Energy Reports 2 (2016) 89–98

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Design and assessment of solar PV plant for girls hostel (GARGI) of MNIT University, Jaipur city: A case study

Rahul Khatri

Guest Faculty, Centre for Energy & Environment, Malaviya National Institute of Technology, Jaipur, India

ARTICLE INFO

Article history:
Received 4 December 2015
Received in revised form
12 April 2016
Accepted 9 May 2016
Available online 24 May 2016

Keywords:
PV plant
Financial assessment
Payback period & carbon credits

ABSTRACT

In this paper designing and assessment of a solar PV plant for meeting the energy demand of girl's hostel at MNIT University Jaipur city was analyzed. A solar PV plant was designed with its financial and environmental assessment considering recent market prices. All the aspects related to a solar PV plant were considered for financial feasibility of PV plant near this location. The different financial parameters which affect the financial feasibility of PV plant were considered i.e. discount rate, effective discount rate, rate of escalation of electricity cost, salvage value of the plant etc. The environmental aspect related with the energy generated with PV plant i.e. reduction in carbon emission and carbon credits earned was also considered. Result obtained with the assessment of the proposed plant with different discount rate and current rate of inflation shows that the max IRR 6.85% and NPV of $1,430,834 was obtained with a discount rate of 8% and an inflation rate of 7.23% when no land cost considered and if land cost was considered the maximum IRR was 1.96% and NPV of $630,833. Minimum discounted payback of the plant will be 13.4 years if inflation was considered.

1. Introduction

In current era the use of renewable technology for energy generation is growing at a faster rate. Considering the low stock of conventional fuels and consistent price rise the use of solar energy at places where solar radiations are available throughout the year must be utilized to its maximum. At the same time as the efficiency of the solar systems is low a real time financial analysis must be done to identify the conditions in which it will be most economical. The use of energy for the production and installation of the renewable system must be taken into account to calculate their energy payback time. This paper present a complete analysis and assessment of a PV plant for Gargi Hostel for girls at MNIT Jaipur which comprises of 406 rooms and can have at least same amount of girls residing at a time in hostel. The idea of developing environmentally friendly PV plants was discussed (Chena et al., 2012) and suggests that huge green energy source generated from the sun, PV industry will gain the best opportunity to grow up. We should grasp the opportunity to build the most suitable environmental friendly PV power plant. Considering this as an opportunity to propose a clean source of energy for complete energy demand of the girl's hostel, a solar PV plant design and its assessment has been carried out.

The study carried out for photovoltaic systems size optimization techniques suggests that optimization of PV system is strongly depends on meteorological variables such as solar energy, ambient temperature and wind speed (Khatib et al., 2013) so it becomes important to have a detailed analysis at various locations for accurate results. This paper will identify the designing and assessment issues and will allow developing energy strategies for the areas similar to that of the study. A case study on Gambia (Sowe et al., 2014) evaluate the feasibility between crystalline Si (c-Si) and thin film (Cd–Te) modules on the basis of NPV and IRR. Based on technical and economic assessments of the c-Si and Cd–Te PV power plants, the Cd–Te PV power plant presented the reasonable technology for rural electrification in The Gambia. Similar case study (Messinaa et al., 2014) having two 2.4 kW_p grid-connected PV systems installed at different locations i.e. Tepic and Temixco-Morelos concluded that the Temixco-Morelos PV system supplied nearly 90% of electrical energy need for the house and identifies grid-connected PV in the urban and suburban areas or stand-alone PV systems for the remote agricultural communities in Mexico is both feasible, and should form part of the national sustainable policies.

In this paper a 336 kW_p on site solar PV power plant was designed with the land required for it and its economic analysis is proposed. This paper cover all the preferences addressed by the (Soni and Gakkhar, 2014) in their paper i.e. Costs, Payback period as an economical parameter, location and CUF as a technical parameter and type of cell and performance ratio as PV parameters.

E-mail address: rahulkhatri2311@gmail.com.

http://dx.doi.org/10.1016/j.egyr.2016.05.002

Nomenclature

MNIT	*Malaviya National Institute of Technology*
PV	*Photovoltaic*
NPV	*Net Present Value*
kW_p	*Kilowatt peak*
(EPBT),	*Energy Payback Time*
(LCCE)	*Life Cycle Conversion Efficiency*
EPF	*Electricity Production Factor*
Ah	*Ampere-hour*
V	*Voltage*
DOD	*Depth-of-Discharge*
MPPT	*Maximum Power Point Tracking*
CUF	*Capacity Utilization Factor*
GHG	*Green House Gas*
E_m	*Energy for Materials*
E_{mf}	*Energy for manufacture PV system*
E_t	*Energy for Transport*
E_i	*Energy for Installation*
E_{mg}	*Energy for Management*
E_g	*Annual Electricity Generation*
E_{sol}	*Solar Energy*
L_s	*Life of Plant*
C_u	*Cost per unit of Electricity*
CRF	*Capital Recovery factor*
i	*Discount Rate*
$i*$	*Effective Discount Rate*
j	*Inflation Rate*
e	*Escalation Rate of Electricity*

Sharma and Tiwari (2013) provides an inclusive comparative life cycle assessment of on-field PV system dealing on an existing setup. Energy metrics (energy payback time, electricity production factor and life cycle conversion efficiency) of hybrid photovoltaic (PV) modules have been analyzed and presented for the composite climate of New Delhi, India (Tiwari et al., 2009). A review has been done to estimate the environmental impacts of different solar PV based electricity generation systems using life cycle assessment technique (Sherwani et al., 2010). A study on the life cycle assessment of PV systems (Kannan et al., 2006) used EPBT as an indicator for primary energy use, life cycle cost analysis are performed for a distributed 2.7 kW_p grid-connected monocrystalline solar PV system operating in Singapore and concludes that GHG emission from electricity generation from the solar PV system is less than one-fourth that from an oil-fired steam turbine plant and one-half that from a gas-fired combined cycle plant, it shows great impact on the environment.

The methodology adapted was based on the literature survey and the process flow of the paper is shown in the Fig. 1. This paper provides design and analysis of a 336 kW_p SPV plant with different parameters associated with real time market prices and future escalation of the prices. This paper analyzes feasibility study for the plant near the site location with its energy metrics i.e. Energy Payback Time (EPBT), Life Cycle Conversion Efficiency (LCCE) etc. A satellite image of the hostel location with its sunpath is shown in Figs. 2 and 3 which shows the availability of the land near the site.

2. Energy demand of the hostel

A detailed survey of each room of hostel and sections of the hostel was carried out to identify the amount of load connected to it. Tables 1–5 provides the complete details of the different equipment's their wattage and hours of operation (on the basis of survey) (How to Design Solar PV System). Total energy that needed to be supplied by the solar PV system is estimated as 1368 kWh/day.

Table 1
No. of rooms in hostel.

Floor	Rooms
Ground	56
First	78
Second	89
Third	91
Fourth	46
Fifth	46
Total	406

3. Solar photovoltaic power plant designing

Design of solar photovoltaic power plant consists of PV modules sizing, inverter sizing, battery sizing and module circuit design. For designing solar PV plant geographical details and weather data of the site is required. Table 6 and Fig. 4 provides a monthly average radiation data for the Jaipur city which is located at 26.9260°N, 75.8235°E in Rajasthan state of India (Synergy Enviro Engineers). Fig. 5 provides the location of Jaipur city in Rajasthan and its global daily radiation data.

3.1. Panel generation factor (How to Design Solar PV System)

Panel Generation Factor is a key element in designing a solar PV plant which gives for every Wp capacity in the panel we can expect to get an average of Wh/day and it is different in each site location, for Jaipur city considering 5.30 kWh/m^2;

$$\textit{Panel Generation Factor} = \frac{\textit{Daily Solar Radiation}}{\text{Standard Test conditions Irradiance for PVpanels}} = \frac{5.3 * 10^3}{1000} = 5.30. \quad (1)$$

3.2. Energy required from PV modules (How to Design Solar PV System)

Energy required from PV modules will be daily energy demand of the hostel and compensation for the system losses which is generally taken as 30%, therefore the total energy required will be

$$\text{Energy required} = (\textit{Energy Demand} * \textit{System Losses Compensation Factor}) = 1368 * 1.3 = 1778.4\ \text{kWh/day}. \quad (2)$$

3.3. Watt Peak rating for PV modules (How to Design Solar PV System)

Total Watt peak rating for PV modules is calculated to identify system sizing which depends on the energy required from modules and panel generation factor

$$\text{Watt Peak rating for PV Modules} = \frac{\textit{Energy required from PV modules}}{\textit{Panel Generation Factor}} = \frac{1780}{5.30} = 336\ kW_p. \quad (3)$$

3.4. PV modules (How to Design Solar PV System)

A nearby supplier of PV module was identified for a realistic analysis and availability of the modules, Ajit Solar with PV module model of ASPL V-60 was considered in this analysis. This module was selected as the supplier is local and agreed on the mentioned cast i.e. 0.62$ per W. Table 7(i) gives full specifications of the selected module and Table 7(ii) provides the modified efficiency

Table 2
Energy required in rooms.

S.No.	Name of equipment	Nos.	Rating (W)	Hours of operation	Energy required (kWh)
1.	Tube light	01	40	12	0.48
2.	Fan	01	60	18	1.08
3.	Laptop	01	60	6	0.36
4.	Server (LAN port)	01	15	6	0.09
5.	Mobile charger	01	5	2	0.01
			One room		2.02
			For 406 rooms		820.12

Table 3
Energy required per floor other than rooms.

S.No.	Component	Nos.	Electrical equipment			Total wattage (W)	Hours of operation	Total (kWh)
			Type	Quantity	Rating (W)			
1.	Stairs	4	CFL	4	15	240	12	2.88
2.	Bathroom	8	CFL	10	15	1200	12	14.40
3.	Lobby	–	CFL	84*2	15	2520	12	30.24
4.	Water cooler	2		2	1550	3100	4	12.40
							For one floor	59.92
							For five floors	299.60

Table 4
Energy required for miscellaneous.

S.No.	Component	Quantity	Electrical equipment			Total wattage (W)	Hours of operation	Total (kWh)
			Name	Quantity	Rating (W)			
1.	Mess	01	Tube lights	39	40	1 560	4	2.88
			Fans	27	60	1 620	9	14.58
			Water cooler	01	1550	1 550	12	18.60
2.	Common room	02	Tube lights	12	40	960	12	11.52
			Fans	08	60	960	18	17.28
3.	Laundry room	01	Washing machine	06	4300	25 800	2	51.60
			Dryer	06	5.6	25 800	2	51.60
4.	Elevators	02				7 950	10	79.50
							Total	247.56

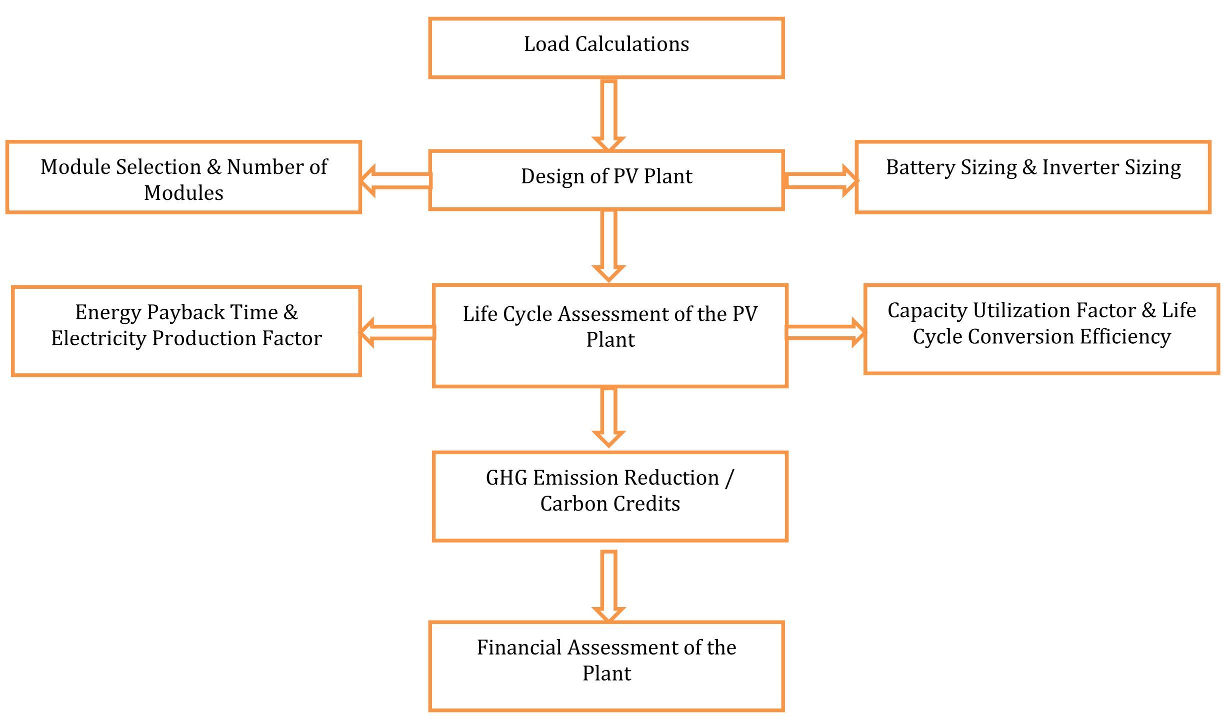

Fig. 1. Process flow for design and assessment of the PV plant.

Fig. 2. Satellite view of Gargi Hostel MNIT Jaipur.

Fig. 3. Sun path on Sep-22 at Gargi Hostel using SunCalc.

of cell, based on temperature variations on the location; the total no of modules required for the proposed plant depends on the peak rating of the modules.

$$No.\ of\ modules\ required = \frac{Total\ Watt\ Peak\ Rating}{PV\ module\ Peak\ Rated\ Output} = \frac{336 * 1000}{230} = 1460\ \text{Modules}. \quad (4)$$

Battery sizing (How to Design Solar PV System)

Designing an onsite power plant always requires a storage medium and in case of PV plant batteries is the most common storage medium, in present case as it is an educational institute it is very important to have storage medium importantly for exam days. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days. MNIT is located in Jaipur city with minimum power cut periods therefore single day of autonomy is enough for the hostel requirements.

Table 5
Total energy required per day.

S.No.	Component	Total energy required per day (kWh)
1.	Rooms	820.12
2.	Floor's components	299.60
3.	Miscellaneous	247.56
	Total	1367.28

Battery Specifications:

Nominal Voltage = 48 V

Depth of Discharge = 40%

Battery Capacity = 175 Ah

Battery Efficiency = 90%

Life of a Battery = 4 years

Table 6
Solar radiation data for Jaipur (26.9260°N, 75.8235°E) (Synergy).

Month	Average (kWh/m^2)
Jan	4.19
Feb	5.00
Mar	6.09
Apr	7.08
May	7.23
Jun	6.64
Jul	5.15
Aug	4.81
Sep	5.42
Oct	5.00
Nov	4.27
Dec	3.68
	Annual Average 5.3 ($kWh/m^2/day$)

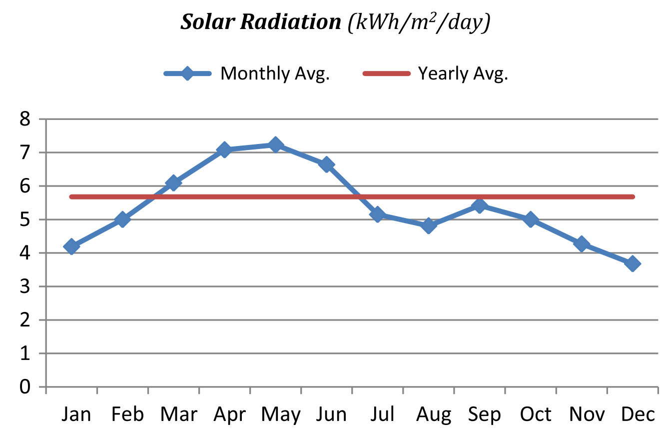

Fig. 4. Monthly solar radiations variations in Jaipur city (Synergy).

Table 7(i)
PV module specifications (Ajit Solar ASPL V-60) ASPL Product Information.

Module type[a]	ASPL V60
Peak power output watt (W_p)	230
Current at peak power output amp (I_{max})	7.77
Voltage at peak power output volt (V_{max})	29.60
Short circuit current amp (I_{sc})	8.28
Open circuit voltage volt (V_{oc})	37.10
Dimensions (mm)	1665 * 995 * 50
Cell efficiency	16%
Power tolerance	±3%

[a] Electrical specifications mentioned above are at standard test conditions of 100 mW/sq cm. AM 1.5 and at 25 °C cell temperature and are within normal production tolerance of ±10%.

$$\text{Batter Capacity Required (Ah)} = \frac{(\text{Total Wh required}) * \text{Days of Autonomy}}{\text{Nominal Battery Voltage} * (1 - \text{DOD}) * \text{Battery Efficiency}} \quad (5)$$

$$\text{Batter Capacity Required (Ah)} = \frac{1368 * 10^3 * 1}{48 * 0.6 * 0.9} = 52\,778 \text{ Ah.}$$

No. of Batteries required:

The total no. of batteries required depends on the capacity of each battery, in present analysis; Trojan J185E-AC 12V Deep Cycle Battery costing $205.5 is used (atbatt.com);

$$\text{No. of Batteries} = \frac{\textit{Battery Capacity Required}}{\textit{Single Battery Capacity}} = \frac{52\,778}{175} = 302 \text{ Batteries.} \quad (6)$$

Table 7(ii)
Modified cell efficiency based on temperature variation (Dubey et al., 2013).

Month	Average temperature	$T-T_{ref}$	$\beta(T-T_{ref})$	Efficiency (η)
Jan	23	−2	−0.00816	0.1613
Feb	26	1	0.004082	0.1593
Mar	32	7	0.028571	0.1554
April	38	13	0.053061	0.1515
may	41	16	0.065306	0.1496
June	40	15	0.061224	0.1502
July	35	10	0.040816	0.1535
Aug	33	8	0.032653	0.1548
Sept	35	10	0.040816	0.1535
Oct	34	9	0.036735	0.1541
Nov	30	5	0.020408	0.1567
Dec	25	0	0	0.16
			Average η	0.1550

Table 8
Life cycle and environmental assessment of the plant.

S.No.	Parameters	Value
1	EPBT (energy payback time)	8.24 yr
2	Electricity production factor	0.12
3	Capacity utilization factor	0.152
4	Life cycle conversion efficiency	0.072
5	Total embodied energy of the plant	1516.59 kWh/m^2
6	CO_2 emission from embodied energy	5794 tonnes Of CO_2
7	Yearly CO_2 mitigation	702.5 tonnes Of CO_2
8	Net CO_2 mitigation	15 281 tonnes Of CO_2
9	Carbon credits earned	$10,300

3.5. *Inverter rating (How to Design Solar PV System)*

Size of the inverter required for the plant depends upon the peak watts requirement. The peak requirement of the hostel is 336 kW_p. The inverter must be large enough to handle the total amount of watts peak requirement. The inverter size should be 25%–30% bigger than total watts requirement;

The inverter size = 336 ∗ 1.3 = 450 kW.

Cost effective *Solectria PVI* 82 kW *Grid Tied Inverter* 480 V_{AC} *PVI*-82 kW (Solectria) inverter costing $36 306 was selected for the system with 82 kW rated Power and max open circuit voltage of 600 V_{DC}, integrated with PV Maximum Power Point Tracking (MPPT).

According to the rated power of the inverter the no. of inverters required is:

$$\textit{No. of inverters} = \frac{\textit{Inverter Size}}{\textit{Rated Power of an Inverter}} = \frac{450}{82} = 6. \quad (7)$$

3.6. *Module circuit (How to Design Solar PV System)*

The module circuit means the no. of modules to be connected in series i.e. the size of an array and voltage input to the inverter and total no. of arrays in the solar field.

Size of an array depends on the inverter maximum V_{oc} and V_{oc} of the module used.

$$\text{Size of an array} = \frac{\textit{Maximum Open Circuit Voltage of Inverter}}{\textit{Open Circuit Voltage of each PV Module}} = \frac{600}{37.1} = 16 \text{ Modules.} \quad (8)$$

Maximum voltage input to the inverter

$$(\textit{Maximum Voltage from a Module} * \textit{No. of Modules in Series}) = (29.6 * 16) = 474 \text{ V}$$

Total No. of Arrays in the solar field will be

$$= \frac{\textit{No. of Modules}}{\textit{No. of Modules in an Array}} = \frac{1460}{16} = 91 \text{ Arrays.} \quad (9)$$

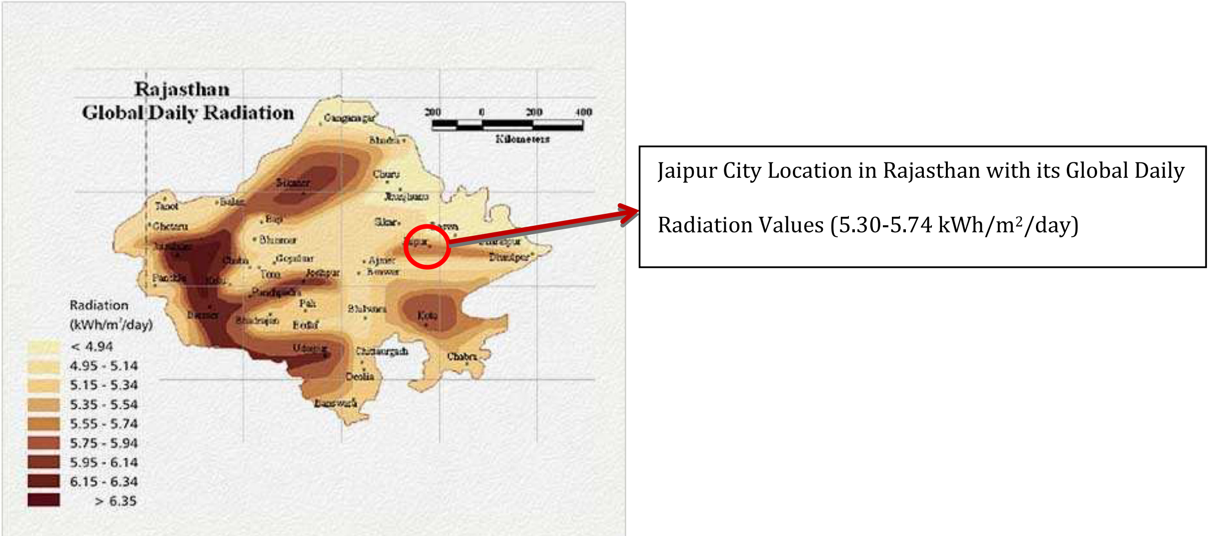

Fig. 5. Global daily radiation in Rajasthan.

4. Life cycle assessment of the PV plant

The assessment of any renewable system includes the amount of energy consumed by the system components for their materials; manufacturing transportation i.e. embodied energy of the system amount of energy generated by the plant, its energy payback time (EPBT) its life cycle conversion efficiency (LCCE) and capacity utilization factor (CUF). Table 8 provides the complete details of the life cycle assessment of the proposed plant.

4.1. Energy payback time of the plant

Energy payback time is defined as "How long does a PV system have to operate to recover the energy that went into making the system" and it is given by;

$$\text{EPBT} = \frac{(E_m + E_{mf} + E_t + E_i + E_{mg})}{E_g} \tag{10}$$

where;

E_m: Primary energy demand to produce materials comprising PV system.
E_{mf}: Primary energy demand to manufacture PV system.
E_t: Primary energy demand to transport materials used during the life cycle.
E_i: Primary energy demand to install the system.
E_{mg}: Primary energy demand for end-of-life management.
E_g: Annual electricity generation in primary energy terms.

The value for the total energy consumed in materials, manufacturing, transport, installation and management for each m^2 area of the module was proposed by Tiwari et al. (2009).

$(E_m + E_{mf} + E_t + E_i + E_{mg}) = 1516.59\ \text{kWh/m}^2$ of module, therefore;

Total area of modules

$$= \text{No. of Modules} * \text{Length} * \text{Width of Modules}$$
$$= 1460 * 1.665 * 0.995 = 2418\ \text{m}^2 \tag{11}$$

Total Embodied Energy is $= 2418 * 1516.59 = 3667$ MWh

Annual Electricity Generated $(E_g) = 1368 * (325)^{\#} = 444.6$ MWh/year.

No. of Clear Sunny days in Jaipur (Pandey et al., 2012),

Energy Payback Time (***EPBT***)

$$= \frac{\text{Total Embodied Energy of Modules}}{\text{Annual Electricity Generated from Plant}}$$
$$= \frac{3667}{444.6} = 8.24\ \text{years}. \tag{12}$$

4.2. Electricity production factor (EPF)

It is defined as the ratio of the annual energy output to the input energy and it predicts the overall performance of the PV module. EPF is reciprocal of EPBT. Thus

$$\text{EPF} = \frac{E_g}{(E_{mg} + E_{mgf} + E_t + E_i + E_{mg})} = \frac{444.6}{3667} = 0.12. \tag{13}$$

4.3. Capacity utilization factor (CUF)

Capacity Utilization Factor (CUF) is the ratio of actual energy generated by SPV plant over the year to the equivalent energy output at its rated capacity over the yearly period. The energy generation for SPV project depends on solar radiation & number of clear sunny days

$$\text{CUF} = \frac{\textit{Annual Energy Generated for each kW peak capacity}}{\text{8760 hours}}$$
$$= \frac{\frac{444\,600}{336}}{8760} = 0.152. \tag{14}$$

4.4. Life cycle conversion efficiency (LCCE)

It is the net energy productivity of the PV system with respect to the solar input (radiation) over the life time of the PV system,

$$\text{LCCE} = \frac{E_g * L_s - E_{em}}{E_{sol} * L_s}$$
$$= \frac{(444.6 * 10^3 * 30) - 3667 * 10^3}{4463.628 * 10^3 * 30} = 0.072. \tag{15}$$

5. Estimating Greenhouse Gas Emissions Reduction, Mitigation and Carbon Credit

Photovoltaic is a clean source of energy requiring no fuel and no GHG emissions during its service periods. India is highly dependent on the coal based thermal power plants for electricity generation and the average CO_2 emission is 0.98 kg of CO_2 per kWh.

5.1. CO_2 emissions

CO_2 emission from the embodied energy of the PV plant includes the emissions in manufacturing, materials etc. The average CO_2 emission for electricity generation and considering other embodied emissions from coal based thermal power plant is 0.98 kg of CO_2 per kWh (Sharma and Tiwari, 2013). If the transmission and distribution losses and, for Indian conditions are taken, the average CO_2 per kWh can be taken as 1.58 kg.

$$CO_2\ Emissions = (E_{em} * 1.58) = \left(3667 * 10^3 * 1.58\right) = 5794\ tonnes\ of\ CO_2. \quad (16)$$

5.2. CO_2 mitigation

The CO_2 mitigation is the amount of CO_2 emission reduction by generating the energy from the PV plant that would otherwise released by the thermal power plant in case of India.

$$Yearly\ CO_2\ mitigation = \left(E_g * 1.58\right) = 444.6 * 10^3 * 1.58 = 702.5\ tonnes\ of\ CO_2. \quad (17)$$

5.3. Net CO_2 mitigation

Net CO_2 mitigation for the proposed PV power plant will be the difference between the CO_2 emission and CO_2 mitigation over its entire life i.e. 30 yr.

$$Net\ CO_2\ Mitigation = (Yearly\ CO_2\ Mitigation * L_s) - (CO_2\ Emissions) = (702.5 * 30) - 5794 = 15\,281\ tonnes\ of\ CO_2. \quad (18)$$

5.4. Carbon credits

Carbon Credits are awarded against reduction in greenhouse gases emissions CO_2 etc. Carbon credits can be traded in the international market at their current market price. One carbon credit is earned against reduction in one tonne of CO_2 emissions (tCO_2e). In present work the net CO_2 mitigation is 15 281 tCO_2e. The current market price of one carbon credit is \$0.67/ tCO_2e (Certified), Rakhi Sharma et al. used \$31/tCO_2e which is nearly 50 times more than the current exchange rate.

Carbon Credits (\$) = 15 281 ∗ 0.67 = \$10,300

Yearly Earnings from carbon Credits : \$350 (19)

#\$1.48/€.

6. Financial assessment of the plant

Renewable energy technologies have enjoyed a period of rapid growth in recent years. They will have to become price competitive to sustain their growth. For the financial assessment of the plant the realistic values or the current market prices of the components associated with the project must be taken, most of the studies for the financial assessment does not include the real market prices, Chandel et al. (2014) uses modules that cost \$530 for 215 W P_{max} which is highly unrealistic in current market. This study uses the current market prices of the components for a real time financial analysis. Table 9 gives details of the cost breakup for the proposed plant. Table 10 gives a complete list of parameters used for the financial assessment of the plant and Table 11 gives complete details of the result obtained from the financial assessment of the plant.

Table 9
Cost break-up for solar PV plant.

S.No.	Particular	Cost (\$)
1	Module cost	208,333
2	Batteries cost	428,333
3	Inverters cost	216,667
4	Miscellaneous cost	45,000
5	Land cost	800,000
	Total cost without land cost	898 333
	Total cost with land cost	1,698,333

The project cost includes

i. Cost of Modules.
ii. Cost of Batteries.
iii. Cost of Inverters.
iv. Miscellaneous {Operation and Maintenance cost, Installation Cost, Electrical Items (Cables etc.), Packing and Freight}.

6.1. Cost of modules

Ajit Solar ASPL V-60 module is considered in the designing of the plant. The global module cost is decreasing every day, the market trends shows that currently it is around \$0.62 per W_p in India (Global PV Module Pricing).

$$Total\ module\ cost = 336 * 10^3 * 0.62 = \$208{,}320. \quad (20)$$

6.2. Cost of inverters

Inverter is an electronic device which is able to convert a DC potential normally derived from solar panels or battery into a stepped-up AC potential which may be quite comparable to the voltage that is found in domestic AC outlets. *Solectria PVI* 82 kW *Grid Tied Inverter* 480 V_{AC} *PVI*-82 kW (Solectria) was considered for this system.

Cost of One Inverter = \$36 300

Total Cost of Inverters = \$36 300 ∗ 6 = \$217,800. (21)

6.3. Cost of batteries

Batteries store energy being produced by a given generating source, and when this source is unavailable this energy can be used by the load. The inclusion of storage in any energy generating system will increase the availability of the energy. Trojan J185E-AC 12 V Deep Cycle Battery costing \$205.5 (atbatt.com) was used. The battery life was considered as five years as there will be no frequent use of batteries and annual maintenance contract will improve the life of the battery. The replacement cost was considered after every five years considering the applicable discount rate

Cost of (4 ∗ 12 V) Battery with Rack = (\$205.5 ∗ 4 + \$150 ∗ 4) = \$1422

Total Cost of Batteries = \$1422 ∗ 302 = \$429,444. (22)

Table 10
Parameters for economic assessment.

S.No.	Particular		Value
1	Discount rate	i	8%, 10%, 12%
2	Inflation rate	j	7.23% (July-2014)
3	Effective discount rate[a]	i *	0.7%, 2.6%, 4.5%
4	Price of unit energy	$/kWh	0.13
5	Escalation in price of unit energy	e	2%
6	Cost of land	$	166.67/m^2
7	Rs to $		Rs 60/$

[a] Effective discount rate $i* = \frac{i-j}{1+j}$.

Table 11
Financial analysis of the SPV plant.

Considering 2% escalation in price/kWh				
With land cost	NPV ($)	IRR	Discounted payback period	Simple payback period (yr)
Discount rate@ 8%	Negative	−4.92%	NEVER	
@ 10%	Negative	−6.65%	NEVER	27.35
@ 12%	Negative	−8.32%	NEVER	
Effective discount rate ($i*$)				
Discount rate@ 8% = 0.7%	630,833	1.96%	23.6 yr	
@ 10% = 2.6%	21,167	0.08%	29.3 yr	27.35
@ 12% = 4.5%	Negative	−1.74%	NEVER	
Without land cost				
Discount rate@ 8%	Negative	−0.38%	NEVER	
@ 10%	Negative	−2.18%	NEVER	14.47
@ 12%	Negative	−3.93%	NEVER	
Effective discount rate ($i*$)				
Discount rate@ 8% = 0.7%	1,430,834	6.85%	13.4 yr	
@ 10% = 2.6%	821,167	4.87%	15.16 yr	14.47
@ 12% = 4.5%	412,834	2.96%	18.19 yr	

6.4. Miscellaneous cost

Miscellaneous cost including Operation and Maintenance cost, Installation Cost, Electrical Items (Cables etc.), Packing and Freight, it comes out to be nearly $0.13/W$_p$ (Chandel et al., 2014), thus total miscellaneous cost of the proposed plant will be

$$\textit{Miscellaneous cost} = 0.13 * 336 * 10^3 = \$43{,}680. \tag{23}$$

6.5. Land required

Financial assessment includes the land cost of the site therefore two cases were taken while assessment i.e. once land cost was considered and in second case land cost was not considered. If land cost is to be considered for the plant the area required for plant must be calculated. The area of the plant depends on the modules layout and their arrangements.

Number of PV modules required 1460; the arrays can be arranged as 7 arrays in a row and 13 such rows. So the area required will be

Dimension of one PV module = 1.665 m ∗ 0.995 m

No of Modules connected in series = 16

Width of an array = 0.995 ∗ 16 = 16 m^2

$$\text{Width of the solar field} = \textit{No. of array in row} * 16 = 7 * 16 = 112\text{ m} \tag{24}$$

No. of rows in solar field = 13

Assuming Ground Cover Ratio of the plant as 0.5,

the pitch distance between consecutive array will be

= 1.665 ∗ 2 = 3.4 m

Total length of the solar field

= (3.4 ∗ 12) + 1.665 m (Either for first or last row) = 43 m

$$\text{So total area required for the plant is} = 112 * 43 = 4816\text{ m}^2. \tag{25}$$

6.6. Cost of land

The MNIT university is located near Jaipur airport in Malaviya Nagar where the current price of the land is $166.67/m^2 near to the proposed site, the total investment required to

$$\text{acquire the land will be} = 166.66 * 4816 = \$802{,}635. \tag{26}$$

6.7. Cost per unit of electricity (C_u)

Cost of energy is the price at which electricity must be generated from a specific source to break even over the lifetime of the project. It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and is very useful in calculating the costs of generation from different sources.

The cost of energy is calculated using capital recovery factor, NPV net present value and annual energy generated from the system. Table 12 gives values of C_u at different discount rates, with and without land cost.

$$\text{The } C_u = \frac{\text{Annualized uniform cost}}{\textit{Annual energy generated}} \tag{27}$$

where; Annualized uniform cost = NPV ∗ CRF

NPV = Net present value

$$\text{CRF} = \text{Capital Recovery factor} = \frac{i\,(1+i)^n}{\left\{(1+i)^n - 1\right\}},$$

$$i = \text{discount rate}, n = \text{life of plant}. \tag{28}$$

7. Results

The analysis of a solar PV plant designed for a girl's hostel is carried out. The PV technology is not used only for reducing

Table 12
Cost per unit of electricity (C_u).

System	Discounts rate (i)	CRF	NPV * CRF	$/kWh
With land cost	8	0.088	Negative	–
	10	0.106	Negative	–
	12	0.124	Negative	–
Without land cost	8	0.088	Negative	–
	10	0.106	Negative	–
	12	0.124	Negative	–
System	Effective $i*$	CRF	NPV * CRF	$/kWh
With land cost	0.7	0.037	630,833	0.0525
	2.6	0.048	21 167	0.0023
	4.5	0.061	Negative	–
Without land cost	0.7	0.037	1,430,834	0.12
	2.6	0.048	821,167	0.089
	4.5	0.061	412,834	0.057

the consumption of fossil fuels but it can be a continuous source of energy for critical areas like hostel of universities where uninterrupted supply is demanded. As this is a case study it will imply on the places like Rajasthan or an area with abundant solar energy available for nearly whole year. In this paper the efforts have been made to identify the requirements of the plant for continuous supply of energy to the hostel and its feasibility was identified with its environmental and financial assessment. This will be useful for energy planning and developing new strategies for PV implementation.

Reduction in CO_2 emissions from the energy generated with solar energy which could be otherwise generated with highly polluting coal based thermal power plant was also analyzed. For a precise assessment the embodied energy of the plant is also taken into account, which was used to analyze the energy payback time of the plant i.e. 8.24 years with a capacity utilization factor of 0.152. The PV technology used can also earn carbon credits from reduction in CO_2 emissions and in the present case the proposed plant is capable of earning nearly 15 281 Carbon credits which worth $10,300, however the recent market prices are very low for the carbon credits still a real value is used in this paper.

The peak capacity required for meeting the energy demand of the hostel is 336 kW_p which require an area of nearly 4816 m^2, as discussed abundant land is available inside institute campus the land cost must not be a factor in its financial assessment but this paper proposes an analysis for the location not only for the site therefore two cases with and without land cost are considered so that the effect of land cost on the financial viability of the project could be identified.

The effect of the other financial parameters like the rate of escalation of energy with 2% which is currently available @ $0.13/kWh and current rate of inflation of the country i.e. 7.23% is also considered as an important factor for the financial viability of the project; the inflation is a variable parameter so the assessment was done with and without inflation, the inflation is analyzed with the term effective discount rate. The results obtained from the financial assessment of the plant are shown in table where the simple payback period for the plant without considering land cost is 14.47 years which increases to 27.35 years if land cost is considered. With effective discount rate the minimum discounted payback is 13.4 years without considering land cost and 23.6 years if cost of land is considered. The maximum IRR with effective discount rate is 6.85% without land cost. Cost of energy C_u is the price at which electricity must be generated from a specific source to break even over the lifetime of the project, the maximum C_u resulted in this paper is $0.12/kWh. Table 13 shows complete details associated with the proposed plant.

This case study brings a complete analysis of a proposed PV plant for girl's hostel and the possible future scope of this study will be the practical implementation which will help in developing a sustainable environment and improving policies for the better use of solar energy.

8. Conclusion

This paper has attempted an assessment of a Solar PV plant for girl's hostel of MNIT University in Jaipur city and examines its financial viability with parameters associated and real time market prices. The findings of the presented study are concluded as:

- The 336 kW_p system designed for the hostel requires 1460 modules of 230 W_p with an array containing 16 modules each, the plant requires an area of 4816 m^2 this can cost about nearly the same as the capital cost of the plant.
- The EPBT of the plant comes out to be 8.24 years with a life cycle conversion efficiency of 0.072. The capacity utilization factor of the proposed plant is nearly 0.152.
- The carbon credits that can be earned from the plant was results as 15 281 tCO_2e which worth of $10,300 at a price of $0.67/Credit which is very low but a real time price from European Energy Exchange on 26/09/2014 was considered.
- For the financial assessment of the plant an 2% escalation every year in energy cost was considered and a real time inflation rate of 7.23% (July-2014) (Inflation India) in India was considered which resulted in high impact on the financial viability of the proposed plant, for the discount rate of 8% and effective discount rate of 0.7% the IRR is nearly three times if the land cost is not considered i.e. 6.85% and 1.96% respectively.

Table 13
Assessment of the proposed PV plant.

S.No	Particular	Value
1	Capacity of the plant	336 kWp
2	Life of the plant	30 yr
3	Area required for the plant	4816 m^2
4	Cost of plant without land cost	$898,333
5	Cost of plant with land cost	$1,698,333
6	Savings from total energy generated in life time (13 338 MWh)@ Rs 0.13/kWh	$1,778,334
7	Savings from carbon credits earned (15 281)@ $0.67/Credit	$10,300
8	Salvage value of the plant @ 15% of total Initial cost	$113,334
9	Simple payback period with land cost	27.35 yr
10	Simple payback period without land cost	14.47 yr
11	Minimum discounted payback with land cost & effective discount rate	23.6 yr
12	Minimum discounted payback without land cost & effective discount rate	13.4 yr
13	Maximum IRR with land cost	−4.92%
14	Maximum IRR without land cost	−0.38%
15	Maximum IRR with land cost & effective discount rate	1.96%
16	Maximum IRR without land cost & effective discount rate	6.85%

The result shows that even in areas where solar energy is abundantly available the effect of the real time market prices could affect the financial viability of the project and its energy saving potential. The life of the plant, the current discount rate, inflation rate and escalation in energy cost must be considered for detailed analysis of the plant. In the current market scenario with low cost of renewable technology the role of other financial parameters affects the financial viability of the project therefore it is necessary to analyze all the parameters carefully before installing a PV plant especially in areas where land cost is a considerable parameter. This paper can be utilized to identify shortcomings in the energy policies and strategies for the countries or states trying to reduce their GHG emissions and making this technology more attractive and financially viable.

References

ASPL Product Information, Ajit Solar. http://www.ajitsolar.com/products.html (accessed 09.25.14) online.
atbatt.com. Trojan J185E-AC 12V Deep Cycle Battery. http://www.atbatt.com/trojan-j185e-ac-12v-deep-cycle-battery.asp?cr_brand=Trojan&cr_product=J185E-AC (accessed 09.25.14) online.
Certifiedx Emission Reduction Futures, European Energy Exchange. https://www.eex.com/en/market-data/emission-allowances/derivatives-market/certified-emission-reductions-futures#!/2014/09/26 (09.26.14) online.
Chandel, Mevin, Agrawal, G.D., AnujMathur, SanjayMathur, 2014. Techno-economic analysis of solar photovoltaic power plant for garment zone of Jaipur city. Case Stud. Therm. Eng. 2, 1–7.
Chena, Nuofu, Zhang, Xiulan, Baia, Yiming, Zhang, Han, 2012. Environmental friendly PV power plant. Energy Procedia 16, 32–37.
Dubey, Swapnil, Narotam Sarvaiya, Jatin, Seshadri, Bharat, 2013. Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world—a review. Energy Procedia 33, 311–321.
Global PV Module Pricing, greentechmedia. http://www.greentechmedia.com/articles/read/global-pv-prices-will-increase-nine-percent-in-2014 (accessed 09.25.14) online.
Government, Rajasthan Solar Energy, Bureau of Investment Promotion in Rajasthan. http://investrajasthan.com/solar-energy.cms (accessed 09.22.14) online.
How to Design Solar PV System, Leonics. http://www.leonics.com/support/article2_12j/articles2_12j_en.php (accessed 09.24.14) online.
Inflation India—current Indian inflation, inflation.eu. http://www.inflation.eu/inflation-rates/india/inflation-india.aspx, online.
Kannan, R., Leong, K.C., Osman, R., Ho, H.K., Tso, C.P., 2006. Life cycle assessment study of solar PV systems: An example of a 2.7kW$_p$ distributed solar PV system in Singapore. Sol. Energy 80, 555–563.
Khatib, Tamer, Mohamed, Azah, Sopian, K., 2013. A review of photovoltaic systems size optimization techniques. Renewable Sustainable Energy Rev. 22, 454–465.
Messinaa, Sarah, Paz Hernández Rosales, I., Saldaña Durán, Claudia E., Jesús Quiñones, J., Nair, P.K., 2014. Comparative study of system performance of two 2.4 kW grid-connected PV installations in Tepic-Nayarit and Temixco-Morelos in México. Energy Procedia 57, 161–167.
Pandey, Shreemat, Shanker Singh, Vijai, Pal Gangwar, Naresh, Vijayvergia, M.M., 2012. Determinants of success for promoting solar energy in Rajasthan, India. Renewable Sustainable Energy Rev. 16, 3593–3598.
Sharma, Rakhi, Tiwari, G.N., 2013. Life cycle assessment of stand-alone photovoltaic (SAPV) system under on-field conditions of New Delhi, India. Energy Policy 63, 272–282.
Sherwani, A.F., Usmani, J.A., Varun, , 2010. Life cycle assessment of solar PV based electricity generation systems: A review. Renewable Sustainable Energy Rev. 14, 540–544.
Solectria PVI 82 kW Grid Tied Inverter 480 VAC PVI-82 kW, pvpower.com. http://www.pvpower.com/solectriapvi82kwinverter82kw.aspx (accessed 09.26.14) online.
Soni, M.S., Gakkhar, Nikhil, 2014. Techno-economic parametric assessment of solar power. Renewable Sustainable Energy Rev. 40, 326–334.
Sowe, Samba, Ketjoy, Nipon, Thanarak, Prapita, Suriwong, Tawat, 2014. Technical and economic viability assessment of PV power plants for rural electrification in the gambia. Energy Procedia 389–398.
SunCalc, SunCalc. (http://suncalc.net/#/26.8647,75.8147,17/2014.09.22/10:49) (accessed 9.22.14) online.
Synergy Enviro Engineers, http://www.synergyenviron.com/tools/solar_insolation.asp?loc=Jaipur%2CRajasthan%2CIndia, online.
Tiwari, Arvind, Barnwal, P., Sandhu, G.S., Sodha, M.S., 2009. Energy metrics analysis of hybrid—photovoltaic (PV) modules. Appl. Energy 86, 2615–2625.