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Financial Analysis of Solar Rooftop PV System: Case Study in Indonesia

Elieser Tarigan*

Department of Electrical Engineering, Center for Environment and Renewable Energy Studies (PuSLET), University of Surabaya, Indonesia. *Email: elieser@staff.ubaya.ac.id

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ABSTRACT

The primary barrier to the dissemination of photovoltaic (PV) technology is its high cost as compared to other alternative options. This paper discusses some financial aspects of rooftop PV systems: module cost, BOS cost, useful lifetime, minimum attractive rate of return, and O&M cost. An equation and numerical calculation were made for estimating the unit cost of electricity of a rooftop system. The numerical calculation and simulation were made by taking the condition of Indonesia as the case study. It was assumed that (i) the useful lifetime of the PV system is 20 years, (ii) the annual maintenance cost is 2% of the total capital cost of the system, (iii) taxes and insurance costs are not to be paid, and (iv) capacity utilization is 20%. It is found that rooftop PV systems have the potential to provide power at competitive prices for residential with other alternative options for power generation.

Keywords: PV System, Financial, Rooftop, Electricity, Unit Cost
JEL Classifications: C58, G18, H41, H50, Z18

1. INTRODUCTION

With the increasing awareness about the environmental impact of traditional energy sources and the desire to reduce energy costs, solar rooftop photovoltaic (PV) systems are one option for the electrification sector (Khezri et al., 2022). Solar energy is a clean, renewable, and abundant source of energy that can be harnessed for various purposes, including lighting, heating, and powering system. Solar rooftop PV system is a set of solar panels that are installed on the roof of a building to generate electricity from sunlight. The panels are composed of photovoltaic cells that convert sunlight into direct current (DC) electricity. The DC electricity is then converted into alternating current (AC) electricity by an inverter, which is the power that is used to run most of the electrical appliances and electronic devices (Chowdhury and Rahman, 2021).

The Indonesian Government, Ministry of Energy and Mineral Resources (MEMR), has set a goal of 23% renewable energy of total national energy needs by 2025 (ESDM, 2016). The photovoltaic (PV), rooftop system regulation was recently introduced by the Government of Indonesia (Peraturan Menteri ESDM No. 49 Tahun 2018 Tentang Penggunaan Sistem Pembangkit Listrik Tenaga Surya (PLTS) Atap, 2018; Tarigan, 2020). This is Permen ESDM (or MEMR RegulationNo 49/2018). This regulation permits and encourages all users to produce electricity using the PV system on roofs. The energy produced can be exported or fed into a utility grid. MEMR Regulation No. 49 is the most current Indonesian solar energy policy. It was adopted in 2018 and established a net metering system for customers of PLN. This includes residential, commercial, and industrial customers who have solar rooftop installations that produce excess power. The regulation requires prior approval from PLN before a rooftop PV system can be constructed or installed. Approval and verification require submission of an application to the relevant PLN distribution center along with required technical information such as the PLN customer ID number, the roof PV system's capacity, one-line diagram, and specifications.

However, the rooftop PV system is still not familiar in Indonesia. Based on different sources (Kennedy, 2018; Maulidia et al., 2019; www.djk.esdm.go.id, 2019), it is estimated that only about 14.7 MW of PV systems are currently on-grid in Indonesia and 48 MW are under construction. There is also an estimated 326MW in the pipeline. Compared to neighboring South East Asian countries like Thailand (2.6GW) or the Philippines (868MW), this capacity is relatively small (Hamdi, 2019; UNEP DTU Partnership, 2016)

The primary barrier to large-scale dissemination of PV technology is a paradigm with its high cost as compared to other alternative options (Jing et al., 2023; Khezri et al., 2019; Sharma and Production, 2020). This paper discusses the financial aspects of rooftop PV power generation: module cost, the balance of system (BOS) cost, the useful lifetime of the PV system, minimum attractive rate of return (or discount rate), and operating and maintenance (O&M) cost. An equation that is expressed in the components of the peak power rating and the total cost per peak watt is derived for calculating the unit cost of electricity (UCE). The aim of the study is to estimate the unit cost of electricity of a rooftop system in general. The case study is done by taking Indonesia, as the condition base. Several values of installed cost in dollars per peak watt were considered, along with three different values of minimum attractive rates of return.

1.1. Rooftop PV System and Componen Costs

A rooftop PV system is a solar power system that is installed on the roof of a building, such as a home or business. This type of system typically consists of two main components i.e., solar panels and inverter to convert the DC electricity generated by the panels into AC electricity. A rooftop PV system is assosiated with a grid-connected system where the PV system does not need batery energy storage, as energy production is either self-consumed or exported to the grid. An export- import energy meter is commonly used for such system (Kumar Behura et al., 2021; Zulkifli et al., 2020).

There are many types of PV cells available, including monocrystalline, multi crystalline and multi-junction. Monocrystalline cells have a high efficiency, but they require a more complex manufacturing process. Polycrystalline cells may be more expensive than monocrystalline cells, but they are still very efficient. Concentrating sunlight through lenses or mirrors can increase the efficiency of PV cells. The output of PV power systems is affected by many parameters like change in irradiation, variation in temperature and dirt/dust deposition. When solar radiation is increased, you will see an increase in the output of PV modules. Efficiency drops when temperature rises. The panels' surface temperature can be reduced to improve efficiency and prevent thermal deterioration. These systems are now competitive and highly popular due to their recent advancements and lower operating costs (Rathore et al., 2021).

A rooftop PV system uses the grid-connected system inverter to provide AC electricity. One of the key components of a grid-connected PV system is the inverter, which is responsible for converting the DC electricity generated by the solar panels into AC electricity that can be used in the home or business, as well as feeding any excess electricity back into the grid. There are two types of inverters used in grid-connected PV systems: string inverters and micro inverters (Durmuş, 2019; Tiwari et al., 2021). String inverters are the more traditional option and are typically used in larger installations. They are designed to connect multiple solar panels in a series, or string, and convert the DC electricity generated by the panels into AC electricity that can be fed into the grid. Micro inverters, on the other hand, are smaller and more modular than string inverters. They are installed on each individual solar panel and convert the DC electricity generated by that panel into AC electricity that can be fed into the grid. This allows for greater flexibility in system design, as well as improved performance and reliability (Khan et al., 2020).

Both string and micro inverters have their own advantages and disadvantages. String inverters are typically less expensive and more efficient than micro inverters when used in larger installations. However, they can be subject to performance issues if one panel in the string is shaded or otherwise not operating at peak capacity. Micro inverters, on the other hand, are more expensive but offer greater flexibility in system design and improved performance in shaded or unevenly lit environments. They also provide greater visibility into the performance of individual panels, which can help with maintenance and troubleshooting (Marwa et al., 2021; Tiwari et al., 2021).

The component cost of a rooftop PV system will depend on a number of factors, including the size of the system, the quality of the components, and the location of the installation. However, the following are some of the main components of a typical rooftop PV system cost:

- Solar panels: The cost of solar panels can vary depending on the type, efficiency, and brand
- Inverter costs: An inverter is used to convert the DC electricity generated by the solar panels into AC electricity that can be used for AC powered appliances
- Mounting and racking system: This is used to fix the solar panels securely onto the roof of the building. The cost may vary depending on the type of roof and complexity of installation
- Electrical wiring and safety equipment: Proper wiring and safety equipment such as a combiner box, disconnect switch, fuses, and breakers are required for a safe and reliable system
- Monitoring system: Some solar systems include monitoring devices that allow you to track the performance of the system
- Operating and maintenance.

On the other hand, the cost for a rooftop PV system would come from the component costs and depend on several factors which can be classified as (Tarigan et al., 2014a; 2015):

- PV module cost
- Balance of system (BOS) cost
- Useful lifetime of PV system
- Minimum attractive rate of return (or discount rate), and
- Operating and maintenance (O&M) cost.

2. METHODS

To calculate the unit cost of electricity (UCE), an equation is used that is divided into the components of peak power rating and total cost per peak watt. The unit cost of PV electricity is estimated using a typical numerical calculation.

2.1. Formulating PV U*nit* Cost of Electricity (UCE)

The unit cost of electricity of a rooftop PV system (UCE) can be expressed as:

$$UCE = \frac{Levelized\ annual\ cost}{Anual\ energy\ production} \quad (1)$$

The Levelized annual cost consists of costs for recovery, operating and maintenance (O & M) cost, insurance, taxes, etc. The annual capital recovery cost in return, can be mathematically formulated as the factors of capital cost and recovery cost. It can be written as (Khezri et al., 2019; Tarigan et al., 2014b; 2015):

$$Annual\ capital\ recovery\ cost = P_o\left[\frac{d(1+d)^n}{(1+d)^n - 1}\right] \quad (2)$$

Where:
P_0 = capital cost (USD)
d = discount rate (%)
n = lifetime of PV system (in year)

The capital cost P_0 consist of the cost that related to all initial costs including PV module costs, balance of system or BOS costs (which are containing inverter costs, mounting and racking, electrical wiring and safety equipment), as well as monitoring equipment.

By considering the annual O&M cost is m fraction of the capital cost, P_0; insurance, taxes, and other components cost is t fraction of the capital cost, P_0, then the levelized annual cost C_{ann} can be mathematically expressed as:

$$C_{ann} = P_o\left[\frac{d(1+d)^n}{(1+d)^n - 1} + m + t\right] \quad (3)$$

The annual energy production of a rooftop PV system, (E_{ann}) depends on the capacity utilization factor *(CUF),* where the value is different for different locations. For this study, the location is taken in Surabaya, Indonesia (See sections 2.2 dan 3). Mathematically the value of E_{ann} can be calculated as:

$$E_{ann} = (8{,}760) \times (PV\ peak\ power) \times (CUF) \quad (4)$$

The value 8.760 is the number of hours during 1 year, and PV peak power is the capacity of PV system under standard test conditions. Based on Equation 1, Equation 3, and Equation 4, the unit cost of electricity of a PV system *UCE* can then be formulated as (Tarigan, 2018; Tarigan et al., 2015):

$$UCE = \frac{C_{wp}\left[\frac{d(1+d)^n}{(1+d)^n - 1} + m + t\right]}{8{,}760\, x\, CUF} \quad (5)$$

Figure 1: Geographic position of Surabaya

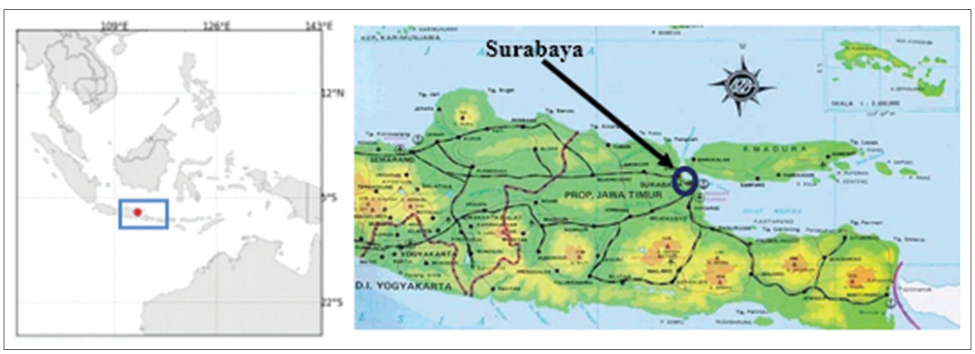
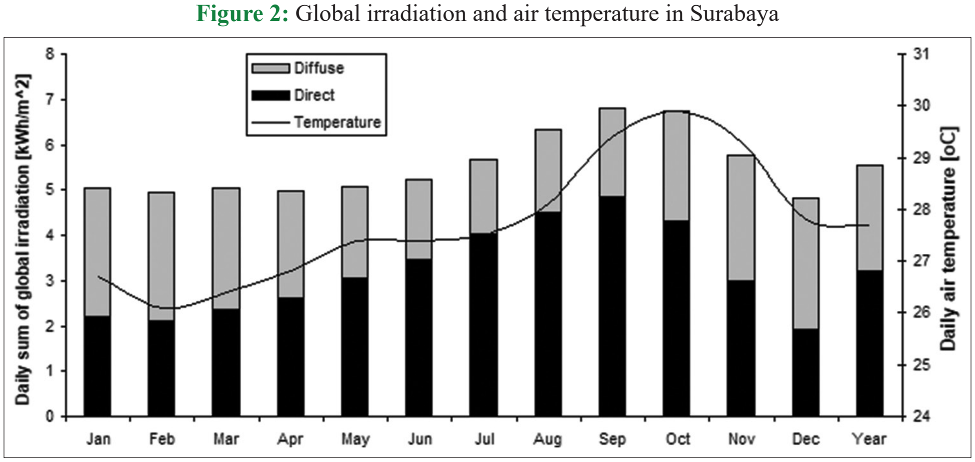


Figure 2: Global irradiation and air temperature in Surabaya



Where C_{wp} is the total cost per peak watt of PV module. Obviously, C_{wp} is the price of the solar module, which is the main component. For estimating the unit cost of PV electricity power at competitive rates with other options for power generation, a typical numerical calculation is done using equation 5.

2.2. Determination of PV System Capacity Utilization Factor

This study is conducted by taking Surabaya, Indonesia, as the case study, especially for the determination of the value of capacity utilization factor, CUF of rooftop PV systems. Simulation using SolarGIS-pvPlanner (Solargis.info, 2014) was carried out to obtain the specific energy production (kWh/kWp) of the PV system. The specific energy production is then used to determine CUF. Surabaya is located at 07°19' 17.83" South and 112°46' 3.19" East. The geographic position of Surabaya is shown in Figure 1.

3. RESULTS AND DISCUSSION

3.1. Solar Energy Potential

Solar energy is available in the form of irradiation. The potential of solar energy in a particular location is commonly expressed as global horizontal irradiation (GHI) in kWh/m^2.day. Global irradiation components can be classified as direct, diffuse, and reflected. As previously mentioned, the solar energy potential in this study is determined using SolarGIS simulation.

Figure 3: The unit cost of PV electricity for different discount rates

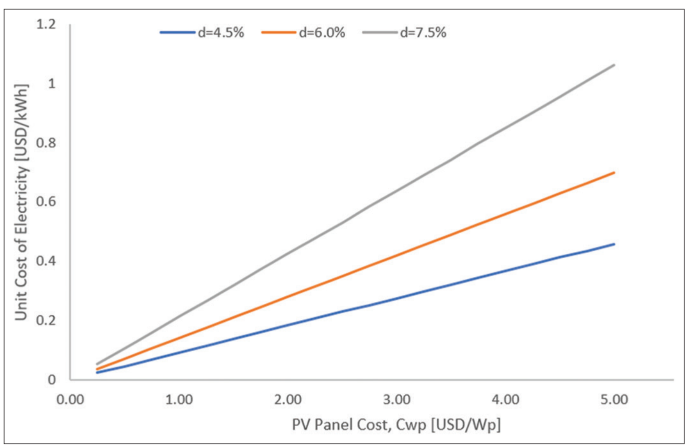


Figure 2 shows the global horizontal irradiation and air temperature over a year in Surabaya. The global radiation on the horizontal surface averages 5.54 kWh/m^2.day with a maximum value of 6.81 kWh/m^2.day (September), and a minimum 4.82kWh/m^2 (December). While the diffuse radiation is very significant, especially in March-October, it is relatively low throughout the year. About 45% of global radiation is diffuse radiation.

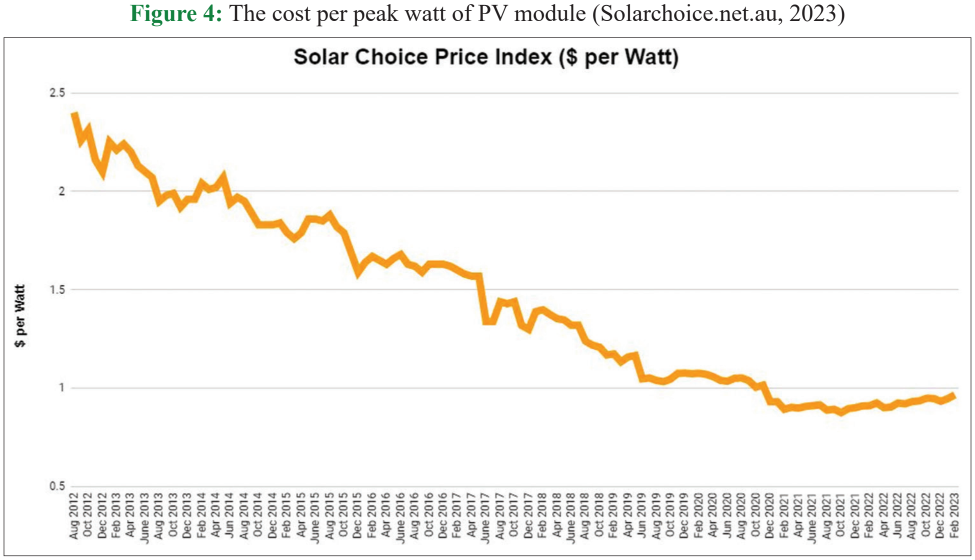
The global radiation was higher in April-October than in other months in the past. This is because dry seasons are more common in this area than the rainy season, which results in lower average solar radiation. The season period has been unpredictable in recent years. Further investigation is needed to determine if it may be related to the PV application as well as other issues like global warming and climate change.

Simulation results for the rooftop PV system show that one kWp of Si-c type of the solar panel in Surabaya can produce about 1400 kWh of electricity per year. This number gives the value of the utility capacity factor of 1400/8.760 = 0.16. This value is used for numerical simulation to calculate the unit cost of electricity of a PV system. The unit cost of electricity (UCE) of the rooftop PV system is calculated by numerical simulations using Equation 5. A variety of values for the installed cost per peak watt in dollars were considered, along with three different minimum attractive rates. It is assumed that:

- The useful life of the PV system is 20 years
- The annual maintenance cost is 5% of the total capital costs of the system
- Taxes and insurance are not paid as there is not yet regulation in Indonesia for this, and
- Capacity utilization is 0.16 as previously discussed.

Figure 3 shows the unit cost of PV electricity for different discount rates. The value of UCE mainly depends on the Cwp (total cost per peak watt of PV module). It is obviously seen that Cwp is the price of a solar module, which is the main component of the solar module.

Figure 4: The cost per peak watt of PV module (Solarchoice.net.au, 2023)



The development of solar module technology has been significantly fast with mass production. This has resulted in decreasing of solar module costs, especially over the last decade. Figure 4 shows the cost per peak watt of PV modules over the years (Solarchoice.net.au, 2023) in the US. However, the price might be slightly different for different locations. Currently cost per peak watt of a PV module in Indonesia is about 1.2 USD (Tokopedia, 2023).

The unit cost of electricity *(UCE)* of the rooftop PV at the present time is found to be around 0.094–0.124 USD per watts. On the other hand, the electricity price from the utility currently in Indonesia is about 0.1 USD per kWh (GlobalPetrolPrices.com, 2022). It can be concluded that PV systems have the potential to provide power at competitive prices with other alternative options for power generation, including the electricity provided by the government, PLN.

4. CONCLUSION

Financial analysis of solar Rooftop PV system has been carried out in this paper. Several financial aspects of rooftop PV system has been simulated to determine the unit cost of electricity *(UCE*), including module cost, BOS cost, the useful lifetime, minimum attractive rate of return, and O&M cost. At the present time, the unit cost of electricity by a rooftop PV system in Indonesia is around 0.094-0.124 USD per kWh. It can be concluded that in Indonesia, the PV systems currently can provide power at competitive prices compared to other options, such as electricity from the PLN (government electricity grid).

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