Tarigan, Elieser

Article

Techno-economic analysis of residential Grid-Connected Rooftop Solar PV Systems in Indonesia under MEMR 26/2021 Regulation

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(1), 412-417.

Techno-Economic Analysis of Residential Grid-Connected Rooftop Solar PV Systems in Indonesia Under MEMR 26/2021 Regulation

Elieser Tarigan*

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

Received: 22 September 2023 **Accepted:** 18 December 2023 **DOI:** https://doi.org/10.32479/ijeep.15277

ABSTRACT

Grid-connected commercial rooftop solar PV systems have been widely used worldwide to provide affordable, clean energy and long-term energy security solutions. This is especially true in cities where space is limited and rooftops are not being used. According to the Ministry of Energy and Mineral Resources (MEMR) No 26/2021 regulation in Indonesia, the rooftop PV system is allowed to be integrated with electricity grid with an export-import metering. The owner of the rooftop PV system will not only reduce their electricity bill, but also offset the energy over a period of 10 years. This paper provides a design and sizing analysis of a small scale rooftop solar PV system for residential. This study uses the PVsystEM and SolarGIS tools to estimate the amount of energy produced by a 3 kWp solar system. It also provides a financial evaluation of the system's profitability, with particular attention to commercial buildings that are covered under MEMR regulation. This detailed analysis can be used by asset owners to decide the best way forward in terms of sustainable energy production and cost savings, as well as addressing the energy security problem.

Keywords: Energy, PV System, Rooftop, MEMR, Electricity
JEL Classifications: C58, G18, H4, H50 & Z18

1. INTRODUCTION

Solar energy has emerged as a beacon of hope within the landscape of renewable energy sources, offering the promise of reduced reliance on fossil fuels and a mitigation strategy against greenhouse gas emissions (Ben Jebli et al., 2019). As the world faces the urgent need to transition to cleaner energy solutions, Indonesia, blessed with its equatorial position, stands at a unique advantage. The abundant and consistent daily solar energy available throughout the year in this tropical archipelago presents an exciting opportunity. In this article, we delve into the untapped potential of solar energy in Indonesia, particularly through rooftop photovoltaic (PV) systems, and explore the current policies and prospects for residential solar power.

Statistically, Indonesia boasts a daily solar irradiation capacity that could yield over 500 gigawatts of potential solar energy sources (Dang, 2017; UNEP DTU Partnership, 2016). This solar treasure trove is particularly enticing given the nation's geographical location, which ensures stable and substantial daily solar energy generation for the majority of the year. However, despite the impressive solar potential, Indonesia's solar PV sector has yet to reach its full potential. As of the time of writing, the country has an estimated 14.7 MW of operational solar PV systems, with an additional 48 MW under construction and a substantial 326 MW in the planning stages. While these numbers signify progress, they pale in comparison to neighbouring Southeast Asian countries like Thailand, with a robust 2.6 GW, and the Philippines, boasting 868 MW of solar PV capacity (Hamdi, 2019).

The success of rooftop PV system implementation in any country hinges on a plethora of factors, including technical considerations and policy and regulatory frameworks. It is vital for electricity consumers and industry stakeholders to consider these elements to ensure the efficient and widespread use of PV systems. The global landscape offers a wealth of insights into solar energy policy development. For instance, in India, Goel (2016) (Goel, 2016) delved into the policies, challenges, and future prospects of solar rooftop systems. India has set an ambitious target of achieving 175 GW of renewable energy capacity by 2022, with 40 GW allocated to grid-connected solar PV rooftops. China, on the other hand, has been exploring the economic performance of industrial and commercial rooftop photovoltaics. Xin-gang and Yi-min (2019) (Xin-gang and Yi-min, 2019) reported short payback periods and low risks for small rooftop PV investments, with a levelized cost of electricity ranging from 0.2727 to 0.5573 CNY/kWh. In Palestine, the techno-economic impact of rooftop PV systems in schools has shown a significant increase in their adoption as alternative energy sources for different buildings (Ibrik and Hashaika, 2019).

The Indonesian government, under the Ministry of Energy and Mineral Resources (MEMR), has set an ambitious target of achieving 23% of the nation's total energy needs from renewable sources by 2025 (ESDM, 2016). To support this goal, new regulation governing photovoltaic (PV) rooftop systems were introduced in 2021, known as Permen ESDM or MEMR regulation No 26/2021. This regulation allows and actively encourages various users, including residents, public facilities, and commercial buildings, to generate electricity by installing PV systems on their rooftops. The energy produced can either be used on-site or exported to the utility grid, offering an exciting opportunity for distributed energy generation.

This paper specifically focuses on the current solar rooftop PV system policies in Indonesia, with a strong emphasis on their implementation in the residential sector. By analyzing existing policies and feed-in tariffs (FiTs), we aim to shed light on the benefits of residential solar power from the user's perspective. To illustrate the potential, we conducted a simulation for a 3 kWp rooftop PV system designed for residential use using solar Pvsyst (Pvsyst.com, 2019) and SolarGIS (SolarGis, 2021). This simulation helps us understand the economic viability and energy generation potential for homeowners considering solar adoption.

Indonesia's solar energy potential is undeniable, with its daily solar irradiation capacity exceeding 500 GW (Dutu, 2016). However, harnessing this potential requires robust policy support, technical infrastructure, and active stakeholder engagement. The recent introduction of regulations encouraging rooftop PV systems is a significant step forward in this direction. As Indonesia strives to achieve its renewable energy targets, residential solar power could play a pivotal role in reducing carbon emissions and enhancing energy security. The information and findings presented in this article not only serve as an overview of the current state of solar energy in Indonesia but also provide a roadmap for expanding solar rooftop PV systems, particularly in the residential sector. With the right policies and investments, Indonesia can truly harness its solar potential and shine as a beacon of sustainable energy in Southeast Asia.

2. SOLAR PV SYSTEM REGULATION IN INDONESIA

Since 2013, the Indonesian government, under the auspices of the Directorate General of New and Renewable Energy and Energy Conservation (DGNREEC) within the Ministry of Energy and Mineral Resources (MEMR), has published the regulation of solar energy within the country. The initial policy, MEMR Regulation Number 17/2013, was introduced during a period when solar technology was often seen as costly and less dependable compared to conventional alternatives (Hamdi, 2019). This perception hindered the development of a solar energy market in Indonesia. Over time, regulatory changes have taken place in Indonesia, as illustrated in the solar energy policy roadmap in Figure 1.

Table 1 provides a comprehensive comparison of various solar regulations that have been enacted in Indonesia. These regulations predominantly address critical issues such as the requirement for local content, feed-in tariffs, procurement methods, residential applications, rules for build-own-operate-transfer (BOOT) projects, and procedures for deemed dispatch in cases of force majeure. Notably, none of the previous regulations explicitly covered rooftop PV systems until the introduction of the latest MEMR Regulation Number 26/2021.

3. METHODOLOGY

Determining the size of a photovoltaic (PV) system involves analyzing the consumer's electricity load profile, with the ultimate goal of ensuring that the cost of generating 1 kw-h (kWh) using the PV system is lower than the grid tariff price. To calculate the PV system's size, factors like the location's sun peak hours, the average daily electricity consumption over a year, and the available roof space for installation are taken into account (Benatiallah et al. 2007).

The selection of PV system components depends on the power rating specified by the appliance manufacturers and a careful estimation of each appliance's power requirements, but this approach is typically suitable for smaller PV installations. In contrast, large PV plants require a more comprehensive analysis of electricity demand based on historical electricity consumption profiles.

To aid in the simulation and modelling of solar PV projects, there are commercially available softwares such as Solar GIS PV planner and Pvsyst (Pvsyst.com, 2019; Solargis.info, 2014). This study utilized these softwares to model a PV system. The softwares library provide extensive information about commonly used photovoltaic modules, inverters, and other components necessary

Figure 1: Solar energy policy roadmap in Indonesia

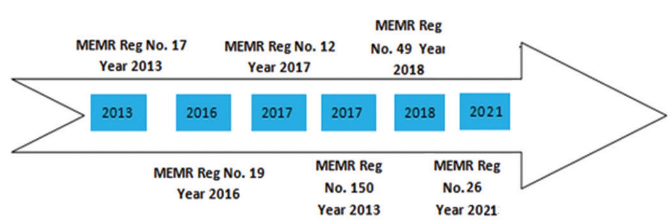


Table 1: Solar energy policies in Indonesia

Regulation items	MEMR regulation number 17/2013	MEMR regulation number 19/2016	MEMR regulation number 12/2017, and number 50/2017	MEMR regulation number 49/2018	MEMR regulation number 26/2021
Local content requirement	Yes	Yes	Yes	Yes	Yes
FiT	0.30 USD/kWh for >40% local content 0.25/kWh for <40% local content	The range between 0.145 and 0.25 USD/kWh, various for different location	Ranges from US$ 0.048 to 0.144/kWh depending on the location	Net metering system. exported energy is offset with imported energy from grid. Exported electricity is valued at 65% for compensation. The balance is accumulated for up to 3 months	Net metering system. Exported energy is offset with imported energy from grid. Exported electricity is valued at 100% for compensation. The balance is accumulated for up to 6 months
Procurement method	Auction based on quota per annum Direct appointment allowed if only 1 company bids	Auction based on quota for certain predetermined regions Project size per developer is subject to a limit based on the available quota in the region	Direct selection based on quota capacity	Self-procurement	Self-procurement
Deemed dispatch	Not regulated	Not regulated	In case of force majeure The National Grid, PLN is not obligated to pay deemed dispatch to IPPs	For commercial users are charged with parallel operation charges which include an emergency charge	For commercial users are charged with parallel operation charges which include an emergency charge

MEMR: Ministry of energy and mineral resources

for PV system project. Additionally, it factors in various losses such as partial shading effects, mismatches among connected PV modules, wiring losses, inverter inefficiencies, and the impact of temperature fluctuations on electrical output power calculations. This feature enhances its accuracy in estimating the amount of electrical energy that a designed system can generate.

Grid-connected photovoltaic (PV) systems rely on a crucial component known as the power conditioning unit (PCU), namely inverter. This PCU plays a pivotal role by converting the DC power generated by the PV array into AC power that matches the voltage and quality standards set by the utility grid (Durmuş, 2019; Khan et al., 2020; Tarigan, 2020). This entails creating a two-way connection between the PV system, AC output circuits, and the electric utility network. Typically, this connection takes place through an on-site distribution panel or service entrance. This setup enables the AC power generated by the PV system to be used for on-site electricity needs or to be fed back into the grid when the PV system's output exceeds the on-site electricity demand. This safety mechanism is a mandatory feature in all grid-connected solar PV systems (Marwa et al., 2021; Tiwari et al., 2021).

An essential aspect of on-grid PV systems is the use of net metering, or so called export-import energy metering. Traditional service meters operate like odometers, recording power consumption at a specific point of service through a rotating disc linked to a counting mechanism. These discs function based on a physical principle known as the eddy current. In contrast, digital electric meters employ digital electronic technology to measure power. They use solid-state current and voltage sensors to convert analog measurements into binary values, displaying these values on the meter through liquid crystal display (LCD) readouts.

Inverters are a key differentiator between grid-connected systems and standalone ones. In the context of grid-connected systems, inverters must be capable of synchronizing with the line frequency to efficiently supply surplus power back to the grid. Net meters have the capacity to track both the electricity consumed and generated in a unique cumulative format. The recorded power registration reflects the net power consumption, which is the total power used minus the amount of power produced by the solar power cogeneration system. Utility companies that provide grid-connection services supply and install these net meters.

The configuration of a grid-connected PV system is straightforward when compared to an off-grid PV system, which necessitates the use of battery storage. This grid-connected system consists of photovoltaic solar panels, an inverter, a meter, wiring, and a mounting system, as illustrated in Figure 2. The solar PV panels convert sunlight's photons into direct current (DC) electricity. This DC electricity is then processed by the inverter, which converts it into alternating current (AC) to power the building's appliances in the house (Khan et al., 2020; Tiwari et al., 2021). Any surplus electricity is sent back to the utility grid, where it is metered using an export-import energy meter. The meter also tracks the electricity imported from the utility grid.

The specific location chosen for this case study is referred to as "building A,". This building is situated in the Rungkut area of Surabaya, Indonesia, and boasts a roof with ample open spaces, free from obstructions like nearby buildings or trees. The roof is robust, constructed from clay and concrete tiles, which ensures it can support the weight of the PV system being installed. The other input site parameters is as shown in Table 2.

To adhere to the MEMR regulation for residential buildings, the load profile data were gathered and scrutinized. This data was used in determining the appropriate dimensions for the solar PV system. Currently, the customer relies entirely on electricity supplied by the utility grid. The PV system's size capacity were determined by analyzing the customer's electricity usage pattern The average peak sun hours amounted to 5 h. The total annual electricity consumption for that year tallied up to 4,680 kw-h. The electrical appliances used and the consumed power and energy is listed in Table 3. This house building is categorized under the Residential Tariff, which implies electricity costs of Rp. 1500 per kWh (http://listrik.org, 2017).

4. RESULTS AND DISCUSSION

4.1. Solar Energy and PV System Potential

The length of time the sun shines (day length) varies slightly throughout the year in Surabaya. However, due to the location of Surabaya, as well as other parts of Indonesia, around the equator, the day length is about 12 h evenly throughout the year. However, during May-July the day length is slightly lower 12 h, in turn during December – February the following year, it is slightly higher than 12 h. Meanwhile the minimum zenith angle (minimum solar zenith angle) is in the range of 0^o-30^o. Daily global solar radiation and air temperature for 1 year from the simulation results are shown in Figure 3. The components of global radiation consist of direct radiation, diffuse radiation and reflected radiation. From the simulation, it was found that global solar radiation on a horizontal surface in Surabaya is in the range between 4.82 kWh/day.m^2 and 6.81 kWh/day.m^2 with an average of 5.04 kWh/day.m^2. Maximum radiation occurs in September, and minimum radiation in December. It was also found that the diffuse radiation component was significant throughout the year in Surabaya, while the reflected radiation component was relatively small. Air temperature in Surabaya is in the range of 24-36°C.

Figure 2: Grid-connected PV system configuration

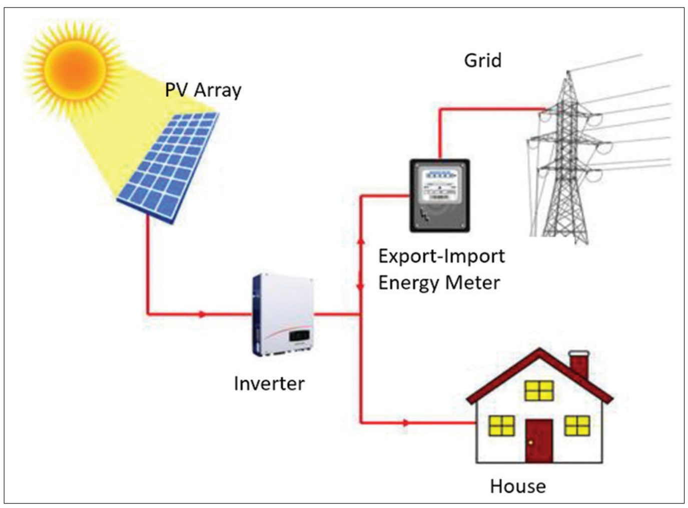
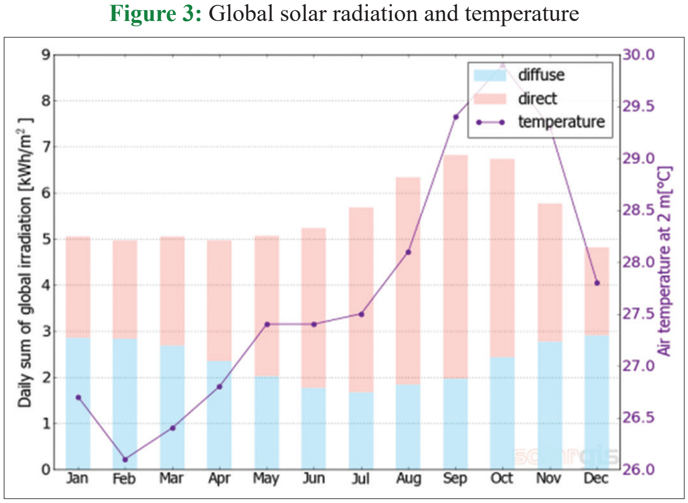


Figure 3: Global solar radiation and temperature



Referring to energy demand as shown in Table 1, it is estimated that the pattern of electrical power consumption for 24 h is as shown in Figure 4. The power consumption is relatively large high from 17.30 pm to 08.00 am in the morning. This can be understood as the household activities occur during that time period. Meanwhile, from 9.00 to 17.00, electrical power consumption is relatively small, when the power is only to supply several electrical appliances that require continuous power such as refrigerators, and other electrical appliances. Under normal conditions the maximum power requirement is around 1400 Watts, while the largest electricity requirement is for air cooling (AC) with energy consumption of 49% of the total energy requirements.

Referring to the solar energy potential in Surabaya, the pattern and amount of daily energy consumption, as well as the applicable regulations regarding rooftop PV system, a simulation was carried

Table 2: Site parameters

Parameter	Input/value
Site name	Surabaya
Location	7° 19' South, 112° 46' East
Elevation above sea level	3.1 m
Panel tilt	18°
Azimuth	90° N
Panel capacity	3000 Wp
Type of modules	Crystalline silicon
Mounting system	Fixed mounting, free standing
Inverter efficiency (%)	97.4
DC/AC losses (%)	5.5/1.5
Availability (%)	99.0

DC: Direct current, AC: Alternating current

Table 3: Household electrical appliances and daily energy used

Electrical appliances	n	Power (W)	Period of use (h)	Daily energy need (kWh)
AC	2	400	8	6.40
Lighting	12	10	8	0.96
Fritz	1	80	24	1.92
Rice cooker	1	300	4	1.20
Water pump	1	300	2	0.60
TV	1	100	5	0.50
Washing machine	1	500	1	0.50
Other appliances	-	-	-	0.92
Total				13.00

AC: Alternating current

out for the capacity of rooftop PV system that could supply electricity needs. For ideal weather conditions, the potential for solar energy in Surabaya, as previously discussed, reaches an average of 5.04 kw-h/day.m^2. However, under real conditions, the energy output will vary depending on various factors, such as weather, clouds, air pollution, etc. For ideal conditions, simulation results show that the electrical power produced from the PV system from 8.00 to 17.15 exceeds the electrical power needed by the house. During these hours the PV system electrical power will be exported to the grid and recorded as export power. On the other hand, outside of this period, electricity from PV system is relatively small or even zero at night. In this case, electrical power will be imported from the PLN (National Grid) network. In the calculation system, according to regulations, the monthly electricity bill is the difference between total exports and imports in 1 month. the total energy produced from rooftop PV system is 13 kWh, this value is the same as the electricity needs of the house in the simulation.

The output energy of solar cells is influenced by weather and climate factors, but this has been included in the simulation parameters, so it is hoped that the simulation results can be close to actual conditions. Simulation is very useful for finding out initial estimates of various factors on the energy output of a PLTS system before building the actual system. A good initial estimate will have an impact on cost and investment estimates.

The monthly energy output of rooftop PLTS system with a capacity of 3 kWp, compared to the home's electrical energy needs is as shown in Figure 5. It can be seen that from the months April to September, the energy output of the PV system exceeds the home's needs. Meanwhile, from October to March electricity consumption exceeded the PV system production. This can be understood as October to March is the rainy season in Surabaya, so the energy output of the PLTS system is not as large as the dry season. In total in 1 year, the energy output of a rooftop solar system with a capacity of 3 kWp is 4200 kWh. Meanwhile, the energy needed by a residential house in a year is 4680 kWh or around 10% higher than the energy output of a PV system.

4.2. Economic Analysis

The results of the simulation for the rooftop PV system in Surabaya indicate that a 1 kWp Si-c solar panel can generate approximately 1400 kWh of electricity annually, resulting in a utility capacity factor of 0.16 (i.e, 1400/8,760). This factor is crucial for calculating the unit cost of electricity for the PV system through numerical simulations, using the following Equation (Tarigan et al., 2014).

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

Where:
UCE = unit cost of electricity (USD/kWh)
C_{wp} = the total cost per peak watt of PV module (USD/Watt)
CUF = capacity utility factor
d = discount rate (%)
n = lifetime of PV system (in year)
m = maintenance cost (fraction of capital cost)
t = tax and incentive (fraction of capital cost)

The calculation involves varying the installed cost per peak watt in dollars and considering three different minimum attractive rates. The assumptions made for this calculation are as follows: the PV system has a 20-year lifespan, annual maintenance costs are 5% of the total capital costs, taxes and insurance are not applicable due to the absence of Indonesian regulations, and the capacity utilization is 0.16 as discussed earlier.

Figure 6 illustrates the unit cost of PV electricity at different discount rates, with the primary determinant being the *Cwp* (total cost per peak watt of the PV module). Notably, *Cwp* represents the price of the solar module, a pivotal component. The rapid technological advancements and mass production in solar module technology have led to significant cost reductions over the past decade, though prices may vary by location. Presently, the cost per peak watt of a PV module in Indonesia is approximately 1.25 USD (Tokopedia, 2023).

The current unit cost of electricity (*UCE*) for the rooftop PV system falls within the range of 0.093 to 0.123 USD per watt. In

Figure 4: Power consumption pattern

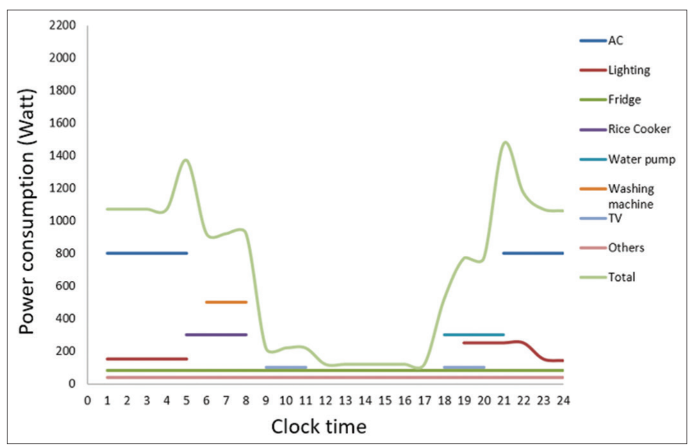


Figure 5: Monthly PV system energy output v.s. energy consumption

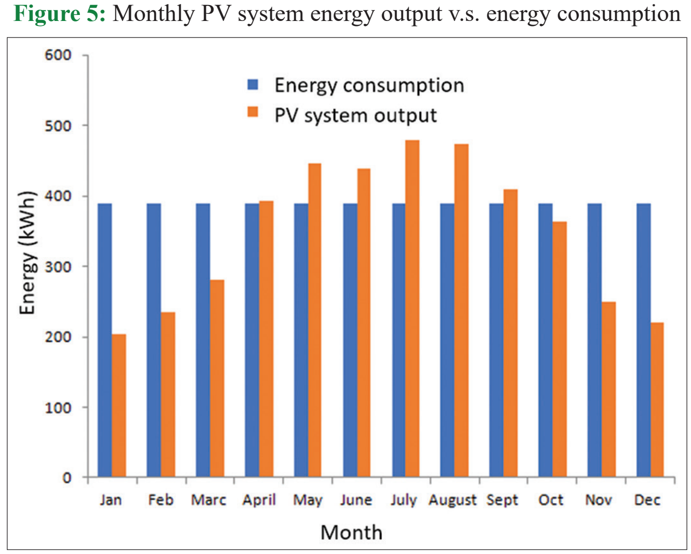
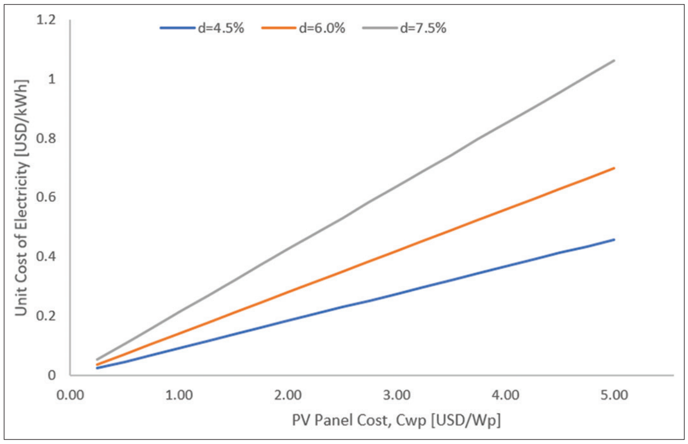


Figure 6: The unit cost of PV electricity for various discount rates



comparison, the prevailing utility electricity price in Indonesia stands at around 0.10 USD per kWh (http://listrik.org, 2017) (GlobalPetrolPrices.com, 2022). These findings suggest that rooftop PV systems have the potential to offer competitive power generation costs when compared to other alternative options, including government-provided electricity by National Grid, PLN.

5. CONCLUSION

The solar energy regulations in Indonesia have been reevaluated, and a simulation of a typical household's rooftop PV system in Surabaya, Indonesia, has been carried out. The most recent solar energy policy in Indonesia, specified in MEMR Regulation No. 26 of 2021, has established a net metering program for PLN customers, encompassing residential, commercial, and industrial clients who generate surplus power from rooftop solar installations. According to the current regulations, PLN customer electricity bills are computed monthly by subtracting the energy produced by the rooftop PV system (in kWh export) from the energy consumed (in kWh import) as measured by the export-import energy meter. The price for electricity generated by rooftop PV customers and exported to the grid is set at 100% of the applicable National Grid, PLN tariff. Considering the current rooftop solar PV regulations, including the export surplus value of only 100% of the import tariff, as well as the availability of on-grid inverter units for PLTS systems, it can be concluded that to meet the needs of a house in Surabaya which requires 13 kWh of energy per day, the capacity required rooftop PLTS is 3 kWp.

The simulation results show that with a 3 kWp rooftop PV system would meet up to 90% energy needs annualy. The current unit cost of electricity (*UCE*) for the rooftop PV system falls within the range of 0.093 to 0.123 USD per watt. In comparison, the prevailing utility electricity price in Indonesia stands at around 0.10 USD per kWh. These findings suggest that rooftop PV systems have the potential to offer competitive power generation costs when compared to other alternative options, including government-provided electricity by National Grid, PLN.

REFERENCES

Ben Jebli, M., Ben Youssef, S., Apergis, N. (2019), The dynamic linkage between renewable energy, tourism, CO2 emissions, economic growth, foreign direct investment, and trade. Latin American Economic Review, 28(1), 1-19.

Benatiallah, A., Mostefaoui, R., Boubekri, M., Boubekri, N. (2007), A simulation model for sizing PV installations. Desalination, 209(1), 97-101.

Dang, M.Q. (2017), Solar Energy Potential in Indonesia. In: 19th International Conference of Young Scientist. p. 199.

Durmuş, G.B. (2019), Modeling and Comparison of Micro Inverter and String Inverter in Photovoltaic Systems. Available from: https://acikbilim.yok.gov.tr/handle/20.500.12812/58321

Dutu, R. (2016), Challenges and policies in Indonesia's energy sector. Energy Policy, 98, 513-519.

ESDM, K. (2016), Rencana Umum Energi Nasional (RUEN). Available from: https://www.esdm.go.id/id/publikasi/ruen

GlobalPetrolPrices.com. (2022), Indonesia Electricity Prices. GlobalPetrolPrices.Com. Available from: https://www.globalpetrolprices.com/Indonesia/electricity_prices

Goel, M. (2016), ScienceDirect solar rooftop in India : Policies, challenges and outlook. Green Energy and Environment, 1(2), 129-137.

Hamdi, E. (2019), Indonesia' s Solar Policies: Designed to Fail? Available from: https://ieefa.org

Ibrik, I., Hashaika, F. (2019), Techno-economic impact of grid-connected rooftop solar photovoltaic system for schools in Palestine: A case study of three schools. International Journal of Energy Economics and Policy, 9(3), 291-300.

Khan, M.Y.A., Liu, H., Yang, Z., Yuan, X. (2020), A comprehensive review on grid connected photovoltaic inverters, their modulation techniques, and control strategies. Energies, 13(6), 4185.

Marwa, A.Y., Ahmed, A.E., Tamer, H.A. (2021), Assessment of PV String Optimizer Circuit Versus String and Central Inverters During Partial Shading Conditions. In: 2021 22nd International Middle East Power Systems Conference (MEPCON).

Pvsyst.com. (2019), PVSYST. Available from: https://www.pvsyst.com

SolarGis. (2021), SolarGis PVPlanner. Available from: http://solargis.info/pvplanner

Solargis.info. (2014), SolarGIS PV Planner. SolarGIS. Available from: https://solargis.info

Tarif Dasar Listrik PLN Maret. (2017). Available from: https://listrik.org/pln/tarif-dasar-listrik-pln

Tarigan, E. (2020), Simulasi optimasi kapasitas PLTS atap untuk rumah tangga di Surabaya. Multitek Indonesia: Jurnal Ilmiah, 14(1), 13-22.

Tarigan, E., Djuwari, Purba, L. (2014). Assessment of PV power generation for household in Surabaya using SolarGIS-pvPlanner simulation. Energy Procedia, 47, 85-93.

Tiwari, S., Pandey, R., Goswami, M. (2021), Performance Comparison of 3kW Residential Grid-Connected Photovoltaic System between Microinverter and String Inverter Topology using System Advisor. Available from: https://www.academia.edu/download/73252652/IRJET_V8I9166.pdf

Tokopedia. (2023), Jual Solar Panel. Tokopedia. Solar Panels Price Search. Available from: https://www.tokopedia.com/search?st=product&q=solar%20panel&srp_component_id=02.01.00.00&srp_page_id=&srp_page_title=&navsource

UNEP DTU Partnership. (2016), Indonesian Solar PV Rooftop Program (ISPRP). Kenya: UNEP DTU Partnership.

Xin-Gang, Z., Yi-Min, X. (2019), The economic performance of industrial and commercial rooftop photovoltaic in China. Energy, 187, 115961.