Techno-economic Feasibility Analysis of 100 kWp Solar Photovoltaic System for an Educational Building in Sirsa (India)

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Abstract: The PV solar system on the rooftop of buildings is a good source of renewable electric energy. India has very large number of educational institutions with large non-invested rooftop with shortage of electrical energy supply. The present work aims to undertake a techno-economic feasibility assessment of a grid connected 100kWp capacity solar PV system proposed to be installed on the rooftop of an educational institution in Sirsa (India). RETScreen software was used to design and simulate the proposed system in order to analyse the technical, economic and environmental implications of the system. Findings show that, there is a high potential for electricity generation in most months of the year. Considering electricity export rate of Rs 4 per kWh, 70 % debt on initial investment, debt term, inflation rate and other parameters the equity payback period (PBP) estimated to 6 years, net present value (NPV) of the project becomes positive in the 6th year and internal rate of return (IRR) is found more than the discount rate. All these economic indicators show that the project is economically feasible. Moreover, the system has a low levelized cost of electricity (LCOE) as compared to the existing grid tariff, the study adds significantly to the national objective to reduce its dependency on fossil fuels while meeting local energy requirement.

Keywords: Payback period (PBP), internal rate of return (IRR), Net present value (NPV), Levelized cost of electricity (LCOE),

I. INTRODUCTION

The world's need for energy to generate power continues to increase, and that energy is derived from several resources. Conventional sources such as fossil fuels still continue to dominate the world's fuel mix, resulting in continuous increases in carbon dioxide in the atmosphere, exacerbating the negative effects of global warming [1]. Further, fossil fuels are a finite resource and their continued consumption will make them unavailable for use by future generations. Therefore, development of clean, secure, sustainable and affordable energy sources should be our priority in this century [2].

Solar energy has been considered as one of the primary solutions to the world's energy crisis. It is one of the purest and clean forms of energy we receive on earth, without any environmental degradation [3]. The global energy needs can be met through the use of solar energy, since it is abundant in nature and is freely accessible energy source at no cost [4]. Solar Photovoltaic (PV) energy as alternative energy supplies to the traditional fossil fuel have been a subject of study for researchers at various forums including climate change summits. However, the technical and economic feasibility of solar projects involve a lot of complexity and depends mostly on geographical location and availability of resources. To address the constraints and factors affecting solar PV systems, this paper aims to undertake a techno-economic feasibility assessment of a grid connected solar PV system capable of meeting an educational building's load, located in Sirsa, India. To achieve the purpose of this study an energy audit has been undertaken to establish the load demand of the building. RETScreen software was used to design and simulate the proposed system in order to analyse the technical and economic feasibility of the PV system. Findings show that, there is a high potential for power generation in most months in the year, and there is extra energy available to be sold to the grid, generating considerable income.

In this research work a grid connected 100 kWp capacity rooftop solar power plant is analysed for Ch. Devi Lal State Institute of Engineering & Technology situated at village PanniwalaMota under Sirsa district (India). The technical performance is estimated on the basis of solar radiation potential of the site, electricity production and capacity factor of the plant. Moreover, economic analysis is presented in terms of levelized cost of electricity (LCOE), payback period (PBP), net present value (NPV) and internal rate of return (IRR). The paper has been structured according to the following: Section 2 describes the methodology adopted in this work, section 3 explores the solar energy potential of the proposed site, and Section 4 describes the technical details of the proposed PV system. In Section 5 results of technical and economic feasibility analysis has been discussed. Finally, Section 6 presents the main conclusions.

II. METHODOLOGY

This research work was conducted in the campus of Ch. Devi Lal State Institute of Engineering & Technology located in village PanniwalaMota under district Sirsa, India. The campus area is located at 29.71°N, 74.93°E; with an altitude of 202 meters above sea level and the annual average rainfall is 398.76 mm [5]. Currently, the entire electricity demand of the campus is supplied by the utility grid through a distribution transformer. A simple micro-grid model proposed in this study is adjusted to the available local energy sources. Micro-grid is built using photovoltaic as renewable energy power plant, combined with the existing grid system. In this configuration, the installed PV power is used optimally. Along with that, the grid system also plays a role as the backup power source. The grid system will supply power when Photovoltaic system is unable to meet the needs of load and will absorb the excess power.

The institute is spread over an area of 43 acres with lush green, pollution free environment. The institute campus has an academic block, boy's hostel, girl's hostel, workshop block and a residential complex for its staff [6]. The total electrical load of the campus is approximately 250 kW. Since facilities never operate at full capacity (i.e. on full load) for entire 24-hour of a day. So, a 100 kWp capacity solar PV system will be sufficient to meet the base load of the building. The system is proposed on the rooftop of the academic block of the institute. Figure 1 show the satellite image for the location of village PanniwalaMota where the said institute is located.

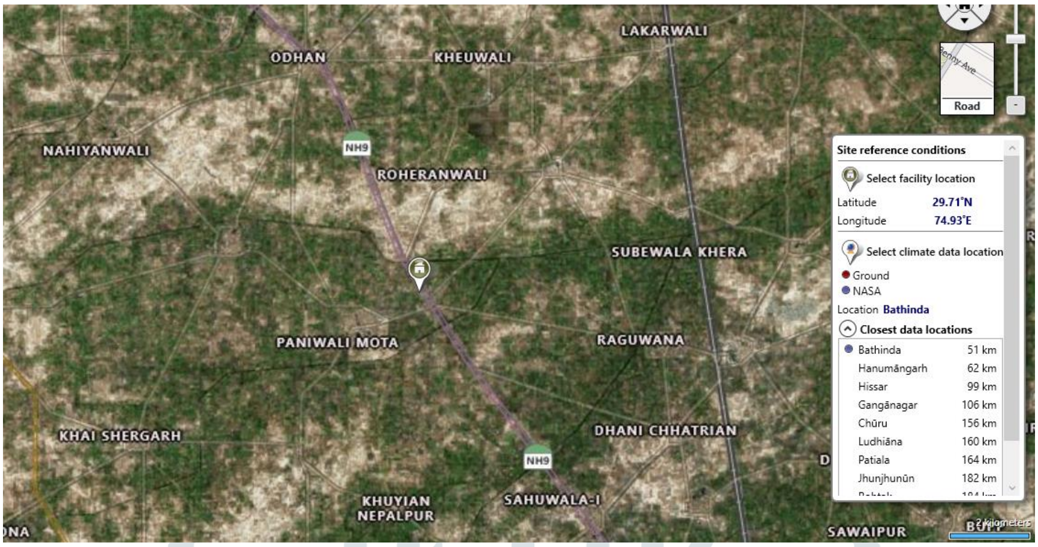

Figure 1: Satellite image for Ch. Devi Lal State Institute of Engineering & Technology, village PanniwalaMota, district Sirsa, India [5]

The performance of the proposed PV plant is evaluated through RETScreen Software Suite (usually shortened to RETScreen) is a clean energy software package developed by the Government of Canada [5]. Analysis of this plant includes:

A. Technical feasibility:

Technical feasibility analysis is based on the solar power plant's capacity, utilization, and determination of the specifications of its components, orientation of the solar panels and electricity generated by the plant. Several factors influence the electricity generated by a solar power plant, including solar radiation at the research site, the slope and direction of the solar panel, sunlight, temperature, and the technical performance of each component used. All of these parameters have been estimated in this research work.

B. Economic feasibility:

There are several ways that can be used to determine the profitability of a project. The most common methods used to examine the profitability of a PV project are payback period (PBP), net present value (NPV), net cash flow (NCF), and internal rate of return (IRR). In this research, NPV, IRR and payback period will be used [7];

Payback period (PBP): The payback period (PBP) is the first economic method applied in this study. It represents the length of time that it takes for a proposed facility to recoup its own initial cost, out of the revenue or savings it generates. The project investment is unacceptable with respect to economics when the PBP presents a high value (long payback periods). PBP does not incorporate the time value of money; moreover, assumptions on discount or interest rates are not required. Otherwise, the shorter PBP indicates the better investment [7].

Net present value (NPV): Net Present Value (NPV) of the project is the value of all future cash flows, discounted at the discount rate, in today's currency. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. NPV determines whether or not the project is generally a financially acceptable investment. Positive NPV values are an indicator of a potentially feasible project. In using the net present value method, it is necessary to choose a rate for discounting cash flows to present value [7].

Internal rate of return (IRR): It represents the true interest yield provided by the project equity over its life. It is calculated by finding the discount rate that causes the net present value of the equity to be equal to zero. Hence, it is not necessary to establish the discount rate of an organization to use this indicator. An organization interested in a project can compare the internal rate of return to its required rate of return (often, the cost of capital). If the internal rate of return is equal to or greater than the required rate of return of the organization, then the project will likely be considered financially acceptable. If it is less than the required rate of return, the project is typically rejected [7].

Levelized cost of electricity (or LCOE): The levelized cost of electricity (LCOE) or levelized cost of energy is a measure of the average cost of electricity per unit for a plant over its life time. The LCOE represents the revenue per unit of electricity generated that would be required to recover the costs of the generating plant during an assumed plant life. Or, it represents the electricity export rate required in order to have a Net Present Value (NPV) equal to 0.

III. SOLAR ENERGY POTENTIAL OF SIRSA (INDIA)

The Solar PV system is proposed for Ch. Devi Lal State Institute of Engineering & Technology at the village PanniwalaMota under Sirsa district which is located at a latitude of 29.71°, longitude of 74.93° and falls under 'very hot-dry' climate zone [5].

Table 1: Annual Climate Data for Sirsa
Source: RETScreen [5].

Months	Daily Solar Radiation horizontal ($KWh/m^2/d$)	Air temperature (°C)	Relative Humidity (%)	Precipitation (Rain) (mm)
January	3.43	13.3	37.5%	12.09
February	4.38	16.4	36.5%	21.00
March	5.32	22.8	29.0%	14.57
April	6.15	29.4	20.9%	10.50
May	6.48	35.1	17.9%	15.50
June	6.52	37.0	28.0%	50.70
July	5.83	35.0	46%	97.34
August	5.54	33.0	53.5%	98.57
September	5.31	30.8	47.5%	61.20
October	4.76	26.4	31.0%	8.06
November	3.94	20.8	25.5%	2.40
December	3.26	15.6	30.5%	6.82
Annual	5.08	26.3	33.7%	398.76

Table 1 presents the variations in daily average solar irradiation, air temperature, relative humidity and precipitation for each month at the location of Sirsa. The annual average solar irradiation is around 5.08 $kWh/m^2/day$. Such a level of solar irradiation is considered to be good. The highest irradiation in the world is 7-8 $kWh/m^2/day$ in, for example, North Africa. The solar irradiation in Sirsa is lower than that of western and southern states of India, like Rajasthan, Gujarat, Tamil Nadu, Maharashtra, Andhra Pradesh and Karnataka, which have average irradiation of 6-7 $kWh/m^2/day$ and are considered to be the most solar suitable regions in the country [8]. But the city of Sirsa receives higher irradiation in comparison to many other cities of the world.

The graphical variations in daily solar radiation and air temperature throughout the year for Sirsa have been plotted in figure-2. These data are generally needed to assess the amount of electricity generating potential of a photovoltaic power plant. It is observed that the highest average daily radiation of 6.52 $kWh/m^2/day$ was recorded in the month of June, whereas the lowest average solar radiation was 3.26 $kWh/m^2/day$ in December. The daily mean and maximum solar radiation values are generally higher in summer (May-June-July), whereas comparatively, lower values are seen in winter months (November-December-January). It is obvious that for all months of the year except December and January the daily average solar radiation is more than 4 $kWh/m^2/day$. For four months of the year (March, July, August and September) daily average solar radiation obtained is between 5 $kWh/m^2/day$ & 6 $kWh/m^2/day$ and for three months of the year (April, May & June) it is more than 6 $kWh/m^2/day$. As, the electricity production from PV panel is directly proportional to the solar irradiance incident on it [9]. So, there is a high potential for electricity generation in most months of the year. Thus, the location of Sirsa has a considerable solar energy potential to produce electricity using PV technology.

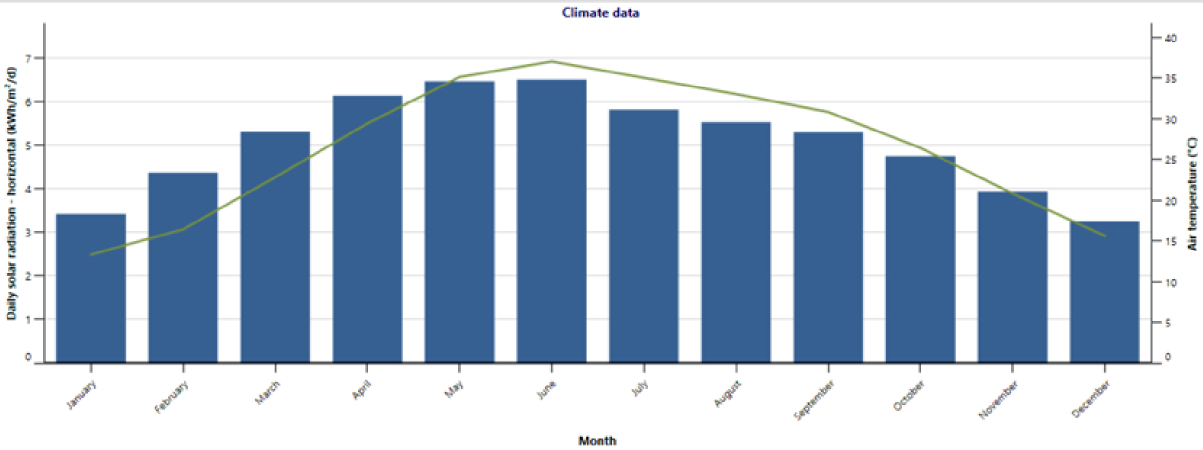

Figure 2: Variations in daily average solar radiation and air temperature.

IV. SOLAR PV SYSTEM DESCRIPTION

PV modules are arranged to form a solar array to provide the specific power at a specified voltage and current. In this context, a 310 W peak PV module, which encloses monocrystalline silicon solar cells, is considered for obtaining 100 kWp installed capacity of a power plant which includes 323

Table 2: Technical Specifications of the Photovoltaic module:

Item Description	Item Specification	Item Description	Item Specification
Technology	Photovoltaic	Total Capacity of PV system	100 kWp
Type	Monocrystalline	No. of modules required	323
Capacity per module	310 Wp	Cells per module	60 cell module
Module Efficiency	19.05 %	PV System voltage	1500 V
Open circuit voltage	40.7 V	Module dimension	1640 mm x 992 mm x 36 mm
Short circuit current	9.91 A	Module Area	1.627 m^2
Voltage at maximum power	33.1 V	Type of Tracker	Two-axis tracker
Current at maximum power	9.37 A	Nominal operating cell temp.	45 °C

no. of modules calculated **[10]** using the technical specifications in Table 2. The proposed PV system is installed on the roof of the building; covering a surface of approximately 526 m^2.

Tracking System: A tracker is a device supporting the solar collector which moves the collector in a prescribed way to minimize the angle of incidence of beam radiation on the collector's surface. Hence incident beam radiation (i.e. solar energy collected) is maximized. Solar trackers may be classified (figure-3) into three types; One-axis trackers track the sun by rotating around an axis located in the plane of the collector. The axis can have any orientation but is usually horizontal east-west, horizontal north-south, or parallel to the earth's axis; Azimuth trackers have a fixed slope and rotate about a vertical axis; and Two-axis trackers always position their surface normal to the beams of the sun by rotating about two axes. Two-axis tracker device has been selected for the proposed PV system.

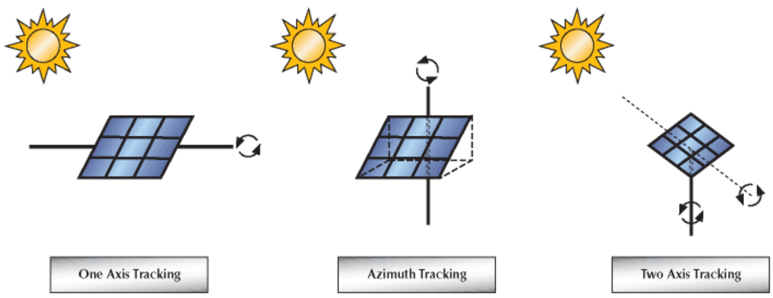

Figure 3: Types of Trackers

V. RESULTS & ANALYSIS

5.1 Data inputs and assumption:

The proposed PV system has a 100kWp capacity. The initial investment cost has been taken at the rate of Rs 75,000/- per kW [11, 12]. This includes cost of equipments (cost of modules, inverter,

Table 3: Assumptions of various rates & associated parameters used in the economic feasibility:

Item Description	value
Inflation rate	2 %
Discount rate	9 %
Reinvestment rate	9 %
Fuel cost escalation rate	2 %
Debt ratio	70 %
Debt interest rate	7 %
Debt term	15 years

Table 4: Cost & revenue assumptions of the PV plant:

Components	Value	Unit
Initial Investment cost	75000	Rs/kW
Annual Operation & Maintenance Cost	900	Rs/kW
Project life	25	Years
Electricity export rate	2/3/4/5/6	Rs Per kWh
GHG reduction credit rate	200	Rs per tCO_2*
Land Lease	Not applicable	Not applicable

* tCO2 - per ton of CO_2

mounting system, cables etc.), transportation, installation, feasibility study etc. The annual operation and maintenance cost is taken as Rs 900 per kW [13]. The useful project life is assumed to be 25 years. It is planned that 70% of the total initial investment has been financed through loan and remaining amount will be paid by the institute from its own resources. All of these costs and interest rates given in Tables 3 and 4 were used for economic feasibility analysis in this research.

5.2 Electricity Production and Capacity:

The data for daily solar radiation (kWh/m^2/d) and electricity production (kWh) is shown in table 5. It can be observed that the amount of solar radiations received in each month is more when a two axis tracker is used to support the collector. The tracking system moves the collector in a prescribed way to maximize the solar radiation incident, so that is why the annual average of daily solar radiations increased from 5.08 kWh/m^2/d to 7.27 kWh/m^2/d (table 5) resulting in an increase in the electricity production also. The PV system in horizontal mode i.e. without tracking system, produces 1,84,725.915 kWh of electricity annually whereas there is a significant increase of 42 % (i.e. production rises to 2,62,518.65 kWh annually) in annual electricity production is observed when two axis tracker system is used. The good amount of electricity produced shows that the selected region has an enormous potential for solar power generation.

Table 5: Annual Irradiation & Electricity Production Data for Sirsa
Source: RETScreen [5].

Months	Daily Solar Radiation horizontal (without tracker) (kWh/m^2/d)	Daily Solar Radiation (with two axis tracker) (kWh/m^2/d)	Electricity generated (without tracker) (kWh)	Electricity generated (with two axis tracker) (kWh)
January	3.43	6.09	11,468.599	19,819.925
February	4.38	6.66	12,930.140	19,271.671
March	5.32	7.64	16,777.029	23,798.061
April	6.15	7.96	18,114.337	23,334.428
May	6.48	8.42	19,195.910	24,896.168
June	6.52	8.28	18,539.852	23,527.707
July	5.83	7.24	17,400.381	21,593.291
August	5.54	7.13	16,705.397	21,433.554
September	5.31	7.14	15,652.818	20,872.314
October	4.76	7.55	14,844.094	23,120.562
November	3.94	6.98	12,281.067	21,163.874
December	3.26	6.11	10,816.290	19,687.094
Annual	5.08	7.27	1,84,725.915	2,62,518.648

Capacity factor represents the ratio of the average power produced by the power plant over a year to its rated power capacity [14]. The capacity factor of the plant is estimated to 29.90% which is more than the nominal range of values required (5 % to 20 %) and shows the proposed PV system is highly feasibility and location of the PV plant is viable for production.

5.3 Economic feasibility analysis: The economic analysis is a key factor for decision making in any plant. The results of various economic feasibility indicators including PBP, NPV, IRR, and LCOE [15] are as follows;

Payback period (PBP): Table 6 & 7 presents the first economic method which is the payback method (PBP). The simple payback period (table 6) is 7.5 years (highlighted in red) at an electricity export rate of Rs 4 per kWh and project cost of Rs 75,09,750/- The quicker the regaining of the cost of an investment is, the more desirable is the investment which is the basic assumption of PBP.

The analysis also calculates the equity payback period, which represents the length of time that it takes for the owner of a facility to recoup its own initial investment (equity) out of the project cash flows generated. The equity payback period considers project cash flows from its inception as well as the leverage (level of debt) of the project, which makes it a better time indicator of the project merits than the simple payback period. In our case considering electricity export rate of Rs 4 per kWh and total project cost of Rs 75,09,750/- the payback is achieved in 6 years (table 7- highlighted in red). If the electricity export rate is increased to Rs 5 per kWh then payback time reduces to 3.5 years and an export rate of Rs 6 per kWh will further reduce the PBP to 2.5 years. Consequently, the result of PBP for the proposed location of Sirsa seems economically feasible.

Table 6: Simple payback period (in years) of the proposed PV plant:

Electricity export rate (Rs/kWh)	Project cost 1 (60,07,800/-) -20%	Project cost 2 (67,58,775/-) -10%	Project cost 3 (75,09,750/-) 0%	Project cost 4 (82,60,725/-) +10%	Project cost 5 (90,11,700/-) +20%
2	12.6	14.2	15.7	17.3	18.9
3	8.1	9.1	10.2	11.2	12.2
4	6	6.7	7.5	8.2	9
5	4.8	5.3	5.9	6.5	7.1
6	3.9	4.4	4.9	5.4	5.9

Table 7: Equity payback period (in years) of the proposed PV plant:

Electricity export rate (Rs/kWh)	Project cost 1 (60,07,800/-) -20%	Project cost 2 (67,58,775/-) -10%	Project cost 3 (75,09,750/-) 0%	Project cost 4 (82,60,725/-) +10%	Project cost 5 (90,11,700/-) +20%
2	21.2	24	> 25	> 25	> 25
3	7.9	12.3	16	17.7	19.3
4	3.6	4.7	6	7.8	10.6
5	2.4	2.9	3.5	4.3	5.2
6	1.8	2.1	2.5	2.9	3.4

Net present value (NPV):

The variations of NPV with Investment costs of the PV project are shown in table 8 and graphically in figure 4.

Table 8: NPV variations at a range of ±20 % @ project cost and discount rate of 9 %.

Electricity export rate (Rs/kWh)	Project cost 1 (60,07,800/-) -20%	Project cost 2 (67,58,775/-) -10%	Project cost 3 (75,09,750/-) 0%	Project cost 4 (82,60,725/-) +10%	Project cost 5 (90,11,700/-) +20%
2	-14,30,324	-21,20,856	-2811389	-35,01,923	-41,92,453
3	11,48,292	4,57,760	-2,32,772	-9,23,304	-16,13,837
4	37,26,909	30,36,376	23,45,844	16,55,312	9,64,780
5	63,05,525	56,14,993	49,24,461	42,33,928	35,43,396
6	88,84,141	81,93,609	75,03,077	68,12,545	61,22,013

For electricity export rate of Rs 2 per kWh the NPV is negative (table 8) and payback period is more than 25 years (table 7) exceeding the life time period of the project. For export rate of Rs 3 per kWh and project investment of Rs 75,09,750/- and more the NPV is again negative and long payback periods are predicted. So, under these conditions results indicates that the project is either non-feasible or have very low potential.

Whereas, considering the electricity export rate of Rs 4 per kWh or more the NPV is positive and increasing with the export rate and the payback period is reducing (table 7) significantly. With assumptions of various rates and other financial parameters detailed in table 3 and table 4 the proposed solar PV plant estimates NPV to a positive amount, which suggests that the PV project is financially acceptable and potentially feasible.

Figure 4: NPV (in Rs) variations over a range of ±20 % of total investment cost.

Yearly Cash flow:

Yearly cash flows are the yearly net flow of cash for the project. It represents the estimated sum of cash that will be paid or received each year during the entire life of the project. Table 9 shows that the cumulative cash flow changes from negative to positive in the 6th year. It indicates that the PV system has recovered its investment and is now onward it is generating revenue. Besides, the figure 5 shows the graphical view of the positive and negative cash flow changes by years.

Table 9: Yearly Cash flow

Year	Cash flow (Rs)	Cumulative Cash flow (Rs)	Year	Cash flow (Rs)	Cumulative Cash flow (Rs)
0	-2252925	-22,52,925	13	3,56,334	25,45,494
1	3,80,990	-18,71,935	14	3,54,002	28,99,497
2	3,79,152	-14,92,783	15	3,51,624	32.51,121
3	3,77,277	-11,15,506	16	9,26,369	41,77,490
4	3,75,364	-7,40,142	17	9,23,895	51,01,385
5	3,73,413	-3,66,729	18	9,21,372	60,22,757
6	3,71,423	4,695	19	9,18,797	69,41,554
7	3,69,394	3,74,088	20	9,16,172	78,57,726
8	3,67,323	7,41,412	21	9,13,494	87,71,219
9	3,65,212	11,06,623	22	9,10,762	96,81,981
10	3,63,058	14,69,681	23	9,07,975	1,05,89,957
11	3,60,861	18,30,541	24	9,05,133	1,14,95,090
12	3,58,620	21,89,161	25	9,02,234	1,23,97,324

Internal rate of return (IRR):

The development of a PV project would be acceptable if the IRR is equal to or greater than the required rate of return or discount rate. The rate of cost is called the discount rate. Figure 6 shows the variations of IRR as a function of the investment cost and electricity export rate for the location of Sirsa. As can be seen from this figure, the IRR (under reference conditions i.e. Project cost of Rs 75,09,750 and electricity export rate of Rs 4 per kWh) is 17.9 % and exceeds the discount rate (which is 9%). So, the proposed PV project is considered financially acceptable.

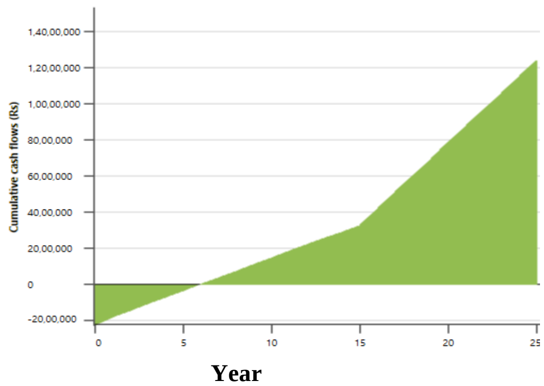

Figure 5: Yearly Cumulative cash flow

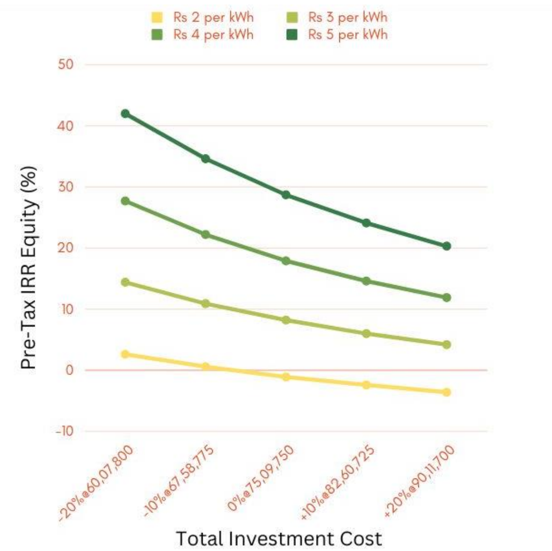

Figure 6: Pre-Tax IRR-Equity (%) distribution at a range of ±20 % of total investment cost

Levelized Cost of Electricity (or LCOE):

In table 9 the LCOE (Rs/kWh**)** is calculated as a function of project cost (Rs) in the range ±20% and interest rate in the range 4% to 7%. From the figure 7 it can be seen that LCOE is

Table 9: LCOE (in Rs/kWh) of the proposed PV plant:

Debt Interest rate (%)	Project cost 1 (60,07,800/-) -20%	Project cost 2 (67,58,775/-) -10%	Project cost 3 (75,09,750/-) 0%	Project cost 4 (82,60,725/-) +10%	Project cost 5 (90,11,700/-) +20%
4	2.29	2.53	2.76	3.0	3.23
4.75	2.36	2.60	2.84	3.9	3.33
5.5	2.42	2.67	2.92	3.17	3.43
6.25	2.49	2.75	3.01	3.27	3.52
7	2.55	2.82	**3.09**	3.36	3.63

affected by the debt interest rate and project cost. LCOE increases with the increase in project cost as well as with the increase in debt interest rates and vice-versa. With project life time of 25 years, loan term of 15 years at the rate of 7% and inflation rate is considered 2%, the LCOE of the solar plant is calculated to Rs 3.09 per kWh which is much lower as compared to the existing grid tariff. It shows with 70% loan the project is still financially viable.

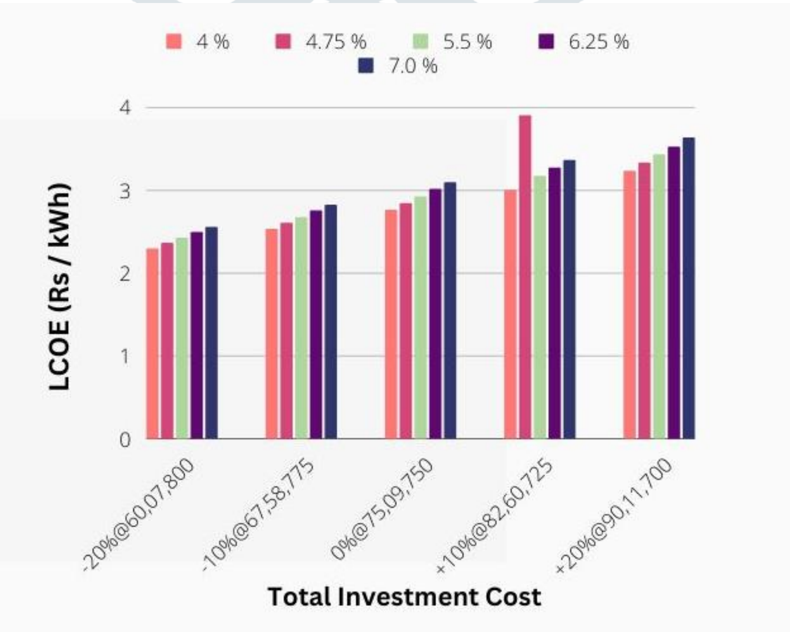

Figure 7: LCOE (Rs/kWh) as a function of the total investment cost (Rs) in the range ±20% and interest rate in the range 4% to 7%.

VI. CONCLUDING REMARKS

The Techno-economic analysis of PV project of 100 kWp at Sirsa (India) is focused on estimating the total investment cost, payback period (PBP), net present value (NPV), internal rate of return (IRR) and levelized cost of electricity (LCOE) generation. The annual production and capacity factor of 2, 62, 518.648 kWh and 29.9 % respectively shows that the project is highly feasible. The net present value (NPV) is positive and internal rate of return (IRR) is more than the discount rate, showing that the project is profitable. Moreover, the Levelized cost of electricity (LCOE) of the plant is low and payback period (PBP) is ensuring the return on investment. With above outcome, it can be concluded that this project is suitable and will reduce the dependency on the conventional non-renewable plants.

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