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Technical, economic and environmental analysis of residential scale of the rooftop PV system in Surabaya, Indonesia

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Abstract. This work studies the technical, economic, and environmental of a 3 kWp rooftop photovoltaic (PV) system for residential in Surabaya, Indonesia. The studies were conducted based on the data from a built instalation of rooftop on-grid PV system. In addition, analysis were carried out using SolarGIS PV planner, RETSCreen, and PVsyst simulation tools. The results show that a 3 kWp rooftop system in Surabaya could produce electricity of about 3,898 kWh per year. Under present conditions, economic analysis shows that the rooftop PV system investment would give the payback period of about 5 years. Environmentally, the 3 kWp PV system would result of the reduction of greenhouse gas (GHG) emission of about 3.8 tons of CO_2 per year.

1. Introduction

The Indonesian Government under the Ministry of Energy and Mineral Resources (MEMR) has recently set a target of 23% of renewable energy to replace fossil-based energy to fulfill the total national energy demand by 2025[1]. From various of available renewable energy resources, solar power is one of the most promising of renewable energies, particularly for Indonesia which is benefitting its position around the equator line. In this connection, the photovoltaic (PV) rooftop system regulation [2] has recently been introduced to encourage users, including residents, public, and commercial buildings roofs to generate electricity using PV.

Before installing the real of a real system, the study should be made to estimate the technical and, cost, and environmental terms of energy generated by a rooftop PV system. Every geographical position has different potential and characteristics of solar energy. Simulation techniques are commonly done for specific locations [3–7]. Rachchh *et al.* (2016) [5] used mathematical analysis to maximize the number of solar panels installed in a given area by optimizing several installation parameters. Redweik *et. al.* (2013) [3]developed a solar three-dimension (3D) urban model to calculate the solar energy potential on the roof and facades of a building in urban areas. Ko *et al.* (2015) [6] evaluated the potential of rooftop PV in Taiwan considering the shadow effect caused by building structures using the Hillshade module. Limited studies have been reported about rooftops with on-grid PV system in Indonesia [2], [8], [9].

The rooftop PV system can be categorized into two types, i.e. on-grid with and without reverse power blocking. An on-grid system with the reverse system is characterized with the property is connected to the national grid in order to receive electricity, but any surplus electricity generated by the system is prevented from being directed back into the grid. On the other hand, for another type, electricity generated can be used at the property and any surplus can be directed back into the grid. In some cases, this feed-back is compensated for [10]. The schematically a residential on-grid rootop PV system is shown in Figure. 1[11].

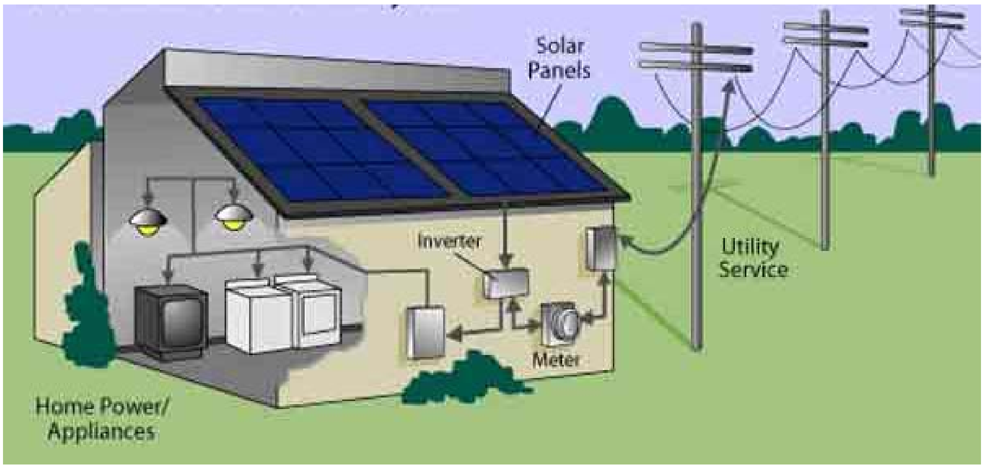

Figure 1. Schematic diagram of a residential on-grid rooftop PV system (Image source [11])

The aim of this study is to evaluate a rooftop on-grid PV system, specifically for a typical residential building in Surabaya, Indonesia. Electricity consumption of households in Surabaya varies and depending on the Statistically, it is shown that the majority houses in Surabaya A 3 kWp of PV system which is connected with the national grid of Indonesia (PLN) are studied in terms of technical, economical, and environmental aspects. The comparison result along with studies on recent national policies gives a feasibility study of the rooftop PV system implementation. The results from this work are expected to help in demonstrating the advantages and challenges of installing a rooftop on-grid PV system, particularly for households in Indonesia.

2. Methods

There are several types and sizes of houses commonly available in Surabaya. In terms of capacity by the national grid, the houses with 1300 kVA and 2200 kVA [12] installation are dominating the houses in Surabaya. The amount of energy consumption with these capacities varies between 3 – 15 kWh/day. Hence, the analysis and simulation in this study are conducted for a 3 kWp capacity of the on-grid PV system, which assumes that it would be able to supply the daily energy demand.

The 3 kWp rooftop PV system, installed and mounted on the roof of a building located in Surabaya Indonesia is analyzed in terms of technical, economical, and environmental aspects. The exact astronomical position of the system is -7^{o}19'S and :112^{o}46' E ; altitude: 3m. The system consists of twenty-two modules with a capacity of 140 Wp for each module. The module specification of the module is shown in Table 1. The system uses a 3 kVA DC-AC inverter, which delivers output energy to the building's utility grid system through a panel distribution. A full year of energy output recorded from the real installation is compared to the simulation results. The photograph of the module and the inverter system are shown in Figure. 2.

Table 1. The specification of PV Module

Parameters	Value
Maximum voltage [Vpm]	17.323 V
Maximum current [Ipm]	8.1 A
Maximum system voltage [Vmax]	1,000 V
Maximum series fuse rating	10 A
Open circuit voltage [Voc]	21.91 V
Short circuit current [Isc]	8.7 A
Maximum power [Pmax]	140 W

(a) (b)

Figure. 2. Photograph of the PV system showing solar panels (a) and on-grid inverter (b).

2.1. Simulations
The simulation is conducted using a combination of RETScreen [13], SolarGIS PV Planner [14] and PVsyst [15] simulation tools. RETScreen software simulation provides analysis tools that enable feasibility analysis for an on-grid PV system, as well as various renewable energy systems. The SolarGIS PV Planner provides an online assessment on any selected site. The software applies numerical simulation from the climate databases.. The availability of the solar insolation at a selected area is predicted by the software from the real measurement data of the nearest weather station. PVsyst is a computer software package for the study, sizing, simulation and data analysis of complete PV systems. It provides tools that can be used to analyze accurately different configurations of PV systems, including grid-connected, stand-alone, pumping and DC grid.

2.2. Simulation's Parameters
The input parameters for simulation were set as closed condition as possible with the real installation. For the module type, the crystalline silicon (c-Si) PV module was selected (the same type as the real module installed). The other parameters for SolarGIS simulation, such as the mounting type, installation type, azimuth of modules, tilt of modules, shading by the horizon, inverter efficiency, DC loses and total AC loses which were set as close as possible to the real conditions.
For financial and emission analysis several parameters were set to simulate using the RETScreen software. Table 2 shows the input parameters used in the RETScreen simulation. The values of the parameters are attempted to fit with the present condition.
For PVsyst simulation, the feature tools of the "project design of grid-connected system" were chosen to use. All known and changeable parameters such us type of orientation, PV modules,

modular size, inverters size, arrays structure, etc., were simulated to find out optimum output.While default values were used for unknown parameters.

Table 2. Simulation parameters for feasibility analysis

Parameters	Value
Debt ratio	50 %
Debt interest rate	6 %
Inflation rate	5 %
Project life	20 yr
Electricity export rate	1.2 USD/kWh.
GHG emission factor	0.709 tCO_2/MWh
Debt Term	10 yr
Capacity factor	14%

3. Result and Discussion

3.1. The real energy output

The energy output from the 3 kWp rooftop on-grid PV system was monitored and recorded on monthly basis, which was from the accumulation of daily energy production. The period of recording (for this study) was from April 2018 to March 2019. Figure 3 shows the monthly output energy in kWh. It is obviously seen that the monthly energy production varies 296 – 369 kWh per month. The highest energy output was about 369 kWh, produced during October. While, the minimum energy output was about 296 kWh during June. The annual energy output was about 3,898 kWh. By taking 360 days for one year, the daily average energy output is about 10.82 kWh, which varies from 7.50 – 16.0 kWh per day. The amount of energy would fulfill the energy need for most typical households in Surabaya as previously mentioned above.

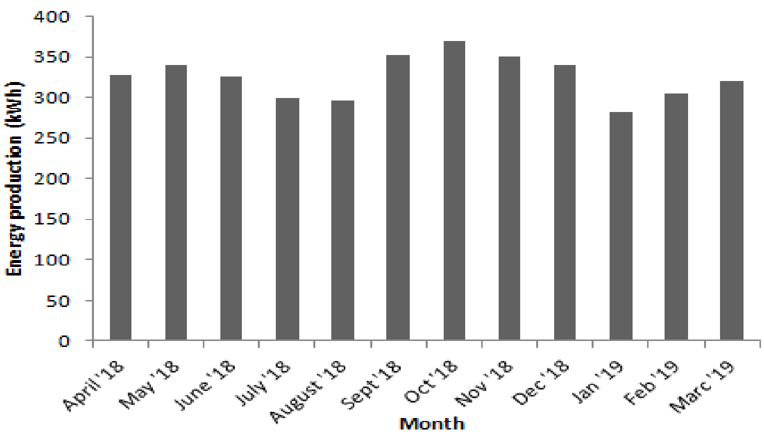

Figure 3. Energy production from a real installation PV system

Even though the dry season period in Surabaya was from June to August, energy production was found slightly lower than the other periods. This is predicted due to dust and particles covered the modules which reducing solar irradiance received by the modules. The cleaning of the module is highly recommended during the dry season as proposed in previous studies [16]. Further investigation on the effect of the energy production dust during the dry season is also recommended. The peak of the rainy season in Surabaya during January – February might the reason for low energy output.

3.2. Simulation Results

Solar energy conversion into electricity is affected by many factors, including materials properties and environmental operating conditions. The later factors are simulated to find out optimum conditions. The Solar GIS PVplanner simulation results showed the potential of the site solar irradiation presented in the form daily sum of global irradiation. The average values on a horizontal surface in Surabaya is about 5.54 kWh/m^2 per day and vary between 6.81 kWh/m^2 and 4.82 kWh/m^2. The global solar irradiation consists of direct, diffuse, and reflected components. The diffuse component of radiation is quite significant especially during March – October, while reflected radiation relatively small throughout the year. The monthly global from simulation results is shown in Figure 4. The global radiation in the past time was usually higher during month April – October than the other months due to dry season, meanwhile low radiation during December – March due to rainy season. However, in the present time, the season period is likely unpredictable, and further investigation should be done. Daily air temperature showed that the ambient temperature in Surabaya varies about 26 – 30°C.

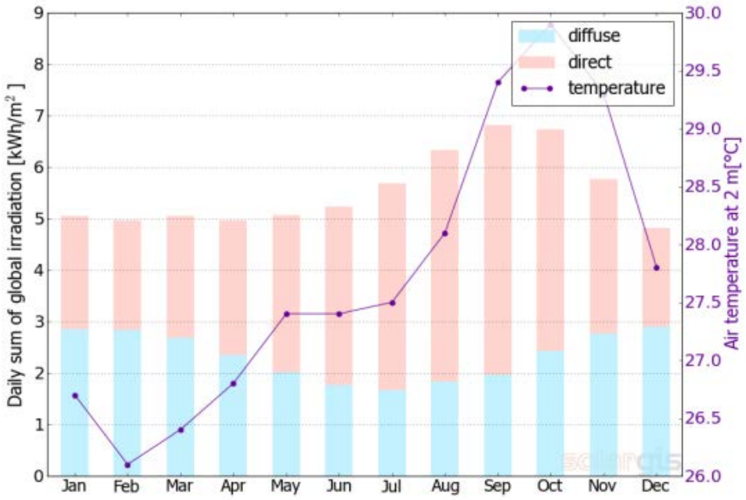

Figure. 4. Global irradiation and air temperature in Surabaya

The results of the simulation on energy output by 3 kWp PV system for similar months with real measurement above show slightly different as presented in Figure 5. Total annual energy production from the system by the simulation is found at about 4,200 kWh. The lowest energy production was in December and January which is about 190 kWh.

It was found that energy production by simulation was slightly higher than the real PV installation for the periods of April – September. While for the rest of the period, the real system produced slightly higher than the simulation. The difference between the real and simulation results is about 7.2%. Further specific studies are recommended to conduct to investigate the reason for the difference. However, many many factors causing the difference, such as dust, shading, weather, etc.

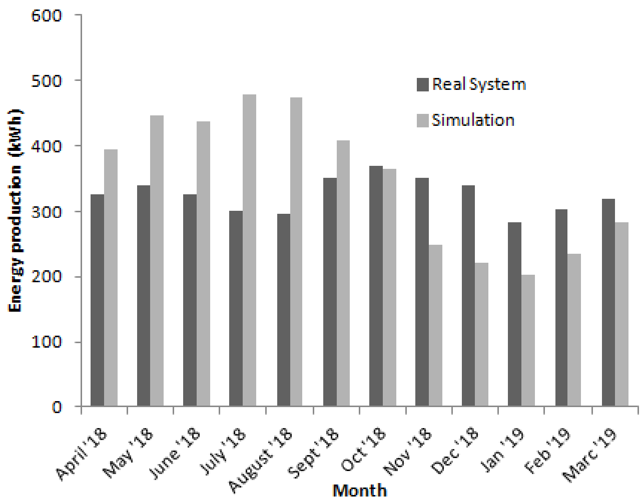

Figure 5. Comparison of energy output between the real PV system and simulation

3.3. Economic Analysis

A quick survey on the retail price of PV system components on the market recently in Surabaya was conducted using the internets. There was a variation of price for each of the components by different brands, types and vendors or suppliers. The average prizes among all surveyed data are used for economic analysis. The retail price of components and cost for installing 3kWP rooftop on-grid PV is presented in Table 3.

Tabel 3. Cost componen for 3 kWp PV system

Components	Retail Price or Cost (USD)
PV panel 3 kWp	2,400
Inverters 3000 W	350
Cabling	100
Construction cost	250
Total	3,100

Assuming that the price of one kWh of electricity is 0.10 USD/kWh, then during one year , based on the real system as mentioned above, the system will generated earning: 3,898 (kWh/year) x 0.10 (USD/kWh) × 1 (year) = 389.8 (USD/year). Lifetime for PV panels is considered about 25 years, while for inverters are 6 -7 years. A financial simulation was carried out with RETScreen software with financial parameters as presented in Table 2. The annual cumulative cash flows are presented in Figure 6. The cumulative cash flow in the figure is from the accumulation of money value of electricity produced by the PV system in comparison to system incremental of installation cost. It can be seen that under current conditions, rooftop on-grid PV system investment would give about 5-6 years of the payback period.

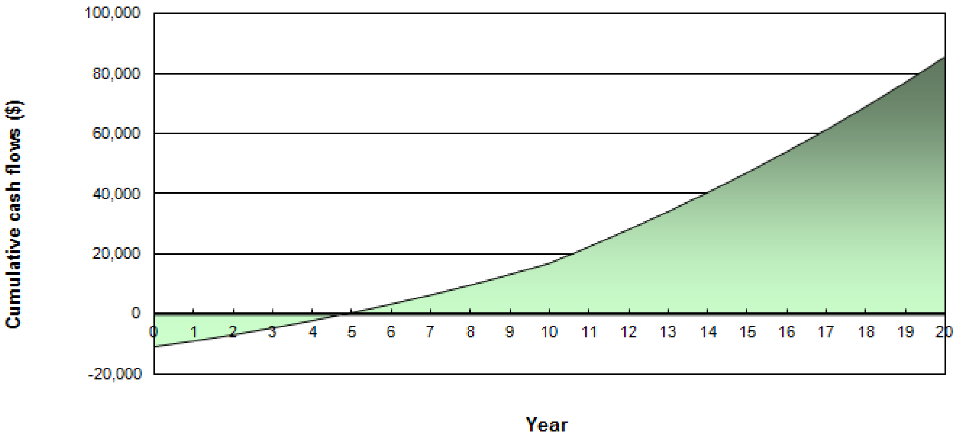

Figure 6. Cumulative cash flows of PV system investment

3.4. Environmetal analysis

Using any renewable energy to replace fossil fuel for power generation would result in a positive impact on the environment. Burning of fossil fuels for power plants results in the negative impact where it releases greenhouses gas (GHG) such as: Sulphur dioxide (SO_2), nitrogen oxide (NO_x), and Carbon dioxide (CO_2). In addition, it also produces a large amount of ash that needs particular handling. The conversion of GHG reduction from using of 3 kWp solar panel in Surabaya (due to replacing the burning of fossil fuel with the equivalent of produced energy) [13] is presented in Table 4.

Table 4. Greenhouse gasses reduction by 3 kWp PV system

Greenhouse gasses from the coal power plant	Per kWh	For annual energy production of *E = 1336 kWh*
SO2	1.24 g	4.98 kg
NOx	2.59 g	10.38 kg
CO2	970 g	3,885 kg
Ash	68 g	272.4 kg

GHG reduction as shown in Table 4. is just representing by applying PV system by a household. The amount of reduction GHG should be multiplied by the number of houses with PV systems if the number of the house installing PV increases.

4. Conclusions

Simulation and experimental study of 3 kWp rooftop on-grid PV System in Surabaya, Indonesia has been carried out. The annual energy production by the real system was about 3,898 kWh which means that the average daily energy production is about 10.8 kWh. This number would able to supply a typical simple household in Surabaya. The energy output from the simulation results was found slightly different from the real one, where the simulation results are about 7.2% is higher than the real. A particular further investigation is recommended to do to find the reasons for the difference. Economic analysis shows that, under current conditions, a grid-connected PV system investment would give about 5-6 years of the payback period. Environmentally, the 3 kWp rooftop on-grid PV system would reduce GHG emissions by about 3.8 tons CO_2 per year.

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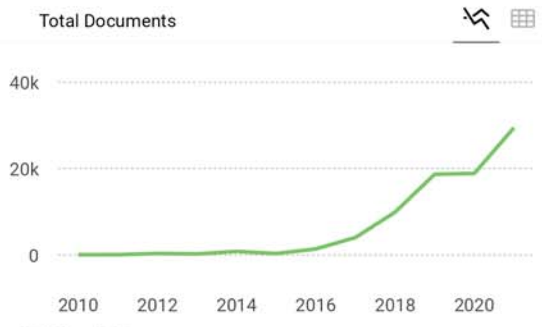

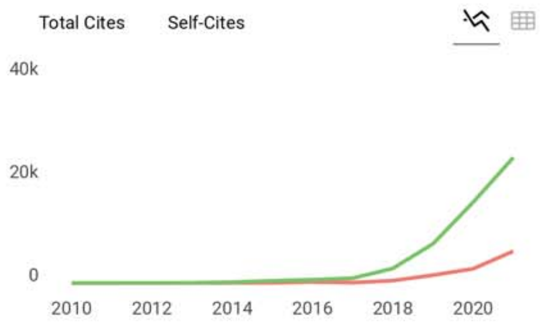

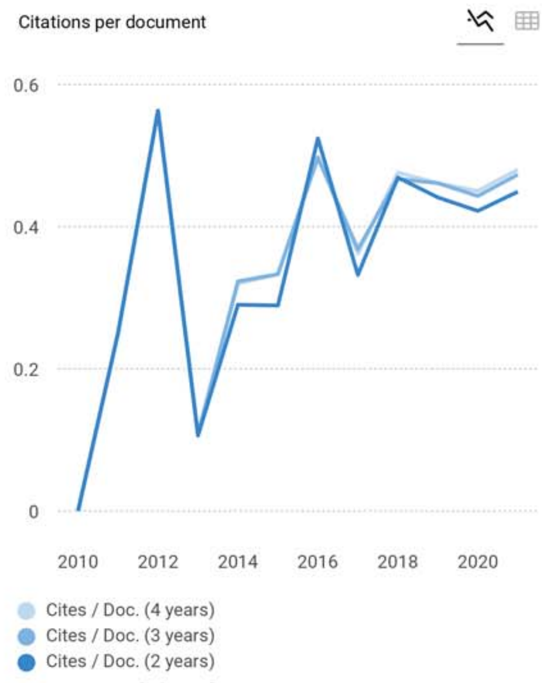

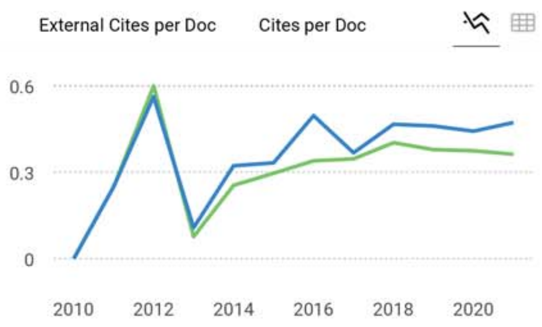

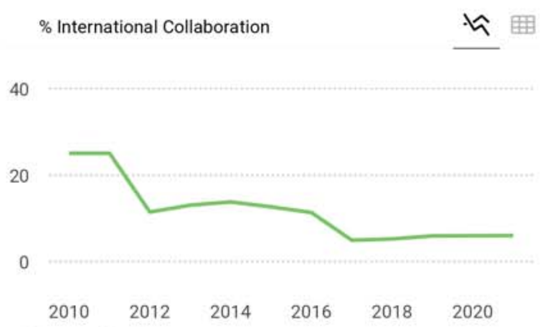

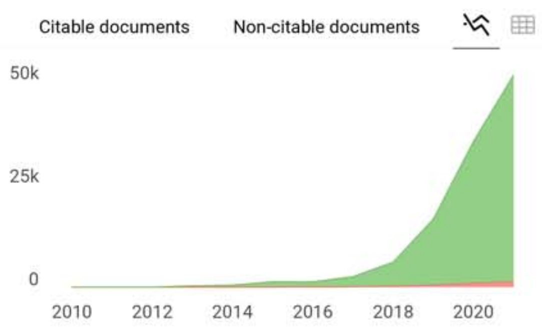

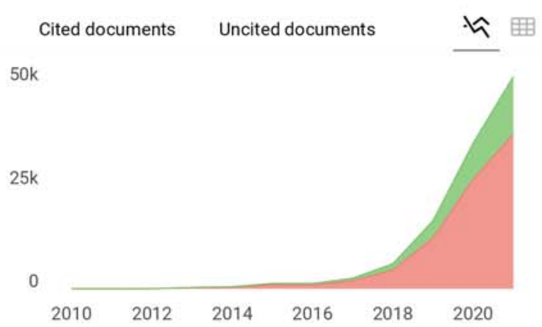

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