Monitoring Results of a 10kwp On-Grid Photovoltaic System in the Context of the Current Regulation for Solar Rooftops in Indonesia

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Abstract. To fulfil the Paris climate agreement, the Indonesian government aims to increase the share of renewable energy. New regulation for solar rooftops came into effect in January 2019 to give more security for investments in solar projects. However, for a majority of consumers, the implementation of the regulation and economical operation of a PV system brings many hurdles. A 10 kWp PV on-grid system at UKRIM University is monitored to gain information about energy data, return of investment (RoI) and levelized costs of energy (LCOE). Based on the monitoring results, three different consumer types (social institutions, residential buildings and offices) are analyzed with respect to profitability. For the PV installation at UKRIM, an RoI of 17 years is calculated. The LCOE is calculated as 0.08 USD/kWh and thus higher than the levelized feed-in price of only 0.076 USD/kWh. The current ten kWp PV system can offset 80% of the electricity demand of the building it is connected to. Nevertheless, the most economical size would be only seven kWp, showing that the most green (zero net energy) and the most economical system (fastest RoI) can differ greatly. The slow RoI makes a PV on-grid system economically not interesting for social tariffs. Though residential buildings and office buildings can achieve faster RoI, mainly because of higher electricity prices.

1. Introduction

In the Paris Agreement 2016, Indonesia, among 195 other countries, determined contributions to mitigate global warming. Indonesia aims to achieve 23% of renewable energy by 2025 until 2018, Indonesia reached 8% [1] The global technical potential for solar energy is 78,400 PWh/year [2]. The electricity generation by solar energy is still small compared to neighbour countries as seen in Figure 1.
Figure 1. Solar electricity generation 2018 - Indonesia’s Electricity Generation is low compared to neighbour countries [2].

1.1. Situation in Indonesia

Indonesia, as a tropical country, has high and even solar irradiation between 3.6-6 kWh/m²/day. Photovoltaic can play a key role for CO2 reduction and energy supply in Indonesia[3]. However, the installed capacity of solar photovoltaics (PV) at the end of 2018 is still less than 100 MW [4]. Regulations for net metering scheme exist but are often not well understood by homeowners. The low electricity price makes PV systems less compatible as the savings are correspondingly smaller. Indonesia is using a net metering scheme that reduces every kWh feed into the grid with the factor 0.65. This means that 1 kWh send to the grid is credited as 0.65 kWh [5].

1.2. Aim of this research

The aim of this research is to understand the influence of different building types with their respecting electricity tariffs and their load profiles on the economy of a rooftop PV system. For this, the electricity production of the installed solar PV system is monitored and compared to the load profile of the building. The focus is on how different load profiles can influence the Return of Investment (RoI). Furthermore, monitoring results can help to increase lifetime performance and reduce PV electricity costs.

2. The PV system

The renewable study center of Universitas Kristen Immanuel, Yogyakarta (UKRIM) has installed a ten kWp PV grid-connected system. The following Table 1 gives an overview.

| Description                  | Amount | Size       | Total Size |
|------------------------------|--------|------------|------------|
| Photovoltaic module          | 36     | 275 Wp     | 9900 Wp    |
| Canadian Solar CSK6-275P     |        |            |            |
| Inverter                     | 1      | 10000 W    | 10000 W    |
| SMA Tripower STP-10000 TL-20 |        |            |            |
| Orientation                  | 7° North | Location  | 7.77°      |
|                              |        |            | 110.45°E   |

Table 1. Overview of the PV system at UKRIM
The PV system is designed as a grid-connected system to supply an adjacent building with two faculties and classrooms. Three strings of 12 multi-crystalline modules each are connected to a 3-phase DC/AC Inverter. The AC current is fed into the building, and excess energy is injected into the grid, passing a two bi-directional electricity meter.

**Table 2. PV module specifications at standard test conditions (STC)**

| Parameter                        | Value     |
|----------------------------------|-----------|
| Nominal Max. Power ($P_{max}$)   | 275 W     |
| Opt. Operating Voltage ($V_{mp}$)| 31.0 V    |
| Opt. Operating Current ($I_{MP}$)| 8.88 A    |
| Open Circuit Voltage ($V_{OC}$)  | 38.0 V    |
| Short Circuit Current ($I_{SC}$) | 9.45 A    |
| Module Efficiency                | 16.8 %    |

**Figure 2. Top-view of the PV System at UKRIM**

**Table 3. Grid Inverter Specifications**

| Parameter                        | Value     |
|----------------------------------|-----------|
| DC Input (PV generator connection)|           |
| Maximum DC Power at $\cos \phi = 1$ | 10250 W |
| Maximum input voltage            | 1000 V    |
| Rated input voltage              | 580 V     |
| AC output (grid connection)      |           |
| Rated power at 230 V, 50 Hz      | 10000 W   |
| Maximum apparent AC power at $\cos \phi = 1$ | 10000 VA |
| Nominal AC current at 230 V      | 14.5 A    |
| Maximum output current           | 14.5 A    |
| Operating frequency range at AC power frequency 50 Hz | 45.5 Hz to 54.5 Hz |
| Displacement power factor $\cos \phi$, adjustable | 0.8 under excited to 1 to 0.8 overexcited |
| Feed-in phases                   | 3         |
| Maximum efficiency $\eta_{max}$  | 98 %      |
2.1. Monitoring

The goal of the monitoring is to analyze the integration of the solar PV system into the building energy supply. Focus is to measure the amount of energy that is used directly in the building and the energy that is exported to the grid. Daily values of PV production, energy export to the grid and import from the grid are taken to calculate self-sufficiency and self-consumption of the building. Energy production of the PV system is monitored in 5 minutes of time steps by the inverter. Daily values for energy export and import are read from the bi-directional electricity meter. Hourly values are read during daytime and interpolated for night time to create a load profile for a workday. As solar radiation is not directly measured, this monitoring is not used to evaluate the performance of the PV system. Instead, production is compared to available data for irradiation[6].

3. Methods

3.1. LCOE – how much does one kWh from solar energy?

To determine, if the energy production costs are competitive to other technologies, Levelized Costs of Energy (LCoE) are calculated. LCoE is commonly used to compare the costs of different technologies or to evaluate the performance of variations of the same technology. LCoE can, therefore, help to compare different PV system variants against each other and evaluate if these variants are competitive against electricity prices of the energy provider. LCoE can vary for different location as the energy production is dependend on local solar irradiation [7]. LCoE describes the costs of every unit of energy by dividing the total costs by the total energy production.

\[
LCoE = \frac{\text{Total Life Cycle Costs}}{\text{Total Life Cycle Energy Production}}
\] (1)

The value of money that is used for investment is decreasing over time. To take this effect into account, future costs (for example for maintenance) are determined in today's value. The present value can be calculated with the discount factor:

\[
\text{Discount Factor} = \frac{1}{(1 + r)}
\] (2)

With

\[ r = \text{discount rate} \]

The discount rate \( r \) is a factor that discounts future costs and discounts them to translate them to present value. According to [8] LCoE can be calculated as:

\[
LCoE = \frac{\sum_{t=1}^{n} I_t + M_t + F_{t}}{(1 + r)^t} \frac{E_t(1 - \text{deg})^n}{\sum_{t=1}^{n} (1 + r)^t}
\] (3)

With the initial investment \( I_t \), the operational and maintenance costs \( M_t \) and fuel costs \( F_{t} \) in the year \( t \). The energy production of the first year \( E_t \) with the degradation of the system \( \text{deg} \). Fuel costs for a PV system are, of course, \( F_{t_{\text{pv}}} = 0 \). The costs and energy production are then summed up over the expected lifetime \( n \).

3.2. Net metering scheme

The income of a solar system is dependent on environmental factors, like orientation, solar in-plane irradiation, technical factors like efficiencies of the PV modules and the inverter as well as economic regulations like the net metering scheme, that allows owners to sell excess power to the grid. The selling price of the net-metering scheme according to the governmental regulation No.49 [5] is defined
as 65% of the buying price from PLN. For an unsubsidized household with 1467 IDR/kWh (0.103 USD), the feed-in tariff is 953.6 IDR/kWh (0.067 USD/kWh). For a social tariff with 900 IDR/kWh (0.063 USD/kWh) the feed-in tariff is 585 IDR/kWh (0.041 USD/kWh). Before the regulation came into account, 100% of the electrical tariff could be saved as seen in a study from 2016 [9]. The profitability of net-metering schemes versus feed-in tariffs depends on several parameters. One study concludes that net-metering schemes can often lead to long periods for ROI [10]. Another study for the European market with higher electricity prices shows a higher profitability index for countries with net-metering schemes [11].

3.3. Load profiles, self-consumption and self-sufficiency

When the tariff for excess energy sold to the grid is smaller than the electricity price, the most economical way is to use the energy produced by the PV system directly in the building. The amount of energy that can be used in the building depends on the matching of the power consumption of the building and production of the PV system. The energy produced by the PV system that can be consumed directly in the building saves the full buying price. The part of the electricity, produced by the PV system that is directly consumed in the building, is called self-consumption. It can also be described as the overlapping part of PV production and energy consumption at a given time. Self-sufficiency is the part of PV energy utilized in the building per total energy consumption in the building. The power utilized in the building is limited by whichever of PV production (P(t) and building consumption L(t) is the smallest and can be calculated as

\[ M(t) = \min\{P(t), L(t)\} \]  

(4)

So that self-consumption and self-sufficiency can be calculated as

\[ \varphi_{SC} = \frac{\int_{t=t_1}^{t_2} M(t)dt}{\int_{t=t_1}^{t_2} P(t)dt} \]  

(5)

\[ \varphi_{SS} = \frac{\int_{t=t_1}^{t_2} M(t)dt}{\int_{t=t_1}^{t_2} L(t)dt} \]  

(6)

A smaller PV system, compared to electricity consumption, leads to higher self-consumption as the output is small compared to demand. However, the self-sufficiency is decreasing with higher self-consumption. While residential buildings have high energy demand in evening hours, office buildings usually have their peak demand at noon [12]. Therefore, office buildings can achieve higher self-consumption and sell less electricity to the grid.

3.4. Return of Investment (ROI)

While LCoE gives a levelized cost for energy production, another standard method is the calculation of the ROI. The ROI is a measure for the performance of an investment. It gives the ratio between net profit and the cost of an investment and is calculated as:

\[ ROI = \frac{\text{Current Value of Investment} - \text{Cost of the investment}}{\text{cost of Investment}} \]  

(7)

The ROI of a PV system is dependent on the cost of investment and annual profits. This takes into account the net-metering scheme, as well as maintenance costs, among others [13].
4. Monitoring results

4.1. Energy production

The energy production of the PV system was monitored in a 5 min resolution. Because of a faulty connector, the system was disconnected for maintenance. The mal-functioned connection caused the inverter to disconnect. After maintenance, the output could be increased by 38%. Data in this paper are calculated for the part after maintenance if not mentioned otherwise.

![Figure 3. Daily energy production of the PV system. After maintaining a connection, the production increased by 38% compared with the daily average before maintenance. The dashed lines show the average daily value before and after maintenance.](image)

4.2. Levelized costs of energy

The LCoE of the PV system at UKRIM is calculated based on the following values:

| Description                          | Value                      |
|--------------------------------------|----------------------------|
| Investment                          | 1358.66 USD per kWp        |
| Maintenance and operation (1.5%)     | 201.7 USD                  |
| Fuel costs                           | 0 USD                      |
| Discount rate                        | 4%                         |
| Electricity yield in the first year  | 14454 kWh                  |
| Degradation of energy production     | 0.5%                       |

For longer life cycles, lower LCoE is calculated, as the investment costs can be distributed over more years. A typical lifetime of a photovoltaic system is 30 years. The LCoE is however calculated for 20, 25 and 30 years respectively. The levelized costs are similar to a study conducted in India 2018 for a 10 MWp grid-connected PV system [14].

| Life cycle | LCoE in IDR/kWh | LCoE in USD/kWh |
|------------|----------------|-----------------|
| 20 years   | 1212           | 0.083           |
| 25 years   | 1084           | 0.074           |
| 30 years   | 1002           | 0.069           |
Compared to the statistical report of PLN 2018, the costs per kWh for photovoltaics is 7672,68 IDR/kWh (0.54 USD/kWh) – around 7-8 times higher than the calculated LCoE. The average price for electricity production of PLN is 1160,89 IDR/kWh (0.081 USD/kWh). The wholesale price for unsubsidized residential buildings and business up to 200 kVA is 1467,28 IDR/kWh. This means that solar PV system today already can achieve grid parity. The state electricity company PLN (Perusahaan Listrik Negara) provides subsidized electricity prices for social institutions like schools and universities. This social tariff customers like universities are only 900 IDR/kWh. Assuming that electricity costs rise by 5%, levelized costs for 20, 25 and 30 years for the social tariff and the household tariff are calculated as:

**Table 6.** Levelized costs for electricity utilization for the social tariff, assuming an average increase of 5% for 20, 25 and 30 years

| Social tariff | Levelized costs for electricity utilization in IDR/kWh | Levelized costs for electricity utilization in USD/kWh |
|---------------|--------------------------------------------------------|------------------------------------------------------|
| 20 years      | 1466                                                   | 0.103                                                |
| 25 years      | 1656                                                   | 0.117                                                |
| 30 years      | 1871                                                   | 0.132                                                |

For residential building and business, the levelized costs for electricity are calculated as:

**Table 7.** Levelized costs for electricity utilization for the unsubsidized tariff, assuming an average increase of 5% for 20, 25 and 30 years

| Residential buildings and business | Levelized costs for electricity utilization in IDR/kWh | Levelized costs for electricity utilization in USD/kWh |
|-----------------------------------|--------------------------------------------------------|------------------------------------------------------|
| 20 years                          | 2390                                                   | 0.168                                                |
| 25 years                          | 2700                                                   | 0.190                                                |
| 30 years                          | 3050                                                   | 0.215                                                |

The results can be summarized in Figure 4. The system installed at UKRIM with a social tariff has the same LCOE, but due to the low FiT, surplus energy from the PV system will be injected to the grid without gain. Residential buildings and offices, however, can sell surplus energy to the grid to a higher price than the LCOE.
Figure 4. Overview of Levelized costs for three building types for a life-cycle 25 years

4.3. Self-consumption, self-sufficiency and load profile

Self-consumption and self-sufficiency data are calculated from daily sums of energy production and consumption, as seen in Figure 5. For weekdays a higher self-consumption and self-sufficiency are monitored, as the most electricity is consumed during occupancy hours. On weekends, the building is usually not occupied, resulting in low electricity demand in the daytime. At night time, the demand is increasing due to lighting. Consequently, for a full week, self-consumption and self-sufficiency are lower. The weekly PV production normalized by the weekly energy consumption increases, due to low energy consumption on weekends. The sunny day had a better matching of consumption and PV production in the morning. Nevertheless, because of fluctuations in energy consumption from intermitting loads like refrigerators, 24% of PV production was injected into the grid, leading to a self-consumption of 76% and self-sufficiency of 38%. The building consumed 95 kWh on that day, and the PV system produced 47 kWh.

Figure 5. Self-consumption and self-sufficiency. Weekdays have higher self-sufficiency and self-consumption - full weeks have a higher PV production normalized by energy consumption. The dashed lines show typical values according to [15].
4.4. Return of Investment

The return of investment was calculated with the assumptions made in Table 8.

| Assumptions                      | UKRIM   | Office building | Residential building |
|----------------------------------|---------|-----------------|----------------------|
| Investment (USD)                 | 13450   | 13450           | 3169                 |
| Electricity price (USD)          | 0.063   | 0.103           | 0.103                |
| FiT (USD)                        | 0.041   | 0.067           | 0.067                |
| Self-consumption (%)             | 65%     | 65%             | 40%                  |
| Maintenance in % of Investment   | 1.5%    | 1.5%            | 1.5%                 |
| Installed capacity in kWp         | 10      | 10              | 10                   |
| Annual energy yield in kWh       | 14600   | 14600           | 14600                |
| Annual electricity price inflation in % | 5      | 5               | 5                    |

![Figure 6](image1.png)

**Figure 6.** Load profiles monitored for a cloudy day with a lower consumption (left) and a sunny day with higher consumption (right).

Figure 6 shows that PV production and energy consumption on weekdays have a high overlap so that a high self-consumption can be achieved in both days. On a cloudy day, activities started later, so that surplus energy from the PV system was injected into the grid. PV production on a cloudy day was...
39 kWh, and consumption was 69 kWh. Self-consumption was calculated as 38% and self-sufficiency at 57%.

Figure 7. ROI for UKRIM

Figure 8. ROI for the office building

Figure 9. ROI for residential building

Figure 7, 8, and 9 show the fastest payback time for the office building. The higher feed-in price and higher self-consumption make it the most competitive option, followed by the residential building. The installed system at UKRIM has the lowest payback time with 17 years due to the low tariff to sell excess power to the grid.

4.5. Additional limitations

The basic price for electricity bills is calculated by the installed capacity x 40 hours x price per kWh. UKRIM has an installed capacity of 23 kVA. Therefore, the minimum consumption is 23 kVA x 40 hours = 920 kWh. Regardless of the real consumption, this minimum consumption will be charged, for the social tariff with 828000 Rp or 58.31 USD. This is limiting the savings potential for PV systems. As UKRIMS building is still under construction, the actual consumption is lower than the expected consumption for the whole building. At the moment the monthly consumption is 1800 kWh. Thus only around 50% can be set-off by the PV system. If the net energy (the consumed energy minus the
produced energy) is below 920 kWh, the surplus will be accumulated for three months and if not used nullified. For a known consumption a maximum energy yield and therefore PV system can be calculated to achieve maximum economic value. The maximum allowed capacity for a PV system is the installed capacity of the energy meter.

As seen in Figure 10, the solar system reduced the costs of electricity in all three months. If savings by the PV system lead to a price lower than the necessary payment, the first payment has to be paid, and the difference is lost for the customer. In August, the savings lead to payments that are below the original payment. This gain is lost. In September the solar system was down for maintenance, so savings are just above the necessary payment. In October, the estimated savings again can not fully credited. This situation will change when electricity demand is rising.

Figure 10. electricity payments with and without a solar system. The red dashed line shows the necessary payment. The dashed lines in October show estimated payments

4.6. Discussion of Results
The permission for the PV system was granted end of June 2019. The second floor of the building opened starting with the new semester in August 2019. This doubled the energy consumption of the building. All monitoring results should, therefore, be understood as preliminary results. It is shown that LCoE is lower than the electricity price. However, the FiT for buildings with social tariffs is similar to LCoE, so that no gain will be made. Only high self-consumption can help to have the fastest payback-time. Office buildings with high demand at daytime are the most economical type for installations. Residential buildings have a lower self-consumption typically, but are still more economical than a building with social tariff, due to the higher electricity price. The high necessary payment for electricity counteracts with the goal to replace grid power with solar power.

5. Conclusion
The monitoring helped to discover errors and increase yield by eliminating the error. Furthermore, it could show which influence load profiles can have to achieve a faster ROI. Low electricity prices and high basic prices make solar rooftop system still hard to compete. High self-consumption however, can make PV systems more attractive. This is mostly given for office buildings. Also, residential buildings can have a faster ROI owing to higher electricity prices. To help Indonesia achieving the goal of 23% of renewable energy, solar rooftops can play an important role. To make this scheme
more attractive, the feed-in price should reflect the economic situation of photovoltaics. Lower basic prices can help to increase the solar fraction in an economical way.

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