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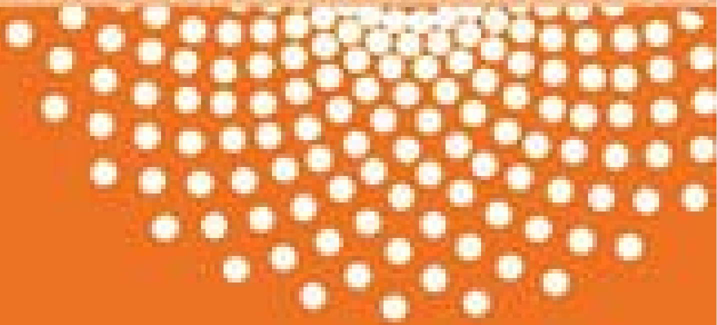

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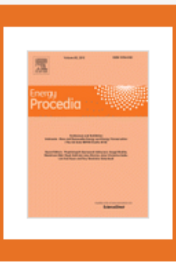

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Conference and Exhibition Indonesia - New and Renewable Energy and Energy Conservation (The 3rd Indo EBTKE-ConEx 2014)

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Edited by Praptiningsih Gamawati Adinurani, Anggi Nindita, Maizirwan Mel, Hugh Outhred, Cary Elcome, Zane Vincevica-Gaile, Lim Kok Kuan, Roy Hendroko Setyobudi

Volume 65, Pages 1-394 (2015)

Last, but not least, we hope Indo EBTKE-ConEx 2014 provided an interesting program and served as an excellent forum for innovative and technical discussions. We look forward to seeing you all at Indo EBTKE-ConEx 2015.

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Techno-Economic Simulation of a Grid-Connected PV System Design as Specifically Applied to Residential in Surabaya, Indonesia

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Abstract

This paper simulates the feasibility of installing a grid-connected photovoltaic (PV) system in a typical residential in Surabaya, Indonesia. The study was conducted to evaluate the technical, economic and environmental aspects of PV system for supplying of household electricity energy needs. A 1 kWp grid-connected PV system simulation is carried out with PVsyt and RETScreen software. The simulation expected to help in demonstrating the advantages and challenges of installing of a grid-connected PV system for residential in Surabaya.

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Peer-review under responsibility of the Scientific Committee of EBTKE ConEx 2014

Keywords: Grid-connected; photovoltaic; PVsyst; residential; RETScreen; simulation

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Nomenclature

CO_2	carbon dioxide	**MPP**	maximum power point
GHG	greenhouse gas	**NO_x**	nitrogen oxides
IAM	air mass of one	**RETScreen**	renewable energy system simulation software
IRR	internal rate of return	**PVsyst**	photovoltaic system simulation sofware

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Peer-review under responsibility of the Scientific Committee of EBTKE ConEx 2014
doi:10.1016/j.egypro.2015.01.038

kWp	kilo watt peak	**SO_2**	sulfur dioxide
d	1 day = 24 h = 86 400 s	**yr**	1 year = 365 d
h	hour		

1. Introduction

The importance of renewable energy resources which are environmentally friendly and reliable energy technology has been increased for a substitute to replace fossil fuels, related to the current energy shortage, global economic growth and environmental pollution [1]. Indonesia area lies around equator line, it has a tropical climate where solar energy is available throughout the year. Under such a climatic condition, PV systems should become a favorable renewable energy source.

Grid connected PV power generation system has the advantage of more effective utilization of generated power [2]. While most of current research concentrates on autonomous PV system, there appears to be a few studies on grid-connected PV system in residential power systems [3]. Despite the feasibility analysis of PV systems for residential [4], very limited studies had been presented with quantitative information on the optimized design of grid connected PV system for residential application in urban and tropical climate such us Surabaya. Limited information has hindered seriously the application of solar PV system for residents [3].

Simulation techniques are commonly used to demonstrate and analyze the performance and feasibility of various components of the PV system before they are put in a real installation, hence reducing materials and installation costs [4 – 6]. This work presents a techno-economic simulation of grid-connected PV system design as specifically applied to residential in Surabaya, Indonesia. The simulation expected to help demonstrate the advantages and challenges of installing of a grid-connected PV system for residential in Surabaya.

2. Research method

In previous study [4] it was reported that there are several types and sizes of house commonly built in Surabaya. In term of installed electricity capacity by national grid, the houses with installed 1 300 kVA are dominating the houses in Surabaya. Hence, the analysis in this work is focused on this type of house. Referring to the previous study [4] where the basic energy needs for a typical targeted household in Surabaya is 3.2 kWh· d^{-1}, and considering of some additional energy might be needed, the simulation in this study was carried out for a 1 kWp capacity of grid-connected PV system. A simple diagram for a grid connected PV system is shown in Fig 1.

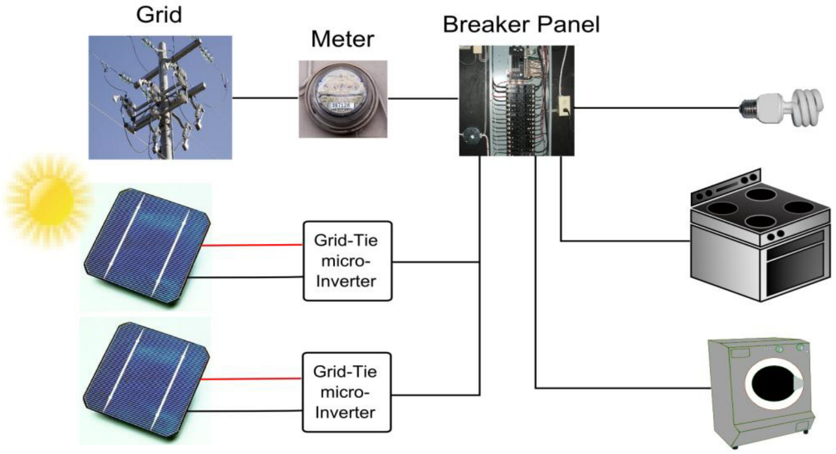

Fig 1. Diagram of a grid-connected PV system (image from http://en.wikipedia.org/wiki/Photovoltaic_system)

The system are simulated with RETScreen [7] and PVsyst [8,9] software in term of: technical; energy model; cost analysis; green house gas analysis; and financial analysis. Financial analysis and simulation is conducted for two scenarios or assumptions :(i) grid-connected system without incentive (where the price of PV electricity sent to the grid is the same as the price of electricity from the grid), and (ii) the condition with feed-in tariff of USD 0.25 $(\text{kWh})^{-1}$. The Minister of Energy and Mineral Resource of Indonesia recently issued Regulation No. 17 of 2013 to stipulate among other things: (i) new procedures for purchase of power from solar photovoltaic power projects in Indonesia which require developers to bid in capacity quota tenders; and (ii) feed-in tariff for solar photovoltaic power projects (at the certain capacity) of USD 0.25 $(\text{kWh})^{-1}$, or USD 0.30 $(\text{kWh})^{-1}$ if the photovoltaic module contains 40 % or more local components [10]. However, the regulation is currently not valid for small capacity and/or recidential/individual PV power generation.

RETScreen is software analysis that enables feasibility analysis for various renewable energy systems including grid-connected PV system. One of its main features is the weather database [11]. The software uses the data from the nearest airport, to estimate the amount of insolation available. In this work the data from Juanda Airport is utilized for estimating of solar insolation in Surabaya. Juanda airport is located relatively closed to Surabaya, therefore the same level of solar radiation were expected. PVsyst is a computer software package to study, sizing, simulating 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. Moreover, PVsyst allow user to evaluate the simulation results in order to identify the best technical and economical solution and closely compare the performances of different technological options for any specific photovoltaic project. Tools provides the database meteo for particular sites and components management. It also peforms a wide choice of general solar tools (solar geometry, meteo on tilted planes, etc.), as well as a powerful mean of importing real data measured [9].

Table 1.General parameters for PVsyst simulation

Parameters	Input/Values
Project name	Residential 1kWp grid-connected
Site	Surabaya
Field type	Fixed tilted plane
Field parameters	Plane tilt 15°, azimuth 0.0 (facing north)
System type	Grid-connected
Simulation (data)	Generic meteo data
Pv modules	Gepv-100
Number of modules	10 unit
Unit power (one module)	100 Wp
Nominal power	1.00 kWp
Mpp voltage	15.7 V
Mpp current	6.4 a
Inverter	BBS-1000
Inverter unit power	1.0 kW
Number of inverter	1 unit
Pnom AC of inverter	1.00 kW

The data parameters of location for the simulation are as following: Site: Surabaya; Country: Indonesia; geographic coordinates: –7°19'S and112°46' E; altitude: 3 m. Weather data for PVSyst simulation was obtained from RETScreen database, consisting of daily average of solar radiation, temperature, and wind speed. The value of Albedo effect for urban sites commonly ranges from 0.14 to 0.22, and in this simulation we used the average of 0.2. [9]. The feature tools of the "project design of grid-connected system" of PVsyst was used in the simulation work. For optimization, all the other known and changeable paremeters such us type of PV modules, orientation, modular size, tructure of arrays, size of inverters, etc., were simulated, while defult values were used for unknown parameters. Tabel 1 shows general parameters used in the simulation.

3. Results

The technical simulation results for 1 kWp grid-connected PV system in this work consists a number of significant data i.e., balances, meteorological data and incident energy, incident energy, optical factors, system loses, inverter loses, energy used and normalized performance coefficients. The results of the simulation can be performed on daily, monthly, or annual basis.

3.1. System balances

System balances consists of horizontal global radiation, ambient temperature, global incident in collector plane effective global, collector for IAM and shading, array virtual energy at MPP, effective energy at the output of the array, and energy supplied to the user. The simulation elucidated system balances on annually basis in Table 2.

Table 2. The annual system balances

Parameters	**Values**	
Horizontal global radiation	1 886.8	kWh · m^{-2}
Ambient temperature	27.72	°C
Global incident in coll. plane	1 884.7	kWh · m^{-2}
Effective global, coll. for 1AM and shading	1 826.2	kWh · m^{-2}
Array virtual energy at MPP	1 428.6	kWh
Effective energy at the output of the array	1 366.0	kWh
Energy supplied to the user	7.76	%

3.2. Incident energy

Incident energy gives information on the horizontal diffuse irradiation, wind velocity, sky diffuse incident in collector plane, albedo incident in collector plane, incident sky diffuse/global ratio, global corrected for incidence (IAM), effective global, corrected for IAM and shadings, effective diffuse, and corrected for IAM and shadings.

Tabel 3. The annual incident energy

Parameters	**Values**	
Horizontal diffuse irradiation	835.86	kWh · m^{-2}
Ambient temperature	27.72	°C
Wind velocity	2.5	m · s^{-1}
Global incident in coll. plane	1 884.7	kWh · m^{-2}
Sky diffuse incident in coll. plane	817.16	kWh · m^{-2}
Albedo incident in coll. plane	11.379	kWh · m^{-2}
Incident sky diffuse/global ratio	0.434	
Horizontal global radiation	1 886.8	kWh · m^{-2}
Global incident in coll. plane	1 884.7	kWh · m^{-2}
Global corrected for incidence (IAM)	1 826.2	kWh · m^{-2}
Effective global, corr. for IAM and shadings	1 826.2	kWh · m^{-2}
Effective diffuse, corr. for IAM and shadings	783.68	kWh · m^{-2}

In addition, incident energy simulation also performs horizontal global radiation and ambient temperature as already showed in Table 2. Table 3 shows the summary of annual values for incident energy parameters.

3.3. Optical factors

Optical factors consists of transposition factor global incident over global horizontal, IAM factor on beam IAM factor on global, and combined IAM and shading factors on global incidence. The average value of the global incident over global horizontal was found at 0.999. Meanwhile, the other optical factors value shows 0.976.

3.4. Losses

The losses were categorized into detailed system losses and inverter losses. The component for system losses includes module quality loss, module array mismatch loss, Ohmic wiring loss, array virtual energy at MPP, array virtual energy at fixed voltage, and PV to user line Ohmic losses. On the other hand the inverter losses consists of available energy at inverter output, inverter efficiency, global inverter losses, inverter loss during operation (efficiency), inverter loss due to power threshold, inverter loss over nominal inverter power, inverter loss due to voltage threshold, and inverter loss over nominal inverter voltage. The summary for energy losses annual based is summarized in Table 4.

Table 4. Detailed system losses annually

Parameters	Values	
Module quality loss	39.232	kWh
Module array mismatch loss	30.628	kWh
Ohmic wiring loss	14.642	kWh
Array virtual energy at MPP	1 428.7	kWh
Array virtual energy at fixed voltage	62.706	kWh
PV to user line ohmic losses	39.232	kWh
Available energy at inverter output	1 366.0	kWh
Inverter efficiency	95.6	%
Global inverter losses	62.706	kWh
Inverter loss during operation (efficiency)	62.687	kWh
Inverter loss due to power threshold	0.020	kWh
Inverter loss over nominal inv. power	0.000	kWh
Inverter loss due to voltage threshold	0.000	kWh
Inverter loss over nominal inv. voltage	0.000	kWh

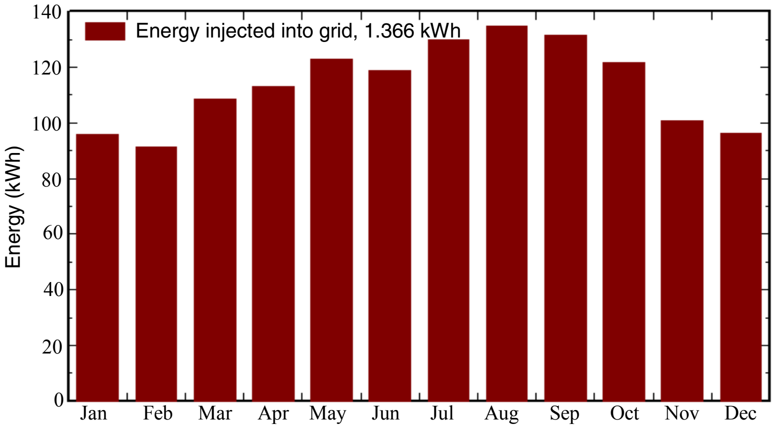

Fig 2. Monthly energy production of 1 kWp PV system

3.5. Energy use

The total amount of energy injected to the grid is 1 366 kWh · yr^{-1}. This number is the sum of monthly energy produced by the system that are slightly varies throughout the year. Monthly energy injected to grid is shown in Figure 2. The rate of energy injection as function of global incident radiation is shown in Figure 3.

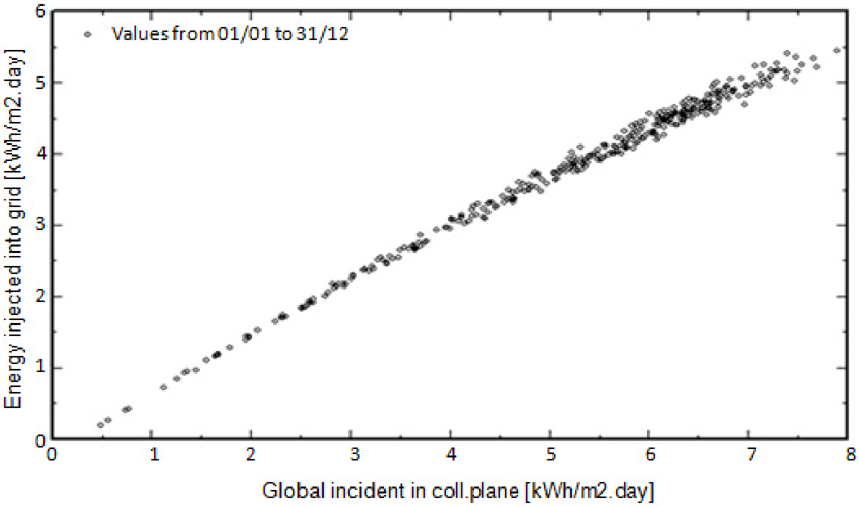

Fig. 3.Daily energy injected from 1kWp PV into grid as fuction of global solar incident.

3.6. Normalize performance coefficients

Normalize performance parameters values consist of reference incident energy in collector plane, normalized array losses, normalized array production, normalized system losses, normalized system production, array loss/incident energy ratio, system loss/incident energy ratio, and performance ratio. The summary of the values is performed in Table 5.

Table 5. Normalize performance coefficients

Parameters	**Values**	
Reference incident energy in coll. plane	5.16	kWh · m^{-2} · d^{-1}
Normalized array losses	1.250	
Normalized array production	3.91	kWh · $(kWp)^{-1}$ · d^{-1}
Normalized system losses	0.172	
Normalized system production	3.74	kWh · $(kWp)^{-1}$ · d^{-1}
Array loss/incident energy ratio	0.242	
System loss/incident energy ratio	0.033	
Performance Ratio	0.725	

4. Analysis and discussion

4.1. Technical analysis

The result of the simulation indicated the highest level of solar radiation in Surabaya occurred during September, with an average insulation on the horizontal surface of of 6.05 kWh · m^{-2} · d^{-1} and corresponds to average solar radiation of about 252 W · m^{-2} (with a 24 hour calculation based). The lowest level of the solar radiation was during June with an average solar insulation of 4.73 kWh · m^{-2} · d^{-1} or 197 W · m^{-2} of average solar radiation. From this value can be concluded that the potential of solar energy in Surabaya is relatively high in comparison with other places even in the same latitude around the equator. The periods of high level radiation, however, very much depends on the weather condition which recently relatively difficult to predict.

From a 1 kWp grid-connected PV system installed in Surabaya, the electricity that can be expected to be supplied into the grid is about 1 366 kWh · yr^{-1}. That means about that 3.75 kWh of electricity is produced by the PV system which being injected to the grid every day. According to previous work [4] a typical house hold in Surabaya which having 1 300 VA utility grid would need a basic demand about 3,2 kWh per day of electricity. It can be than concluded that basically 1 kWp of PV system would be able to supply the energy needs. (The assumption was the house uses fans as cooling system instead of air condition system).

The performance ratio, which indicates the ratio between actual yield (output of inverter) and target yield (output of PV array), in the simulation was found to be 73 %. Data showed that about 27 % of solar energy falling in the analyzed period is not converted in to usable energy due to factors such as losses in conduction, contact losses, thermal losses, the module and inverter efficiency factor, defects in components, etc. Commonly the value of performance ratio ranges from 60 % to 80 % [9]. The percentage of lost energy during generation process until finnaly injected into the grid is showed in Figure 4. It obviously seen that the highest lost number occur on the array and inverter losses which which are 22 % and 4.4 % respectively.

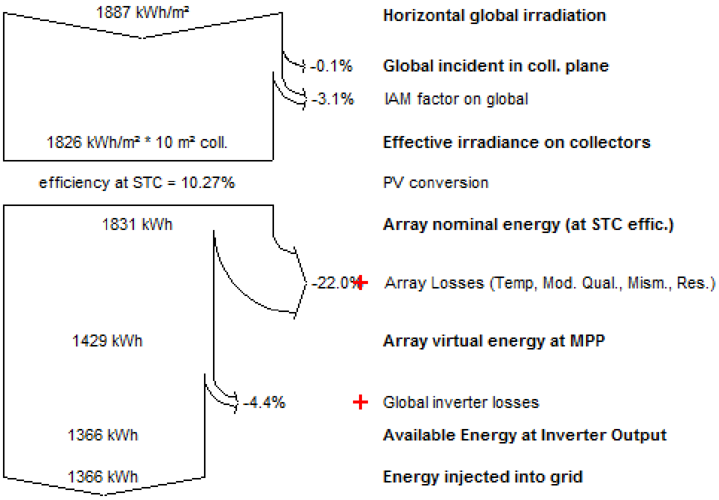

Fig.4. Grid-connected PV system loses diagram

In real installation, it is very important to match between the voltage of inverter and that of the PV array. It was achieved in the simulation with the selected inverter. Some inverters, however, have higher efficiency in certain voltage, therefore the PV array should adapt to this voltage of maximum efficiency. Use of several inverters cost more than using a single inverter with higher power [9].

4.2. Economic analysis

A small market survey on the retail prize of PV system components recently in Surabaya was carried out through the internet. It was found that there was variation of prize for each the components in term of different brands, as well as different vendors or suppliers. In this analysis the average prizes among of all surveyed data were used. The retail component prize and cost for installing of 1 kWp grid-connected PV in Surabaya is summarized in Table 6. Assuming that the price of one kWh of electricity is USD 0.10 $(\text{kWh})^{-1}$, then during one year the system will generated earning : 1 336 $(\text{kWh} \cdot \text{yr}^{-1})$ x USD 0.10 $(\text{kWh})^{-1} \times 1$ yr = USD 133.6 yr^{-1}. Life time for PV panels is considered about 25 years, while for inverters is 5 years.

Table 6. Cost component for 1 kWp PV system

Components	Retail Prized or Cost (USD)
PV panel 1 kWp	1 750
Inverters 1000 W	550
Cabling	100
Construction cost	400
Total	2 800

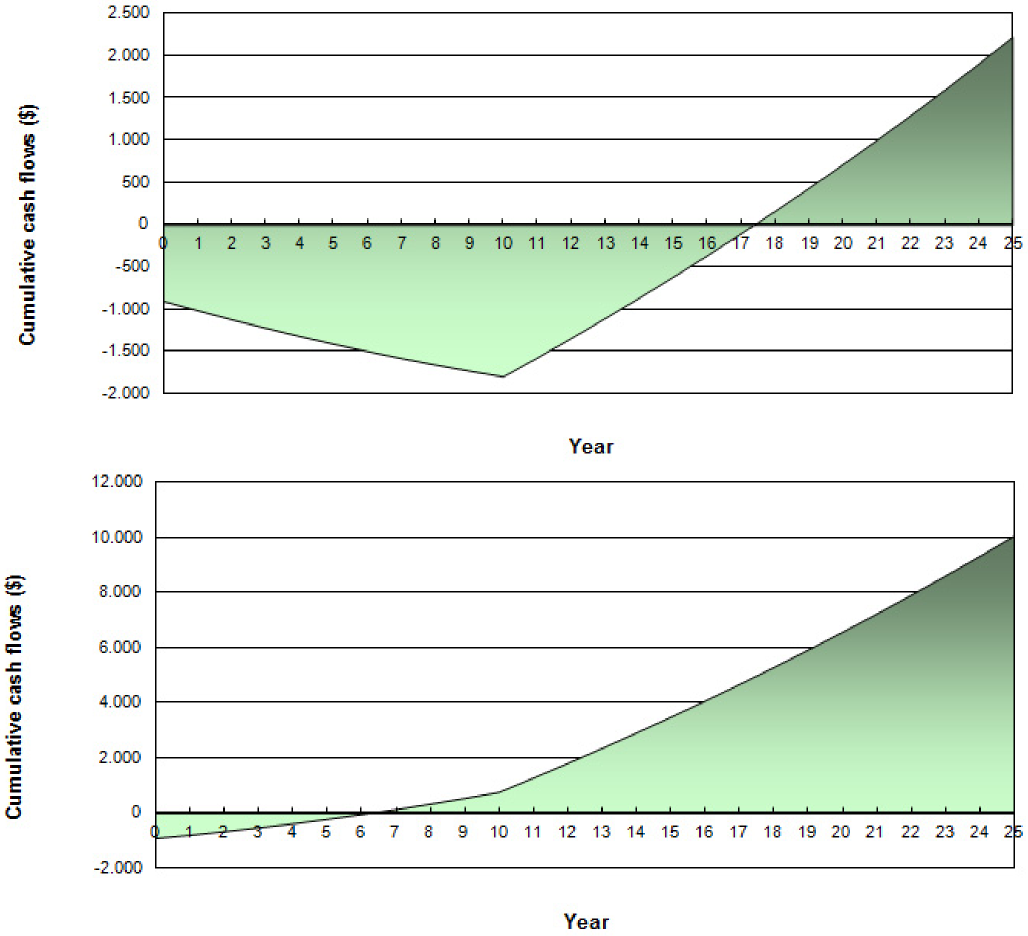

Fig 5. Cumulative cash flows of PV system: upper: without financial support; lower: with feed-in tarif 0.25 USD $(\text{kWh})^{-1}$

Financial simulation was carried out with RETScreen software with financial parameters: inflation rate 4 % ; debt ratio 70 %; debt interest rate 7 %; and debt term of 10 years. As previously stated, two scenarios was performed i.e., (i) grid connected system without incentive (where the price of PV electricity sent to the grid is the same as the price of electricity from the grid), and (ii) the condition with feed-in tariff of USD 0.25 $(\mathrm{kWh})^{-1}$. The simulation results is shown in Table 7.

Table 7. Financial viability of PV system with and without incentive

Financial viability	Without incentive	With Feed-in tariff (USD 0.25 $(\mathrm{kWh})^{-1}$)
Pre-tax IRR-equity	5.4 %	22.8 %
Pre-tax IRR-assets	0.7 %	10.2 %
Simple payback	20 yr	8 yr
Equity payback	17.6 yr	6.5 yr

It is obviously seen that without any financially support from government, at current time, a grid-connected PV system is not financially viable to design to meet the entire electrical need of typical residential house. Feed-in tariff of USD 0.25 · $(\mathrm{kWh})^{-1}$ which is applied, PV system would be feasible for investment. The cumulative cash flows over time for financial PV system with and without incentive is shown in Figure 5

4.3. Environmental analysis

Replacing of fossil fuel power generation with any kind of renewable energy resources would result in positive impact to the environment. The negative impact of burning fossil fuels for power plant is that it releases green houses gas (GHG) such as: nitrogen oxide (NO_x), sulphur dioxide (SO_2) and carbon dioxide (CO_2), besides it also produces large amount of ash that must be handled. Table 8 shows the green house reduction from using of 1 kWp solar panel in Surabaya to replace the electricity by burning of fossil fuel [9].

Table 8. Green house gasses reduction by 1 kWp PV system

Green house gasses from coal power plant	Per kWh	For annual energy production of *E = 1 336 kWh*
SO_2	1.24 g	1.66 kg
NOx	2.59 g	3.46 kg
CO_2	970 g	1 295 kg
Ash	68 g	90.8 kg

The amount of reduction of GHG as shown in Table 8 is just from applying PV system by a household. When the number of house installing PV increases, then the amount of reduction GHG should be mutliplied by the number of houses with PV systems.

5. Conclusion

The average daily global radiation available in Surabaya was 5.17 kWh · m^{-2}· d^{-1}, or approximately 1 887 kWh · m^{-2} · yr^{-1} based on 365 days per year. The highest insolation level was recorded at a value of 1 005 W · m^{-2}. Based on this solar energy potential, the 1 kWp grid-connected PV system could send electricity to the grid about about 1.3 MWh · yr^{-1} on average. Technically, it will meet basic electricity demand of a household in Surabaya.

There are no grants or incentives are currently being introduced by Indonesian government for a small scale grid-connected PV system, as results, an investment will take over 17,6 years before it starts to produce a profit.

That means at present time, without any financially support from government, a grid-connected PV system not financially viable to design to meet the entire electrical need of typical residential house in Surabaya. While, with by applying feed-in tariff at USD 0.25 $(kWh)^{-1}$ the payback time period will be about 6,5 years. Environmentally, the reduction rate of green house gasses (GHG) by applying of 1kWp PV system is estimated about 1.66 kg of SO_2; 3.46 kg of NO_x; 1 295 kg of CO_2; and 91 kg of ash per year.

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Energy Procedia

Country	United Kingdom - SIR Ranking of United Kingdom
Subject Area and Category	Energy Energy (miscellaneous)
Publisher	
Publication type	Conferences and Proceedings
ISSN	18766102
Coverage	2009-ongoing
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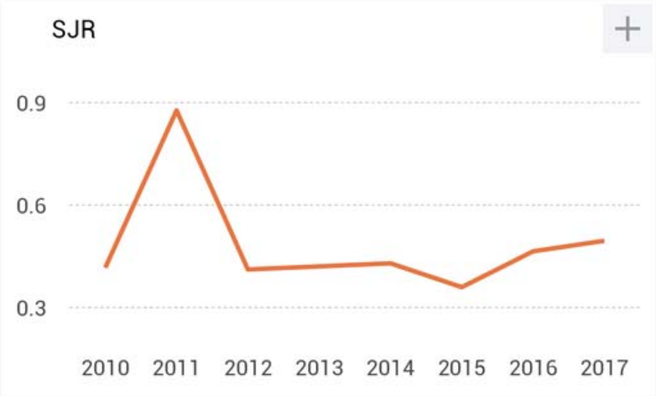
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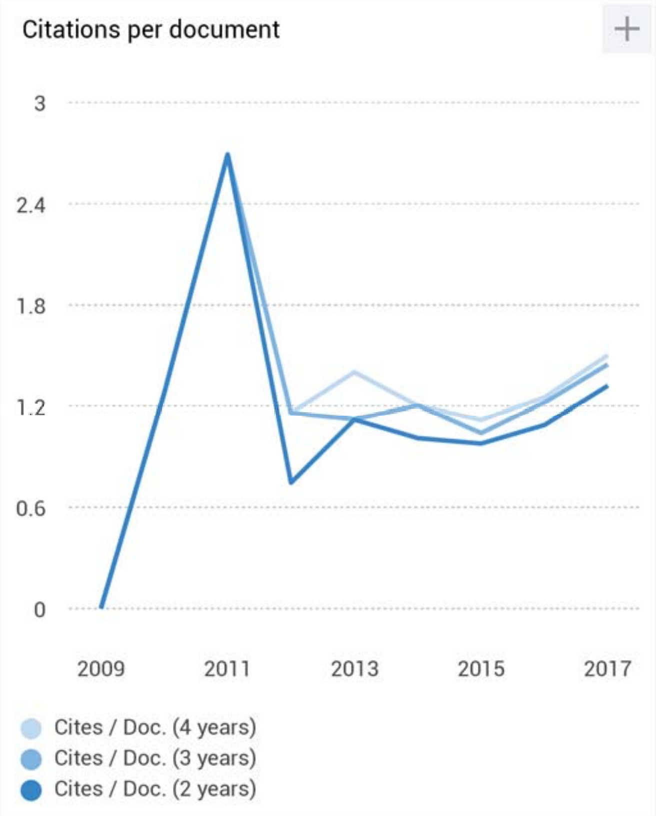
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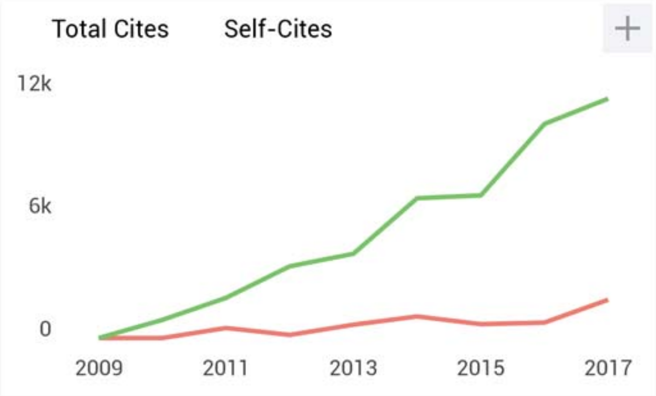
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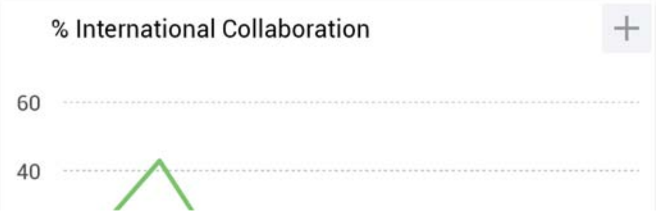
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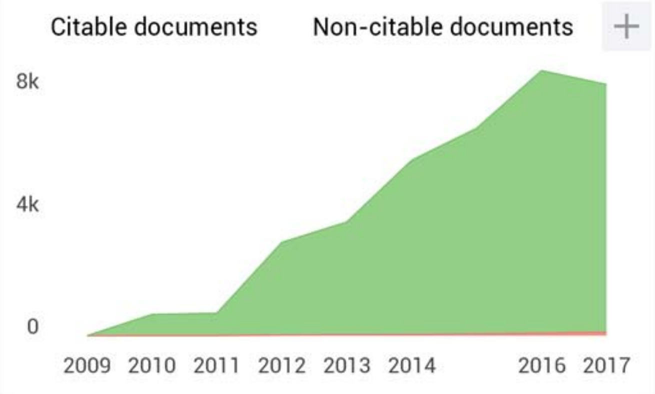

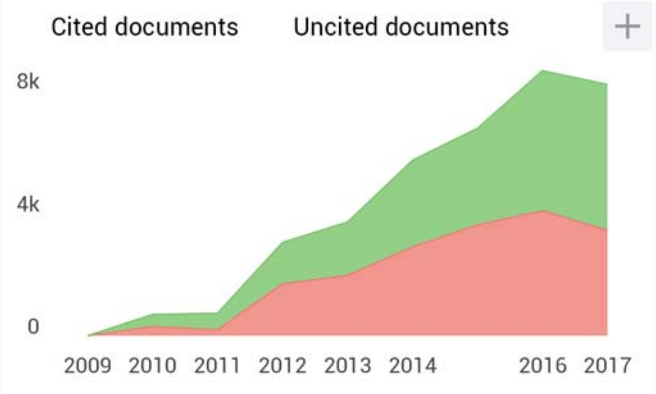

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