for the utility-1 with a projected energy production in the 25th year is 215.84 MWh, while for the validating calculation was carried out, the amount of energy production in the first year is 255 MWh and 214.92 MWh in 25th year, while the forecasting of utility-3 the amount of energy production in the first year is 1.673 MWh and 1.434 MWh when the calculation is validated. The manual calculation was carried out with the assumption that the Peak Sun Hours value at location is 3.73 hours and the annual degradation value of the current PV performance is 0.71% (refer to PV module specification). The validation calculations will be used as a reference for the repowering simulation and will be compared to how big the difference in energy production between current status and simulation.

3.2.3. Repowering analysis
In this section, we will simulate when PV rooftop are at the end-of-life (25th year) and we do repower the old one by replacing all the main components (PV and Inverter) with the latest PV and Inverter technology. The purpose of replacing these old components is that we get greater energy production and also the ability to synchronize the inverter with the grid is getting better but with the same PV and inverter installation area and maximizing the land area that has been used. So, investors do not need to be difficult to assess new land area to build PV rooftop. The following is an implementation of the latest technology used in the repowering simulation.
Table 5. Comparison of current technology with the advance technology for repowering

| Description                        | Current Status          | Repowering          |
|------------------------------------|-------------------------|---------------------|
| Capacity (Wp)                      | 340                     | 500                 |
| Material                           | Multicrystalline        | Monocrystalline     |
| Efficiency (%)                     | 17.5                    | 21                  |
| Annual degradation rate (%)        | 0.71                    | 0.55                |
| Module dimensions (mm)             | 1960 × 992 × 40         | 2187 × 1102 × 35    |
| Maximum power voltage-$V_{MPP}$ (V)| 38.2                    | 42.8                |
| Maximum power current-$I_{MPP}$ (A)| 8.90                    | 11.69               |
| Open circuit voltage-$V_{OC}$ (V)  | 46.2                    | 51.7                |
| Short circuit current-$I_{SC}$ (A) | 9.50                    | 12.28               |
| Operational temperature            | 40~+85°C                | 40~+85°C            |

The latest PV technology used is the latest technology that comes out in 2020. Of course in the next 25 years there will be technological developments again, so this research may be updated in the future using technology developed in that year.

Table 6. Results obtained which refers to the availability of land area and the latest technology of PV

| Description                        | Current Status Utility-1 | Current Status Utility-3 | Repowering Utility-1 | Repowering Utility-3 |
|------------------------------------|--------------------------|--------------------------|----------------------|----------------------|
| Capacity (kWp)                     | 183.6                    | 1227.4                   | 240                  | 1606.5               |
| Number of PV (pcs)                 | 540                      | 3610                     | 480                  | 3213                 |
| Land area (m²)                     | 1048                     | 7005                     | 1048                 | 7005                 |
| Total electricity production during system lifetime (kWh) | 4.571.029 | 29.881.274 | 7.601.151 | 38.036.938 |
| Number of Inverter (kW_{AC})       | 3 x 50                   | 20 x 50                  | 2 x 100              | 15 x 100             |
Table 7. Results of annual energy production between current status and repowering for 25 years

| Year | Current Status | Repowering | Deviation |
|------|---------------|------------|-----------|
| 1    | 1.499.129     | 1.962.361  | 463.232   |
| 2    | 1.488.485     | 1.948.428  | 456.943   |
| 3    | 1.477.917     | 1.934.594  | 456.677   |
| 4    | 1.467.424     | 1.920.859  | 453.435   |
| 5    | 1.457.005     | 1.907.221  | 450.216   |
| 6    | 1.446.660     | 1.893.679  | 447.019   |
| 7    | 1.436.389     | 1.880.234  | 443.845   |
| 8    | 1.426.191     | 1.866.884  | 440.694   |
| 9    | 1.416.065     | 1.853.630  | 437.565   |
| 10   | 1.406.011     | 1.840.469  | 434.458   |
| 11   | 1.396.028     | 1.827.402  | 431.374   |
| 12   | 1.386.116     | 1.814.427  | 428.311   |
| 13   | 1.376.275     | 1.801.545  | 425.270   |
| 14   | 1.366.503     | 1.788.754  | 422.250   |
| 15   | 1.356.801     | 1.776.053  | 419.252   |
| 16   | 1.347.168     | 1.763.443  | 416.276   |
| 17   | 1.337.603     | 1.750.923  | 413.320   |
| 18   | 1.328.106     | 1.738.491  | 410.386   |
| 19   | 1.318.676     | 1.726.148  | 407.472   |
| 20   | 1.309.314     | 1.713.892  | 404.579   |
| 21   | 1.300.018     | 1.701.724  | 401.706   |
| 22   | 1.290.787     | 1.689.642  | 398.854   |
| 23   | 1.281.623     | 1.677.645  | 396.022   |
| 24   | 1.272.523     | 1.665.734  | 393.211   |
| 25   | 1.263.488     | 1.653.907  | 390.419   |
| Total| 34.452.303    | 45.098.089 | 10.645.786|
From the results above, it can be concluded that when repowering is carried out on PV rooftop with a capacity of 1.41 MWp, the total capacity increases to 1.84 MWp. This is due to the development of PV technology used in these plants. In addition, with the same total area of PV laying, we can reduce the number of PV in both utilities. Although the number of PV used is reduced, the required area remains the same due to the difference in dimensions between the PV currently used (before repowering) and when repowering has been carried out. In addition, the number of inverters used was also reduced from 23 units to 17 units. The repowering simulation shows that the amount of energy produced for 25 years increased by 24%.

3.3. Case studies: economic analysis
The value of Levelized Cost of Electricity is the main objective of this research. There are several efforts to reduce the LCOE value including: reduce system cost (USD/Wp), reduce cost of capital, increase energy yield, and increase system lifetime [7]. LCOE value for PV currently ranges from 0.06-0.11 USD/kWh [8]. The main parameters for calculating the LCOE value include the Capital Expenditure of the PV rooftop which divided into three parts: PV Module, Inverter, and Balance of System (BoS). BoS on rooftop PV usually includes cable costs, mounting structures, permits, logistics, and other costs [9]. The following table are the data that will be used to calculate the LCOE value.

| Table 8. Input data for economic calculation |
|---------------------------------------------|
| Description          | Current Status | Repowering   |
| CAPEX (USD)          | 998.800        | 1,531,717    |
| O&M (USD/year)       | 17.978         | 30.634       |
| Lifetime (year)      | 25             | 25           |
| Energy Yield (kWh)   | 34,452,503     | 45,098,089   |
The investment cost of PV and inverter in the current status condition follows the price trend in the construction year (2019) with an investment cost of PV, inverter, and Balance of System (BoS) of 0.51 USD/Wp, 0.10 USD/Wp, and 0.34 USD/Wp. Meanwhile, the investment cost during repowering conditions follows the current price trend with the investment cost of PV, inverter, and BoS at a price of 0.43 USD/Wp, 0.12 USD/Wp, and 0.3 USD/Wp. The cost of Operation and Maintenance for solar energy is low, unlike fossil power plant, the O&M cost is assumed to be only 1.8% of the annual CAPEX value. In addition to determining the LCOE calculation, this study also calculates NPV, and IRR. Assumed a debt and loan share value of 30% and 70% and a Weighted Average Cost of Capital value of 7.4% and a discount factor of 12%.

Table 9. Results of the economic analysis LCOE for all the case studies.

| Description     | Current Status | Repowering |
|-----------------|----------------|------------|
| LCOE (USD/kWh)  | 0.13           | 0.11       |
| IRR (%)         | 4.48           | 5.67       |
| NPV (USD)       | 634.846        | 635.197    |
| Payback Period (year) | 16             | 14.5       |

From the results above, we can see that when repowering was carried out for PV rooftop, we can reduce the LCOE value by 0.02 USD/kWh. LCOE value will be cheaper as the technology develops from the two main components in on-grid system namely PV and inverter. Economically, repowering is also an attractive business for Indonesia's future. We can see that the IRR and NPV values also increase and the payback period of the investment is also getting faster, the value will continue to increase in the future because the price of PV and inverter technology will be more competitive. If we compared to other renewable energy power plant, solar energy is indeed taking a long time to return its investment capital cost, unlike hydro power and geothermal where the payback period value is usually around 7 to 10 years. It is because the current solar energy is intermittent and does not use energy storage or batteries, so the capacity factor (CF) of solar PV is usually in the range of 15 – 20% and if the system is added to the battery, then the value of the LCOE will increase.

4. Conclusion and outlook

Repowering has a good impact on the development of renewable energy in the future. The results of this study show that the replacement of the main components in PV rooftop (PV modules and inverters) with the latest current technology can increase the energy production by up to 24%. In addition, the capacity also increased from 1.41 MWp to 1.85 MWp with the number of PV modules and inverters being used decreasing. This study finds the LCOE is reduced by 0.02 USD/kWh. As PV and inverter technology develops in the future, it is predicted that the LCOE of solar PV will gradually decrease and will be more competitive.

This study can help solar energy stakeholders and decision makers in Indonesia to better understand the main features of repowering initiatives and could support future decisions concerning national regulations, e.g. rules and tariffs of the incentive mechanism as well as authorization process. In addition, this study can also be analyzed further in terms of environmental issues and public acceptance.
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