Solar powered green campus: a simulation study

Akshay Suhas Baitule[1] and K. Sudhakar[1,2]*

[1]*Energy Centre, Maulana Azad National Institute of Technology, Bhopal, MP, India;* [2]*Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pahang, Malaysia*

Abstract

Large-scale deployment of the renewable energy system in India is required to achieve a target of 175 GW of green electricity by 2022. Higher educational institutes with a lot of free areas can play a vital role in reducing the conventional energy consumption and carbon footprint. The main aim of this paper is to locate and analyze the feasibility of developing 100% solar PV based academic campus at MANIT – Bhopal, India. Annual electricity consumption of MANIT, Bhopal is analyzed and accordingly 5 MW capacity solar PV based captive plant is proposed. Free open space area of the campus including rooftop area is inspected through geographical coordinates utilizing the NASA surface meteorology data and Google SketchUp. The performance of the proposed solar campus is analyzed using PVSyst and Solar Advisory Model (SAM) software. The proposed plant at MANIT campus can generate around 8000 MWh per annum of electricity to meet the 100% energy requirements of the campus with the annual reduction of 73 318.0 tonnes of carbon footprint. Development and promotion of such sustainable green concepts will be a significant step towards transforming the academic campus into an energy efficient and environmentally sustainable community.

Highlights

- Annual electricity consumption of academic campus is analyzed.
- Land area is assessed for rooftop and land based solar installation.
- Detailed analysis of 5 MW solar plant using PVSyst and SAM.
- Financial and environmental benefits of sustainable green campus are highlighted.

Keywords: PVSyst; Solar Advisory Model (SAM); photovoltaic; MANIT; 5 MW

*Corresponding author: sudhakar@ump.edu.my

Received 15 May 2017; revised 24 July 2017; editorial decision 24 July 2017; accepted 4 August 2017

1 INTRODUCTION

India is one among various countries to ratify the ‘Paris climate change agreement’, which advocates generation of minimum 40% of electricity from non-fossil fuel sources. The current statistical data of India shows that there is a need for rapid transformation in the energy sector and this cannot be achieved using conventional methods. There is an ambitious target to generate 175 GW of renewable energy electricity by 2022, of which 100 GW of electricity is to be generated from solar energy [1]. Out of 100 GW solar energy, 40 GW would be through individual rooftop systems. There is an urgent need to employ renewable energy in every possible form and move toward the sustainable energy sector. Currently (as of 31 October 2016), India produces 8.53 GW electricity through solar power [2].

Mahato *et al.* [3] showed the potential of India to transform to the renewable power sector. India has a large potential of solar energy and most of this energy can be comparably easily tapped for sustainable development of the nation as well as the world. Shukla *et al.* [4] compared the different technologies for residential PV plants and concluded that amorphous

International Journal of Low-Carbon Technologies 2017, 12, 400–410

doi:10.1093/ijlct/ctx011 Advance Access Publication 30 August 2017

technologies give satisfactory performance ratio. As the first step of this development, Shukla *et al.* [5] performed the design and analysis of rooftop solar PV system for Hostel building at MANIT, and determined the payback period of 8.2 years. Similarly, Khatri [6] performed a financial assessment of solar PV plant for girls hostel building as a case study. Werulkar and Prakash [7] analyzed energy saving option of solar PV in the residential sector at Nagpur, which is comparatively near to Bhopal, India. Sharma and Kannan [8] proposed a rough path to reduce carbon footprints for an educational institute. Shiva Kumar and Sudhakar [9] validated the results obtained by PVSyst and PV-GIS software with the measured data of the performance of the Utility scale PV plant. Lee *et al.* [10] performed the economic analysis of the complete campus of new haven university. Raturi *et al.* [11] studied the grid connected PV system for Pacific island countries with a case study of 45 kWp GCPV system located at the University of the South Pacific (USP) marine campus in Fiji. Further, Dawn *et al.* [12] showed the recent developments of India in the solar energy sector. Therefore, for optimal results, c-Si panels are used for the techno-economic analysis purposes.

In the literature reported, there is either economic or technical analysis for a large or small-scale PV plant, but simultaneous technical and economic feasibility analysis based on simulation software Solar Advisory Model (SAM) and PVSYST has not been carried out yet. This research is aimed at fulfilling the research gap of comprehensive and complete feasibility analysis of solar campus which is missing in previous research. Also there is a scarcity of data related to the development of the sustainable green campus in India.This research work is carried out to address the gap in the research and propose sustainable MANIT campus through a case study.

Figure 1. *MANIT campus and sun path diagram [13, 14].*

Table 1. *Site information.*

Latitude	23.2599° North
Longitude	77.4126° East
Elevation	527 ms (from sea level)
Area available	650 acres
Free area available	Approximately 123.524 acres

2 METHODOLOGY

2.1 Geographical location of the site

Maulana Azad National Institute of Technology Bhopal (MANIT – Bhopal), is an Institute of National Importance under the MHRD, Government of India. It is part of the group of publicly funded institutions popularly known as National Institute of Technology. It is one of the largest NIT's in terms of a number of enrolled students and in terms of vast area [2]. The total area of campus is 650 acres. The entire campus consists of administrative and academic building, workshop, Library and community center, Residential accommodation for students and staff,

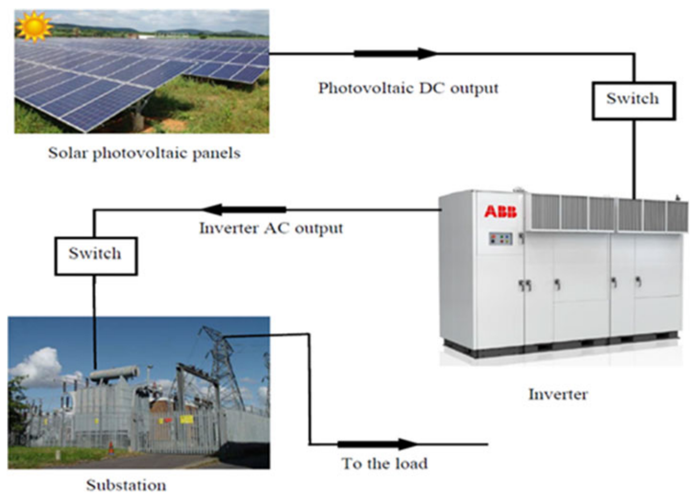

Figure 2. *Block diagram of PV plant.*

Table 2. *Various assumptions used for simulation.*

Sr. no.	Assumption	Value
1	Plant capacity required	5 MW
2	Area required	25 acres
3	Panel used	Renesola, model – JC260M-24/Bbh-b
4	Inverter used	ABB, ULTRA 1500-TL-OUTD-2-US-690-M/S-DNVKEMA
5	Degradation rate	0.5% per annum
6	Tilt angle	23°
7	Taxes	[a] MAT – 20.96% [b] Corporation tax – 33.99%
8	Loan interest rate	11.5%
9	Loan term	25 years
10	Debt fraction	70%
11	Annual running cost	₹ 1 lakh

general amenities such as post office, Shopping complex, a School for children, dispensary, an auditorium with the capacity of 1000 persons and sports complex [2].

MANIT is situated geographically at Latitude – 23.2599° North and Longitude – 77.4126° East. The elevation from the sea level is ~527 m. The sun path diagram at MANIT, Bhopal over the year, is shown in Figure 1 (Table 1).

2.2 Data collection

Annual energy consumption data and electricity bill of MANIT, Bhopal, is collected for the period 2015–16. The following parameters are analyzed:

- Duration of bill
- KWH units used
- KVAH units used
- Various charges included
- Taxes included
- Net electricity bill in Indian National Rupees.

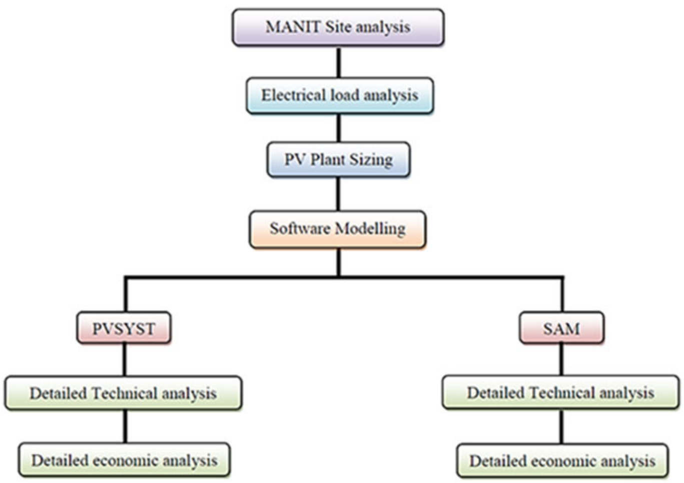

Figure 3. *Framework of the simulation study.*

From these parameters, consumption pattern and average electricity charges are calculated. Due to the vast open area, there are ample spaces for the solar PV based captive power plant.

2.3 Captive solar PV based power plant

This section covers the significant aspects of the design and simulation of the PV system.The various components of the solar PV plant are shown in Figure 2.

The grid connected solar PV system consists of the following components

Plant layout: Total area acquired by the campus is around 650 acres (2.63046 km^2). The free area present in the campus is around 123.524 acres (0.499 km^2). The selected panel for the plant is of 260 W_p. Since, in the Institute campus the free area is divided in different part we can have a captive plant for future expansion of the plant.

Tilt angle: The tilt angle proposed for the solar PV plant is equal to the latitude of the location, as it is best for the maximum absorption of the solar radiation. The latitude of the site, i.e. MANIT, Bhopal is 23.2499°, so the tilt angle is taken to be ~23°.

Solar module: There are different types of solar panels used in the industry. For the large-scale plant, polycrystalline modules are most commonly used. The solar module used for simulation is based on polycrystalline one. The manufacturer of this panel is taken to be Renesola, model – JC260M-24/Bbh-b. The array global power is 4999 W_p at STC and 4498 W_p at operating condition (at 50°C). Array operating characteristics (50°C) are U_{mpp} 591 V and I_{mpp} 7609 A. Degradation rate for the panel is taken to be 0.5%/year.

Inverters: Three number of 1500 KW rating are used for the 5 MW plant. The inverters used are manufactured by ABB Corporation, having a model – ULTRA 1500-TL-OUTD-2-US-690-M/S-DNVKEMA. The operating characteristics of the inverter are 470–900 V operating voltage. The unit nominal power is of 1500 kWac. There are 3 units of the inverter to be installed and the total power capacity is 4500 kWac.

Various subsystems and accessories: Mountings include structures on which panels, inverters and other accessories are placed.

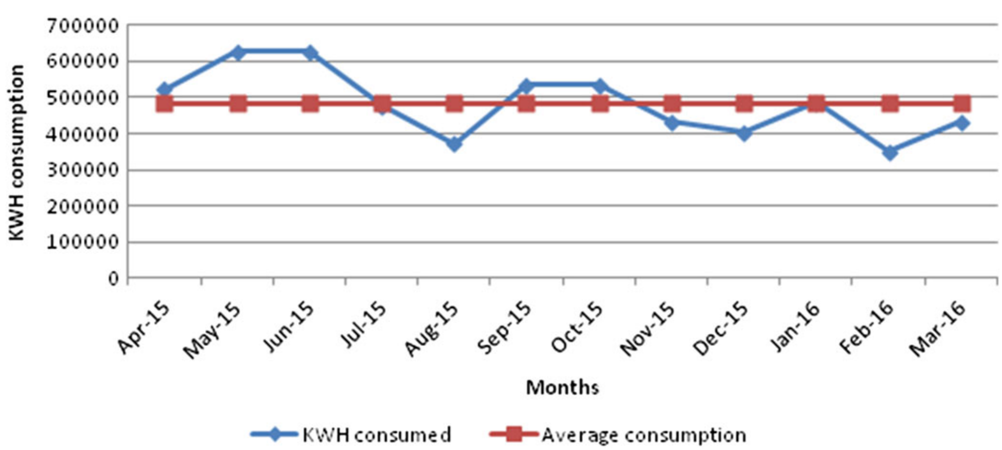

Figure 4. *Annual energy consumption of MANIT.*

It includes also sub-station and its components like transformers, etc., which is essential for grid connection. DC/AC cables are required for connecting panels, inverter and to the grid.

2.4 Performance simulation of the plant

In this work two different software's are used to compare the simulation results obtained for the proposed 5 MW solar PV plant.

PVSyst: PVsyst V6.49 is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transportation) PV systems, and includes extensive meteonorm and PV systems components databases, as well as general solar energy tools. It contains preliminary design and also projects detail design [15].

'SAM' is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry. SAM makes performance predictions and cost

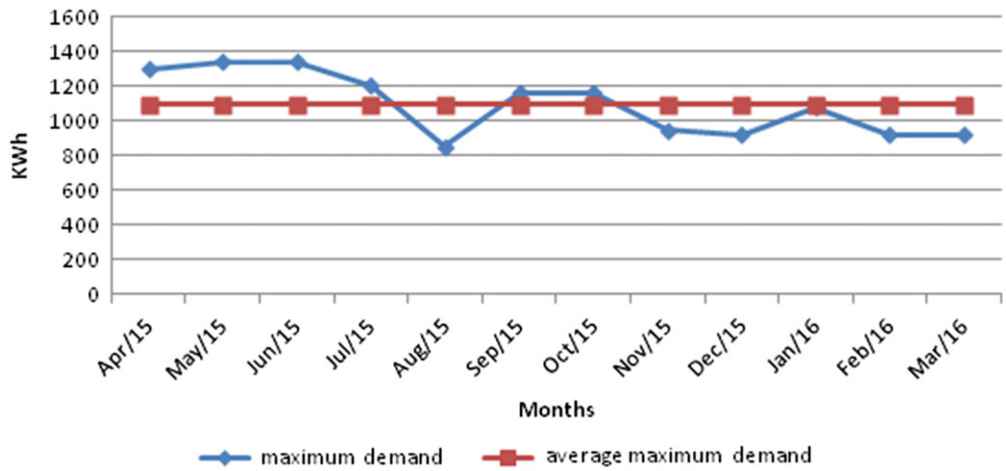

Figure 5. *Maximum demand of MANIT.*

Figure 6. *Free area available in MANIT campus [14].*

of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model. It is also useful for simulation of various renewable systems [16].

2.4.1 *Input data for simulation*

Table 2 shows the various input data used for performance simulation.

The entire framework of the simulation study is illustrated in Figure 3.

3 RESULTS AND DISCUSSION

3.1 Energy consumption pattern, plant capacity siting and sizing

For the purpose of analysis of energy consumption pattern, monthly electricity bill issued by the state electricity department are assessed for the financial year 2015–16. The total monthly energy consumption and instantaneous maximum demand of that month were taken for analysis. The average maximum requirement of the campus was determined.

Table 3. *Area and plant generation capacity of each selected site.*

Figure no.	Area (m^2)	Area (acres)	Estimated plant generation capacity (MW)
[a]	150 986.088	37.309	7.4618
[b]	122 620.453	30.30	6.06
[c]	56 475.641	13.955	2.791
[d]	19 284.756	4.765	0.953
[e]	69 768.193	17.24	3.448
[f]	80 754.766	19.955	3.991
Total	499 889.897	123.524	24.7048

Following important values are obtained from the data analysis:

- Average maximum demand – 1096.733 KVA
- Average power factor – 0.901667

Figures 4 and 5 represent the energy consumption and maximum demand of MANIT. The energy consumption is minimum in the month of February and maximum in the months of May and June. Also in the months of May and June, the maximum demand recorded is the highest, whereas it is lowest in the month of August. There was a substantial variation in energy consumption and the average electricity charges/month, come out to be more that INR 8/kWh. MANIT, due to its large area and academic activity, requires a huge amount of energy and pays ~30–60 lakh electricity bill with some seasonal variation. From the observed average values of maximum demand, Solar plant wattage was estimated.

- Average maximum demand in kW
  =(Average maximum demand in KVA)/(Power factor)
  =1096.733/0.901667
  =1216.339 KW
- Solar panel wattage required [4]
  =(Daily power required)/((Average sunlight hours) ∗ (Performance ratio))
  =16 125.35/(5.5 ∗ 0.8)
  =3664.85 kW
  =3.664 MW

Since, the requirement of MANIT is ~3.664 MW, but to meet the total energy requirements and future growth, 5 MW solar PV based captive power plant is proposed. For 1 MW plant, the

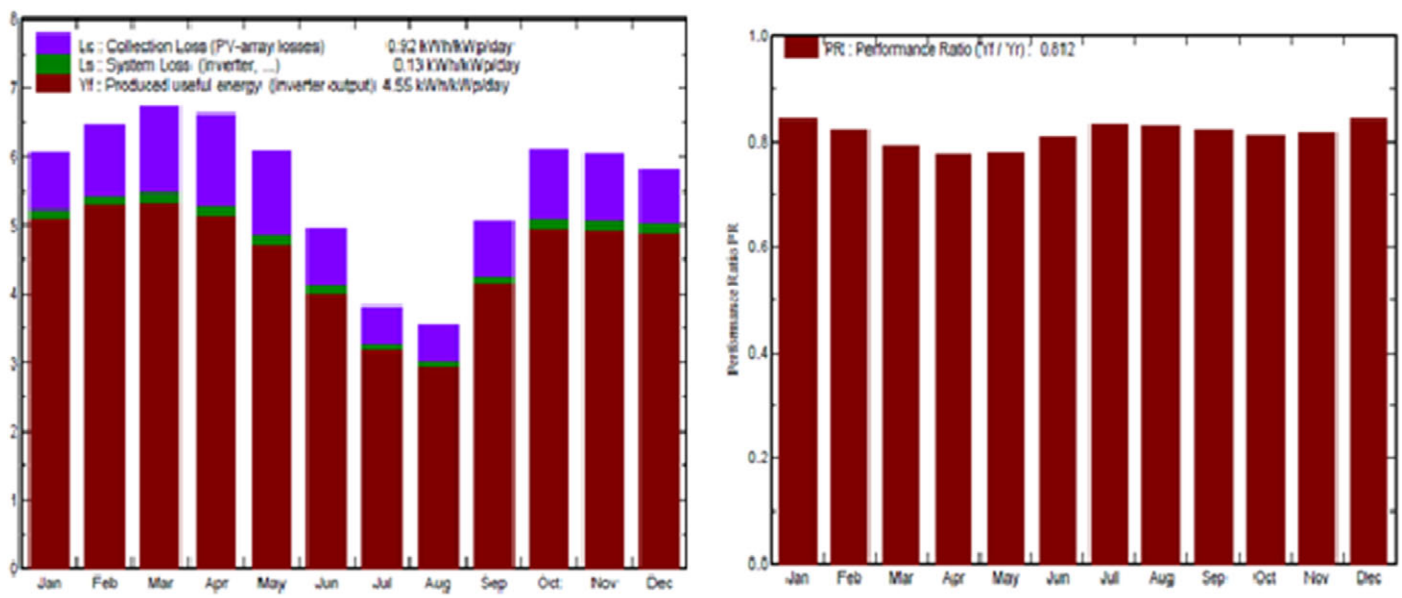

Figure 7. *Normalized energy production and performance ratio of the system.*

Table 4. *Main results and output.*

Months	Global horizontal irradiation, KWh/m^2	Ambient temperature, °C	Global incident in collinear plane, KWh/m^2	Effective global irradiation, KWh/m^2	Effective energy at output of array, MWh	Load, MWh	Energy supplied to user, MWh	Energy injected to the grid, MWh
January	139.5	18.62	187.9	183.3	812.9	487.1	202.4	588.2
February	147.0	21.69	180.8	176.7	763.7	350.0	146.6	595.1
March	188.2	27.58	209.0	203.9	852.9	445.8	194.4	633.2
April	197.7	32.37	198.9	193.1	793.9	522.9	235.6	535.2
May	202.1	34.05	188.6	182.4	755.0	627.4	278.2	454.9
June	163.8	30.68	149.1	143.9	619.6	627.4	272.4	329.7
July	127.4	26.99	118.4	114.1	507.7	477.2	205.2	288.4
August	114.7	25.96	110.0	106.2	470.1	372.8	157.0	299.6
September	143.1	26.55	151.6	147.1	640.2	535.9	229.3	392.9
October	159.7	25.88	189.7	184.8	789.6	535.9	232.5	534.9
November	139.2	22.66	181.3	177.0	762.1	433.0	180.1	560.0
December	130.2	19.03	180.2	175.7	779.0	403.6	166.5	591.1
Year	1852.6	26.02	2045.6	1988.2	8546.6	5819.0	2500.3	5803.3

Table 5. *Array characteristics.*

Sr. no.	Name	Value
1	Strings	873
2	Modules per string	22
3	String voltage (DC V)	671.0
4	Tilt (degree from horizontal)	23
5	Azimuth (degree E of N)	0
6	Tracking	Fixed
7	Shading	No
8	Soiling	Yes
9	DC losses (%)	4.4

area needed is ~5 acres, therefore for 5 MW plant, area needed is around 25 acres. MANIT has 650 acres of land and a lot of free areas is available within the campus. Figure 6 and Table 3 shows the proposed free area available in the campus which combinedly comes around 123.524 acres. Also, this land is unused and not included in the any of the developmental projects under consideration. So, for the requirement of electricity and self-sufficiency of the Institute, there is enough area available. Hence, the area is not a barrier for the captive solar PV plant. As shown, captive solar PV plant of around 24 MW can be installed in the campus [17].

3.2 Performance results

3.2.1 *PV SYST simulation*

The panels are connected in a fashion of 19 modules in series and 1012 such strings in parallel. Therefore, total numbers of such modules are 19 228 in number. The total area occupied by the modules is 31 282 m^2. The total area occupied by the cell is 28 076 m^2, this is the area which actually absorbs the solar radiation. There are three inverters which can be used for the conversion of DC to AC. The capacity of these inverters is 1500 kWac. Therefore, the total inverter capacity is of 4500 kWac.The maximum energy supplied to the user is in the month of May, which is 278.2 MWh. The minimum energy supplied to the user is in the month of February which is 146.6 MWh. whereas the energy injected to the grid is maximum in the month of March which is 633.2 MWh and minimum in the month of July which is 288.4 MWh.

- System production produced energy: 8304 MWh/year
- Specific production: 1661 kWh/kWp/year
- Performance ratio (PR): 81.20%
- The total area occupied by the 19 228 modules is 31 282 m^2. The total area occupied by the cell is 28 076 m^2.

As we can see in Figure 7, normalized energy, i.e. kWh/kWp/day is shown per month. The collection losses per day per month are also given and an average of the year is found to be 0.92 kWh/kWp/day. Similarly, system losses are also given and average comes out to be 0.13 kWh/kWp/day. The average of actually produced energy, which is inverter output is coming around 4.55 kWh/kWp/day. The average value of produced energy per month is found to be minimum in the month of August, which goes as low as just below 3 kWh/kWp/day, this is because of the rainy season and cloudy weather, but the losses are minimum in these months. The maximum produced energy is found to be in the month of March closely followed by April. In the month of March, produced energy is found to be just below 5.5 kWh/kWp/day. Figure 7 also shows the performance ratio of the system. It is a ratio of field yield to the reference yield. It shows the quality and efficiency of the system. The average performance ratio is found to be 0.812, i.e. 81.2%, which is considered good. The variation in performance ratio is very negligible, but lowest performance ratio is observed in the month of April. Results show that, the yearly load is 5819 MWh out of which 2500.3 MWh is supplied from the plant. Whereas 5803.3 MWh of electricity generated is fed into the grid. The maximum energy generation is observed in the month of March, whereas minimum energy generation is found to be in the month of August (Table 4).

From Table 5 and Figure 8, it is observed that the net electricity production is around 8304 MWh/year and this system does

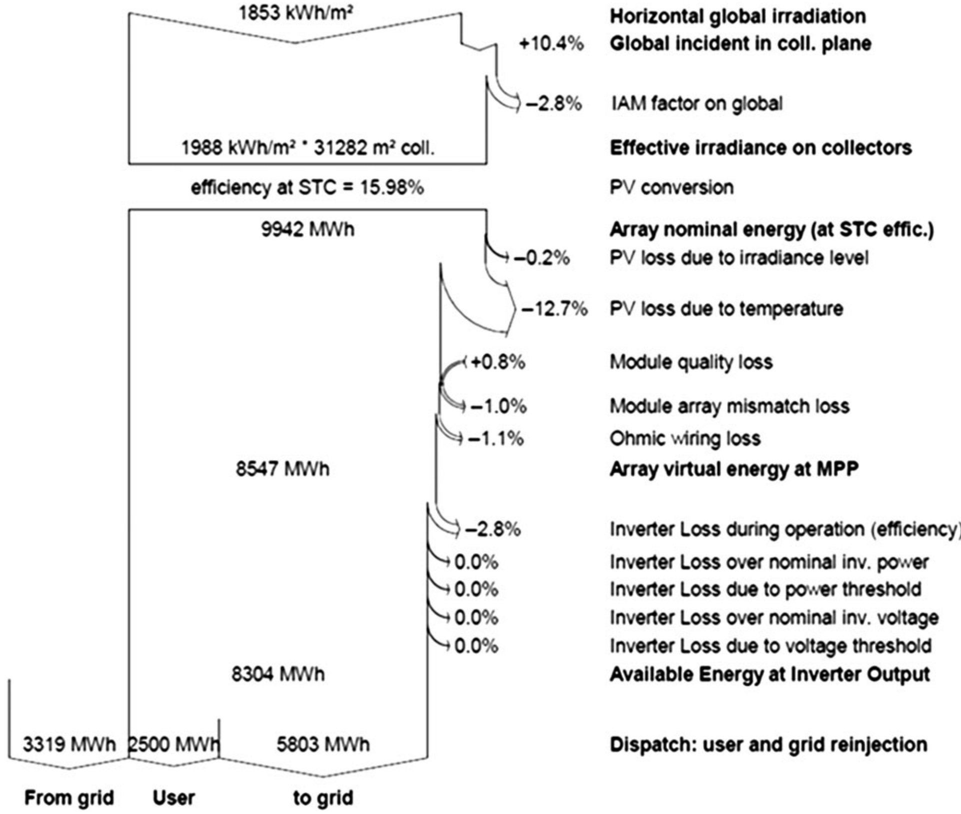

Figure 8. *Loss diagram from PVSyst.*

Table 6. *Annual results of year 1.*

Sr. no.	Result	Value
1	GHI	5.5 kW/m^2/day
2	POA	4.0 kW/m^2/day
3	DC from array	6.5 GWh
4	Net to inverter	6 245 000 DC kWh
5	Gross from inverter	6 087 000 AC kWh
6	Net to grid	6 026 000 AC kWh
7	Capacity factor	13.77
8	Performance ratio	0.74

not supply completely to load or to grid. This is because, the software assumes that total load is distributed for every hour of the day for a complete month and solar energy is not available for 24 h a day. Around 5803 MWh is supplied to the grid and around 2500 MWh to the user, while it takes 3319 MWh from the grid.

3.2.2 *Loss diagram over the whole year*

SAM simulation. To compare the performance, the plant performance is simulated using SAM with all the parameters and components same as that of PVSyst simulation.There are various characteristics of the array, which are obtained from the SAM simulation results, which includes total number of strings, modules per strings, etc. It was assumed that tilt angle is 23 degree, and system to be non-tracking. SAM took a total number of strings to be 873 and total 22 modules per string. DC losses are taken to be 4.4%. The summary of the array characteristics is shown in Table 5. The total number of solar panels is 19 206, and total area occupied by panels is found to be 31 248 m^2. The DC to AC capacity ratio is taken to be 1.11, whereas AC losses (%) are taken to be 1.0.

After simulation, software predicts the results for complete life, but mainly results of the first year are shown in Table 6. Total DC from one array is found to be 6.5 GWh and gross from the inverter is found 6.087 AC GWh, performance ratio is found to be 0.74, which is significantly lower than performance ratio found in PVSyst. Whereas, capacity factor is found to be 13.77.

The main results obtained from the SAM, includes the nominal levelized cost of energy which is calculated to be 5.727 ₹/kWh. Net present value of the plant is calculated to be ₹ 481 370 000, i.e. 48 crores, and a payback period of the plant is 4.7 years.

Figure 9, shows the distribution of electricity from the system as well as to the grid. It is found that, electricity from the system is maximum in the month of May, nearly 800 MWh and minimum in the month of January, less than 400 MWh. It is shown that electricity to the load attached, is maximum in months of May and June, whereas minimum in the months of August and February. The interaction of the system with the grid is also shown in the figure. Electricity has to be taken from the grid in 5 months of the year and maximum is to be taken

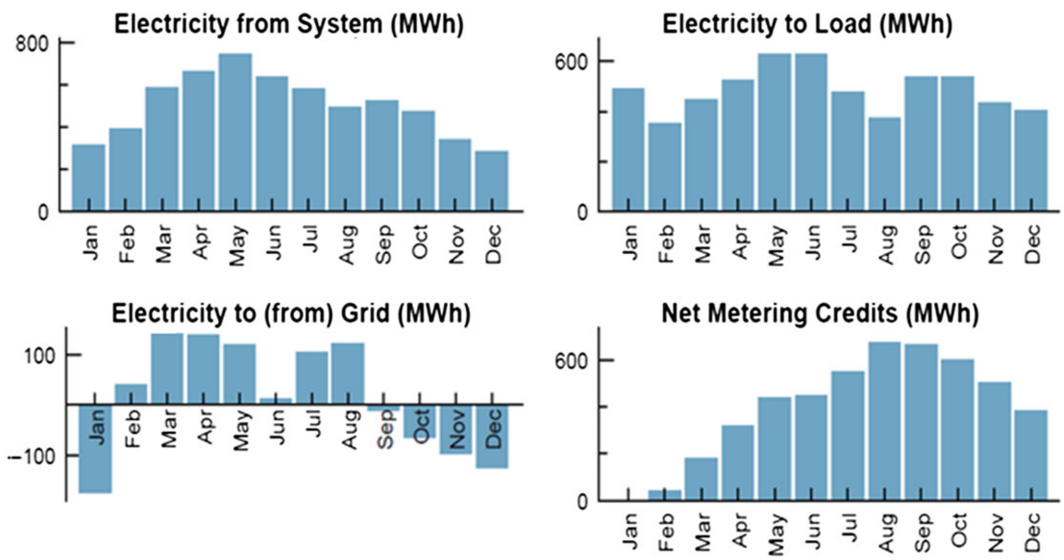

Figure 9. *Electricity distribution from SAM.*

in the month of January, whereas it can be supplied to the grid in 7 months of the year and maximum in the months of March and April. The fourth part of the figure shows the net metering credits earned by the system by supplying electricity to the grid. It comes out to be maximum in the month of August which is more than 600 MWh, and minimum in the month of January, i.e. 0 MWh. Figure 10 shows the various losses considered for the system and are expressed in percentage. As indicated, total annual energy generated by the system is around 6026 MWh. Nearly, 220 MWh of energy is lost due to DC to AC conversion and transportation of electricity.

3.3 Economic analysis

The break-up of different costs based on the guidelines of Central Electricity Regulatory Commission (CERC), India is shown in Table 7. The total yearly cost is coming out to be around 4.55 crore per year, with net investment including taxes is around 36 crore INR.

3.3.1 *PVSyst*

Energy cost and Economic Balance Sheet (PVSyst): The most important factor for the plant is the energy cost of the plant for feasibility. The plant will produce around 8304 MWh/year, out of which 5803 MWh/year will be sold to the grid. The cost of produced energy is coming out to be 5.48 INR/kWh. Figure 11 shows the cumulative balance of the total investment made by Institute and gains by installing the system. As we can see the total savings by the institute in the total life cycle of 25 years of the system is more than 93 crores, which can be seen from the long-term financial balance sheet.

Table 8 shows the economic balance sheet of the plant. It is assumed that running cost will be 1 lakh per year. With the loan of 11.5%, institute has to pay 4.54 crore as an installment per year. Whereas in the lifetime of 25 years, the institute will generate around ₹ 938 894 000, which is a huge amount. Institute will sell ~8.3 crores worth of energy equal to yearly rupees savings of around 3.75 crores.

3.3.2 *Project costs summary (SAM)*

SAM does not have the facility to calculate the values in Indian Rupees. But, it gives the option to input the values and rates as per the user convenience. All the values entered in the simulation are in Indian Rupees and the results obtained are also in INR.

- Total installed cost: ₹ 355 651 648
- Project life: 25 years
- Debt fraction: 70%
- Amount: ₹ 248 956 160
- Term: 25 years
- Rate: 11.5%
- Corporation tax: 33.99%/year
- MAT tax: 20.96%/year
- Sales tax: 0%
- Insurance: 0.5%/year
- Annual peak demand: 1493.3 kW
- Annual total demand: 5 819 028 kWh
- Flat rate (buy = sell): ₹9/kWh

Figure 12 shows the cash flow of the system. It is shown that payback period of the system is around 4.2 years and total life cycle saving of the system in terms of cash is around 137 crores and yearly savings comes around 5.5 crores/year for 25 years.

3.4 Performance comparison

The results obtained are according to the same input parameters for both PVSyst and SAM. PVSyst is commonly used and therefore, it is considered as a benchmark. The slight difference in the results obtained is expressed in percentage as shown in Table 9. The difference is may be due to basic assumption and formulae used by the software for calculation.

Here, PVSyst is giving higher power and performance ratio than SAM, which is around 27.43% in terms of power generated and around 8.86% in terms of performance ratio. In terms of investment, PVSyst is considering the investment of 3.55% higher than the SAM investment. SAM is predicting price per kW at 4.37% higher than PVSyst.

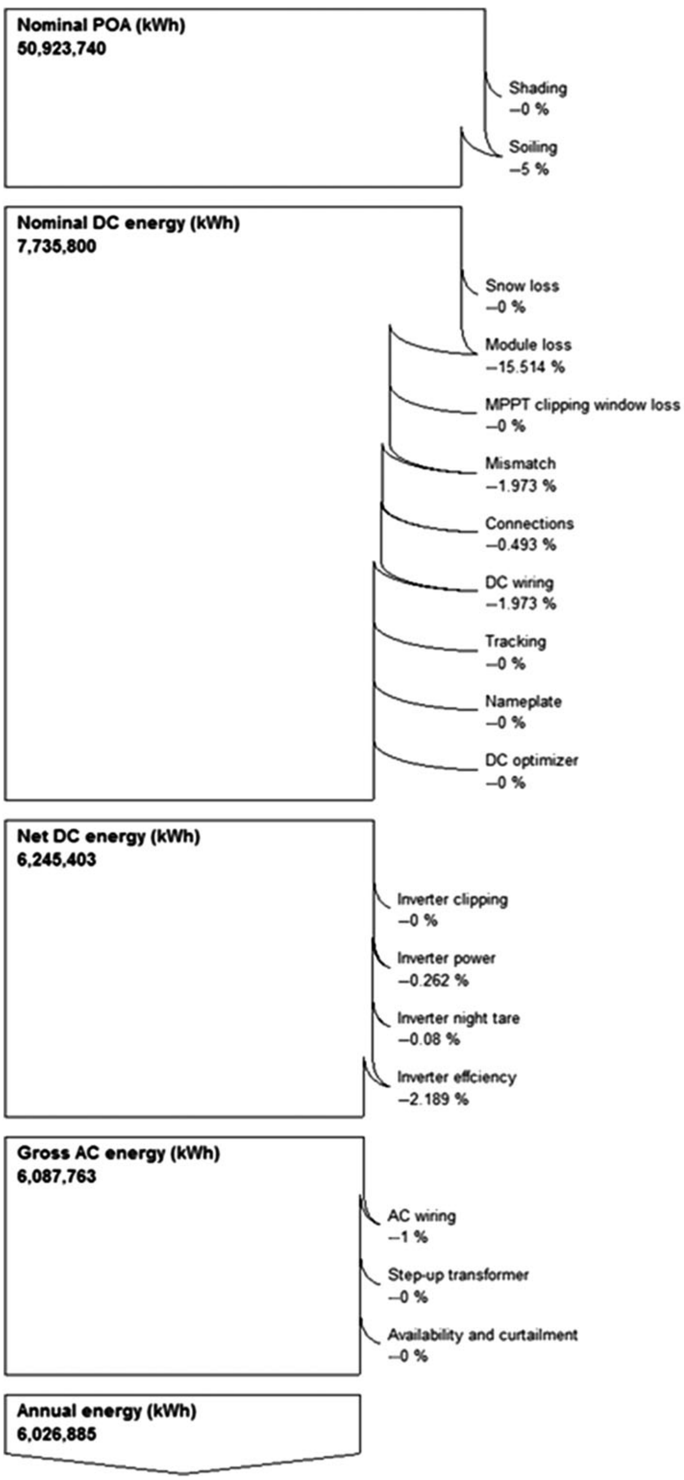

Figure 10. *Loss diagram from SAM.*

3.5 CO_2 reduction potential

Renewable energy system GHG emissions are attributed to the indirect emissions and do not cause any direct emissions [18–21]. Solar PV GHG emissions are due to the energy spent during the manufacturing of the panels [19]. It is taken to be 9762.3T CO_2 for the given module and plant size. Therefore, based on Figure 13, saved CO_2 emission is shown negative, i.e. it is initially emitting carbon and after that for total 25 years it is reducing carbon and it shows linearly increasing slope. Calculation of carbon balance is as follows:

$$\begin{aligned}\text{Carbon balance} &= (E_{\text{grid}} * \text{life of plant} * \text{LCE}_{\text{grid}}) - \text{LCE}_{\text{system}}\\ &= (8303.6*25*[936\ \text{gCO}_2/\text{kWH}]) - (9762.3\text{T CO}_2)\\ &= 173318.0\ \text{tCO}_2\end{aligned}$$

Table 7. *Financial parameters.*

Sr. no	Name	Approximate price (INR)
1	PV modules (19 228 units) [8060 INR/unit]	15.5 crore
2	Supports/integration [910 INR/module]	1.75 crore
3	Inverters (3 units) [4 999 280 INR/unit]	1.5 crore
5	Settings, wiring cost	2 crore
6	Transport and assembly cost	1.75 crore
7	Engineering cost	1.3 crore
8	Gross investment (without taxes)	23.8 crore
9	Total taxes on investment (rate 55.0%)	13 crore INR
10	Net investment (all taxes included)	36 crore INR
11	Annuities (loan 11.5% over 25 years)	4.54 crore/year
12	Annual running costs: maintenance, insurances	1 hundred thousand/ year
13	Total yearly cost (including load repayment)	4.55 crore/year

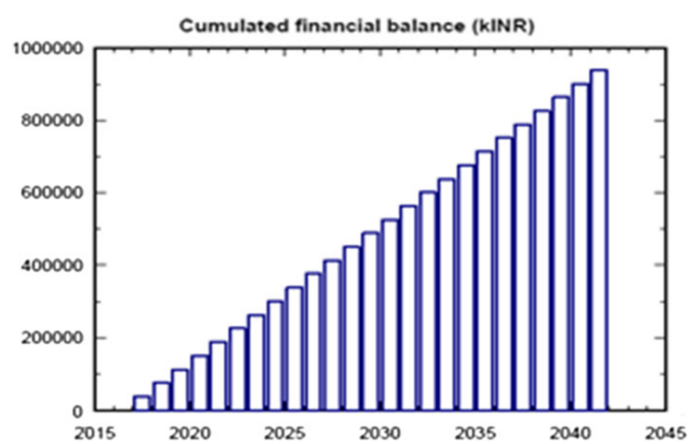

Figure 11. *Cumulative financial balance.*

Table 8 *Long-term financial balance sheet (all values are in 1000 INR)*

Year	Loan 11.5%	Running costs	Sold energy	Yearly balance	Cumulative balance
2017	45 433	100	83 089	37 556	37 556
2018	45 433	100	83 089	37 556	75 112
2019	45 433	100	83 089	37 556	112 667
2020	45 433	100	83 089	37 556	150 223
2021	45 433	100	83 089	37 556	187 779
2022	45 433	100	83 089	37 556	225 335
2023	45 433	100	83 089	37 556	262 890
2024	45 433	100	83 089	37 556	300 446
2025	45 433	100	83 089	37 556	338 002
2026	45 433	100	83 089	37 556	375 558
2027	45 433	100	83 089	37 556	413 113
2028	45 433	100	83 089	37 556	450 669
2029	45 433	100	83 089	37 556	488 225
2030	45 433	100	83 089	37 556	525 781
2031	45 433	100	83 089	37 556	563 336
2032	45 433	100	83 089	37 556	600 892
2033	45 433	100	83 089	37 556	638 448
2034	45 433	100	83 089	37 556	676 004
2035	45 433	100	83 089	37 556	713 560
2036	45 433	100	83 089	37 556	751 115
2037	45 433	100	83 089	37 556	788 671
2038	45 433	100	83 089	37 556	826 227
2039	45 433	100	83 089	37 556	863 783
2040	45 433	100	83 089	37 556	901 338
2041	45 433	100	83 089	37 556	938 894

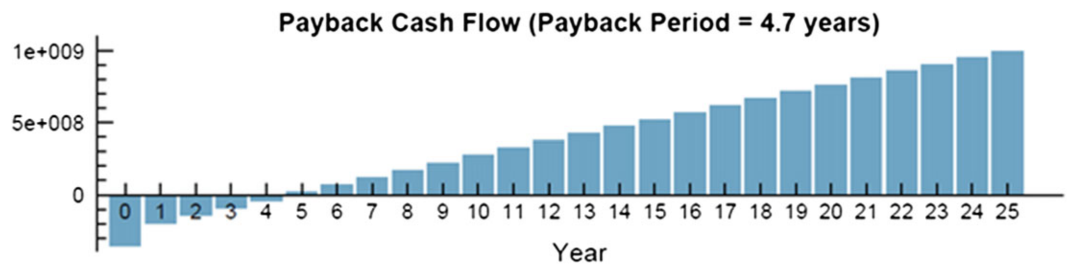

Figure 12. *Payback cash flow over 25 years.*

Table 9. *Performance comparison of PVSyst and SAM results.*

Characteristics	PVSyst	SAM	Percentage difference
Number of modules per string	19	22	–
Number of strings	1012	873	–
Total number of modules	19 228	19 206	–
Performance ratio	81.2%	74%	−8.86%
Annual energy generation	8304 MWh	6026 MWh	−27.43%
Price per KWh	5.48 ₹/KWh	5.72 ₹/KWh	4.37%
Total cost	₹ 36,90,79,345	₹ 35,56,51,648	3.63%
Total cost per watt	73.8 ₹/W	71.18 ₹/W	−3.55%

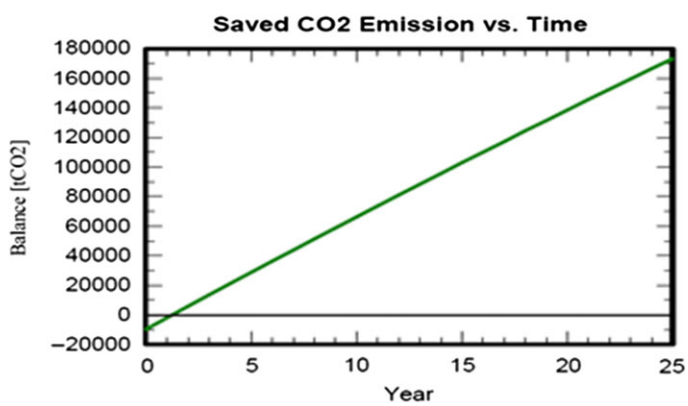

Figure 13. CO_2 emission saved.

- Produced emissions total: 9762.31 tCO_2
- Replaced emissions total: 194 303.6 tCO_2
- Annual degradation: 0.5%
- Lifetime: 25 years
- CO_2 emission balance total: 173 318.0 tCO_2

4 CONCLUSION

The article presents a feasibility analysis of 5 MW Solar Photovoltaic Power Plant for a Higher Educational Institute campus MANIT, Bhopal, India (one of the Institutes of National importance under MHRD, Govt of India) to become self-sufficient in terms of energy requirements. The present study has examined the technical and financial viability of the proposed plant by conducting detailed analysis using SAM and PVSYST. The following are the major conclusion from the study:

- This project is expected to produce 6 –8 GW of clean energy annually based on the SAM and PVSyst results. Since most of the energy needs of the Institute are in the daytime, i.e. during solar hours, the transmission losses can be greatly reduced.
- Through this initiative, Institute can earn around ₹ 5 5 341 788–₹ 938 894 000 of Indian rupees yearly over the life of 25 years.
- This plant will be able to reduce 173 318.0 tCO_2 in its lifetime, which is a significant figure of mitigation of GHG emissions.
- Solar PV technology has a limited lifespan of 25 years. However this proposed capacity can be expanded in future as the campus has enough land area for commissioning of the plant.
- The proposed solar plant will be an ideal opportunity for the Insitute to support current Indian Government's target of achieving 175 GW of energy production by 2022. Self-sufficiency of the Institute campus will be a pioneering step in the context of sustainable development and India's contribution to the UN sustainable development goals 2015.
- Further research is to be done to validate the accurateness and predictability of the software with field data.

REFERENCES

[1] Bishoyi D, Sudhakar K. Modelling and performance simulation of 100MW LFR based solar thermal power plant in Udaipur, India. *Resour Efficient Technol* 2017. http://doi.org/10.1016/j.reffit.2017.02.002.

[2] Shukla AK, Sudhakar K, Baredar P. Design, simulation and economic analysis of standalone rooftop solar PV system in India. *Sol Energ* 2016;**136**:437–49.

[3] Debbarma M, Sudhakar K. Thermal modeling, exergy analysis, performance of BIPV and BIPVT: a review. *Renew Sustain Energy Rev* 2017;**73**: 1276–88.

[4] Shukla AK, Sudhakar K, Baredar P. Simulation and performance analysis of 110 kWp grid-connected photovoltaic system for the residential building in India: a comparative analysis of various PV technology. *Energy Rep* 2016;**2**:82–8.

[5] Debbarma M, Sudhakar K. Comparison of BIPV and BIPVT: a review. *Resour Efficient Technol* 2016. http://doi.org/10.1016/j.reffit.2016.11.013.

[6] Khatri R. Design and assessment of solar PV plant for girl's hostel (GARGI) of MNIT University, Jaipur city: a case study. *Energy Rep* 2016;**2**: 89–98.

[7] Werulkar AS, Kulkarni PS. A case study of the residential solar photovoltaic system with utility back up in Nagpur, India. *Renew Sustain Energy Rev* 2015;**52**:1809–22.

[8] Sharma V, Kannan G. An assessment of carbon footprint at BITS Pilani, Dubai Campus and Proposed Green Campus Initiative. In: *2015 5th International Conference on Environment Science and Engineering* Volume 83 of IPCBEE 2015.

[9] Shiva Kumar B, Sudhakar K. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy Rep* 2015;**1**:184–92.

[10] Lee J, Chang B, Aktas C, *et al*. Economic feasibility of campus-wide photovoltaic systems in New England. *Renew Energy* 2016;**99**:452–64.

[11] Raturi A, Singh A, Prasad RD. Grid-connected PV systems in the Pacific Island countries. *Renew Sustain Energy Rev* 2016;**58**:419–28.

[12] Dawn S, Tiwari PK, Goswami AK, *et al*. Recent developments of solar energy in India: perspectives strategies and future goals. *Renew Sustain Energy Rev* 2016;**62**:215–35.

[13] Shukla KN, Rangnekar S, Sudhakar K. Comparative study of isotropic and anisotropic sky models to estimate solar radiation incident on tilted surface: a case study for Bhopal, India. *Energy Rep* 2015;**1**:96–103.

[14] Free mapping and area calculation tool, available at https://www.freemaptools.com/area-calculator.htm (5 December 2016, date last accessed).

[15] PVSyst software – general features, available at http://www.pvsyst.com/en (1 December 2016, date last accessed).

[16] Blair N, Dobos AP, Freeman J, *et al*. System advisor model, SAM 2014.1.14: General Description, Technical Report, NREL, February 2014.

[17] Shukla AK, Sudhakar K, Baredar P. Exergetic analysis of building integrated semitransparent photovoltaic module in clear sky condition at Bhopal India. *Case Studies Thermal Eng* 2016;**8**:142–51.

[18] Sudhakar K, Rajesh M, Premalatha M. Carbon mitigation potential of Jatropha Biodiesel in Indian context. *Energy Procedia* 2012;**14**:1421–6.

[19] Shukla KN, Rangnekar S, Sudhakar K. Mathematical modelling of solar radiation incident on tilted surface for photovoltaic application at Bhopal, MP, India. *Int J Ambient Energy* 2016;**37**:579–88.

[20] Sahu A, Yadav N, Sudhakar K. Floating photovoltaic power plant: a review. *Renew Sustain Energy Rev* 2016;**66**:815–24.

[21] Sudhakar K, Srivastava T, Satpathy G, *et al*. Modelling and estimation of photosynthetically active incident radiation based on global irradiance in Indian latitudes. *Int J Energy Environ Eng* 2013;**4**:21.