Photovoltaic Solar Energy Simulation of Rooftops of a University Campus Buildings in Surabaya, Indonesia

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Abstract. This work simulates and estimates the useful surface area of roof of the buildings of University of Surabaya for photovoltaic (PV) system installation. A representative building is used in simulation to calculate the panel capacity that can be produced by a roof mounted PV with grid-connected system. It was found that about 10,353 m^2 of roof top of the university buildings could be used for panels installation. The total capacity of the panels is about 2,030 kWp or 2,03 MWp. The capacity consists of four roof directions, i.e., 630 kWp, 535 kWp, 668 kWp and 553 kWp respectively for NE, SE, SW and NW roof directions.

Keywords: Solar energy, Photovoltaic, Campus building, Simulation, Rooftops.

1 Introduction

Solar energy is one of the most common and inexhaustible renewable energies that plays an increasingly essential role recently. Solar energy in the form of radiation can be directly converted into electricity using photovoltaic (PV) technologies. One of the mostly direct usages of solar energy is conversion from solar to photovoltaic electric energy [1].

The assessment of solar energy potential in a location where PV systems is planned to be installed is required and affects the successfulness of deployment of the PV systems. The potential of energy output much depends directly from the local exposure to sunlight. One aspect that should be considered for evaluating real outcomes of roof mounted PV system investments is architectonic buildings. The aspect includes identification of building roof surfaces (flat and slanted); estimation of number of floors for each building; and shape classification of roofs [2].

Computer simulation techniques can be used to predict of the PV system performance before they are put in place hence reducing materials and installation costs [3]. Substantial research has been conducted on the topic of building rooftop PV installation potential [4]. Quantified the rooftop PV power generation potentials in Southeastern Ontario was reported by Wiginton et al. [5]. Five steps were applied determine available rooftop surface area, i.e., sampling, the geographical division of the region, sampling, deducing the relationship between rooftop area and population, reduction of shading and other uses, and conversion to power and energy outputs. Vardimon [6] reported a study of the useful area of rooftops in Israel. The work was carried out using orthoimages to extract building layer images. The available rooftop area was calculated by using GIS data. It was repotted that 32% of annual Israel national consumption was equivalent to the annual rooftop PV electricity production.

Bergamasco et al. [7] studied the assessment of the PV energy potential together with its application to the Pied- mont Region (North-Western Italy). The useful roof area for solar PV system applications was calculated through the analysis of available GIS data.

The objective of this work is to estimate the useful surface area of roof of the buildings of University of Surabaya, specifically for PV panel installation. Further, the work also to calculate the electricity energy that can be produced by a grid-connected PV system if solar panel arrays are mounted on building roofs. A mathematical equation is derived to estimate the unit cost of electricity from a grid connected system under local conditions.

2 Methodology

2.1 Total Surface Area

At the time this study was conducted, there were 29 permanent buildings of campus University of Surabaya. The name and the location of the buildings are shown in Figure 1 as taken from Google EarthTM. When it is not specifically named, the first letter of the name for each building is from initial faculty name, for example, E for economic faculty, F for pharmacy (farmasi in bahasa Indonesia) etc. Therefore building EA refers to building A of economic faculty and building FB refers to building B of faculty of pharmacy, etc. The building are being used for various different academically purposes such class rooms, offices, library, laboratories, canteens. In addition, there are some non permanent and semi permanent buildings and they are excluded in this study. The 29 considered buildings in this study consist of storey buildings with conditions as shown in the Table 1. The total surface area of the campus and the roof of the buildings are determined by using Polygon feature (measuring the distance or area of a geometric shape) of Google Earth TM.

All of the buildings are oriented/tilted 45o to the main geographical direction that have the roofs direction each to North East (NE), South East (SE), South West (SW), and North West (NW) as shown in Figure 1 and Figure 4. The type of the roof is mainly Hip roof and subtype Gablet Roof or Dutch Roof [8] which have four sides and direction as shown in Figure 2. The roofs are installed with a tilt angle of 35o relative to horizontal.

For the area of the roof, measurements were conducted for each side according to the geographical orientation of the roof sides. This is important as the solar panel orientation in the simulation is assumed to follow the roof orientation.

Table 1. Storey Building at University of Surabaya

Storey Building	Buildings
Two-storey	EB, FA, TA, PA, International Village, Canteen
Three-storey	TB,ED
Four-storey	EA, EC, FB, FC, FD, FE,HA,HB,TC, TD, TE, TF,PB, PC, PD, PE
Six-storey	FF, FG, Library, TG

Fig. 1. Map of buildings of University of Surabaya generated from Google Earth ™

Fig. 2. Gablet roof (upper) and Hip roof (lower) types of University of Surabaya buildings

2.2 Useful Roof Surface Area

The useful surface area of the roof where PV system could be installed was determined by considering the geometrics characteristics of a building. The area was obtained by selecting library building as representative sample of the campus buildings under study. The area was calculated from maps generated from Google EarthTM and exported and scaled with Google Sketch up software application. Further, solar panels with various speciations were applied and simulated to the roof to determined mean percentage of effective surface area after eliminating interfering elements. The real picture and the generated picture with roof panels installed of the representative building is shown in Figure 3.

2.3 Shading Factor

When come into real installation, the detail of real building need to further studied specifically for each building. The considerations are including shading factor due to surrounding obstruction that could come from elevator shafts, HVAC, antennas, as well as other elements that could interfere with the PV system. Considering the very small surrounding obstruction within the campus area, for the university buildings in this work, the energy lost due to shading factors is calculated based on value proposed by previous similar work [9], i.e. 2% of total energy production.

Fig. 3. Library building as representative building used in simulation

2.4 Simulation

Grid connected PV system were simulated with the roof-mounted PV panels aligned to the roof orientation. Theoretical sitting of PV panels for different building orientations are graphically shown in Figure 4. Each side of the roofs surface is used as much as possible for mounting of chosen PV panels. Solar energy potential is carried out using solar SolarGIS-pvPlanner following previous study[10].

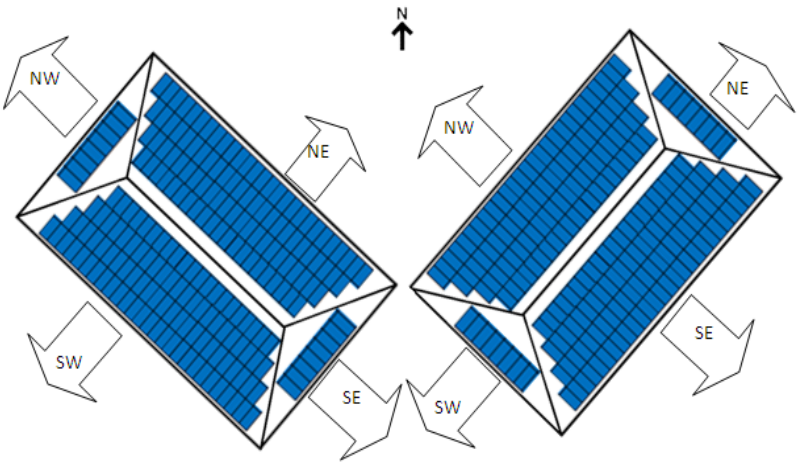

Fig. 4. Theoretical sitting of PV panels for different building orientation

Simulation for grid connected PV system is conducted for representative building (library building) to estimate PV specific energy production, as well as system energy output. Simulation was run using SolarGIS – PVplanner simulation, an online simulator for solar PV systems. The software uses Google Web Toolkit web programming technology to integrates numerical simulation models from the latest research with new climate databases [11]. The simulator provides assessment results at any selected site online [12]. In simulation for library building, PV system installation on the roofs is divided into 9 segments; each is according to position and orientation (Figure 5).

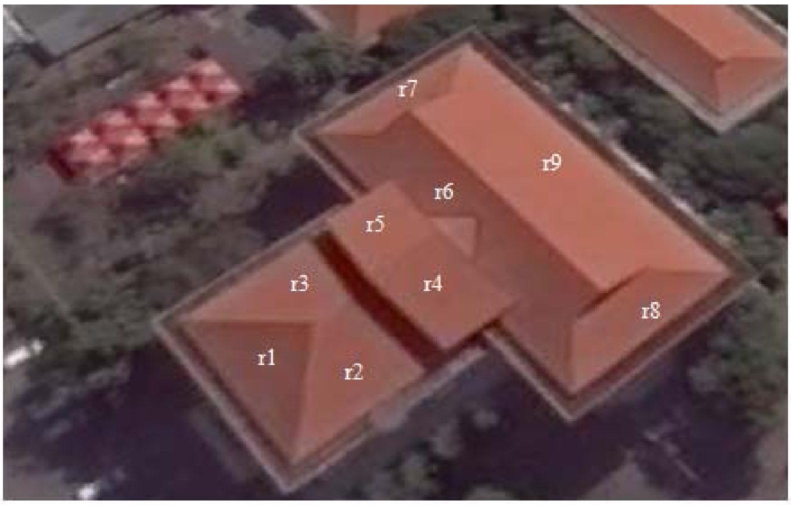

Fig. 5. Roof segments for simulation

2.5 Unit Cost of Electricity Analysis

The unit cost of electricity estimation of the designed grid-connected system was calculated following method by previous work [3]. The components that are related to a grid-connected system cost are module cost, balance of system (BOS) cost, system lifetime, discount rate, and operating and maintenance (O&M) cost. The total cost per peak watt of PV system can be calculated with a derived equation. A numerical calculation could be done to estimate the unit cost of PV electricity. The unit cost of electricity from PV system (C_{pv}) mathematically can be formulated as:

$$C_{pv} = \frac{\text{Levelized annual cost}}{\text{Annual electricity output}} \tag{1}$$

The levelized annual cost of the grid connected PV system consists of annual O& M costs, the annual cost of capital recovery, insurances, taxes, etc. The annual cost of capital recovery in return can be counted as a component of cost of C_c and capital recovery factor with relation [13]:

$$\text{Annual capital recovery cost} = C_c \left[\frac{r(1+r)^t}{(1+r)^t - 1} \right] \tag{2}$$

Where C_c is cost of capital; r is rate of return; and t is the system life time.

If the component cost of annual O&M is assumed as a fraction n of the cost of capital, and the component of taxes, insurance, etc., are assumed as a fraction m of the cost of capital cost, the levelized annual cost can be expressed as :

$$\text{C annual} = C_c\left[\frac{r(1+r)^t}{(1+r)^t-1}+n+m\right] \quad (3)$$

From the capacity utilization factor, *F,* of the PV system, The annual electricity output (annual) can be estimated from PV system capacity utilization factor F with equation:

Annual = (8,760 x (the PV system at maximum power) x (F) (4)

The equation for unit cost of electricity produced by the grid-connected PV system, *Cpv*, can be simplified by expressing of the total capital of cost *Cc* as a product of maximum power and the total cost per peak watt, Cpw. The equation can be expressed as:

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

Numerical calculation was made using equation 5 for estimating the unit cost of PV electricity.

3 Results and Discussion

3.1 Solar Energy Potential

The exact location of the university campus (buildings) as indicated an Google Maps^{TM} is between 7^{o}19'22.98" - 7^{o}19'04.04" South and 112^{o}46'22.02" - 112^{o}22'04.65". Total area of land of the campus is about 88,020 m^2 with about 1535 m of circumfence. Fig 6. shows the Sun path in Surabaya (simulated site location) over a year. The sun path figure shows the terrain horizon, module horizon, and active area with solar and civil time. Shading effect on solar radiation might be happen on module horizon.

The variation of the day length and solar zenith angle yearly in Surabaya area is shown in Fig. 8. It is obviously seen that, if obstructed by higher terrain horizon, the time when the Sun is above the horizon (whic is the local day length) is shorter compared to the astronomical day length.

Global horizontal irradiation (which consists of are direct, diffuse and reflected components) is shown in in Fig. 8. The ambient air temperature during a year is also shown in the Figure. It can be seen from the figure that during March – October, the radiation is quite significant dominated with the diffuse component, while reflected radiation relatively small throughout the year. The simulation results shows that, the maximum value of global solar irradiation was 6,81 kWh/m^2 with daily average is about 5.54 kWh/m2 per day during

September. While less solar irradiation is happen during December, with average of 4,82 kWh/m^2.

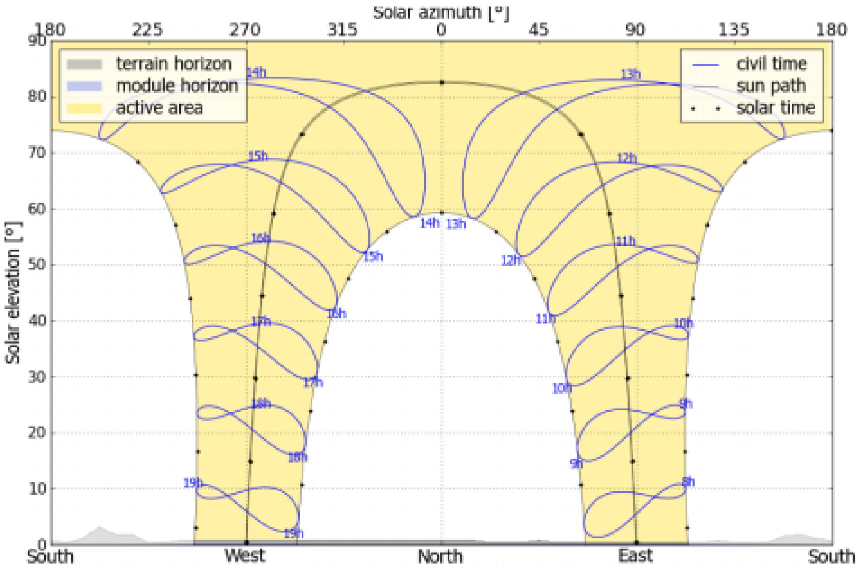

Fig. 6. Sun Path over a year in Surabaya

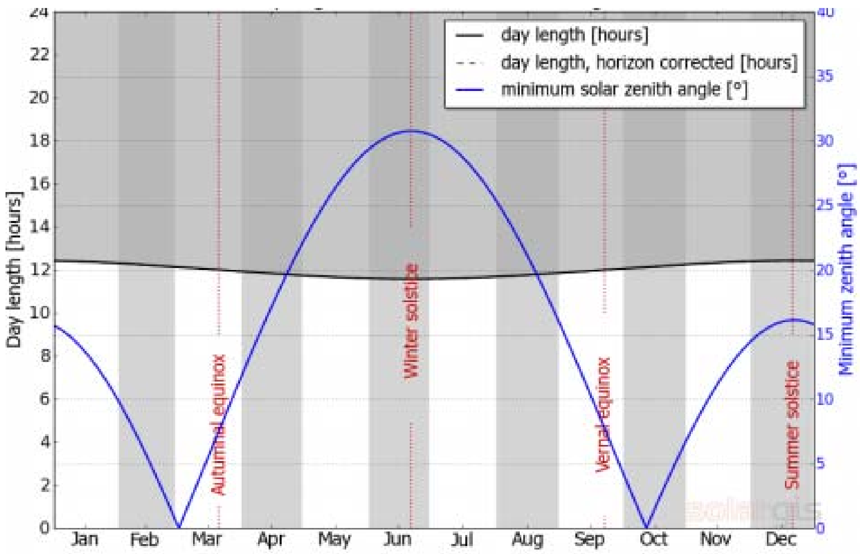

Fig. 7. Solar zenith angle and day length and in Surabaya

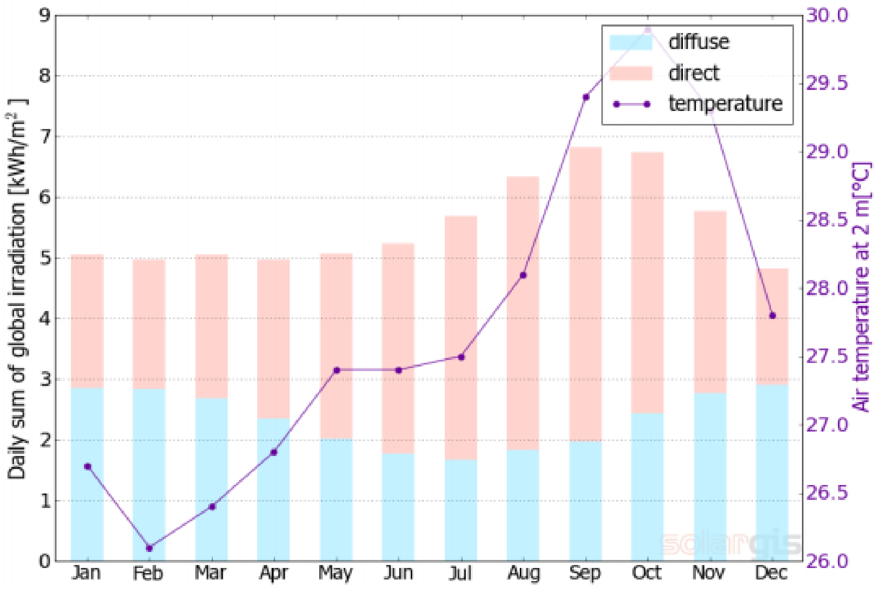

Fig. 8. Global irradiation and air temperature in Surabaya

In past, usually, the global radiation is 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. 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 air temperature in Surabaya varies from 26 – 31 ^{o}C as as shown in Fig. 8

3.2 Solar Roof Effective Area

Total area of the roofs for all buildings of the campus was found about 12,280 m^2, means that total the area of the roof is 14% of the land. It is obviously seen that each of the roof for all buildings consists of four sides. The roof area for each directions were found: North East (NE) with 329 m^2 or 26% ; South East (SE) with 2731 or 22% , South West (SW) with 3409 or 29%, and North West (NW) 353 or 23% of total roof area respectively. The area of each side and direction for each building is summarized in Table 2.

Previous study located in Spain reported that useful roof surface area is ranging between 78,9% - 97,4 % of total roof area, for similar type of roof [14]. In this simulation work the value of 85% is assumed. The estimated useful area of the roof buildings is shown in the right column on Table 2.

Sitting of the PV panels, using an exported and scaled map image with Google Sketch up software, for the chosen roof of representative building showed that up to 85% of the roof area could be placed by panels installation. The sitting panels are as illustrated in Figure 3. Estimated useful roof surface area for library building is presented in Table 3. By installing monocristaline PV module parameters the panel capacity the roof could be estimated through simulation. The total capacity of the panels that can be installed on the roof was found about 233.4 kWp.

Table 2. Roof surface area and orientation for buildings of the university campus

No	Building's Name	Total Roof	Roof Area (m^2) and Orientation				Estimated Useful Area (m^2)
			NE	SE	SW	NW	
1	EA	516	34	224	34	224	439
2	EB	324	42	120	42	120	275
3	EC	304	26	126	26	126	258
4	ED	250	90	35	90	35	213
5	FA	200	50	50	50	50	170
6	FB	380	140	50	140	50	323
7	FC	400	40	160	40	160	340
8	FD	400	160	40	160	40	340
9	FE	440	50	170	50	170	374
10	FF	420	170	40	170	40	357
11	FG	320	40	120	40	120	272
12	HA	420	170	40	170	40	357
13	HB	408	142	62	142	62	347
14	TA	340	30	140	30	140	289
15	TB	400	160	40	160	40	340
16	TC	480	40	200	40	200	408
17	TD	360	140	40	140	40	306
18	TE	360	140	40	140	40	306
19	TF	360	140	40	140	40	306
20	TG	420	40	170	40	170	357
21	PA	280	40	100	40	100	238
22	PB	330	130	35	130	35	281
23	PC	480	200	40	200	40	408
24	PD	380	160	30	160	30	323
25	PE	380	160	30	160	30	323
26	Library	1400	373	187	563	277	1.190
27	Canteen	560	130	150	130	150	476
28	Int.	408	142	62	142	62	347
29	Post grad.	460	40	190	40	190	391

Table 3. Roof segment energy potential for library building

Segment	Orientation	Total Roof Area (m^2)	Estimated Useful Area (m^2)	Estimated PV panels Capacity (Wp)
r1	SW	100	85	16.660
r2	SE	104	88	17.248
r3	NW	104	88	17.248
r4	SW	90	77	15.092
r5	NW	90	77	15.092
r6	SW	373	317	62.132
r7	NW	83	71	13.916
r8	SE	83	71	13.916
r9	NE	373	317	62.132
				Total: 233.436

The total PV panels capacity of the roof for all buildings of University of Surabaya then could be estimated using the numbers from Table 2 and from simulation results for library building on Table 3. Calculation showed that, of 12,180 m^2 roof area for all buildings, about 10,353 m^2 could be use for panels installation. The total capacity of the panels is about 2,030 kWp or 2,03 MWp. The capacity consists of four roof directions, i.e., 630 kWp, 535 kWp, 668 kWp and 553 kWp respectively for NE, SE, SW and NW roof directions.

3. 3 PV Specific Energy Production

SolarGIS-pvPlanner simulation was carried out to estimate the specific energy production of the PV system in Surabaya by varying solar geometry parameters. Table 5 shows the the specific energy production of a crystalline silicon based PV system in Surabaya. In the Table Esm refers monthly sum of specific electricity production in kWh/kWp; while Esd is daily sum of specific electricity production in kWh/kWp. The results in the table is for each for each of panel orientation of : azimuth of 315° (NW), 45° (NE), 225° (SW), and 135° (SE) with inclination 5°, 13°, 0° respectively. It is assumed that mounted system is the most suitable for the roof instalation [10] .

Table 4. Specific Energy production of PV system in Surabaya with variation of azimuth angle

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

From the simulation, it was found daily average specific energy production for crystalline silicon panel for each direction and, by setting 35^{o} tilted panels as shown in Table 5. The tilt angle was chosen following the slope of the roof. Changing of PV panel type in simulation parameter resulted in slightly different results. For all cases the panel facing NE would produce the highest energy. It can be understood as Surabaya is located at South of equator line.

Monthly energy production of grid connected PV system could be estimated using the specific energy production values and the roof panel capacity. For an optimistic case, where all of available roof at the university would be installed by PV panels, monthly energy production would be ranging from 248 mWh to 362 mWh per month. The numbers are after the shading lost of 2%[9], as previously mentioned, has been included in the calculation. Figure 9 shows total monthly energy production come from total of roofs facing SE, SW, NE, and NW respectively.

Table 5. Daily specific energy production in kWh/kWp of Silicon PV Panels in Surabaya following the roof tilt.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Avg
NW	3.75	3.73	3.83	3.82	3.94	4.12	4.45	4.86	5.09	4.95	4.20	3.55	4.19
NE	3.73	3.74	3.89	3.93	4.11	4.32	4.65	5.00	5.15	4.92	4.16	3.52	4.26
SE	3.79	3.74	3.79	3.72	3.79	3.92	4.23	4.67	4.95	4.89	4.22	3.59	4.11
SW	3.79	3.74	3.79	3.72	4.79	4.92	4.23	4.67	4.95	4.89	4.22	3.59	4.11

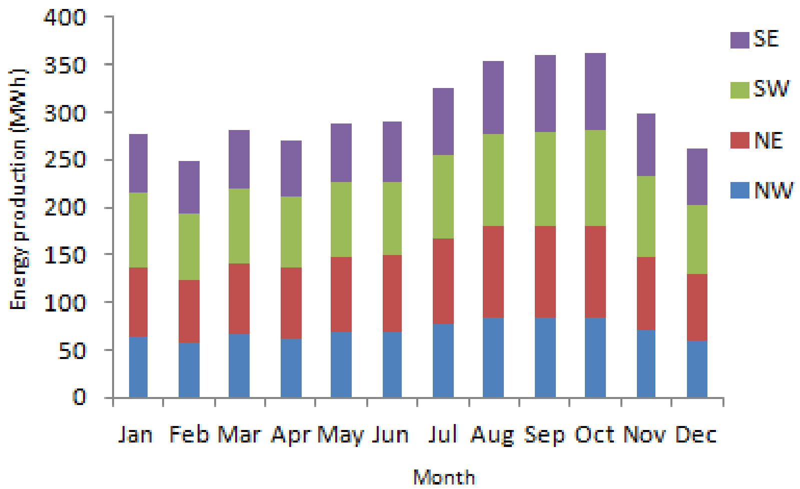

Fig. 9. Monthly energy production of rooftops mounted PV system

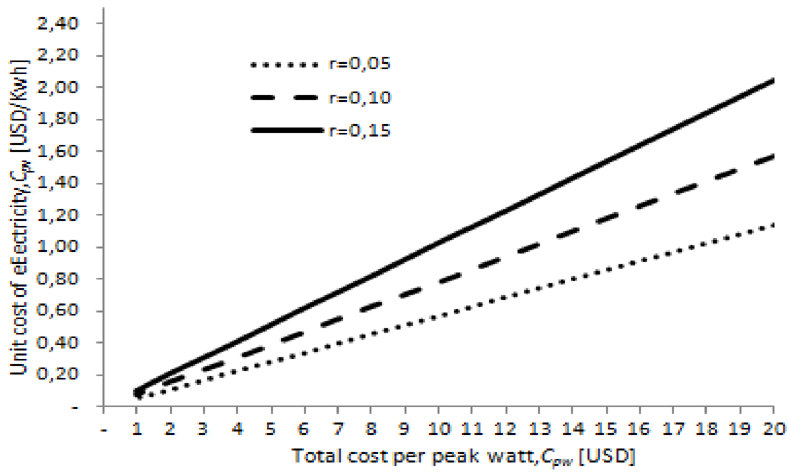

Fig. 10. The unit cost of PV electricity versus total cost per watt with various of rate of return, *r*

3.4 Economic Analysis

Equation 5 was using to make a numerical calculation to estimate real unit cost of PV electricity. In the calculations the following parameters values were considered: t = 20 years, n = 5%, F = 20%, and m = 0 and simulated for four scenarios of r i.e., 0.05, 0.10, and 0.15 respectively. The result of calculation is plotted in a graph as shown in Figure 10. With conversion value from the graph, at present time the means the unit cost of electricity *Cpw* is range 0.20 – 0.40 USD/kWh. For comparison, currently feed-in tariffs for solar PV electricity in Indonesia is 0.25 USD/kWh.

4 Conclusions

Photovoltaic solar energy simulation of rooftops of University of Surabaya campus buildings in Surabaya, Indonesia has been carried out. Total area of the roofs for all buildings of the campus was found about 12,280 m2. The roofs consist of area from four different direction: North East (NE) with 329 m2 or 26% ; South East (SE) with 2731 or 22% , South West (SW) with 3409 or 29%, and North West (NW) 353 or 23% of total roof area respectively. The total capacity of the panels that could be installed is about 2,030 kWp or 2,03 MWp with monthly energy production would range from 248 mWh to 362 mWh per month. From the calculation of unit cost of electricity by PV systems, it is obviously seen that PV system seem have the potential to provide power at competitive cost in comparison to other alternative options of power generation, especially through the technology developments.

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