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Assessment of PV Power Generation for Household in Surabaya Using SolarGIS – pvPlanner Simulation

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ABSTRACT: Consumption of electricity energy in the Surabaya city region is continuingly increasing due to increasing urbanization and the social living style. This paper presents a simulation model used to size and assess the performance of a PV installation using SolarGIS-pvPlanner, particularly for house hold installation. The average daily sum of global irradiation on the horizontal surface in Surabaya is about 5.54 kWh/m^2 per day with domination of diffuse radiation, especially during March – October. The optimum panel orientation for fixed mounted was found with azimuth 45° (northeast) and inclination of 13°. The mounting system type significantly affects the specific electricity production of a PV system. Economic analysis shows that under current conditions, the solar PV system for household electrification is not economically viable in Surabaya.

Keywords: photovoltaic system, simulation, optimization, electricity, SolarGIS-pvPlanner

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1. Introduction

More than 50% of the primary energy requirements of the Indonesian nation are provided by fossil fuels in spite of the country's large potential for renewable energies: micro/mini hydro, biomass, geothermal, solar, and wind (Adra *et al.* 2009). Furthermore, the fragmented topography and scattered population of Indonesia makes it particularly ideal for the implementation of PV systems as a means for electrification. Installed PV capacity in Indonesia was about 20MWp and a presidential decree from 2006 stated that measures would be taken so that the country PV capacity could reach about 80MWp in 2025 (Maeleenn 2009). Since the 1980's, many standalone PV systems fulfilling different functions have been installed throughout Indonesia essentially following governmental initiatives. In this paper, a study on the solar electricity system to provide the required electricity for a household in Surabaya East Java, Indonesia is conducted through a simulation.

Application of PV for households in the city area where the electricity grid have already been available has less been studied in Indonesia. The cost of basic materials and the flexibility of the installation to meet the user needs of energy are the main factors influencing the feasibility of PV power generation (Benatiallah *et al.* 2007). Computer simulation techniques can be used to test the performance of various components of the PV system before they are put in place hence reducing materials and installation costs (Benatiallah *et al.* 2007; Egido 2007). This work presents an assessment of PV power generation for household in Surabaya using SolarGIS – PVplanner simulation (solargis.info 2013). A realistic economic analysis of PV system generation for a typical of single-family house is conducted using the life cycle cost analysis.

2. SolarGIS-pvPlanner Simulator

The SolarGIS-pvPlanner application is an online simulator for solar PV systems. The simulator provides assessment results at any selected site online. It integrates numerical simulation models that result from the latest research with new climate databases using Google Web Toolkit web programming technology (Marcel *et al.* 2012; Huld *et al.* 2010). The SolarGIS methodology is based on using statistically aggregated solar and temperature data stored in the database with a time step of 15 minutes. Simplified input parameters enable to consider key characteristics of a PV system, such as its position, geometry, type and mounting of modules, efficiency of inverter, and assumed losses in DC and AC sections. The model calculates reflectance losses at the surface of PV modules and losses due irradiance and temperature characterising operating performance of modules in a site-specific climate conditions. The other system losses, mainly at the DC and AC section are to be set by a user (Marcel *et al.* 2012). The simulator website address is: http://solargis.info/pvplanner

3. Site Meteorological and Solar Radiation Data

Surabaya is located at 07° 19' 17.83" South and 112° 46' 3.19" East. Geographic position of Surabaya is as shown in Fig 1. The Sun path over a year in Surabaya is shown in Fig 2. The figure shows the terrain horizon, module horizon, and active area with civil (clock time) and solar time. Module horizon, however, may have shading effect on solar radiation.

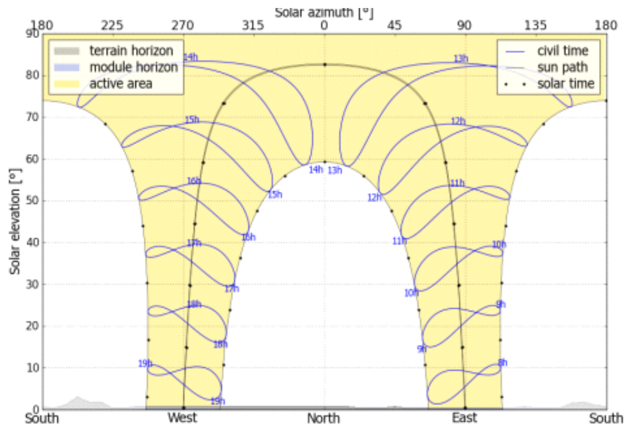

Fig. 2 Path of the Sun over a year in Surabaya

Fig. 1 Geographic position of Surabaya

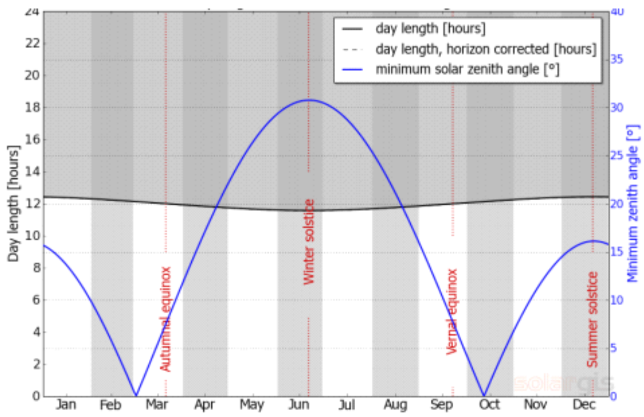

Fig. 3 Day length and minimum solar zenith angle in Surabaya

Change of the day length and solar zenith angle during a year is shown in Fig. 3. The local day length (time when the Sun is above the horizon) is shorter compared to the astronomical day length, if obstructed by higher terrain horizon.

Global horizontal irradiation and air temperature during a year is shown in Fig. 4. The global radiation components are direct, diffuse and reflected. The average daily sum of global irradiation on the horizontal surface is about 5.54 kWh/m^2 per day with maximum value of 6,81 kWh/m^2 (September) and minimum 4,82 kWh/m^2(December). The diffuse component of radiation is quite significant especially during March – October, while reflected radiation relatively small throughout the year.

In the past, the global radiation is usually higher during month April – October than the other months. It can be understood that during this period dry season commonly occur in this region meanwhile rainy season is during December – March which resulted in the lower average solar radiation (Elieser 2010). However, recently, the season period is likely unpredictable, and further investigation should be attempted for this as it might be closely related not only to the PV application but also to other issues such as global warming or climate change.

Daily (diurnal) air temperature, as shown in Fig. 4, indicated that the ambient temperature in Surabaya varies from 26 – 30 °C

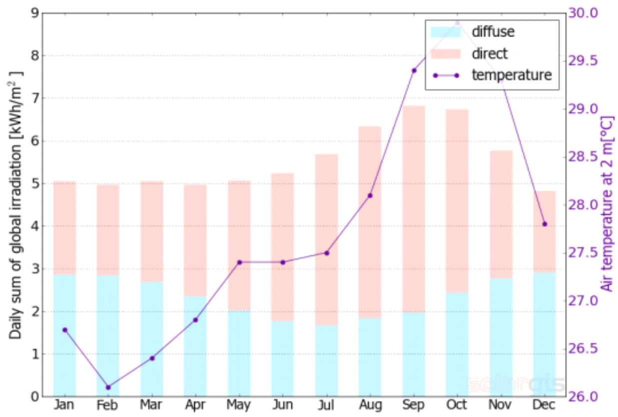

Fig. 4 Global irradiation and air temperature in Surabaya

4. PV Specific Energy Production

Simulation using SolarGIS-pvPlanner was carried out to obtain the optimum specific energy production of the PV system by varying solar geometry parameters, type of PV materials and mounting system.

Table 1 shows the optimum specific energy production of a crystalline silicon based PV system in Surabaya, each for the panel orientation of : azimuth of 315° (northwest), 45° (northeast), 225° (southwest), 135° (southeast) with inclination of 5°, 13°, 0°, and 0°

respectively, and fixed mounted system. (For economic and less complexity installation, it is assumed that mounted system is the most suitable for house hold)

The optimum panel orientation is found to be azimuth 45° (northeast) and fixed tilted 13° from the horizontal. Simulation results showed that variation of panel orientation (with fixed system) would affect energy production up to 4%. Meanwhile adjusting tilted up to 20° does not significantly affect the energy output. Therefore, for a real condition, the tilted could be fixed following the appropriate roof slope, all at once to avoid dirt and leaves falling to the panel to stay on the panel surface which would reduce solar radiation into the panel.

Table 1
Energy production PV system of 0.58 kWp, crystalline silicon, fixed mounting with variation of azimuth and inclination angle. (Esm = monthly sum of specific electricity production [kWh/kWp], Esd = daily sum of specific electricity production [kWh/kWp]

Month	Azim. 315° (northwest), incl. 5°		Azim. 45° (northeast), incl. 13°		Azim. 225° (southwest), incl. 0°		Azim. 135° (southeast), incl.0°	
	Esm	Esd	Esm	Esd	Esm	Esd	Esm	Esd
Jan	116	3.75	115	3.73	117	3.79	117	3.79
Feb	104	3.73	104	3.74	104	3.74	104	3.74
Mar	118	3.83	120	3.89	117	3.79	117	3.79
Apr	114	3.82	117	3.93	111	3.72	111	3.72
May	122	3.94	127	4.11	117	3.79	117	3.79
Jun	123	4.12	129	4.32	117	3.92	117	3.92
Jul	138	4.45	144	4.65	131	4.23	131	4.23
Aug	150	4.86	154	5.00	144	4.67	144	4.67
Sep	152	5.09	154	5.15	148	4.95	148	4.95
Oct	153	4.95	152	4.92	151	4.89	151	4.89
Nov	126	4.20	124	4.16	126	4.22	126	4.22
Dec	109	3.55	109	3.52	111	3.59	111	3.59
Year	1530	4.19	1555	4.26	1500	4.11	1500	4.11

By setting of crystalline silicon panel with azimuth angel of 45° and inclination of 13°, it could be expected daily specific electricity production of 3.52 – 5.15 kWh/kWp, with an average of 4.26 kWh/kWp, or yearly specific electricity production of 1555 kWh/kWp. Specific electricity production (yearly) and performance ratio for different type of solar cells with the same module orientation is showed in Table 2.

Tabel 2
Specicific energy production and performance ratio of different type solar cells

Module Type	Specific energy prod. [kWh/kWp]	Perfor. ratio [%]
c-Si	1555	75.4
a-Si	1742	84.4
CIS	1588	77.0

The mounting system significantly affects the specific electricity production of a PV system. Simulation results on different type of mounting system by taking c-Si based solar cells as the parameter is shown in Table 3.

Table 3
Mounting system effect on the specific energy production for c-Si solar cells in Surabaya

Mounting System	Specific energy prod. [kWh/kWp]
Free standing 1 angle (optimized)	1555
Building integrated (optimized)	1503
Roof mounted (optimized)	1529
Free standing 2 angle (optimized)	1580
Horizontal NS axis tracking	1887
Horizontal EW axis tracking	1603
Vertical axis tracking	1893
Inclined axis	1902
2 axis tracking	1959

5. Energy Requirement Analysis in a House Hold

There are several type and size of houses commonly build in the area of Surabaya. In term of installed electricity capacity by national grid (Perusahaan Listrik Negara, PLN), the houses are categorized into: 450 kVA, 900 kVA, 1300 kVA, 2200kVA, 3500kVA, and several higher capacities. Statistically, the houses with 1300 kVA are dominating with more than 80% of the total houses currently available (surabaya.go.id 2012). Therefore, the analysis here is focused on this type of houses.

A typical single family house with 1300 kVA in Surabaya commonly uses the appliances in Table 4. With the electricity appliances listed in Table 2, the daily electricity load for the typical house is approximately 3.2 kWh.

Table 4
The house hold electricity load

Appliances	Number of Units	Wattage per Unit Used	Operating Hours per Day	Energy Load (kWh/day)
Lighting lamp	3	20	17.30 – 23.00	0.330
Lighting lamp at terrace	1	10	17.30 – 05.00	0.115
Lighting lamp for night sleeping	1	5	10.00 – 05.00	0.035
TV	1	80	Varies (4 hours)	0.320
Water Pump	1	120	Varies (3 hours)	0.360
Fan	2	35	Varies (6 hours)	0.420

Refrigerator	1	100	0.00 – 24.00	1.200
Others	varies	varies	varies	0.5

SolarGIS-pvPlanner simulator requires input value of the capacity of solar PV module (in watt peak, Wp) to be installed in order to simulate. In this work, the value is determined based on the load for the mentioned type of house in above i.e. 3.2 kWh/day, as well as the potential of PV specific energy production in Section 4. The results of simulation indicated that 0.7 kWp of c-Si solar module is needed to fulfill the energy requirement of 3.2 kWh/day. The capacity of needed solar module is equivalent to 0.66 kWp of CIS based.

Simulation is carried out by taking c-Si based solar module, considering the availability of the solar module in the market currently in Surabaya, and as mentioned, for economic and less complexity installation, it is assumed that a fixed mounted system is the most suitable for household. The monthly energy production for a year and its performance ratio of a 0.7 kWp c-Si based solar module is presented in Fig. 5.

6. Life Cycle Cost Analysis

The life cycle cost (LCC) estimation of the designed stand-alone PV system is discussed in this section. The components that are related to a stand alone PV system cost are including: 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.

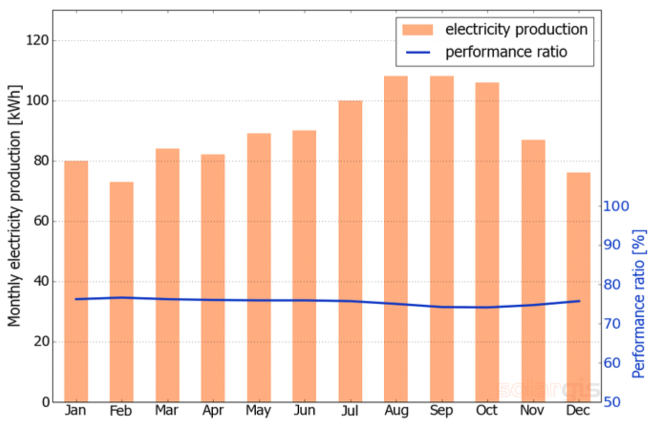

Fig. 5 Monthly energy production and its performance ratio of a 0.7 kWp c-Si based solar module

An equation which is expressed in the components of the peak power rating and the total cost per peak watt is derived below to calculate the unit cost of electricity (UCE) (Kanpal & Garg 2003). A typical numerical calculation is then made for estimating the unit cost of PV electricity.

The unit cost of electricity from PV system *(UCE_{PV})* can be calculated as:

$$UCE_{PV} = \frac{\text{Levelized annual cost of PV system}}{\text{Annual electricity output from the PV system}} \quad (1)$$

The levelized annual cost of the PV system comprises of the annual capital recovery cost, the annual of O & M cost, taxes, insurance, etc.

The annual capital recovery cost in return can be calculated as a product of capital cost C_o and capital recovery factor, i.e.

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

Where C_o is capital cost; d is discount rate; and n is expected useful life time.

If the annual O&M cost is expressed as a fraction *m* of the capital cost, and the cost of insurance and taxes, etc., are expressed as a fraction *t* of the capital cost, the levelized annual cost of the PV system can be written :

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

From the capacity utilization factor, *CUF*, of the PV system, the annual electricity output *(E_{annual})* can be estimated :

E_{annual} = (8,760 x (the peak power of the PV system) x (CUF) (4)

If we express the total capital cost Co as a product of the peak power rating and the total cost per peak watt, C_{pw}, then the unit cost of electricity produced by the PV system, *UCE*, can be calculated as :

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

A typical numerical calculation is made using equation 5 for estimating the unit cost of PV electricity.

Table 5
The unit cost of PV electricity

Cpw (USD/Wp)	Unit Cost of Electricity (USD/kWh)		
	d = 0.05	d = 0.1	d = 0.15
20	1.14	1.57	2.05

15	0.86	1.18	1.54
12	0.69	0.94	1.23
10	0.57	0.78	1.03
8	0.46	0.63	0.82
6	0.34	0.47	0.62
4	0.23	0.31	0.41
2	0.11	0.16	0.21
1	0.06	0.08	0.1

Several values of installed cost in dollars per peak watt have been considered along with three different values of minimum attractive rates of return. In this calculations it is assumed that (i) the useful life time of the PV system is 20 years (ii) the annual maintenance cost is 5 per cent of the total capital cost of the system, (iii) taxes and insurance costs are not to be paid and (iv) capacity utilization is 20 per cent. The result of calculation is summarized in Table 5.

7. Discussion

As previously discussed, a typical household in Surabaya with daily loads of 3.2 kWh would require of 0.7 kWp solar PV system full fill its electricity needs. A small market research, mainly from the internet, was conducted personally by the author in this work to find out the price of the solar electricity components and installation locally in Surabaya. Table 2 shows the average price or cost per item of the PV system component (stand alone system).

Table 6
The component cost data of a PV system

Item	Cost
PV module	$2.5/Wp
Battery	$1.5/Ah
Charge Controler	$ 5.0/A
Inverter	$ 1/W
Instalation	10 % of PV Cost
O&M/Year	5% of PV Cost

Based on the information as in the Table 6, and following the sizing stand alone PV method by Abd El-Shafy (2003) and Sheeraz et al. (2010), it was found that the initial investment for a 0.7 kWp stand-alone PV system applied for considering typical house in Surabaya is approximately 4,300 USD. That means, at present time, the initial cost investment for a stand-alone PV system is about 6.1 USD/Wp.

With conversion value from Table 4 means the unit cost of electricity (UCE) at present time is range 0.34 – 0.62 USD/kWh. While, at the time of writing this article the price of electricity from national grid (PLN) in Surabaya is 0.08 USD/kWh. It is obviously seen that, under current conditions, the solar PV system for household electrification is not economically viable . Even with a better financial support, solar PV system for household still less promising. However from the UCE values showed in Tabel 4, PV systems seem have the potential to provide power at competitive prices with other alternative options for power generation, especially when Cpw is getting lower through the technology developments.

From the house hold electricity loads as listed in Table 2 above, it is obviously seen that the energy is mostly consumed for non-lighting purposes. Only 0.48 kWh of 3.2 kWh energy loads used for lighting. Unlikely household in urban area, house hold in the rural area in many places of Indonesia, such as in the islands and remote area, the lighting is still the basic needs for them. Many of people have been living there with no electricity. Considering such condition, PV system is one of feasible option to attempt.

8. Conclusions

A simulation using SolarGIS-pvPlanner model to size and assess solar potential the performance a PV installation in Surabaya has been carried out. The average daily sum of global irradiation on the horizontal surface in Surabaya is found about 5.54 kWh/m2 per day with domination of diffuse radiation, especially during March – October. The optimum panel orientation for fixed mounted is found with azimuth 45° (northeast) and inclination of 13°. The mounting system type significantly affects the specific electricity production of a PV system. It is obviously seen that, under current conditions, the solar PV system for household electrification where unit cost of electricity of 0.34 – 0.61 USD/kWh, is not economically viable. Even with a better financial support, solar PV system for household still less promising meanwhile, in remote areas where grid electricity is not available, PV system can be financially feasible in the short-term.

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