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Performance and economic analysis of a 27 kW grid-connected photovoltaic system in Suriname

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Abstract: The performance of a grid-connected photovoltaic (PV) system, under the Surinamese weather conditions, is monitored and reported. A measurement and data-logging system provides inputs for the calculation of selected standard key performance indicators (KPI). Calculated KPI's are compared to expected values obtained from modelling the system using the PVSyst software. In addition, results from selected comparable studies are also used to compare the computed KPI's. Using one year data, the annual energy yield (E_{ac}) totalled 37 MWh. This value is 6% higher than the one obtained from the modelling software. The calculated performance ratio (*PR*) and capacity factor (*CF*) of 74.5 and 15.5%, respectively, are also higher than the ones obtained from PVSyst. The difference can be attributed to the irradiance data (satellite data, monthly averages) used for input in the PVSyst software. The above mentioned calculated values for the *PR* and *CF* compared favourably with internationally reported values for systems located in regions with similar weather patterns. Using a total investment cost of 109,000 USD the levelised cost of energy (LCOE) calculated with the RETScreen software equals USD 0.36 /kWh. This LCOE is three times the current energy price in Suriname.

1 Introduction

Suriname, a sovereign state in South America, has a population of ∼500,000 people. About 90% of the population lives in the coastal area while 10% lives in the Hinterland [1]. Suriname has a humid tropical climate with four seasons namely a short- and long-dry season and a short- and long-rainy season. The average temperature throughout the whole year varies between 21 and 32°C. There are no extreme weather conditions like hurricanes, storms and cyclones.

The electrical energy generated in Suriname is produced by centralised power plants using diesel fuel and hydropower, with energy transmitted over long distances to consumers. Around 50% of the generated electrical energy in the coastal area is provided by a renewable energy source (hydro) and the remaining is generated by thermal power plants [2]. The other large renewable energy power plant is a 5 MW PV-plant, which is part of the private electrical network of a mining company.

In the Hinterland, the communities are supplied with electricity from diesel generator sets, running for 4–6 h per day. In addition, small stand-alone PV systems, wind turbines and micro-hydro systems provide electricity in some villages in the Hinterland. At Palumeu, a village ∼350 km from the capital, several small home PV-systems (SHS) totalling 40 kW were put into service in 1994. Lack in experience within the community in operating and maintaining the SHS-systems resulted in batteries failing after just one year of operation. Also, there was no system put into place to cater for the replacement of failing or aging equipment. Similar projects, using different types of RE-technologies, were carried out in several Hinterland communities, all with very low success rates. The main reasons of the failures were flaws in the design, insufficient knowledge about the operation and maintenance and lack of follow-up due to internal conflicts. In contrast, some privately owned RE-systems have been successfully operating for years [3, 4].

A 27 kW grid-connected PV power plant was commissioned in March 2015 in Paramaribo, the capital of Suriname. This pilot project has two objectives:

- to promote and demonstrate the application of grid-connected PV systems in Suriname and
- to get insight on system design, resource assessment and operation and maintenance of grid-connected PV systems.

To meet the objectives of this project, data has been monitored and performance analysis has been carried out, using the guidelines established by the International Energy Agency (IEA). Thus providing insight into the long-term performance of PV systems under actual operating conditions in Suriname.

Internationally several studies have been conducted in the recent years regarding the performance analysis of PV systems. A brief review of selected studies follows. Sharma and Chandel [5] conducted the performance analysis of a 190 kW_p grid interactive solar PV power plant in India. Ghouari *et al.* [6] reported on the data monitoring system and performance analysis of a 1.6 kW_p grid connected PV system in Algeria. Sundaram and Babu [7] also conducted a study on the performance evaluation and validation of 5 MW_p grid connected solar PV plants in South India. Table 6 provides an overview of the reported results. Very little has been published on the performance analysis of PV systems in the Caribbean and Latin America regions. This study aims at filling that void.

2 System description

The 27 kW PV system is located at the headquarters of the State Oil Company Suriname (SOM), in Paramaribo (Lat.: 5.80°N; Long.: 55.20°W), and is part of the company's private low-voltage electrical distribution network. This 480 V/60 Hz grid is connected to the utility high-voltage grid via a 500 kVA transformer. The total installed capacity of the PV system equals 9% of the peak load measured at headquarters (mainly offices) of SOM. Furthermore, the installed capacity of the PV system is also lower than the minimum load measured at SOM, thus ensuring no power is fed into the utility high-voltage grid. Fig. 1 shows the PV system with the main components.

The system contains 108 polycrystalline PV panels manufactured by Linyang solar. Each panel has a rated maximum power (P_{max}) of 250 W. Twelve PV panels are connected in series to form a string. There are nine strings, each connected to the dc-input of a three-phase inverter. There are three 3-phase inverters

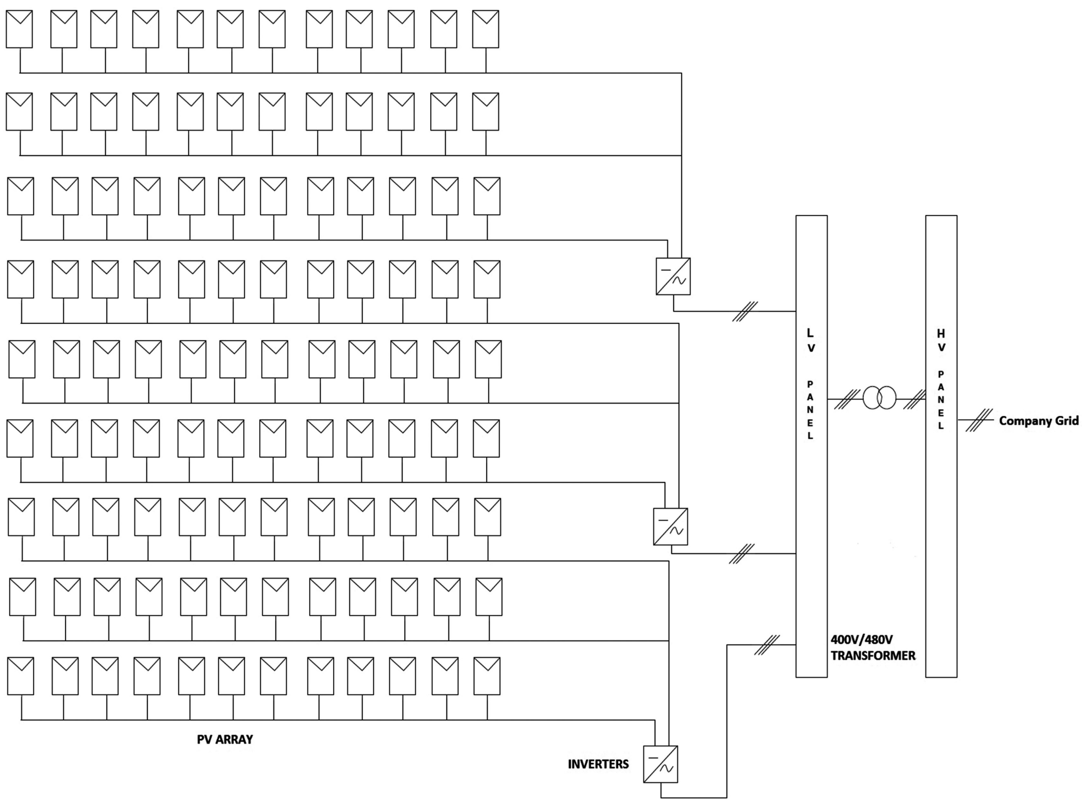

Fig. 1 *Schematic diagram of the 27 kW PV system*

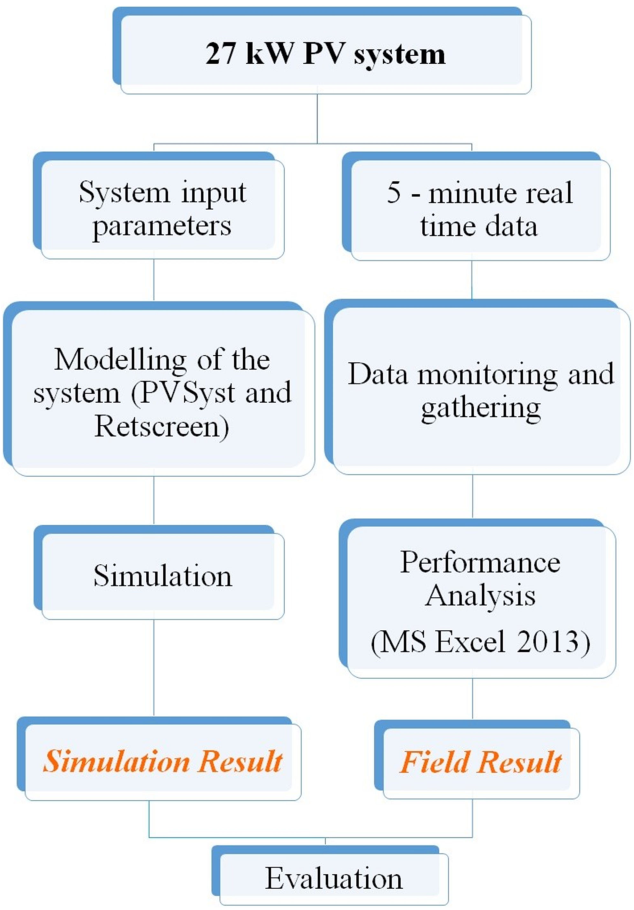

Fig. 2 *Chart flow of methodology*

from Huawei, each with a rated output power of 10 kVA. The inverters have their own smart logger, Smartlogger 1000, which enables monitoring and storing of operational data on a PC.

A weather station together with a monitoring device manufactured by Sungrow is also installed at SOM. This enables the measurement and recording of the environmental parameters: irradiance, ambient temperature, PV-panel temperature, wind speed and wind direction.

Simultaneous recording of instantaneous measurements from both measurements systems is ensured by installing the required software on one PC. Recorded data is then imported into MS Excel for further analysis.

3 Methodology

3.1 Data analysis with real-time data

Twelve months of data, gathered from the inverters, was available for analysis. This data included the instantaneous DC input parameters as well as the AC output parameters (voltage, current, energy and power). The logging interval for the inverters parameters equals 5 min. The acquired data was imported into MS Excel 2013, which was then utilised to calculate the performance indicators using the equations listed in this paragraph (Fig. 2).

Firstly, irradiance data was analysed and as described in the literature [5–11] the performance analysis was conducted using eight key performance indicators (KPI's): *energy output, final yield, reference yield, PV module efficiency, inverter efficiency, system efficiency, performance ratio and capacity factor*. The calculation and comparison of above mentioned performance indicators is carried out on a monthly basis for one year (April 2015–March 2016).

3.1.1 Irradiance:

Due to a combination of factors, reliable data from the weather station at SOM was not available for the first 10 months of operation. As a substitute, for the first 5 months (April–August) solar irradiation data available from NASA (for Paramaribo), and for the next 5 months (September–January) irradiance data measured at Anton de Kom University of Suriname (AdeKUS) were used for the analysis. Solar irradiation data from NASA was utilised because ground measurement data was not available for the first 5 months. The distance between SOM and AdeKUS is 1.62 km. For the last 2 months (February–March), ground measurement data was available at SOM. The details of the data are given in Table 1.

3.1.2 Energy generation: The total daily DC energy generated by the PV system (E_{dc}) can be calculated with the following equation:

$$E_{dc,d} = \sum_{t=1}^{t=T_{rp}} V_{dc} \times I_{dc} \times T_r$$
$$T_r = \text{the recording time interval} \tag{1}$$
$$T_{rp} = \text{the reporting period}$$
$$N = \text{the number of operating days of plant in a month}$$

The monthly DC energy generated by the PV system is given by

$$E_{dc,m} = \sum_{d=1}^{N} E_{dc,d} \tag{2}$$

The total daily AC energy generated by the PV system (E_{ac}) which is fed into the utility grid is given by

$$E_{ac,d} = \sum_{t=1}^{t=T_{rp}} V_{ac} \times I_{ac} \times T_r \tag{3}$$

The monthly AC energy generated by the PV system is given by

$$E_{ac,m} = \sum_{d=1}^{N} E_{ac,d} \tag{4}$$

where $P_{ac} = V_{ac} \times I_{ac}$ is the AC power output.

3.1.3 Yield: The term *final yield* (Y_f) represents the time taken by the PV to generate E_{ac} with respect to its nominal power capacity. Hence it becomes the ratio of final output power generated (E_{ac}) to the rated PV power as specified by the manufacturer at standard temperature conditions.

The daily final yield is given by

$$Y_{f,d} = E_{ac,d}/P_{PV(rated)} \tag{5}$$

The monthly average daily final yield

$$Y_{f,m} = \left(\frac{1}{N}\right) \times \sum_{d=1}^{N} Y_{f,d} \tag{6}$$

Table 1 Solar irradiation data details

Irradiance data source	Resolution	Available	Synthesized year
NASA	daily average solar irradiation per month (kWh/m^2/day)	1 year	5 months (April 2015–August 2015)
AdeKUS	5 min irradiance (W/m^2)	7 months	5 months (September 2015–March 2016)
SOM	5 min irradiance (W/m^2) and daily total solar irradiation (kWh/m^2/day)	2 months	2 months (February 2016–March 2016)

Reference yield (Y_r) yield is the total in-plane solar insolation or global in plane horizontal insolation divided by the reference irradiance under standard temperature conditions which is 1 kW/m^2

$$Y_{r,d} = T_r \times \frac{\sum_{day} G_i}{G_{STC}} \tag{7}$$

The reference yield depends on the daily in-plane solar radiance. It is a measure of theoretical energy available at a given location.

3.1.4 System conversion: *PV module efficiency* (η_{pv}) represents the effective energy generated by the module with respect to the available radiation. The instantaneous PV array efficiency

$$\eta_{pv} = P_{dc}/(G_i \times A_m)$$
$$P_{dc} = \text{instantaneous DC power generated by the PV array system}$$
$$G_i = \text{instantaneous global solar irradation}$$
$$A_m = \text{area of the PV module} \tag{8}$$

The monthly average PV module efficiency is given by

$$\eta_{pv,m} = E_{dc,d}/(G_i \times A_m) \times 100\%$$
$$E_{dc,d} = \text{total daily DC energy output} \tag{9}$$
$$G_i = \text{total monthly global solar irradation}$$

The instantaneous *inverter efficiency* (η_{inv}) is given by (see (10)) The monthly inverter efficiency is given by

$$\eta_{inv,m} = \frac{E_{ac,d}}{E_{dc,d}} \times 100\%$$
$$E_{ac,d} = \text{total daily AC energy output} \tag{11}$$

The instantaneous s*ystem efficiency* (η_{sys}):

$$\eta_{sys} = \eta_{pv} \times \eta_{inv} \tag{12}$$

3.1.5 Performance ratio (PR) and capacity factor (CF): The *PR* quantifies the overall effect of losses, incomplete use of irradiation and component failures on the rated output (see (13)) *CF* of a power plant is a measure of its actual output over a specific period of time, to its rated output. The CF compares how much electricity the power plant actually produces with the maximum it could produce at continuous full power operation during the same period

$$CF = \frac{E_{ac,annual}}{P_{(PV)rated \times 8760}} \tag{14}$$

or

$$CF = \frac{\text{h/day of the peak sun}}{24\,\text{h/day}} \tag{15}$$

3.2 Simulation

In this study, PVSyst 6.3.9 and RETScreen 4.0 software were utilised to model and simulate the performance of the PV system. The financial analysis was carried out using the RETScreen 4.0 software.

$$\eta_{inv} = P_{ac}/P_{dc}$$
$$P_{ac} = \text{AC power output (power delivered by the inverters and fed into the utility grid)} \tag{10}$$
$$P_{dc} = \text{DC power output (power delivered by the PV modules)}$$

$$\mathrm{PR} = \frac{\mathrm{AC\ yield\ (kWh)}}{\left(\mathrm{Installed\ \ capacity\ \ (kWp)} \times \mathrm{Plane\ \ of\ \ array\ \ irradiation} \left(\frac{\mathrm{kWh}}{\mathrm{m}^2}\right)\right) \times 100\%} \tag{13}$$

$$\mathrm{AC\ yield} = \mathrm{AC\ energy\ output(kWh)}$$

Table 2 General parameters used in PVsyst

Parameter	Input/value
site	Paramaribo/Suriname (Lat.: 5.80°N, Lon.: 55.20°W)
field type	fixed tilted plane
field parameter	tilt 15, azimuth 15
planned power	27 kW
system type	Grid – connected
PV module	Linyang LY-Ba250P
inverter	Huawei technologies Sun 2000-10KTL
number of inverters	3
modules in series	12
number of strings	9

Table 3 Parameters for energy analysis

PV terms	Values
solar tracking mode	fixed
slope	15
electricity export rate	\$47–124/MWh[a]
PV type	Poly-Si
PV efficiency	15.6%
power capacity	27 kW
inverter efficiency	98.5%
inverter capacity	30 kW

[a]Fluctuating energy prices and exchange rates.

Table 4 Parameters for cost analysis

Costs	Values
initial costs	\$109,056
O&M	\$2181

Table 5 Parameters for financial analysis

Financial parameters	Values
fuel escalation rate	7.6%
inflation rate	3%
discount rate	8%
project life	25 years

PVSyst makes it possible to design, size and analyse PV systems. It makes also possible to simulate off-grid, on-grid, pumping and DC grid systems. It has databases for meteorological data (such as irradiance), PV modules, inverters and other equipment. RETScreen 4 is an Excel-based clean energy project analysis software tool that can be used to determine the technical and financial viability of renewable energy projects. This software is internationally used as an economical model for technical applications. In this study, the focus lies on the energy-, cost- and financial analysis and to conduct this, guidelines from the literature have been used [12–14].

After simulating the PV system with the two above mentioned software, the simulated and field results were compared. The chart flow of the methodology used for this study is shown in Fig. 2.

Data from NASA was used as the input meteorological data because this data was available in the databases of both software packages. The general input parameters and input values used for the simulation in PVSyst are given in Table 2.

The general input parameters and input values used for the simulation in RETScreen are given in Tables 3–5.

- Energy model: See Table 3.
- *Cost analysis:* According to National Renewable Energy Laboratory (NREL), fixed operational and maintenance cost (O&M) is \$19/kW/year for a PV system with the capacity of 10–100 kW [15] and according to Ringbeck and Sutterluetiit [16] the O&M ranges between 0.5 and 1.5% of the total installation cost. For this study, the annual O&M is assumed to be 2% of the installation cost (\$2181), as there is little experience on the operation and maintenance of PV systems (see Table 4).
- *Financial analysis:* The fuel escalation rate of 7.6% has been determined based on the annual fuel price per barrel, for the period 1983–2012 in [17]. The average inflation rate of the United States Dollar (\$) of 3% has been calculated using the historical annual average inflation rates for the period of 1983–2012 [17, 18]. According to the Fraunhofer Institute for Solar Energy Systems (ISE) the discount rate for renewable energy projects is 7% [19] and according to NREL it is 7.5% for commercial PV systems [20]. This led to the assumption of 8% for the discount rate (see Table 5).

4 Results and discussion

The performance results obtained from the actual measurements and simulations using PVSyst and RETScreen are given in this section.

4.1 Performance analysis results

4.1.1 Irradiance:

The available and calculated daily solar irradiation per month from each source for the period April 2015–March 2016 is given in Fig. 3.

The three available datasets of solar irradiation (G_i), were compared to each other. The daily average G_i per month (kWh/m^2/day) available from NASA was compared to the calculated daily average G_i per month, using the AdeKUS set and the SOM set. For the comparison the mean percentage error (MPE) statistical indicator was used [7] and the results are given in Table 6.

A positive value of MPE in columns 1 and 2 in Table 6, indicates that the monthly calculated value from ground measurement data is higher compared to the NASA data.

The difference between AdeKUS and SOM for the months February and March is relatively small in percentage. This is also the case for the months September to January, when comparing NASA with AdeKUS. Also, the correlation coefficient R^2 between NASA and AdeKUS monthly G_i is 0.82.

This warrants the use of the monthly synthesised data (Fig. 4) set for further analysis.

The daily average G_i varied from 3.72 kWh/m^2/day, measured in February, to 6.02 kWh/m^2/day, measured in October. The daily average-, monthly average- and annual G_i are, respectively, 4.97 kWh/m^2/day, 149.30 kWh/m^2/month and 1791.85 kWh/m^2/year. The daily average G_i in Suriname is comparable with Iran (4.92 kWh/m^2/day) [14] and Mexico [21]. The annual G_i in Suriname is about the same as in France (1700 kWh/m^2/year) and lower than in Spain (2000 kWh/m^2/year) while it is higher compared to reported values in Germany (1100–1300 kWh/m^2/year) [19].

4.1.2 Energy generation:

The maximum monthly AC energy (E_ac) generated was 4130 kWh in October while the minimum was 2149 kWh in February (Fig. 5). The PV system has generated 48% more E_ac in October

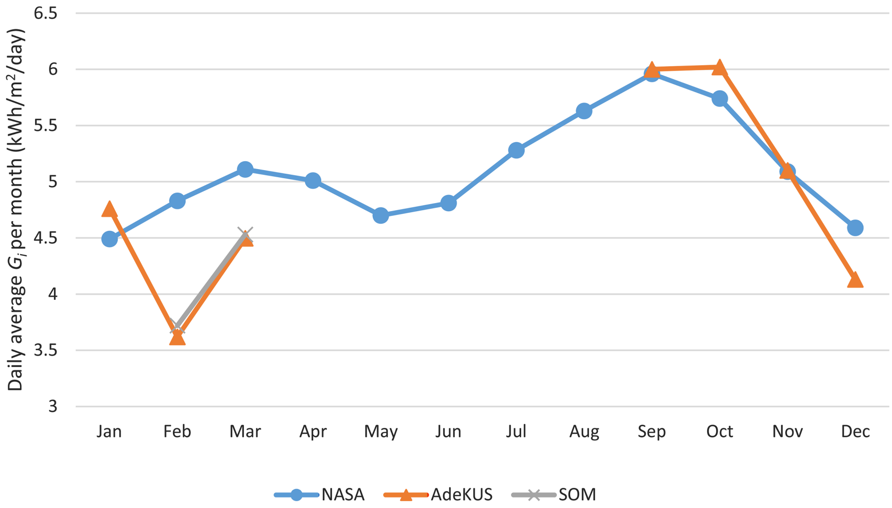

Fig. 3 *Monthly daily G_i available for three different sources*

Table 6 Statistical comparison of monthly G_i data

Month	MPE NASA versus AdeKUS	MPE NASA versus SOM	MPE AdeKUS versus SOM
April	—	—	—
May	—	—	—
June	—	—	——
July	—	—	—
August	—	—	—
September	1%	—	—
October	5%	—	—
November	0%	—	—
December	−10%	—	—
January	6%	—	—
February	−25%	−23%	−3%
March	−12%	−11%	−1%

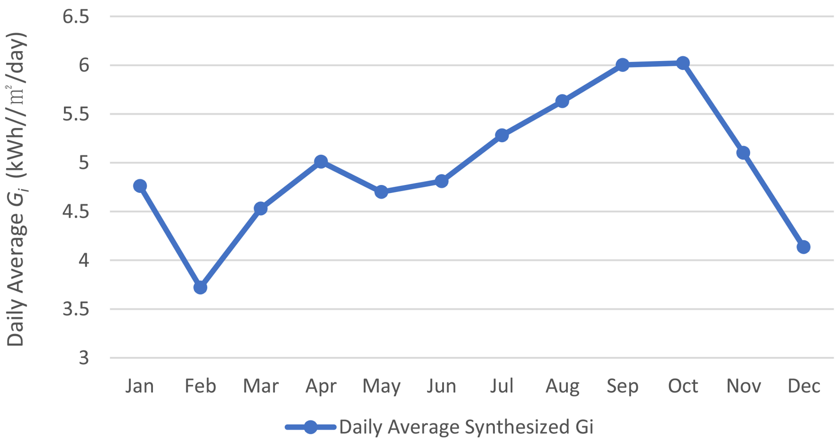

Fig. 4 *Synthesised monthly daily solar irradiation*

compared to February. The annual E_{ac} generation by the PV system was 36957.53 kWh. The PV system has produced 6% more energy compared to the annual production (34970.00 kWh) predicted by PVSyst. This can be caused by environmental aspects like rainfall and cloud cover experienced by the PV system. Also, the irradiance data (NASA) utilised for the input of PVSyst differs from the actual ground irradiance.

The daily- and monthly-average E_{ac} by this system were, respectively, 100.97 kWh/day and 3079.73 kWh/month. The maximum daily E_{ac} was 155.36 kWh (in October). The actual E_{ac} generated by the system for the months December, February and March was lower than the predicted value due to a blown fuse. The fuse was replaced after March 2017.

4.1.3 Yield:

The monthly average Y_f varied from a minimum of 2.7 in February to a maximum of 4.9 h per day in October. The annual average Y_f is 3.7 h per day. The average Y_r varied from a minimum of 3.7 in February to a maximum of 6 h per day in September and October. The annual average Y_r is 4.97 h per day. The monthly Y_r and Y_f are given in Fig. 6.

The daily, monthly and annual Y_r and Y_f are given in Table 7.

4.1.4 System conversion: The module efficiency (η_{pv}) varied between a minimum of 9% and a maximum of 13%. The minimum η_{pv} was calculated for the month June while the maximum was

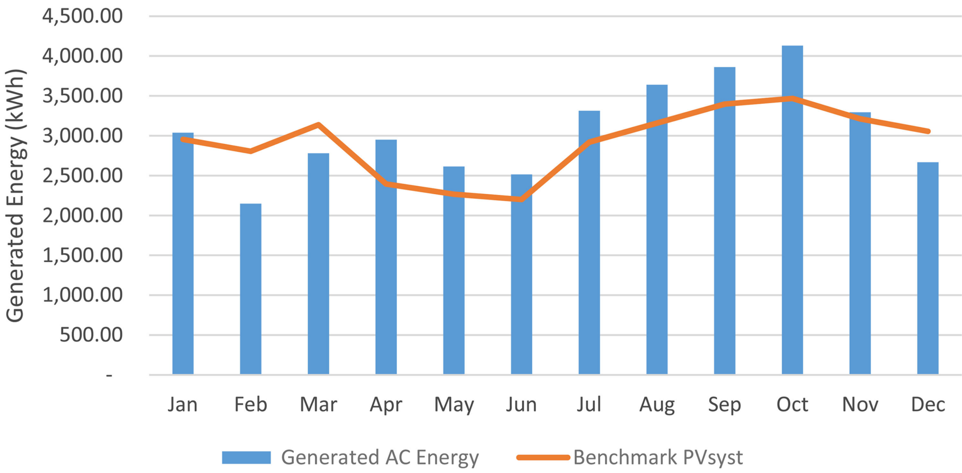

Fig. 5 *Monthly generated energy*

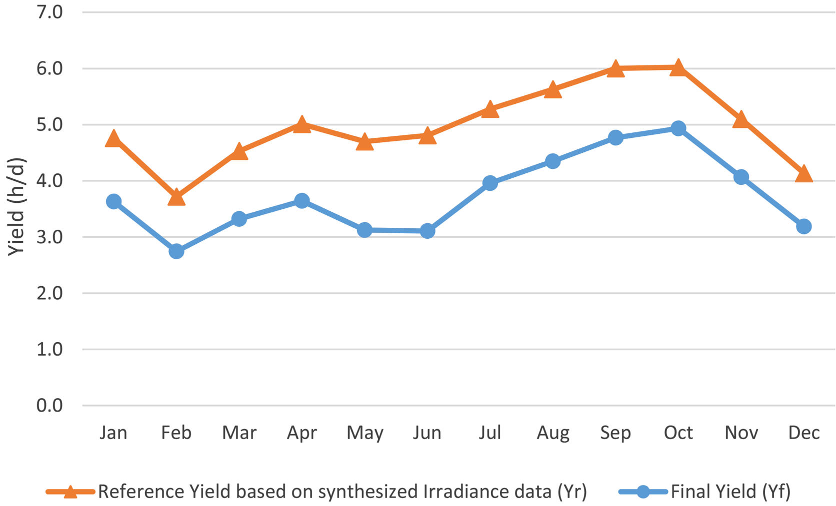

Fig. 6 *Monthly average reference and final yield*

Table 7 Reference and final yield

Yield	Y_r	Y_f
daily	4.97 h/day	3.7 h/day
monthly	151.9 h/month	114.1 h/month
annual	1822.27 h/year	1368.8 h/year

calculated for the months: April, September, October and November. The monthly average η_{pv} is given in Fig. 7.

The annual average η_{pv} was 11.92%, which was 23.59% lower compared to the theoretical efficiency. The theoretical efficiency of 15.6% [22], is determined under standard test conditions (25°C, 1000 W/m^2) but these conditions differ from actual environmental conditions. The difference can also be explained by losses in the long cables (10 m), connecting the DC-combiner box located at the PV array with the inverters.

As the PV system consists of three string inverters, the inverter efficiency of each inverter has been calculated separately. The results are given in Fig. 8.

The annual average efficiency of inverters 1, 2 and 3 were, respectively, 97.17, 96.42 and 97.08%. The theoretical efficiency of each inverter given by the manufacturer is 98.5% [23].

The system efficiency (η_{sys}) varied between 9% in June and 13% in April, September, October and November. The annual average system efficiency was 12%.

4.1.5 PR and CF: The *PR* varied from 82% in October to 65% in June. The annual average *PR* of this system is 74.58%, which is 7% higher than the simulated value in PVSyst (benchmark). The monthly variation of the *PR* and the annual average *PR* is given in Fig. 9.

The annual *CF* (benchmark) was obtained with the software RETScreen. It is not possible to calculate a monthly *CF* value with this software. So, the monthly benchmark *CF* is calculated by introducing the monthly yield, predicted by RETScreen, into equation (14). The results are given in Fig. 10.

The *CF* of this system ranged from 11% in February to 21% in October. The annual average *CF* was 15.5% while the benchmark, determined with the software RETScreen, was 15.3%.

4.2 Performance comparison of various PV systems

The performance parameters of the 27 kW PV system under actual Surinamese operating conditions are compared with internationally reported performance parameters of different PV systems. The performance parameters of the different PV systems from selected locations and of the current study are given in Table 8.

The annual average final yield of 3.7 h/d of this system is comparable with PV systems in Malaysia and Thailand and it is higher than values reported in Algeria, Ireland and Spain (Jaen). A system in Egypt has a higher annual average final yield than this one in Suriname.

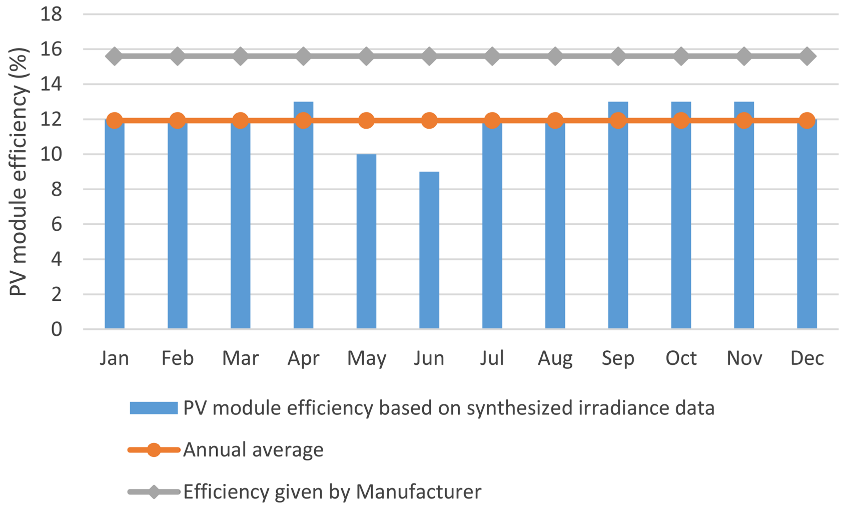

Fig. 7 *Monthly average and annual average module efficiency*

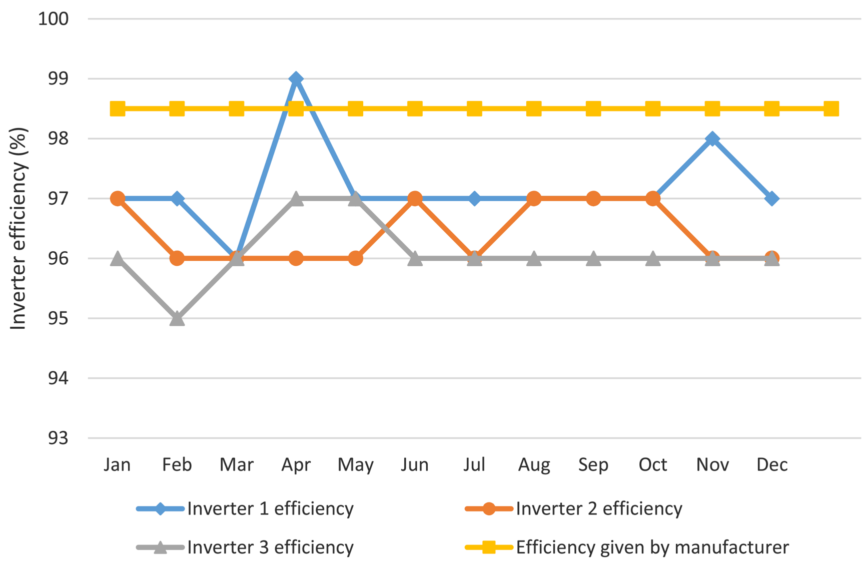

Fig. 8 *Monthly inverter efficiencies*

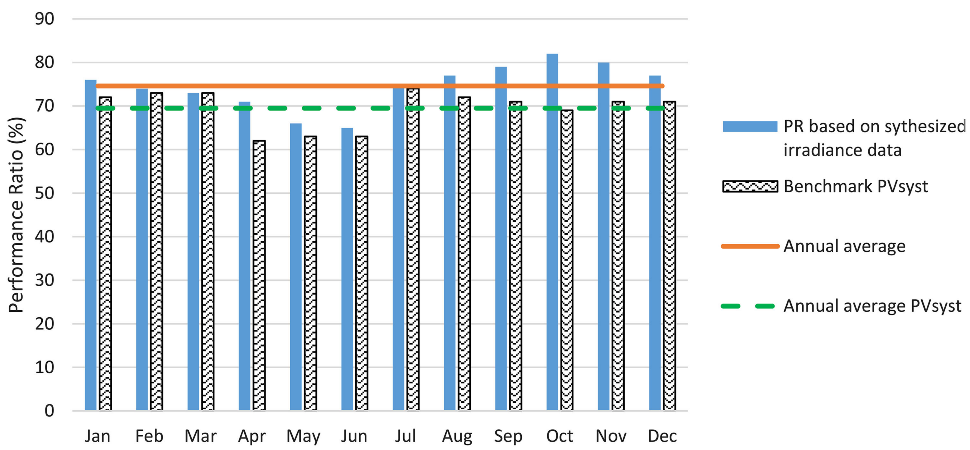

Fig. 9 *Monthly and annual average performance ratio*

The system efficiency in Suriname is 12% and internationally reported system efficiency ranges between 4.02% in Egypt and 12.6% in Ireland.

The monthly *PR* varied between 65 and 82%, which is similar to the reported values in Malaysia (67–89%) [6, 28]. The annual average *PR* in Suriname is in accordance to the reported values in India, Taiwan, France and Thailand. It is higher compared to the values reported in Algeria, Germany and Korea and is lower than in Ireland.

The annual average CF of 15.5% is comparable with PV systems in Greece and Spain. It is higher compared to CF measured in Khatkar-Kalan (India), Ireland, Germany and Korea and lower than in Chile and Thailand.

This indicates that the performance of the PV system under study is well within the range of reported values for PV systems operating under similar weather conditions (Malaysia and Thailand). Countries in Tropical regions have higher production compared to countries with temperate climate like Germany, Spain,

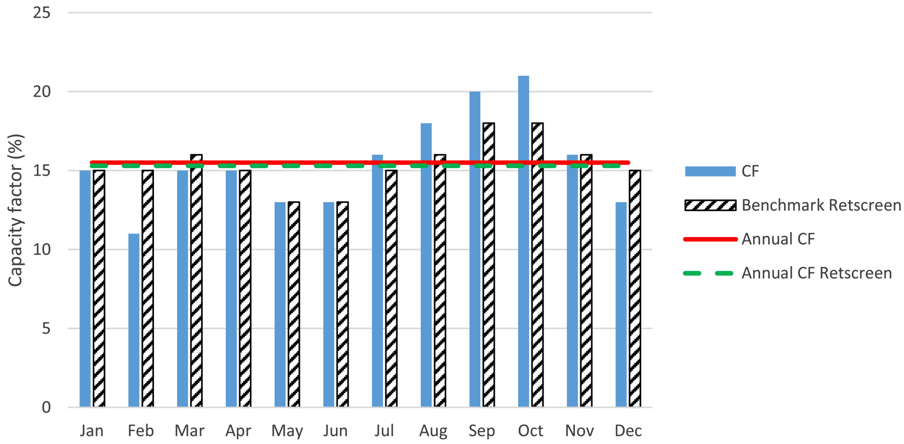

Fig. 10 *Monthly and annual average capacity factor*

Table 8 Performance parameters of different PV systems from selected locations

Location	PV type	$Y_{f,d}$	$Y_{r,d}$	*PR*, %	η_{pv}, %	η_{inv}, %	η_{sys}, %	*CF*, %	Ref.
Algeria, Batna	MC-Si	3.03	5.21	57	9.9	88.2	8.75	—	[6]
Chile	—	—	—	—	—	—	—	22	[8]
Egypt, Cairo	—	4.35	5.6	—	4.22	94.5	4.02	—	[6]
France				76					[9]
Germany	—	—	—	67	—	—	—	12	[8, 9]
Greece, Crete	PC-Si	1.96–5.07	5.34	58–73	—	—	—	15.26	[6, 24]
India, Khatkar-Kalan	—	1.45–2.84	2.29–3.53	74	—	—	8.3	9.27	[5]
India, Sivagangai	A-Si	4.81	—	—	6.08	88.2	5.08	16–23	[7]
Ireland, Dublin	MC-Si	2.4	2.8	81.5	14.9	89	12.6	10.1	[6, 25]
Korea, Daejeon	PC-Si	—	—	63.3	9.2	86	7.9	11.5	[6, 26]
Korea, Daejeon	PC-Si	—	—	71.8	9.5	87	8.3	12.2	[6, 26]
Malaysia, Bangi	PC-Si	3.8–4.3	—	67–89	—	11.8	8–11	—	[6]
Spain, Jaen	—	1.6	3.26	49	5.71	87	4.96	—	[6]
Spain	—	—	—	—	—	—	—	16	[8]
Taiwan				74					[9]
Thailand	—	—	—	—	—	—	—	18	[8]
Thailand, Phitsanulok	—	3.84	5.21	73	—	—	—	—	[6, 27]
Suriname, Paramaribo	**PC-Si**	**3.7**	**4.9**	**74.6**	**11.9**	**96.4–97.2**	**12**	**15.5**	**present study**

Table 9 Breakdown of the installation cost

Costs	Amount, $
system components and logistics	$73,156
civil works	$8800
electric work	$15,900
management fee	$6000
miscellaneous	$5200
total solar installation cost	$109,056

Algeria, Korea and Ireland. Also, on an annual base and for this study period, the effect of higher irradiance values for longer periods (hours of sunshine per day and per season) seems to dominate the effect of higher panel temperatures on the performance of the system.

4.3 Economic analysis results

In this section, the economic analysis results obtained from RETScreen are presented. The total installation cost of this PV system was $109,056. The breakdown of the installation cost is given in Table 9.

The results acquired from the simulation with RETScreen are given in Table 10 and Fig. 11.

The current energy price for industrial users in Suriname is USD 0.11/kWh [29]. The total investment cost of USD 109,056 resulted in an LCOE of USD 0.35/kWh. Internationally reported values vary from USD 0.06/kWh to USD 0.31/kWh [30]. For selected systems in Central America and South America, higher values are reported. Peru attained a solar PPA at $0.48/kWh (April 2016) while Mexico attained a PPA price of $0.35/kWh [31]. The LCOE of USD 0.35/kWh lies within the range of the LCOE of Peru and Mexico but is higher than other selected internationally reported values.

Table 10 Financial analysis results

Financial parameters	Values
pre-tax IRR – equity	negative
pre-tax IRR – assets	negative
after-tax IRR – equity	negative
after-tax IRR – assets	negative
simple payback	180.7 years
equity payback	>project
NPV	$−110,527
benefit–cost (*B*–*C*) ratio	−0.01
energy production cost	$351.20/MWh

The NPV of this project is $−110,527 per year which indicates that the investment cost will not be recovered during the project life (25 years). The payback will be longer than 25 years. This can also be seen in Fig. 11.

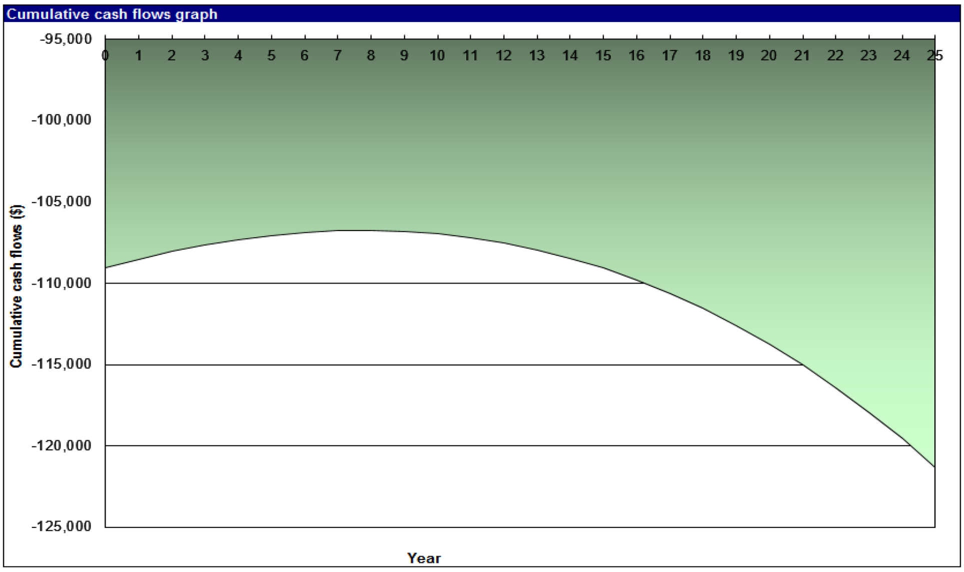

Fig. 11 *Cumulative cash flow graph*

5 Conclusion

The experience gained by designing, building, operating and maintaining this system, combined with the analysis of its performance are a valuable resource for future projects in Suriname.

The following conclusions can be drawn:

- The simulated performance indicator values were lower than the achieved field results.
- The performance indicator values obtained from the field results were within the range of internationally reported values and comparable with systems in countries with tropical climate (Malaysia and Thailand).
- The LCOE of this PV system is 3.5 times the current energy price in Suriname. It is also higher than internationally reported values but is in correspondence with selected projects in Central America and South America.

Recommendations and future research work are

o Study on the effects of soiling, environmental parameters, degradation rate and temperature coefficient on the performance of the PV panels in Suriname.

o Study to achieve an optimal LCOE for PV systems in Suriname.

o Optimisation of the configuration of the system to minimise losses.

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