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Performance Analysis of Grid Connected 4 MW Solar Photo Voltaic Plant installed at Chandranigahapur, Rautahat, Nepal

by

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A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Performance Analysis of Grid Connected 4 MW Solar Photo Voltaic Plant installed at Chandranigahapur, Rautahat, Nepal "** submitted by Ramesh Prasad Sapkota in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

Solar PV technology is becoming more important on a global scale. The use of solar energy is growing and outpacing that of other renewable sources, according to the International Energy Agency, Solar PV will meet 18.4% of the world's energy needs in 2025, trailing only coal and natural gas, which will offer 22.8% and 20.2% of the world's energy needs, respectively.

Technical and financial study are carried out in this thesis, titled "Performance Analysis of Grid Connected 4 MW Solar Photo Voltaic Plant Installed at Chandranigahapur, Rautahat, Nepal.".

In this thesis technical and financial analysis is performed. Energy Generation Data is obtained from the plant and financial and other plant related data is taken from the head office of Api Power Company Limited. Various study-related data were collected during this research. During this study, the data are analyzed, with a focus on the technical and financial parameters. Final Yield (YF), Capacity Utilization Factor (CUF), Performance Ratio (PR), and Efficiency are measured in terms of technical parameters for electricity generation. And sensitivity analysis is done for parameters such as Internal Rate of Return (IRR), Payback Period and Net Present Value (NPV).

According to the simulation, the first year's energy is 6840 MWh, and the final year's energy will be 5699 MWh. The contract energy with the NEA was 6926 MWh, whereas the actual energy produced by the plant in the first year was 6269 MWh. Energy supplied to the grid was 657 MWh or 9.48% less than what was agreed upon in the PPA. Final Yield, Performance Ratio and Capacity Utilization Factor from the measured data was found 3.46 kWh/kWp/day, 0.695 and 17.89%, respectively. Similarly, from the simulated data, Final Yield, Performance Ratio and Capacity Utilization Factor was found 3.78 kWh/kWp/day, 0.848, and 19.52%, respectively. Financial analysis of this study showed that the IRR is 12.68%, NPV is NRs. 659 million, simple payback period is 7.07 years and discounted payback period is 12.60 years from the contract energy as per PPA. Financial indicator was found that IRR is 10.20%, NPV is NRs. 510 million, and simple payback period is 8.39 years, as per actual measured data. Levelized Cost of Energy (LCOE) was found NRs. 6.92/kWh and NRs. 7.65/kWh for the contract and actual energy generated respectively.

The technical and financial data above demonstrates the viability of the solar photovoltaic project and the favorable return on investment as per simulated data but because of the loss in energy due to the frequent fault in the underground cable and the shade in the power plant the energy generation was less than the contract energy, this will affect the revenue and the performance of the solar PV plant.

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LIST OF ABBREVIATION

AC	Alternating current
AD	Anno Domini
AEPC	Alternative Energy Promotion Centre
BCR	Benefit Cost Ratio
BS	Bikram Sambat
CT	Current transformer
CUF	Capacity Utilization Factor
DB	Distribution box
DC	Direct current
DoED	Department of Electricity Development
DSCR	Debt Service Coverage Ratio
GHI	Global Horizontal Irradiance
GoN	Government of Nepal
IEA	International Energy Agency
IEC	International Electrotechnical commission
IOE	Institute of Engineering
IPP	Independent Power producers
IRENA	International Renewable Energy Agency
IRR	Internal Rate of return
kWp	Kilowatt Peak
LA	Lightning arrester
LCOE	Levelized Cost of Energy
MPPT	Maximum power point tracking
MWp	Megawatt Peak
NASA	National Aeronautics and Space Administration

NEA	Nepal Electricity Authority
NOCT	Normal Operating Cell Temperature
NREL	National Renewable Energy Laboratory
NPR	Nepalese rupee
NPV	Net present Value
O&M	Operations and maintenance
PPA	Power Purchase Agreement
PR	Performance Ratio
PV	Photovoltaic
PVSYST	PV System Software
SPV	Solar photovoltaic
SLD	Single Line Diagram
STP	Standard Temperature and Pressure
SWERA	Solar and Wind Energy Resource Assessment
UN	United Nation
WECS	Water and Energy Commission Secretariat
WNA	World Nuclear Association
Wp	Watt peak

CHAPTER ONE: INTORDUCTION

1.1 Background

With the aid of photoelectric effect-based technology, sunlight is transformed into electricity to produce photovoltaic solar energy. Solar Renewable and non-polluting electricity comes from photovoltaic systems. Since solar energy produces no emissions when it produces heat or power, it is environmentally friendly.

Solar energy is predicted to play a significant role in the future global energy mix in both developed and developing nations due to advances in technology and falling photovoltaic (PV) costs.

In all scenarios, renewable energy technologies, headed by solar photovoltaic (PV) and wind, are expected to increase rapidly and now account for up to 30% of electricity output. While renewables are now the cheapest source of new electricity in the majority of markets (IEA, 2022).

Solar PV generation increased by 179 TWh (up 22%) in 2021, surpassing 1000 TWh. In terms of absolute generation increase in 2021, it was second only to wind among all renewable technologies. Solar PV is projected to be a prudent investment in the future and is now the most economical option for new electricity generation in much of the world. (IEA, 2022).

Nepal is located in south Asian region between latitudes of 26°22' N and 30°27' N and longitudes of 80°4' E to 88°12' E. Nepal has a significant amount of solar energy production potential. Solar power is an infinite source of energy. the average global solar radiation (GSR) to this area ranges from 3.6 to 6.2 kWh/m^2/day with about 300 sunny days annually and 6.8 hours of bright sunshine per day with an average solar intensity of 4.7 kWh/m^2/day (WECS, 2010).

The Solar and Wind Energy Resource Assessment (SWERA) estimates that Nepal has a commercial potential for 2,100MW of on-grid solar PV systems.

The Nepalese government has prioritized finding different ways to harness solar energy in all of its recent initiatives regarding the power sector. As a marketing tactic for the grid connection Solar PV, government awareness campaigns will be highly beneficial.

1.2 Problem Statement

In line with the global expansion of solar PV technology, Nepal has a solar plant operating as well. Many more are in line to do the same, although they are all at various stages of construction. Future solar plant will be guided by measurement, technical, and financial parameters from performance study of solar plant.

According to the NEA, a grid-connected solar facility with a capacity of 33.1404 MW has been operational to date in Nepal. The 1077.6 MW solar power plant is currently in various stages (DoED, 2023).

Few studies of grid connected PV systems in Nepal have been conducted, and performance analysis is done for the various plant. The performance of such a major project will eventually determine the level of investment in it. In order to provide some suggestions for prospective future installations, it is necessary to properly assess and study the intended system and performance criteria.

Performance analysis is done to find out how the plant is doing right now. A performance evaluation highlights both the technical issues with the national grid and the value of investments in new, similar Plants. Not much research has been done in this area because there are now very few solar power facilities that are linked to the national grid. In Nepal, which mostly relies on hydroelectric plants, the prospect of grid-connected solar is still unknown.

In order to determine if grid-connected solar PV is the best option for the investor and Nepal's National Grid, this study conduct the technical and financial performance of the solar facility.

The main focus of this thesis is to perform the current technical and financial status of chandranigahapur Solar PV Plant. By simulating using a PVSYST and using actual data it and determining its performance parameters. Financial analysis is carried out to determine the project's fundamental results, such as NPV, IRR. Sensitivity analysis is carried out to identify the parameter that has the greatest impact on financial performance. The conclusions of this thesis's proposals may be used to improve the system that is now in place or to plan comparable initiatives that will be executed in a variety of locations in the future. In order to meet the target for the energy mix, this research also aims to push IPP to build more grid-connected solar PV power plants.

1.3 Objectives of the Study

Main Objective

Main objective of the study is to conduct performance analysis of 4 MW grid connected solar photovoltaic system installed at Chandranigahapur, Rautahat.

The following are the specific objectives of this study:

- To perform technical analysis of grid connected solar photovoltaic system
- To perform financial analysis of grid connected solar photovoltaic system
- To compare the measured and simulated technical parameters

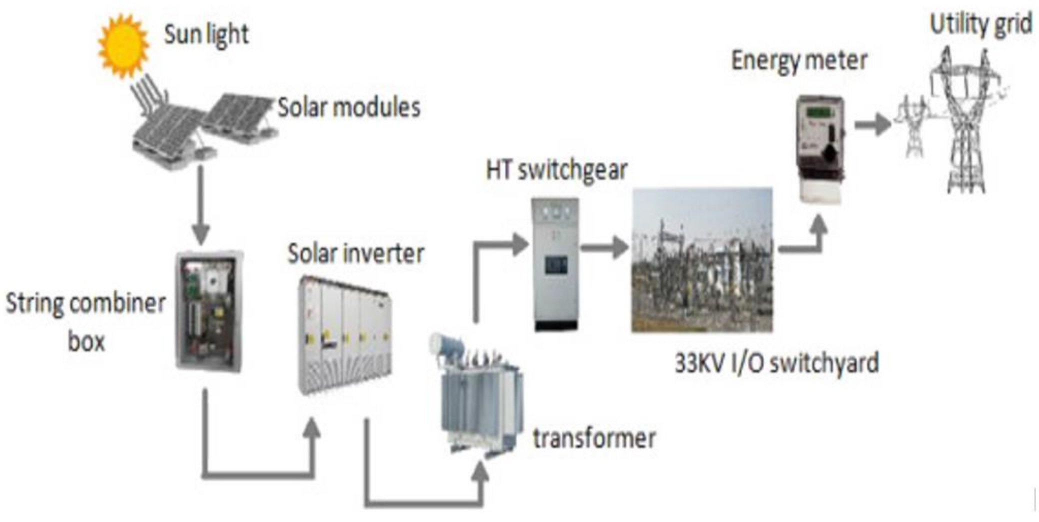
CHAPTER TWO: LITERATURE REVIEW

2.1 Grid Connected Solar PV System

A grid-connected photovoltaic system (also known as an on-grid photovoltaic system) is a system that links a solar photovoltaic system to the power grid.

A solar photovoltaic module which is connected in series and parallel, uses its photoelectric effect to convert sunlight into electric energy. The output of the energy is in DC form. The DC is converted to AC via inverter which is one or more in numbers. The output voltage is in volts and the grid voltage is in kV so this voltage is to be increased to meet the grid voltage. To meet the generated voltage into grid voltage, power transformer is used. Generally, the grid voltage is generally 11 kV, 33 kV and 132 kV.

A PV system that is connected to the grid includes solar panels, inverter, and transformer and grid connection components. There are no energy storage losses, therefore the electricity produced by solar energy is effectively utilized. The general layout is shown in the Figure 2.1.



(Kumar and Sudhakar, 2015)

Figure 2.1: On grid Solar System Layout

PV Module

Photovoltaic (PV) cells turn sunlight into electrical energy. PV cells are small in size and only produce a few Watts (W) of energy. As a result, PV plants are very modular, allowing for production of power in quantities ranging from watts (W) to megawatt (MW). (Hindocha and Shah, 2020).

The solar energy that strikes the panels is converted to DC electricity, and a series and parallel connection system is used to assemble the array of panels. By virtue of their electronic band gap, free electrons released as a result of light absorption can continue to be excited long enough to be gathered into an external circuit. A p-n junction is created when N-type and P-type semiconductor layers join, allowing for just one channel of electron transport. (Hasan, 2021).

Inverters

Inverters are solid state electronics Devices. The PV modules' DC electricity is transformed by them into AC electricity. Inverters can also carry out a number of tasks to increase the plant's production. These include maximizing the voltage across the strings, keeping track of the performance of the strings, logging data, and offering protection and isolation in the event of grid or PV module problems (Hindocha and Shah, 2020).

Transformers

Transformers are the electrical Devices which converts Low voltage to High voltage and vice versa. Generally, in Solar Plant, Transformer converts low voltage to high voltage as grid voltage are generally high 11 kV, 33 kV and 132 kV and so on.

2.2 Solar PV technology in Nepal

To meet Nepal's energy needs, the government of Nepal is intending to generate renewable energy. Grid-connected PV systems are one of the most important technical and financial solutions to Nepal's energy needs. Although many IPPs are interested in megawatt-scale solar projects, it is still uncertain performance of the solar PV in MW system.

As nearly all of Nepal's grid-connected power is produced by 124 hydropower stations with a combined capacity of 1498.628 MW, hydropower plays a significant role in the nation's electricity production. Eight solar power plants are operational and connected to the grid. The installed capacity of these solar farms is 33.1404 MW (NEA, 2023).

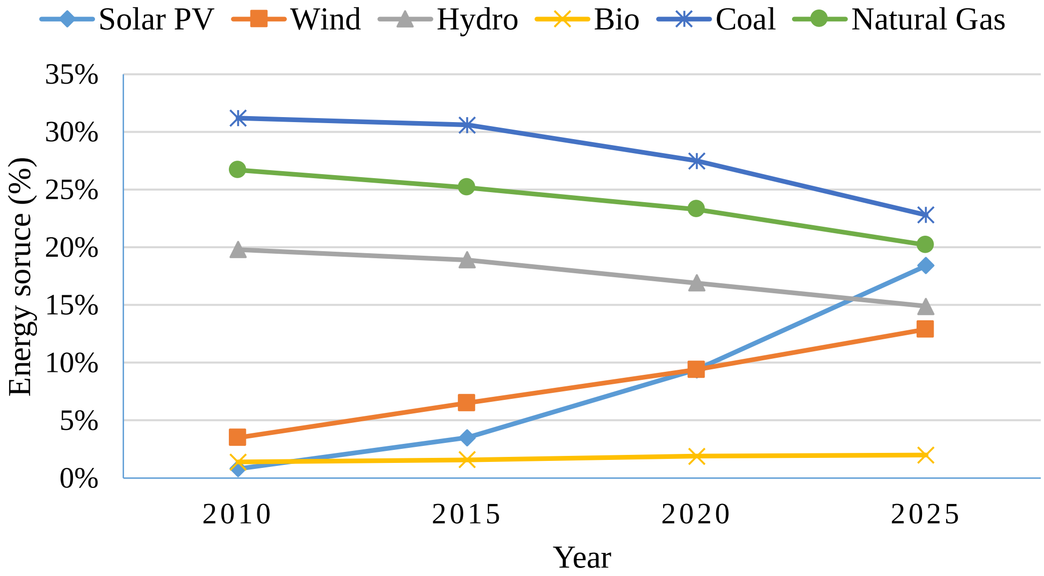
Thirty hydropower projects in Eastern Nepal sustained damage worth NRs.8.5 billion due to floods (myRepublica, 2023). The hydropower developer is diversifying and plans to invest in other sectors in order to continue their business of producing electricity as a result of the numerous uncertainties they are currently facing. Solar energy technology in Nepal has a lot of promise, with grid-connected PV, solar water heaters, and solar residential systems being the main solar energy sources. The majority of Nepal's energy needs are met by hydropower, but the country also receives an average of 4.7 $kWh/m^2/day$ of solar radiation (WECS, 2010), which is used to produced energy from solar PV technology and will connected to the grid.

In Nepal, the northwest region experiences up to 5.5 $kWh/m^2/day$ of global horizontal irradiation (World Bank, 2017), compared to an average GHI of 4.4–4.9 $kWh/m^2/day$ in the southern regions. The country's specific Solar PV electricity generation capacity ranges from 1400 kWh/kWp to 1600 kWh/kWp, or 3.8 to 4.4 kWh/kWp on a daily average. Due to its high height and cold air temperatures, the mountainous area has a larger potential for PV energy generation. The greatest places to develop solar PV systems in Nepal are therefore the hills and lower-elevation Mountains, which have good GHI and lower temperatures (World Bank, 2017).

Despite having a cheap construction cost per MW and low operating and maintenance costs, commercial electricity generation from solar PV plants is still not satisfactory. NEA reduced the PPA rate of grid-tied solar energy from NRs. 7.10 to NRs. 5.94 per unit (Urja Khabar, 2022) is the primary factor.

Many IPP Solar PV plants are in various phases, with 126 MW applying for a survey license, 747.6 MW have received survey license, 133.56 MW receiving a construction license, and 15 MW applying for construction license to the DoED. The 1077.6 MW solar power plant is currently in various stages (DoED, 2023).

According to IEA, the usage of coal and natural gas as energy sources is declining. The use of wind, solar, and bio energy is rising. Solar PV is one of them and is rising quickly. Solar PV only contributed 0.8% of the world's energy in 2010, but by 2015 it had increased to 3.5%, and by 2020 to 9.4% and will be 18.4% in 2025.



(IEA, 2022)

Figure 2.2: Energy source trend in the world

Given the high solar radiation received at various locations throughout Nepal, solar photovoltaic installation should be strongly studied as a feasible option to increase generation capacity and efficiently meet the country's electricity needs. The cost-effectiveness of PV module production processes and an improvement in module efficiency are the results of ongoing advances in PV technology and rising global demand. Large investors are becoming more interested in setting up Solar PV projects as a result of lowering technology prices and rising fossil fuel expenses.

A grid-connected PV system's PR should be routinely monitored because it can help identify underperforming systems and minimize financial losses brought on by operational issues. The advantages of employing PR as a performance indicator over CUF of a grid-connected PV facility are significantly more practical. Since a precise insolation measurement is required and different results could be obtained depending on the sensor, estimating Performance Ratio accurately is challenging and has practical constraints. Even though it is a highly expensive and challenging alternative, it is feasible to equalize PR with module temperature to be able to compare PV systems located in various climate zones (Khalid el. al, 2016).

Nepal has very favorable climatic conditions for the production of solar power. A solar plant that faces south and tilts by 30 degrees can generate 1700 kWh/kWp/Year. It may produce 2300 kWh/kWp/Year if a two-axes sun tracker is used (Chianese et al., 2010).

Shrestha and Shrestha (2014) performed a techno-economic analysis of a one MWp Solar PV system in Trishuli and discovered that the system's ultimate yield was 4.81 kWh/kWp-day, its capacity utilization factor (CUF) was 20.18%, and its performance ratio (PR) was 77.3%.

Kumar and Sudhakar (2015) studied of the performance of a 10 MW grid-connected solar power plant in India revealed a capacity utilization factor (CUF) of 17.68% which varies from 12.67% to 20.04% and the Performance Ratio (PR) was 85.12% and varies from 73.88% to 97.5%.

Aryal (2017) conducted the performance analysis of 115 kWp Solar PV Plant at the Teaching Hospital in Maharagunj and it was discovered that the plant's performance ratio was 17.41%.

Ghimire (2022) conducted the Performance Assessment of an 8.5 MW Grid Connected Solar PV Plant in Butwal, Nepal, and discovered that the Performance Ratio (PR) ranges from 54% to 77% and the Capacity Utilization Factor (CUF) ranges from 9.7% to 15.8%. Financial analysis showed the IRR was 13.28%, NPV was NRs.58.88 million. This study shows the LCOE value was NRs. 6.7/kWh.

Bajracharya and Maharjan (2020) analyzed the Techno-Economic performance of a 64.6 kW Grid-tied Solar System of the Nepal Telecom, Sundhara, Kathmandu. According to the study, the performance ratio and capacity utilization factor are respectively 85.9% and 14.09%. The NPV, IRR and Discounted Payback period of the plant was found, NRs. 2.06 million and 17.22 %, 5.2 years receptively. The result showed the LCOE is NRs. 17.97/ kWh.

Navothna and Thotakura (2022) perform the analysis of 1 MWp solar plant at the coastal region of India. In this study it found that the CUF was 11.3% and the PR was 87.9%.

Similarly, Cavalcante et al. (2019) analyzed the performance of 3 MWp solar power plant in Sao Paulo, Brazil and concluded that the plant is performing good as its PR was 76% and general PR was around 80%.

Padmavati and Daniel (2011) studied performance analysis of 3 MWp grid connected solar photovoltaic power plant in India and found Performance Ratio 0.7, Reference Yield was 5.36 h/d and final Yield was 3.73 h/d. It is also found the annual energy was 1372 kWh/ kWp.

Fuster-Palop et al. (2022) perform the 50 MW solar plant in Spain after the 12th year of operation. This research found performance ratio 79.24% and the Capital Utilization Factor 19.77%. Reference Yield and Final Yield found was 5.44h/d and 4.28 h/d respectively.

Similarly, Gautam and Darlami (2021) performed the technical analysis of 1 kWp solar PV at residential area of Lalitpur and the study results that the performance analysis was 74% and the capital utilization factor was 17.7%. Array Yield, Reference Yield, and Final Yield found was 4.59 (kWh/kWp/day), 5.72 (kWh/m^2/day), 4.24 (kWh/kWp/day).

Dutta et al. (2022) performed the grid connected rooftop solar PV plant (179.58 kWp) at Head office of Nepal Bank Limited and found financial parameter IRR and NPV 20.61% and NRs. 5,161,724.78 respectively. The study also found the payback period was 7.5 years and LCOE was NRs. 4.98 per unit.

In the similar topic Ayompe et al. (2011) measured the performance of the 1.72 kW roof top grid connected photovoltaic system in Ireland and the study showed the performance ratio was 81.5%, Capital utilization factor was 10.1%. Also the Final Yield, Reference Yield and the Array Yield was 2.41 (kWh/kWp/day), 2.58 (kWh/m^2/day), 2.62 (kWh/kWp/day) respectively.

Tiwari et al.(2017) performed 100 kWp grid connected solar photovoltaic power plant at Nepal Electricity Authority Training Centre, Kharipati, Bhaktapur and found performance ratio varies from 34% to 70% and annual average was 54%. Also the annual energy generated was 88.41 MWh. This study showed maximum energy during November which was 10.53 MWh and minimum was 4.39 MWh during January. Capital Utilization Factor was 10.09%.

The similar research carried out previously was studied and presented in the Table 2.1.

Table 2.1: Researches on grid Connected Solar PV Performance Analysis

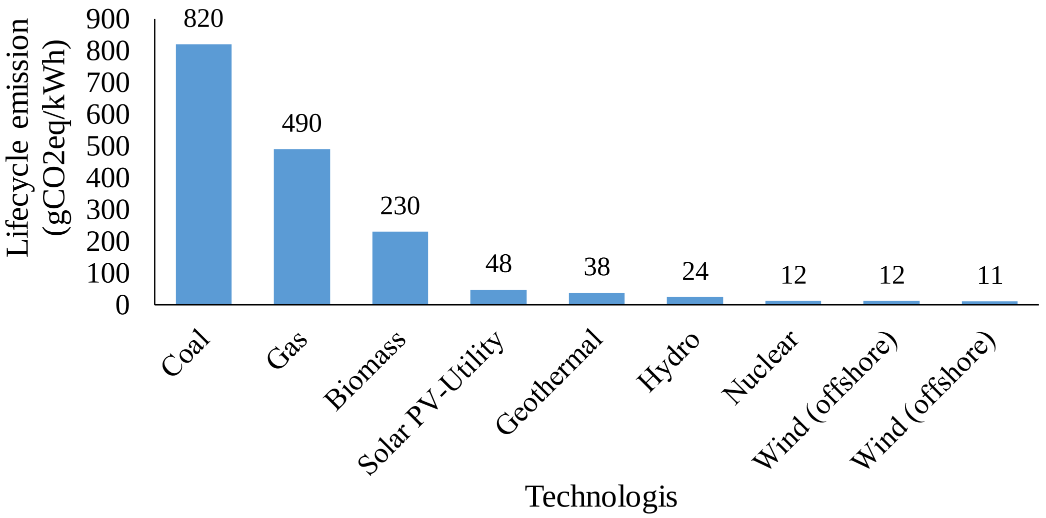
S. N.	Capacity of Plant (MW)	Country	Reference Yield (Y_R) (kWh/kWp /day)	Final Yield (Y_F) (kWh/ kWp/day)	CUF (%)	PR (%)	Source
1.	1	India	-	-	11.3	87.9	Navothna and Thotakura, 2022
2.	3	Brazil	-	-	-	76	Cavalcante et al.,2019
3.	3	India	5.36	3.73	13.7	70	Padmavathi and Daniel, 2013
4.	10	India	-	-	17.68	86.12	Kumar and Sudhakar, 2015
5.	50	Spain	5.44	4.28	19.77	79.24	Fuster-Palop et al., 2022
6.	4.6	Spain	-	4.6	18.1	80	Martin-matinez et.al, 2019
7.	1	Nepal	4.14	2.42	10.09	70	Tiwari, 2017
8.	8.5	Nepal	4.9	3.1	13	64.2	Ghimire, 2022
9.	20	Algeria	-	-	20.76	71.71	Aoun, 2022
10.	17	India	-	-	19	79	Chandel and Chandel, 2021

2.3 Grid impact of Solar PV system in the transmission network

A large-scale PV system power distribution network usually experiences voltage-stability problems during energy generation at particular periods of the day (Nusair and Alasali, 2020). In the case of a penetration of PV generation into the grid overvoltage event will take place and if the PV system does not deliver the energy, voltage problems will cause the system to fail (Maka et al., 2021).

2.4 Environmental benefit of Solar PV plant

Electricity generated from the renewable has less impact to the Environment and Compared to conventional technologies, photovoltaic (PV) technologies have clear environmental advantages. Photovoltaic systems don't emit any greenhouse gases, hazardous chemicals, or noise when they're operating. In addition to helping to supply the rising need for electricity on a global scale, photovoltaic energy also avoids the enormous financial and environmental costs associated with burning fossil fuels and erecting power cables. CO_2 Emission from the different technologies per kWh energy generation are given in the Figure 2.3.



(WNA, 2022)

Figure 2.3: Average life-cycle CO_2 equivalent emission

PV Modules are safe for people, animals, and the environment in any envisioned application or use, according to independent research and publications (WNA, 2022).

2.5 PVSYST Software

One of the most widely used design tools for the analysis of data and the research, sizing, simulation, and sizing of entire PV systems is the PVSYST system. This technology allowed us to produce the most accurate energy yield simulation findings.

The main features of PVSYST are: comprehensive estimate of the used components (modules, inverters, etc.) Hourly simulation with in-depth investigation of numerous loss sources. The PVSYST simulation tool is most frequently recognized and renowned for delivering the most accurate simulation results.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Method

The Research is started with the problem statement and then followed by the literature method then the Study of solar PV system of Nepal and the other region of the world. Study is carried out the similar research done in grid tied solar. Then the performance of the Chandranigahapur solar plant 4 MW is carried out. The detail of research method flowchart has been presented in the Figure 3.1.

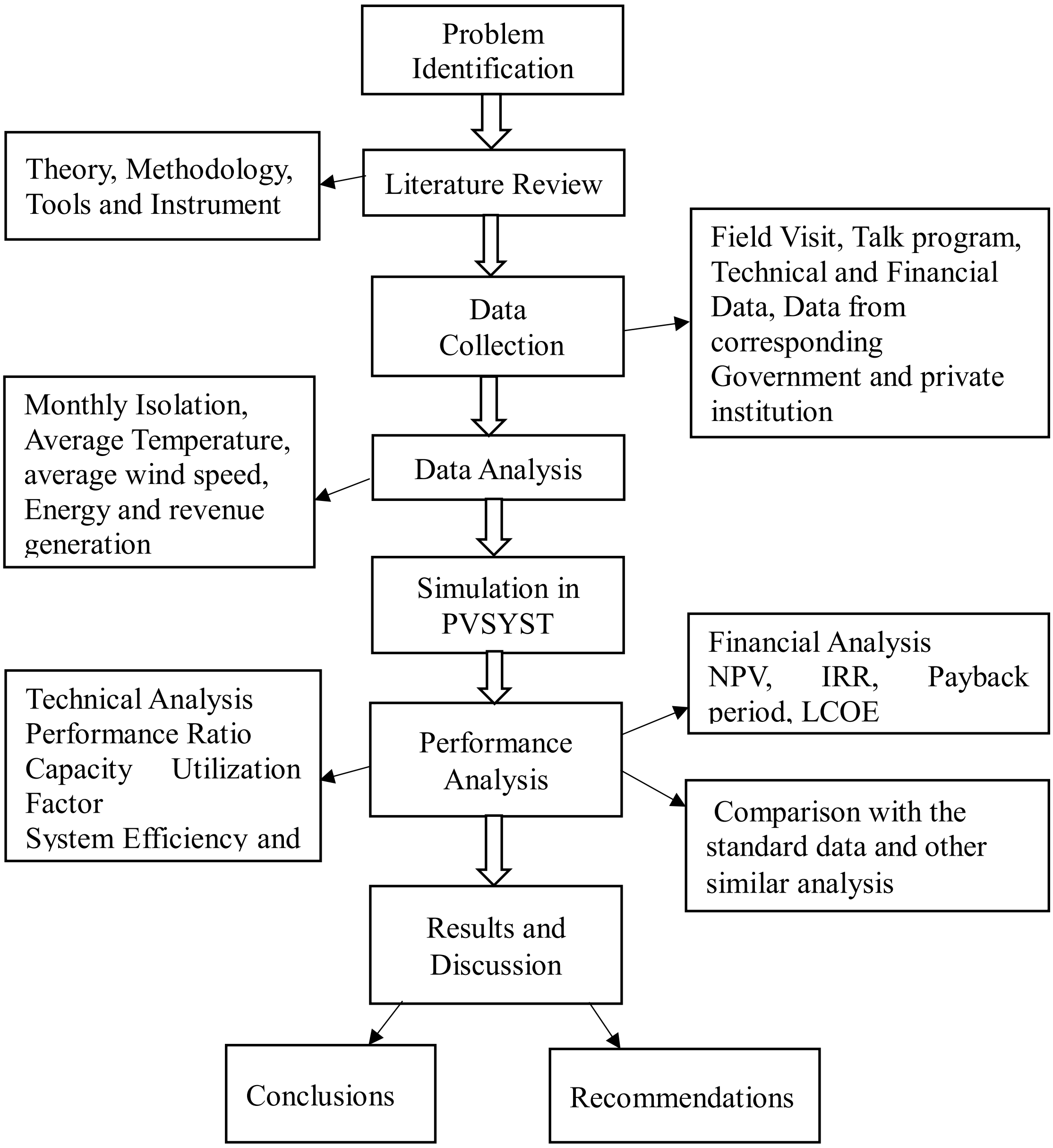


Figure 3.1: Flow Chart of research method

3.2 Performance Analysis procedure

The performance study takes both technical and financial factors into account. For the technical and financial analysis following procedure are carried out.

3.2.1 Collection of data

Different data at the site are measured or collected by SCADA, as well as through site inspection and measurement using various equipment.

These include the following:

- The site's geographic location; the design of the plant;
- The specifications for the solar panels, inverters, transformers, and other electrical equipment;
- The power evacuation system; and
- The pattern of energy generation.

3.2.2 Technical Analysis

The two main performance metrics in the technical sector are performance ratio and capacity utilization factor. Final yield, System yield, Reference yield, and overall plant efficiency are additional measures of a solar power plant's effectiveness.

Technical analysis is supported by data from the plant and the PVSYST software. Calculated performance indicators include the Performance Ratio (PR), Capacity Utilization Factor (CUF), and Final Yield (FY).

Performance Ratio (PR)

This measure the quality of the solar plant. It is calculated in percentage; the higher value is the indicator of good performance. The final yield divided by the reference yield is the performance ratio. The performance ratio is the comparison of plant production to the output that the plant could have attained by accounting for factors like as irradiation, panel temperature, grid availability, aperture area size, nominal power output, and temperature correction values (Kumar and Sudhakar, 2015).

PR is calculated a following formula:

$$\text{Performance Ratio} = \frac{\text{Actual Plant Output in kWh}}{\text{Ideal Plant Output in kWh}} \qquad \text{……..(3.1)}$$

Capacity Utilization Factor (CUF)

The capacity Utilization Factor is a ratio of Actual Energy generation of plant and the maximum energy which will generate by the plant. The capacity utilization factor (CUF) is a way to show the energy the system has delivered. If the system regularly produces its full rated power, its CUF will be unity (Ayompe et al., 2011).

This is calculated by:

$$\text{Capacity Utilization Factor} = \frac{\text{Actual Energy from the Plant (kWh)}}{\text{Plant Output (kW)} \times \text{Time (h)}} \quad ....(3.2)$$

Final Yield (FY)

The "final yield" (kWh/kWp) is the total annual energy generated per kWp installed. This is the ratio of Actual Energy to the Plant capacity and calculated by:

$$\text{Final Yield} = \frac{\text{Actual Energy from the Plant (kWh)}}{\text{Plant Capacity (kWp)}} \quad .....(3.3)$$

The ratio of the total energy generated by solar photovoltaic systems during a given time period under standard test conditions (STC) to their actual output power is known as the final yield. How many hours the solar PV system will operate at its rated capacity is indicated by its final yield (Attrai et al., 2016).

3.2.3 Financial Analysis

Financial analysis is carried out using Microsoft excel. The financial parameter mainly depends on the revenue and the total initial cost. The financial parameters for this study purpose is as follows:

Payback period

This is when the investment should be expected to pay off. Any project's investment will benefit from a payback period that is lower. There are two types of payback periods, one is simple payback period and the other is discounted payback period.

The simple payback period is the period during which only the initial investment is taken into account, and the discounted payback period is added on top of investment recovery.

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Net cash flow per year}} \quad ....(3.4)$$

Internal Rate of Return (IRR)

IRR is a discount rate at which net present value of investment is zero. It calculates the present value of future revenues while considering the discount rate to determine the investment profit. It can be calculated as:

NPV=0, or

Present Value of future cash flow - Initial Investment = 0

$$\sum_{t=1}^{n} \frac{B_t}{(1+IRR)^t} - Bo = 0 \quad .....(3.5)$$

Where:

B_t = Net cash inflow in a time period (t)

B_o = Total Initial Investment cost

IRR = Internal Rate of Return

t = time period

Net Present Value (NPV)

It calculates the present value of future money using the discount rate to determine the investment profit. Net present value (NPV) is the difference between the current values of cash inflows and outflows over a given period. In investment planning, NPV is used to assess the viability of the project (Elamim et al., 2019).

$$\text{NPV} = \sum_{t=1}^{n} \frac{B_t}{(1+i)^t} \quad .....(3.6)$$

Where:

B_t = Net cash Inflow in a time period (t)

i = Discount Rate

t = time period

Levelized Cost of Energy (LCOE)

The LCOE is the ratio of the lifetime NPV of energy produced to the lifetime NPV of cost incurred by the plant. The typical minimal price at which the asset's power must be sold to recover its entire lifetime production expenses is known as the LCOE. (Elamim et al., 2019)

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{P_t + M_t + F_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}} \qquad \text{….(3.7)}$$

Where:

P_t = Capital Investment in year t

M_t = operation and maintenance expenditure in year t

F_t = Fuel expenditure in year t

E_t = Electricity generation in year t

i = discount rate

n = expected life of the system

3.3 Simulation using PVSYST

The PVSYST software is one of the simulation tools developed for evaluating the performance of solar power plants. Based on the chosen module, this software is able to assess the performance of pumping, stand-alone, and grid-connected systems. The application makes precise system yield calculations based on computations performed with complete hourly simulation data.

Results from the solar PV plant are compared to simulation data. The results are also compared with the similar research data. The results are presented graphically. Bar Chart and Line chart is drawn from the calculated data. All the result is documented and the final result is presented.

3.4 Research Tools

PVSYST Software (7.4 version) is used for the simulation of the 4 MW Solar PV Plant and for the financial calculation, MS Excel is used.

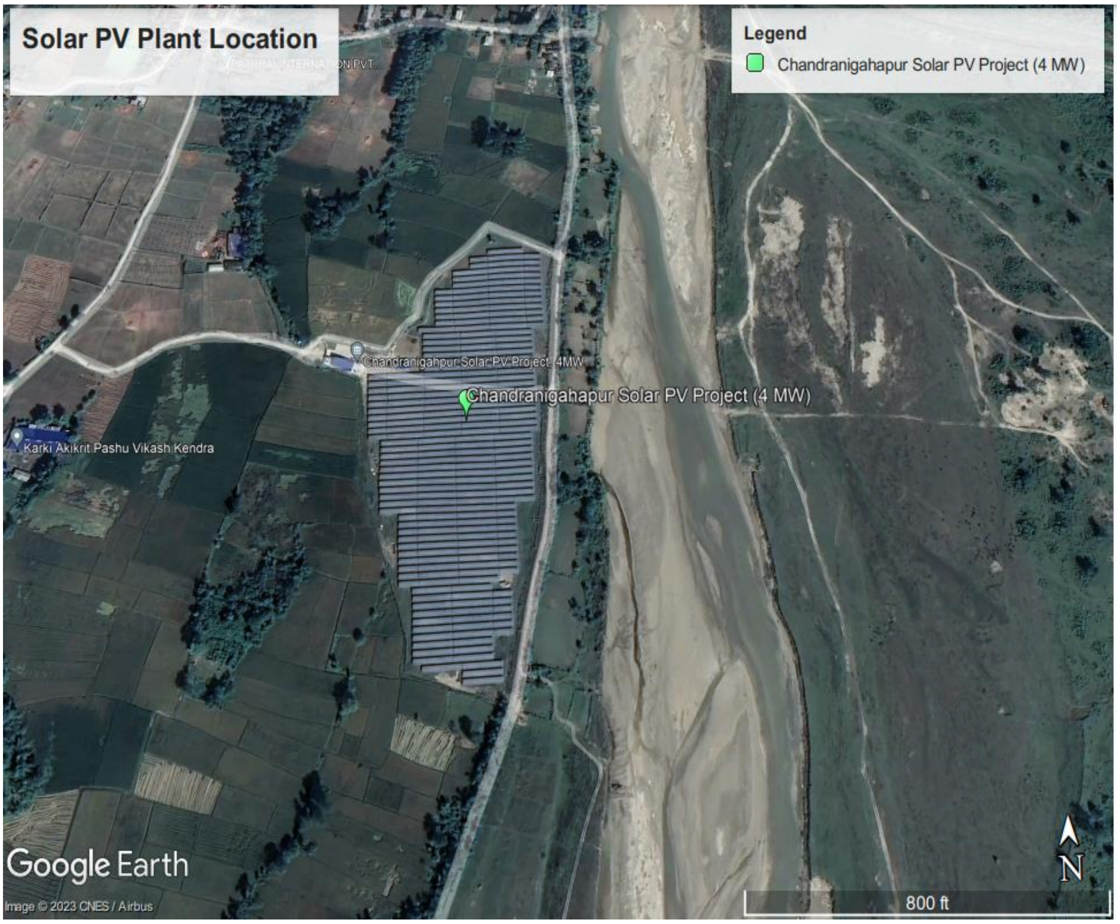
3.5 Plant Description

3.5.1 Project Location

The location of the 4 MW Solar PV plant is at coordinates 27°7'18.51" N and 85°22'29.18" E and is 132 m above mean sea level. The project's location is in Rautahat district's Chandrapur Municipality.

The total land required for development of 4 MW PV plant is approximately 20 acres. The area being acquired by Api Power Company Limited for project is approximately 20 acres, in line with the requirement for a 4 MW Solar PV plant.

Power from the plant shall be stepped up to 33 kV through plant substation and then connected to NEA Substation, which is at a distance of around 2 kilometers from the project site.



(Google Earth, 2023)

Figure 3.2: Location of the Solar PV Plant

3.5.2 Project Overview

The Project is set up as a single modular plot with a maximum power output of 4 MW at AC side and capacity of 4.964 MWp at DC side with one inverter of 5000 kVA rating. Inverters, transformers, and switchgear must all be positioned in the middle of the modular plot to reduce DC ohmic losses. The wires used to connect the PV modules electrically are sized to reduce DC ohmic losses. Through DC cables of the proper grade, the DC electrical output from the PV modules is delivered to junction boxes, which are subsequently linked to inverters. The DC electrical input to inverter is converted to AC output, which is then increased using a single 5 MVA, 690V/33kV transformer. The project step-up transformer is connected to the NEA owned grid substation by 33 kV transmission lines, which are then used to evacuate the 33 kV AC electrical supply into the NEA owned grid.

Table 3.1: Project Description

Nominal Capacity	4 MW
Latitude/Longitude	27°7’18.51” N, 85°22’29.18” E
PV Module	LONGI LR4 72 HPH 450M
PV Module Peak Power (Wp)	450
Total number of String Connection Box	17
Total number of String	197
No. of Modules	11032
Inverter	ABB 9210300228
Inverter AC Power	5000 kVA
Number of Inverter	One (1)
Peak Power of Plant (kWp-DC Side)	4964
Expected CUF AC capacity@ P50%	20.60%
CUF as Contract Energy with NEA	19.77%

3.6 Solar Resources

The annual energy yield of a Solar PV plant is heavily dependent on the solar resource of the site. The indicated site's solar irradiation data has been sourced from NASA's Surface Meteorology and Solar Energy data set and METEONORM global climatological database because there isn't a weather station on the site. Among the most frequently used trustworthy data sources are the NASA Surface Meteorology and Solar Energy data set and the METEONORM global climatological database, both of which have been used to source monthly horizontal plane irradiation data for the site.

3.7 System Components

The main components are solar PV modules, inverters, mounting structure, junction boxes, and monitoring and data acquisition system.

3.7.1 PV Array

LONGI LR4-72HPH-450M Mono Crystalline 450 W Solar Module are used in the Solar Project. Total 11032 solar panels are used to generate total capacity of 4.964 MWp. Total 197 string is connected through 17 SCB.

LONGI solar modules offer good performance across a wide range of climatic conditions with good low light response and temperature response coefficients.

Table 3.2: Solar Module specification

Module Type	Mono Crystalline
Make	LONGI
Model Number	LR4-72HPH-450M
Rated Max power (P_{max})	450 Wp
No. of cell	144 (6×24)
Module Dimension	2094×1038×35 mm^3
Weight	23.5 kg
Junction Box	IP68, Three Diode
Open Circuit Voltage (V_{oc})	49.3 V
Short circuit current (I_{sc})	11.60 A
Voltage at maximum Power (V_{mp})	41.5 V
Current at maximum Power (I_{mp})	10.85 A
Operational Temperature	-40℃ to +85℃
Power Output Tolerance	0 to 3%
Temperature coefficient of P_{max}	-0.34 %/℃
Protection Class	Class II
Module Efficiency (%)	20.7
Total Number of Panels	11032

3.7.2 Grid-tied Inverter

The DC electricity generated by modules is converted to AC with inverters. For a complete reliable system and to ensure high energy yield ABB 9210300228 grid-tied inverters is installed in the plant which have very high efficiency over a wide range of load. There is one number of inverters is connected with a 5000 kVA rating**.** The key parameters of grid-tied inverters are detailed below.

Table 3.3: Inverter specification

Make	ABB
Serial Number	9210300228
Cooling	Air
Type	3R
Protective Class	I
Vdc Max	1500 V
Idc Max	5700 A
Sout	5000 kVA
Iout	4184 A
Vout	690 V

3.7.3 Transformer

There is one number of transformer is used to step up and connect to the grid. The transformer is 3 phase 690 V/33 kV, 5000 KVA with ONAN cooling.

Table 3.4: Transformer specification

Manufacturer	TMC, India
Type of Cooling	ONAN
Serial Number	1000526
Rated Power	5000 kVA
Rated HV	33 KV
Rated LV	690 V
Vector Group	YNd11
DOM	2021

3.7.4 Module Support Structures

A fixed module mounting system of with tilt angle 18° has installed for the PV plant. The mounting structures is appropriate industrial standards and capable of withstanding on-site loading and climatic conditions. Hot-dipped galvanized mild steel and cold-rolled sheets is used to create structural members for module mounting.

3.7.5 Remote Monitoring and Data Acquisition System

The power plant has a communication system to monitor the output of each string and inverter so that system faults can be detected and rectified before they have an appreciable effect on production. The monitoring system have a web based internet portal solution. There is a local display indicating the total amount of energy generated, Voltage and current profile in the period of time.

CHAPTER FOUR: RESULTS AND DISCUSSION

The study of 4 MW Chandranigahpur Solar Plant is carried out the time period of 2078 Bhadra to 2080 Jestha. The Actual Parameters were calculated by the measured data from the plant. Simulation results from PVSYST was also presented in this study. The results from different technical and financial parameter was discussed in this chapter.

4.1 Irradiance

The irradiance for each month has been shown in the Figure 4.1.

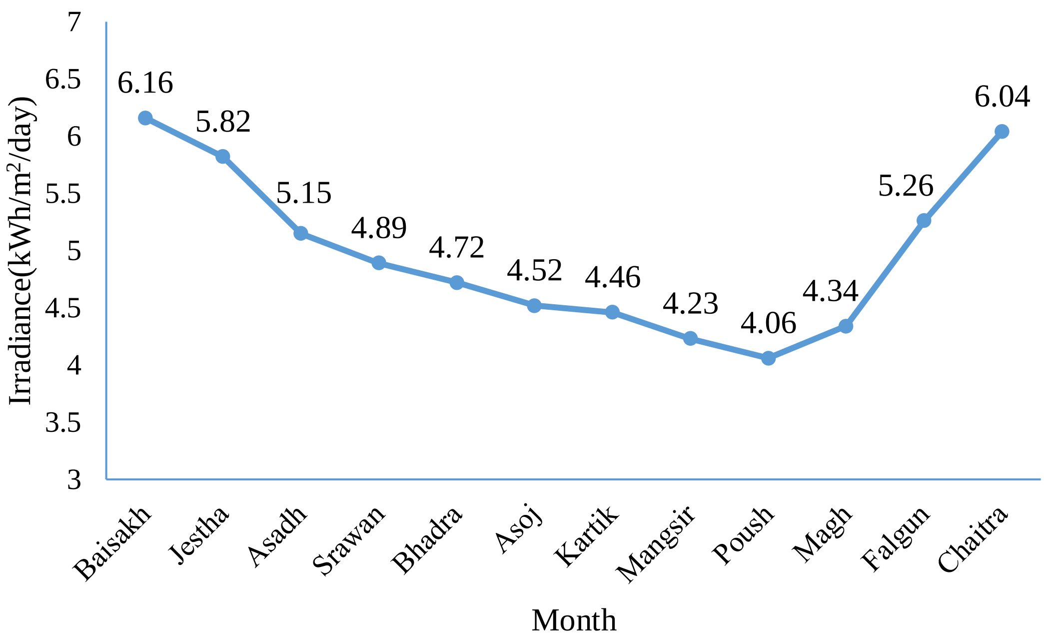


Figure 4.1: Average Solar Irradiance throughout the year

The highest irradiance is in the month of Baisakh which is 6.16 kWh/m^2/day and lowest is in the month of Poush which is 4.06 kWh/m^2/day. The irradiance mainly vary with the weather condition. The Figure 4.1shows that in the summer season irradiance is high and in the winter season irradiance is low.

4.2 Annual Horizontal Irradiation at plant site

Irradiation is taken in the site by Meteonorm software. They are published in hourly format and can be compared to other sources' monthly averages, Meteonorm readings may prove to be accurate. Figure 4.2 shows the Irradiation data from the tow source, Meteonorm and NASA.

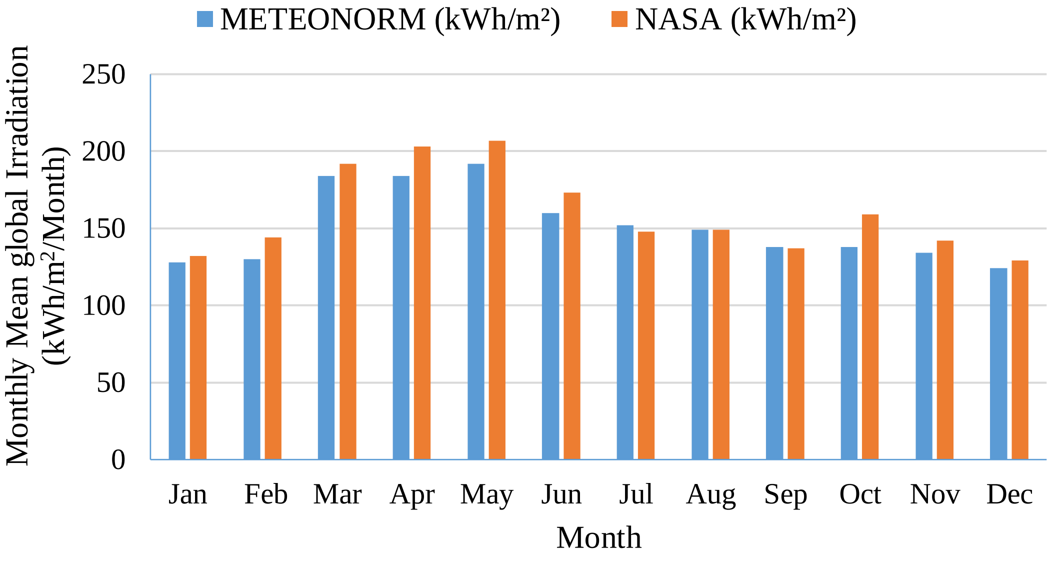


Figure 4.2: Monthly Mean global Irradiation from Meteonorm and NASA

From the Figure 4.2, the NASA and Meteonorm both have almost same pattern of monthly irradiation. March, April and May seems to have higher irradiation. Also the irradiation is low in the winter season. It has been shown that the irradiation is high in every month from the NASA than the Meteonorm software.

4.3 Wind Speed at plant site

Wind speed was obtained from the NASA website and is presented in the Figure 4.3 which is 22 years average wind speed.

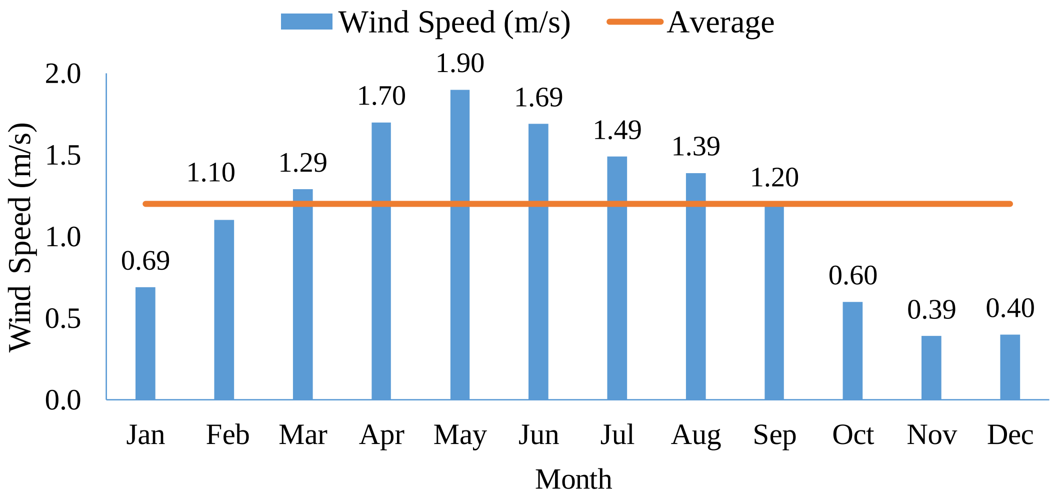


Figure 4.3: Wind speed at the plant site

From Figure 4.3 it has been seen that the annual average wind speed at project site is 1.2 m/s. Maximum monthly average wind speed is 1.90 m/s and minimum is 0.39 m/s.

4.4 Temperature at plant site

Temperature is taken average of 22 years. Temperature data is given below in the Figure 4.4.

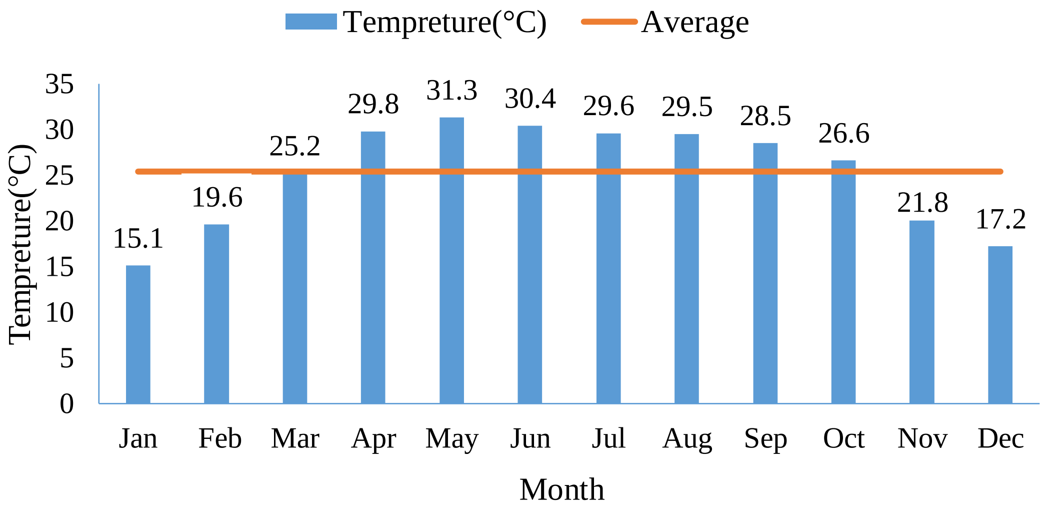


Figure 4.4: Temperature at the plant site

PV modules suffer from a decrease in efficiency with rise in temperature. Average temperature is 25.4°C. The minimum temperature is in the month of January which is 15.1°C and the highest temperature is 31.3°C in the Month of May.

4.5 Energy Generation

The monthly energy generation from the plant is given in the following Figure 4.5.

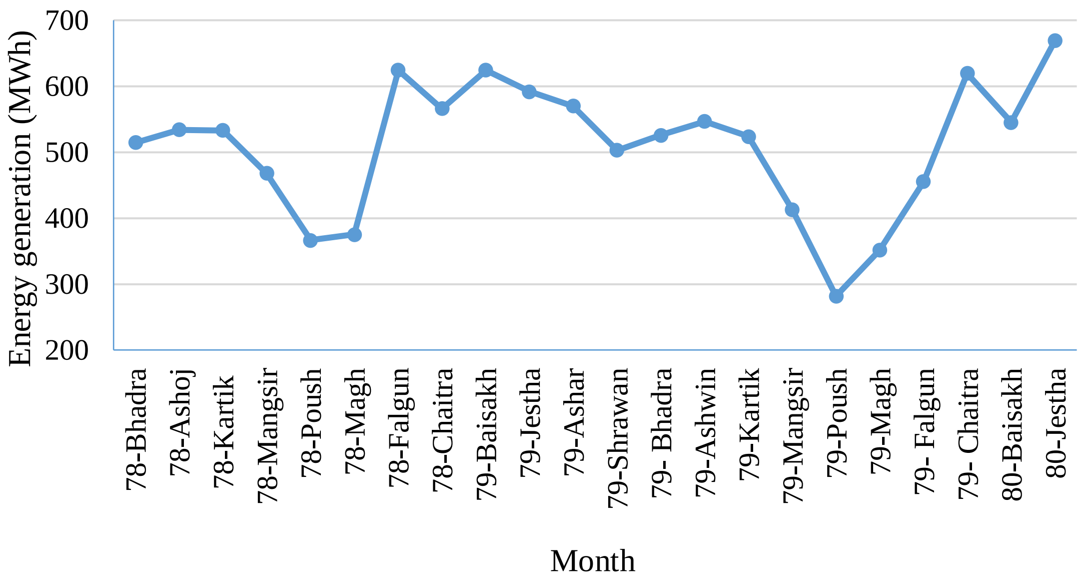


Figure 4.5: Energy generation from the solar PV plant

As in the Figure 4.5, Energy generetion is varies as the Irradiance varies month to month. Highest energy generation is in Jestha 2080 which is 669 MWh. As the Jestha Irradiance is 5.82 kWh/m^2/day. The lowest energy generation is in Poush 2079 which was 282 MWh and the irradiance in the Poush is 4.06 kWh/m^2/day. It was seen that the energy generation pattren is as the irridiation of the month, Higher irridiance give the higher energy and lower irridiance give the lower energy. From the Figure 4.1, the irridiance is low in the month of Bhadra to Magh and higher is in falgun to shrawan. Therefore energy was generated lower in the Poush and Magh and higher in the month of Baiskh and Jestha.

4.6 Measured and the Contract Energy

Measured energy generated from the operation of first year of plant result has been compared with contract energy as shown in Figure 4.6.

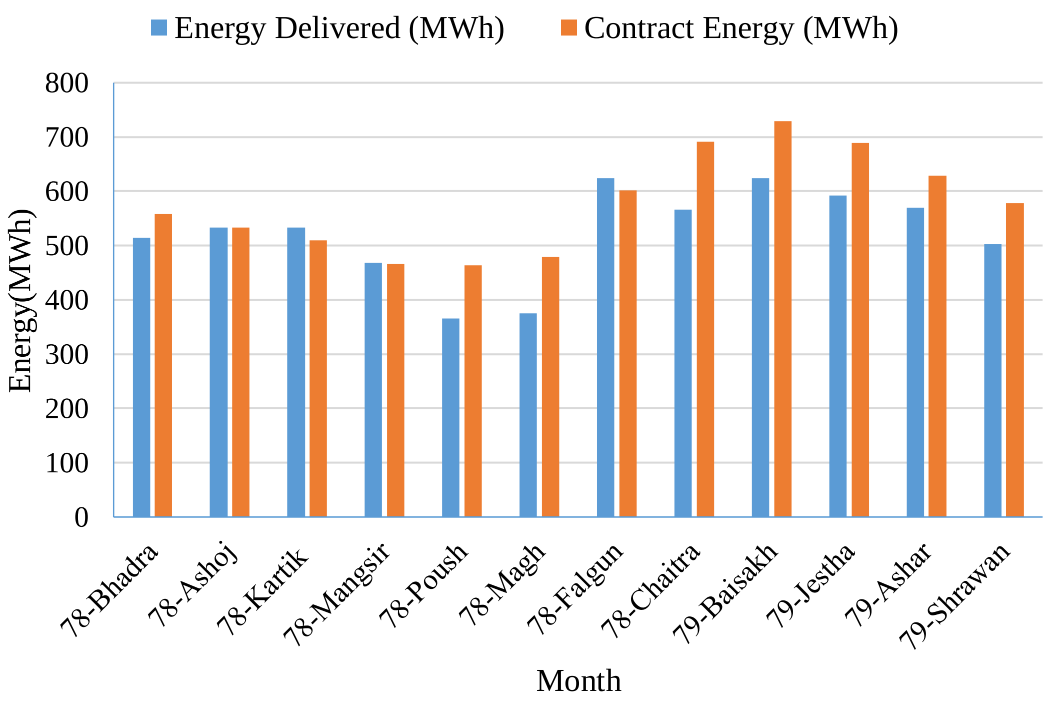


Figure 4.6: Measured and Contract Energy from Bhadra 2078 to Shrawan 2079

The actual energy is lower than the estimated energy, only four month seems that the Delivered Energy is greater than the Contract Energy. Above Figure 4.6 showed the typical month contract energy and the actual energy generated from the plant in one year of operation. As shown in above Figure 4.6 the energy delivered to grid is not as in the contract. As this result shows that only Ashwin, Kartik, Mangsir and Falgum months was delivering the required energy for the first year. In the first year of operation total energy delivered to grid was 6296 MWh and the contract energy was 6926 MWh. This showed that the delivered energy is 657 MWh less than the contract energy in that particular year of operation. The loss was 9.48 % from the contract energy. The maximum loss is in month of Magh which was 21.74%. In delivered energy maximum output from the plant was in the month of Falgun and Baisakh which was 624 MWh and in contract energy maximum energy was contracted in the month of Baisakh which was 729 MWh. And also the minimum energy delivered to the grid was 366 MWh in Poush and contract energy was 466 MWh in Mangsir.

Similarly, measured energy generated from the operation of next ten months has been compared with contract energy as shown in Figure 4.7.

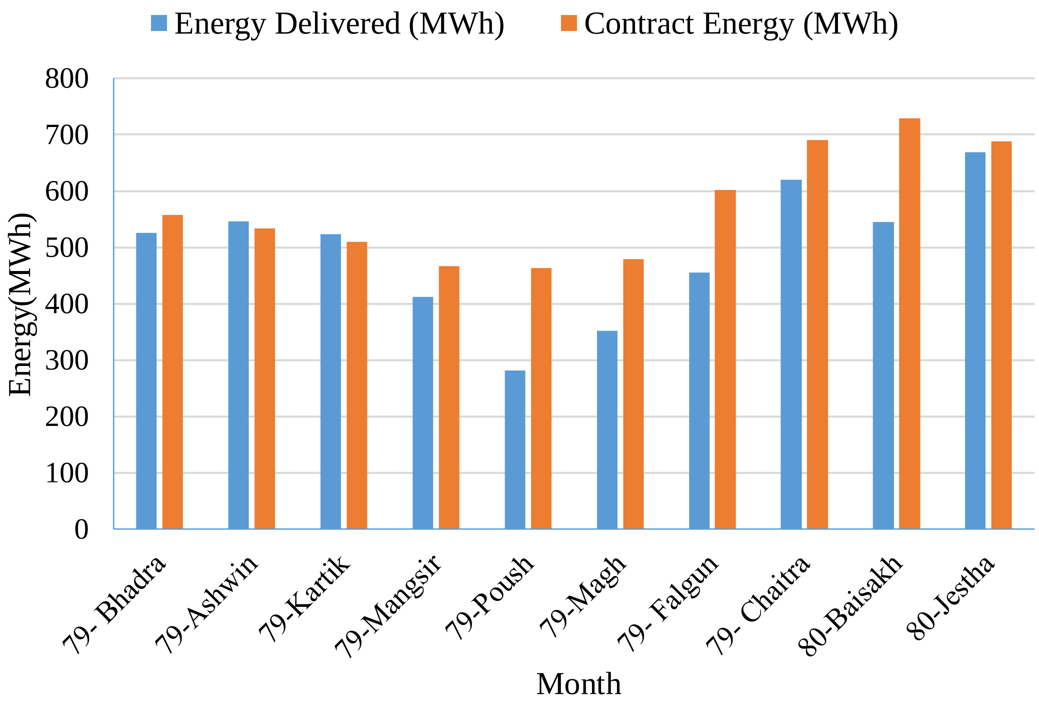


Figure 4.7: Measured and Contract Energy from Bhadra 2079 to Jestha 2080

Similarly, in the second year of production only Ashwin and Kartik month has delivered the required energy in the grid. The Energy is up to 39.20% less as per the agreement in the month of Poush. In the next year also the energy was not delivered as required. Second year is worse than the first as only in 10 months 789 MWh energy was less and average13.8% less energy than the contract energy in the period of 10 months. This is depending on the weather and the plant shutdown at that time. If the weather is clear them the solar energy generation is maximum. If the fault occurs frequently then the fault duration time is to be short and tend to zero.

In Poush 2079, energy loss is highest which 39.20% loss from the contract energy. Till date 11.43% energy is less than the contract energy which was 1446 MWh and revenue loss from this energy was NRs. 10,555,800. This loss is huge for small scale plant like this plant as this loss is just in 22 months of operation. This loss directly hit the financial status of the plant. But some months the energy generated was little higher than the contract energy. In 2078 Kartik and Falgun, energy was 23 MWh higher than the contract energy. And also in the 2079 Ashwin and Kartik, energy was higher by 13 MWh and 14 MWh respectively.

4.7 Measured Final Energy Yield (F_Y), Capacity Utilization Factor (CUF) and Performance Ratio (PR)

Final Energy yield, Capacity Utilization Factor and Performance Ratio from the measured data has been calculated as shown in Table 4.1.

Table 4.1: Final Energy Yield, CUF and PR as per measured data

Month	Monthly average Solar Irradiance (kWh/m^2/ day)	No. of Days	Monthly solar Irradiance (kWh/m^2)	Actual Energy to Grid (MWh)	Final energy Yield (Y_F) (kWh/ kWp)	CUF (%)	PR
2078-Bhadra	4.72	31	146.32	515	103.67	17.29	0.709
2078-Asoj	4.52	31	140.12	534	107.54	17.94	0.768
2078-Kartik	4.46	30	133.80	533	107.33	18.50	0.802
2078-Mangsir	4.23	29	122.67	468	94.24	16.80	0.768
2078-Poush	4.06	30	121.80	366	73.75	12.71	0.606
2078-Magh	4.34	29	125.86	375	75.55	13.47	0.600
2078-Falgun	5.26	30	157.80	624	125.74	21.67	0.797
2078-Chaitra	6.04	30	181.20	566	114.05	19.66	0.629
2079-Baisakh	6.16	31	190.96	624	125.74	20.97	0.658
2079-Jestha	5.82	31	180.42	592	119.20	19.88	0.661
2079-Asadh	5.15	32	164.80	570	114.85	18.56	0.697
2079-Srawan	4.89	31	151.59	503	101.31	16.90	0.668
Year	4.97	365	1817.34	6269	1263	17.89	0.695

The PR and CUF is calculated from the data which was actually fed to the grid. Yearly 6269 MWh Energy was supplied to national grid. Among them the highest was in Falgun and Baisakh which were 624 MWh. Lowest energy generation is in the month of Poush and the actual energy of the Poush month was 366 MWh.

Capacity Utilization factor was calculated from the Actual data. It was calculated both monthly and yearly basis. In month of Falgun, the CUF was found high which was 21.67% and lowest is in Poush which was 12.71%.

Similarly, Performance Ratio was calculated for the entire month. The highest PR value was found in Kartik month which was 0.802 and lowest in the month of Magh which was found 0.600.

Final Energy Yield of the plant at the first year of operation was 1263 kWh/kWp annually and 3.46 kWh/kWp/day. Final Energy Yield was minimum in the month of Poush which was 73.75 kWh/kWp/Month and maximum at the month of Falgun and Baisakh which was 125.74 kWh/kWp/Month.

Yearly CUF and PR was also calculated from the measured data. These values were measured by the yearly basis. The CUF of the plant was found 17.89% and the Performance Ratio was found 0.695 yearly.

4.7.1 Measured Capacity Utilization Factor (CUF)

Capacity Utilization Factor (CUF) from measured data from the plant has been calculated as shown in Figure 4.8.

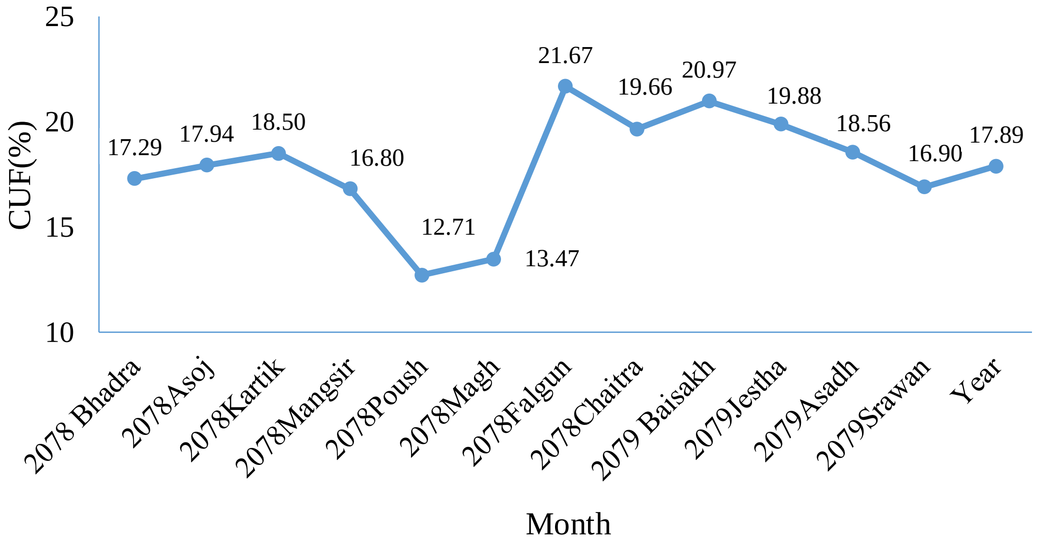


Figure 4.8: Monthly Capacity Utilization factor

Capacity Utilization factor was calculated from the Actual data. It is both monthly and yearly calculated. In month of Falgun, The CUF was found highest which was 21.67% and lowest was in Poush which was found 12.71%. The CUF of the plant was found 17.89% yearly. The CUF was low because the solar irradiance was low at that particular month and high CUF was because of the high solar irradiance. It showed that the CUF was high in the summer season and low in the rainy season and winter season.

4.7.2 Measured Performance Ratio (PR)

Performance Ratio (PR) from measured data from the plant has been calculated as shown in Figure 4.9.

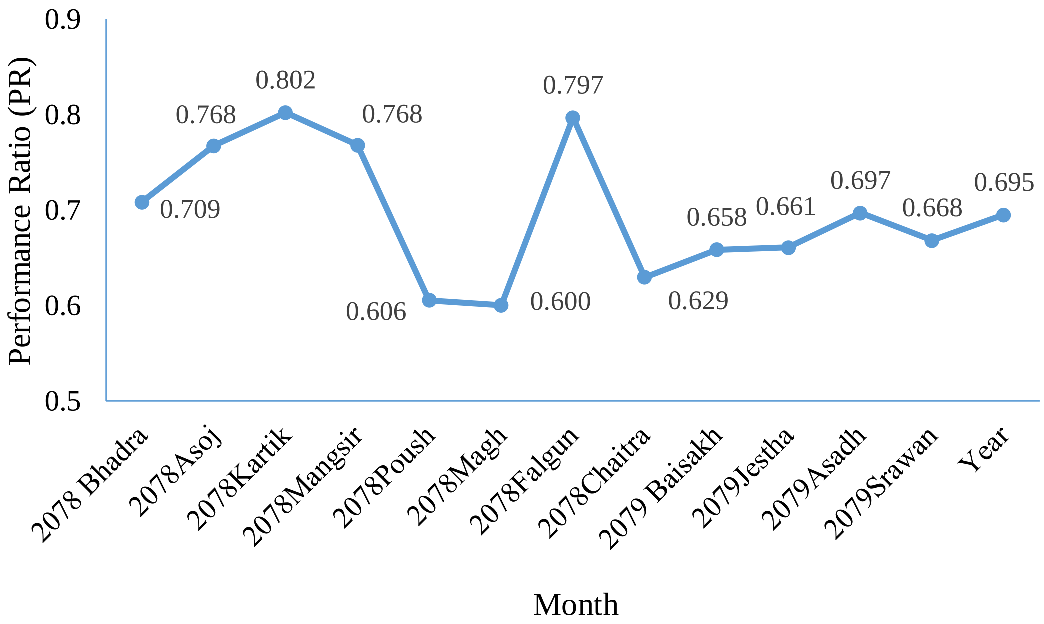


Figure 4.9: Monthly Performance Ratio

Performance Ratio was calculated for the entire month. The highest PR value was found in Kartik month which was 0.802 and lowest in the month of Magh which was 0.600.

The lower PR is in the month of Poush and Magh and also the Bhadra, Asoj, Kartik and Mangsir have higher than the 0.700 that means above 70%. It shows that these months are favorable as the weather is not hot and temperature effect is minimum.

The PR of the plant was found 0.695 yearly. The PR ratio ranges typically from 75- 80 % (GSES, 2015). So this value which was 0.695 was not satisfactory as 30.5% energy is lost from different loss factor.

4.8 CUF and PR as per PPA

Contract energy, CUF and PR as per the PPA with Nepal electricity Authority has been tabulated and as shown in the Table 4.2.

Table 4.2: Monthly CUF and PR as per PPA

Month	Monthly average Solar Irradiance (kWh/m^2/day)	No. of Days	Monthly solar Irradiance (kWh/m^2/Month)	PPA Contract Energy (MWh)	CUF (%)	PR
Bhadra	4.72	31	146.32	557.50	18.73	0.77
Asoj	4.52	31	140.12	533.80	17.94	0.77
Kartik	4.46	30	133.80	509.35	17.69	0.77
Mangsir	4.23	29	122.67	466.13	16.74	0.77
Poush	4.06	30	121.80	463.15	16.08	0.77
Magh	4.34	29	125.86	479.22	17.21	0.77
Falgun	5.26	30	157.80	601.25	20.88	0.77
Chaitra	6.04	30	181.20	690.81	23.99	0.77
Baisakh	6.16	31	190.96	729.34	24.51	0.77
Jestha	5.82	31	180.42	688.53	23.14	0.77
Asadh	5.15	32	164.80	629.04	20.48	0.77
Srawan	4.89	31	151.59	577.75	19.41	0.77
Year	4.97	365	1817.34	6925..92	19.77	0.77

Capacity Utilization factor was calculated from the PPA contract data. CUF and PR were calculated both monthly and yearly. In month of Baisakh, the CUF was found highest which was 24.51% and lowest was in Poush which was found 16.08%.

Monthly Solar irradiance is high in the month of Baisakh which is 6.16 kWh/m^2/day, so the energy generation is high (729.34 MWh). And also irradiance is low in Poush which is 4.06 kWh/m^2/day, so the energy is lowest (463.15 MWh).

Similarly, Performance Ratio was calculated for the entire month. The PR values showed that 0.77 for all months. Yearly CUF and PR was also calculated. These values were measured by the yearly basis. The CUF of the plant was found 19.77% and the Performance Ratio was 0.77 as per in the PPA with NEA.

4.9 Major simulation results from PVSYST

4.9.1 Main result

This simulation is based on the assumption that all the generated energy is being export to the grid, with no any load and battery bank connected to the system. This software is used to determine the total energy generation capacity and total energy that can be injected to the grid form solar panels. This software gives the daily, monthly and yearly simulation and gives the almost exact data output. The performance of solar panels can be simulated through PVSYST in detail. The output energy of 25 years can be determined by the PVSYST Software. The simulation criteria is given in the Table 4.3.

Table 4.3: Simulation Criteria

PV module		Inverter	
Manufacturer	Longi Solar	Manufacturer	ABB
Model	LR4-72 HPH 450 M	Model	PVS980-58-5000kVA-L prelim rev. C
Unit Nominal Power	450 Wp	Unit nominal Power	4864 kWac
Numbers of PV modules	11032	Number of Inverters	1 unit
Nominal(STC)	4964 kWp	Total Power	4864 kWac
Modules	394 Strings × 28 in series	Operating Voltage	978-1500 V
Pmpp	4553 kWp at 50˚C	Maximum Power (≥25˚C)	5000 kWac
U mpp	1050 V	Pnom ratio (DC:AC)	1.02
I mpp	4338 A		
Module area	23979 m^2		
Cell area	21780 m^2		

As the simulation is done in the above parameter. Longi Solar 450 Wp with the 20.7 efficiency is taken as in the plant. Similarly one unit of Inverter with 5000 kW_{ac} is taken for simulation. Losses and other factor is as per the site plant condition and the default value by the PVSYST. Total Module area of 11032 modules is 23979 m^2 with effective cell area 21780 m^2. Nominal output at STC is 4964 kWp and total AC power is 4864 kWac. The monthly energy production has been shown in the Table 4.4.

Table 4.4: Energy generation from PVSYST

Month	$Glob_{Hor}$	$Diff_{Hor}$	T (amb)	GlobInc	$Glob_{EFF}$	Earry	Egrid
	kWh/m^2	kWh/m^2	(°C)	kWh/m^2	kWh/m^2	MWh	MWh
January	102.2	49.2	14.5	127.5	123.1	569	551
February	110.9	60.0	19.4	128.0	123.6	558	541
March	156.1	76.9	25.1	170.8	164.9	721	700
April	148.3	87.6	29.7	151.5	146.2	631	612
May	158.6	100.5	31.4	155.2	149.7	647	629
June	140.1	93.8	31.0	134.6	129.8	567	550
July	134.7	91.1	29.8	129.8	125.1	552	469
August	141.2	89.8	29.7	139.9	134.9	593	575
September	125.3	76.5	28.7	130.9	126.2	554	537
October	129.0	65.6	26.6	145.5	140.5	616	570
November	110.8	52.0	21.4	135.8	131.2	589	571
December	104.0	47.9	16.3	133.6	128.9	593	534
Year	1561.2	890.9	25.3	1683.1	1624.3	7192	6840

The total yearly energy production will be 6840 MWh and lowest will in the month of July which will 469 MWh and the maximum in the month of March which would be 700 MWh. Irradiance is high in the month of March which will be 164.9 kWh/m^2 and lowest at in the month of January and the value will be 123.1 kWh/m^2. Yearly Irradiance received in the module will be 1624.3 kWh/m^2.

From Table 4.4 in July, irradiance is 125.1 kWh/m^2 and energy generation will be 469 MWh and in the month of January and February irradiance is lower than July which are 123.1 kWh/m^2 and 123.6 kWh/m^2 but the energy generation is higher than in the month of July which will be 551 MWh and 541 MWh. So if the temperature increase then energy generation will decrease.

4.10 Comparison of Final Yield

Final yield result generated from simulated result has been compared with measured values as shown in Figure 4.10.

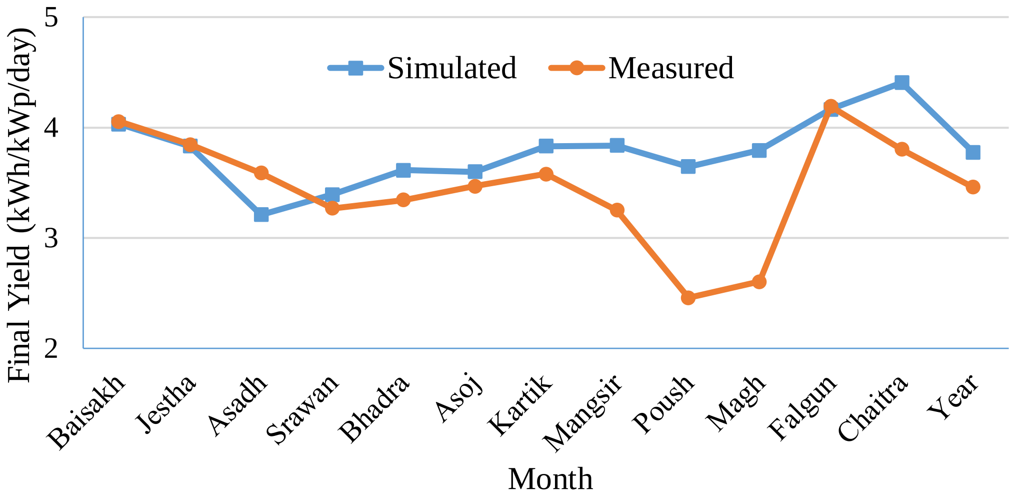


Figure 4.10: Final Yield comparison of Simulated and Measured Data

The final yield varies from 3.21 kWh/kWp/day in Ashad to 4.41 kWh/kWp/day in Chaitra as per simulated data and also from the measured data it shown that the final yield varies from 2.46 kWh/kWp/day in Poush to 4.19 kWh/kWp/day in Falgun. Poush and Magh showed lowest final yield as the irradiance in these month were lowest in the entire year which was 4.06 kWh/m^2/day and 4.34 kWh/m^2/day. And also the irradiance in Poush was 4.06 kWh/m^2/day and as from measured data the lowest final yield was in Poush which was 2.46 kWh/kWp/day. The annual final yield was found 3.78 kWh/kWp/day and 3.46 kWh/kWp/day from simulated and measured data respectively.

4.11 Comparison of CUF

Capital Utilization Factor (CUF) generated from simulated result has been compared with measured values as shown in Figure 4.11.

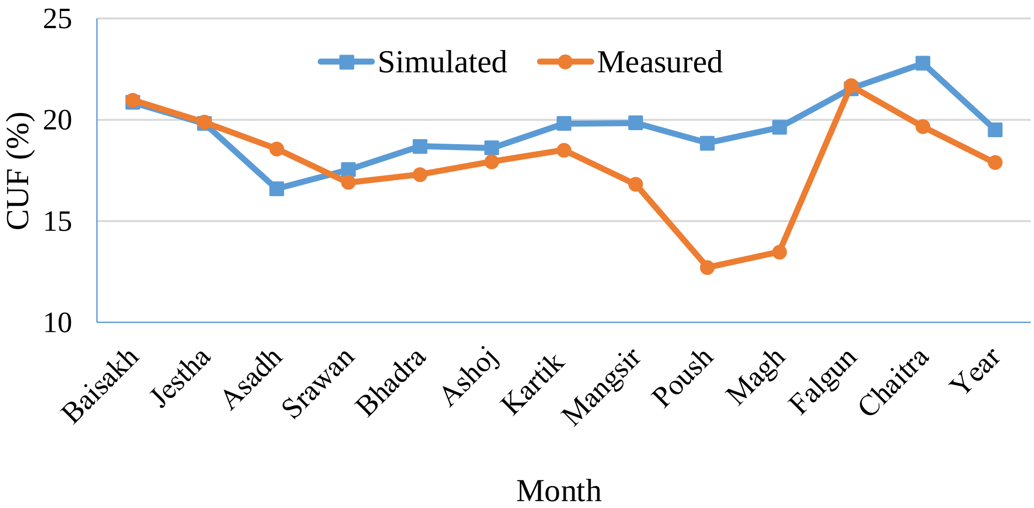


Figure 4.11: CUF Comparison of Simulated and Measured Data

Figure 4.11 showed the capacity utilization factor of the Simulated and measured data. The 4 MW plant measured annual CUF was 17.89% and simulated CUF was 19.52%. And also the lowest CUF was in the month of Asadh (16.59%) in the simulated data and in the Poush (12.71%) in the measured data. This is due to the loss consideration of the Particular design later the loss will be higher or lower. Highest is in the month of Falgun (21.67%) in the measured data and in the month of Chaitra (22.78%) in simulated data respectively.

4.12 Comparison of PR

Performance Ratio (PR) from simulated result has been compared with measured values as shown in Figure 4.12.

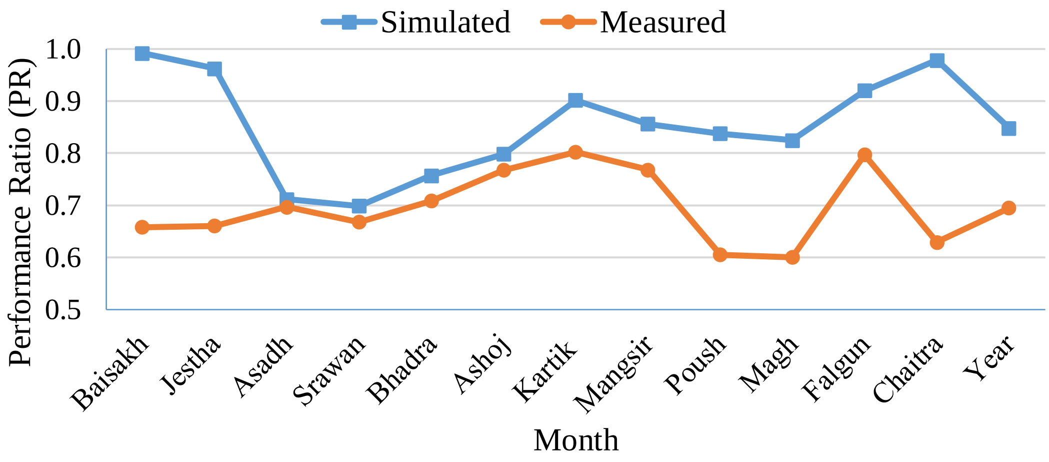


Figure 4.12: PR Comparison of Simulated and Measured Data

Figure 4.12 showed the performance ratio of the Simulated and measured data. Yearly performance ratio of the Simulated data was 0.848 and it varies from 0.669 (Srawan) to 0.992 (Baisakh). And in actual measured values the PR was 0.695 yearly and minimum was 0.600 in Magh and maximum was 0.802 in Kartik. This showed that the plant is good as from the view of simulated data and also from the measured data it is satisfactory but not good enough. Proper care is to be taken as the performance ratio is about 0.695 and from the simulated it was 0.848. Because of the internal fault, shading and soiling loss the measured PR is less than the simulated PR. Losses from these factors are to be resolve time to time.

4.13 Comparison of the Final Yield, PR and CUF with the similar plant

Final Yield (Y_F), Performance Ratio (PR) and Capital Utilization Factor (CUF) has been compared with the similar plant from the previous study. This comparison was done to compare with the similar plant in Nepal, India and the other countries around the globe. The comparison of the results from the different plant has been shown in the Table 4.5.

Table 4.5: Comparison of the PR, CUF and Final Yield with the similar plant

S. N.	Capacity of Plant (MW)	Country	Reference Yield (Y_R) (kWh/kWp/day)	Final Yield (Y_F) (kWh/kWp/day)	CUF (%)	PR (%)	Reference
1.	4	Nepal		3.46	17.89	69.50	This study
2.	1	India	-	-	11.30	87.90	Navotha and Thotakura, 2022
3.	3	Brazil	-	-	-	76.00	Cavalcante et al.,2019
4.	3	India	5.36	3.73	13.70	70.00	Padmavathi and Daniel,2013
5.	10	India	-	-	17.68	86.12	Shivakumar and Sidhakar,2015
6.	50	Spain	5.44	4.28	19.77	79.24	Fuster-Palop et al.,2022
7.	4.6	Spain	-	4.60	18.10	80.00	Martin-matinez et.al,2019
8.	1	Nepal	4.14	2.42	10.09	70.00	Tiwari,2017
9.	8.5	Nepal	4.90	3.10	13.00	64.20	Ghimire,2022
10.	20	Algeria	-	-	20.76	71.71	Aoun,2022
11.	17	India	-	-	19.00	79.00	Chandel and Chandel, 2021

From Table 4.5 it is clear that the CUF of the plant is good as compared to the other similar plant. The Performance Ratio is also considerable as in Nepal we have 70% and 64.2% from the similar plants. The previous study showed that the 69.5% is good but the 30.5% loss occur and that can be minimize by proper design and the proper selection of the material. Final Yield found in this study was 3.46 kWh/kWp/day. This was found also the similar with the other plant. In the reference with solar plant of Nepal it was good but compare with the other similar plant around the world it was satisfactory.

4.14 Loss Diagram over the year

Loss diagram from the PVSYST software has been shown in the Figure 4.13.

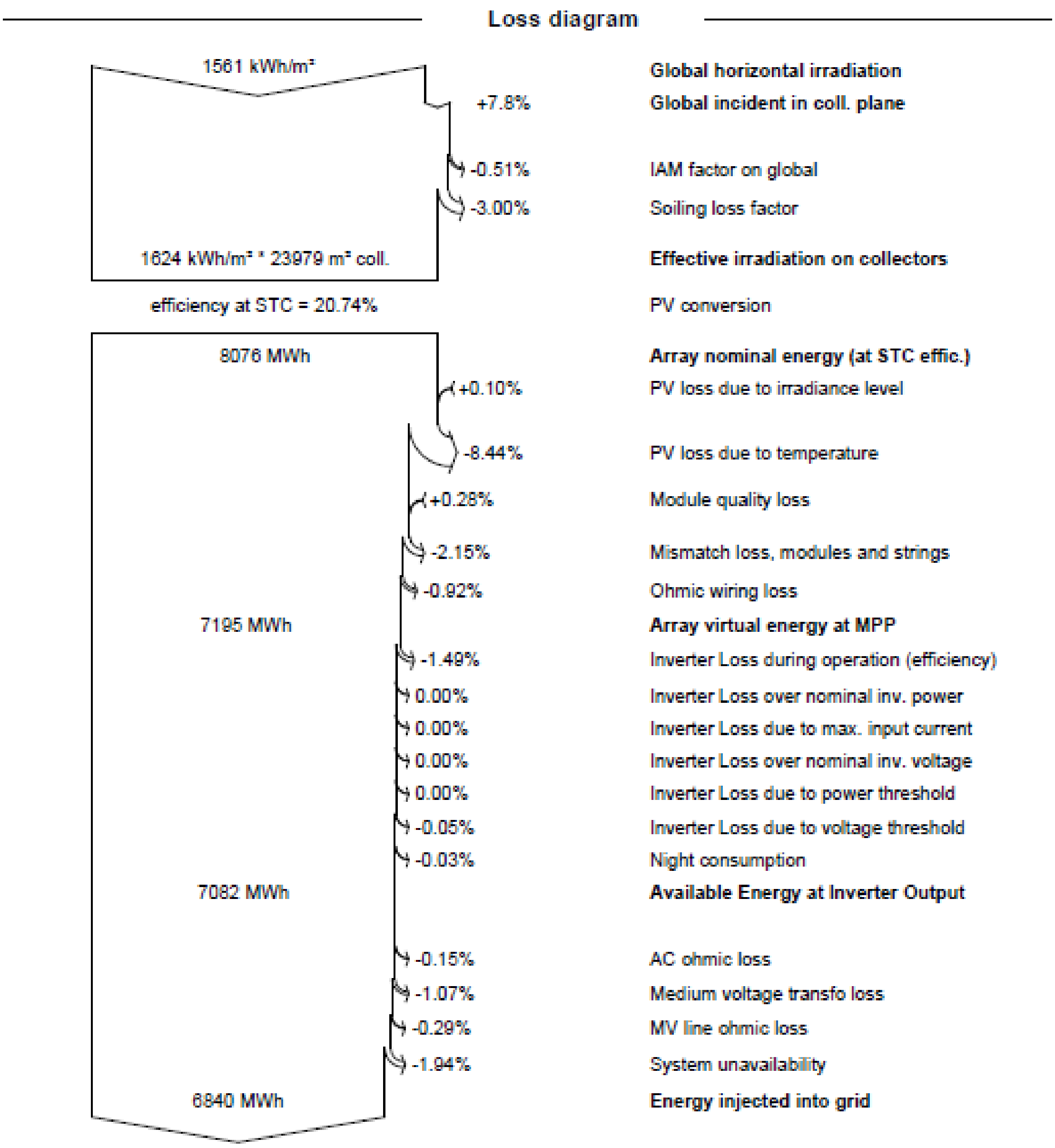


Figure 4.13: Loss Diagram in PVSYST

The losses are in PV due to irradiance level, IAM factor losses, Soiling losses variation in temperature, module quality loss, mismatch loss, DC and AC ohmic losses, Inverter losses Transformer losses, etc. The shading losses are neglected due to the free orientation of module structures. The dust deposition, soiling due to birds and animals, etc. also decrease the panel output power and thus lead to losses.

From this loss diagram different losses are calculated some are by default by the PVSYST. In which PV loss due to temperature is high which nearly 8.44 %. So if the temperature of the module is maintaining then the loss due to temperature will decrease and the energy generation will be higher than the previous. Mismatch loss, Inverter loss, transformer loss and system unavailability are other major losses.

4.15 Comparison of energy delivered to grid with contract energy and the simulated energy

Final yield result generated from simulated result has been compared with measured values as shown in Figure 4.14.

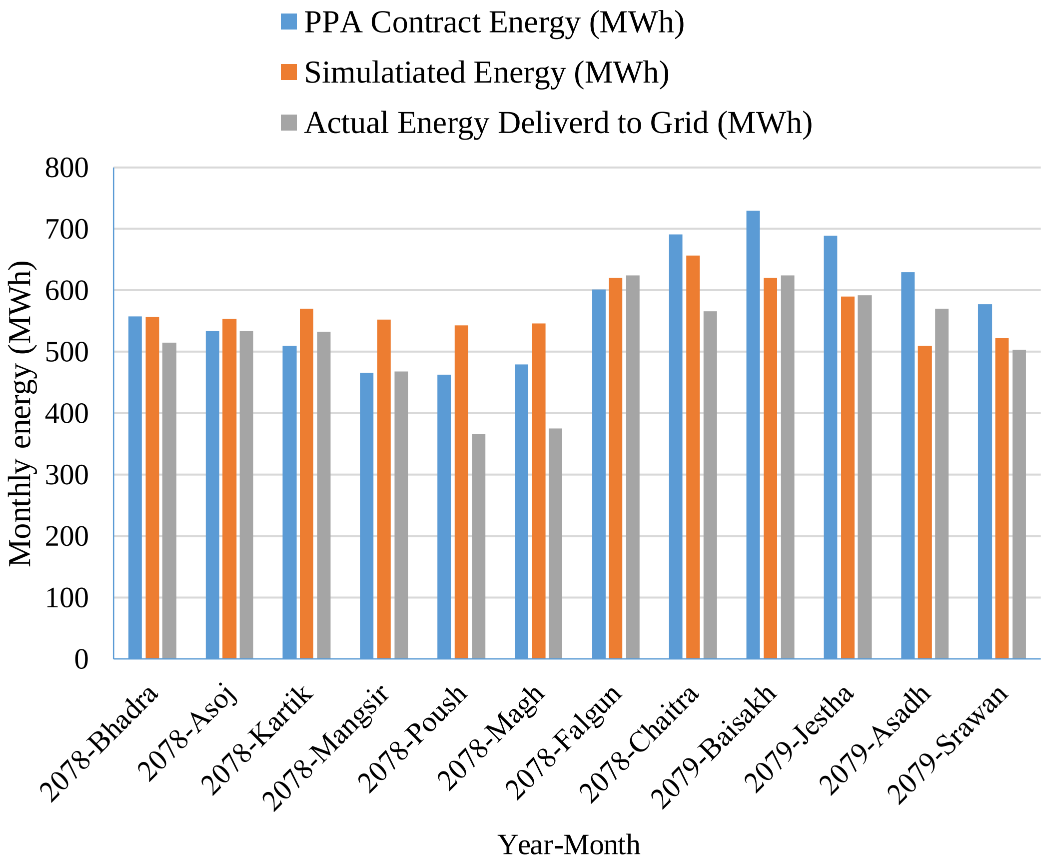


Figure 4.14: Actual Energy, Simulated Energy and Contract Energy in the period of one year.

From Figure 4.14 it has been seen that the contract energy, actual energy and the simulated energy was varies in each months. The annual energy generated from plant was 6269 MWh. As the yearly energy in PPA contract was 6926 MWh and the simulated energy was 6840 MWh, the difference between the simulated and Contract energy is 86 MWh. This showed that the time of contract losses are taken low and the simulation is done after 5 years of the PPA date. In this time of period the simulated energy will decrease. Even in this time the PPA contract energy was found lower than the simulated energy.

The exact delivered energy was found also less than the simulated energy by 571 MWh. This is due to the space unavailable in the plant for installation of the solar panel. The panel is tilted to the 18 degree. Even in the 30 degree tilt the energy is 57 MWh more but this angle is not the big issue.

The energy is higher in the month where the weather is suitable for the solar module that is not very hot and not very cold. In summer season temperature affect the energy generation and in winter shadow affect the energy generation in the plant.

Most of the fault is in underground cable so it is seriously investigating and take proper action to correct it or even change the cable. External fault is because of the transmission line collide with the bamboo. So this is also to be minimize.

In solar PV plant, shadow occur earlier in the evening due to the spacing of the solar module. In winter season it starts even in the 3 pm. Therefore because of the shadow the energy is not achieved as the PPA. For the desired energy Developer have to shift the panel which is not possible but addition of the solar panel is a good solution. From the calculation it is 1155 solar panel will be added to get the energy as PPA. The energy delivered to grid was 9.48% less than the PPA and in next year it was 13.8% till Jestha. Penalty is not charged for the unavailability of the energy as per PPA clause if the energy is less than 80% then the penalty is implemented. The less energy generation as expected will directly hit the revenue generation and the financial parameter too.

In the five months, PPA Energy is more than the simulated energy. This shows that the plant has not required PV module to generate the required energy. This also depend on the simulation date taken at the time of simulation.

4.16 Energy generation in the 25 years of operation

Twenty-five years of energy generation from the plant as per current scenario has been compare with expected or contract energy and the simulated energy as shown in the Figure 4.15.

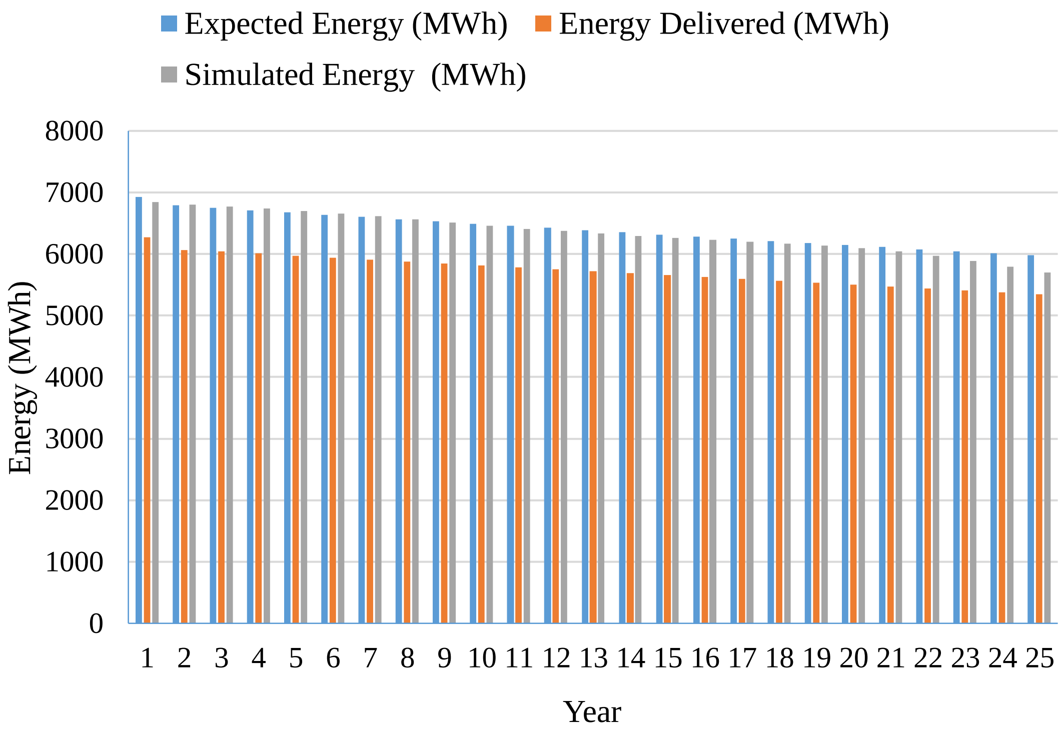


Figure 4.15: Actual energy, Simulated energy and Contract energy in the period of twenty-five years

For the 25 years which is the contract period with the NEA, it is shown that the actual energy is less than the simulated and the contract energy. For expected or contract energy it was 6926 MWh in first year and at the 25th year it will be 5979 MWh which is 13.68% less than the first year. Similarly, actual energy it was 6269 MWh in first year and at the 25th year it will be 535 MWh which is 14.64% less than the first year. And also simulated energy it will be 6840 MWh in first year and at the 25th year it will be 5699 MWh which is 16.68% less than the first year.

Figure 4.15 shows that the contract energy and the simulated energy is in same pattern and nearly equal in every year till the 25th year. This shows that the contract energy is almost accurate with the simulated data and available design parameter like irradiance, temperature, shading and soiling. But the energy is not obtained as per the contract with the NEA till the whole years of operation.

4.17 Grid Impact of the Solar Plant

Grid Impact is also important in the field of grid tied solar PV system. The Energy is delivered to the Chandranigahapur substation 2 km far from the plant. The substation is 33/132 kV and all the transformer is fully capable for the evacuation of the power. The power is connected to the 33 kV busbar of the substation. Power is distributed through the nearest town and village and the rest is voltage up to 132 and fed to the INPS grid.

Following Table 4.6 shows the particular day log sheet. In which power factor is in unity and frequency is near to the 50 Hz. Voltage is almost 34 kV and energy is generated almost same in the particular time interval. In another table shutdown is given which is of a particular one month data. In that month the shutdown is occur because of the under voltage. The power factor is unity.

The daily voltage, power, power factor and frequency of a particular day has been shown in Table 4.6.

Table 4.6: Daily Energy Generation in Plant

Time	33 kV Grid Voltage (kV)			Power (kW)	Reactive Power (kVR)	Power Factor	Energy (MWh)	Frequency (Hz)
	R-Y	Y-B	B-R					
8:00	34.1	33.6	33.7	112.2	4.9	1	3045.66	49.99
9:00	34.0	33.5	33.7	259.8	7.3	1	3045.86	49.98
10:00	34.5	34.1	34.2	515.9	0	1	3046.32	49.93
11:00	34.6	34.1	34.3	473.0	0	1	3046.70	49.99
12:00	34.7	34.3	34.4	595.2	0	1	3047.26	50.03
13:00	34.7	34.2	34.4	472.5	0	1	3047.84	50.04
14:00	34.7	34.2	34.3	426.8	0	1	3048.28	50.00
15:00	34.7	34.3	34.6	441.3	0	1	3048.66	50.30
16:00	35.0	34.8	34.7	198.6	0	1	3048.70	49.97
17:00	34.7	34.3	34.4				3049.10	49.95
18:00							3049.14	

Reactive power fluctuations produce obvious voltage changes, whereas active power fluctuations severely alter the frequency of the electrical network. As PV systems penetrate further into the cloud during transients, voltage flickers become increasingly common. While PV inverters running in the voltage management mode may improve system voltage stability, those operating in the constant power factor mode reduce voltage stability (Ghimire, 2022).

The power shutdown is also because of the transmission line fault. Energy is not able fed because of tripping in transmission line. Main cause of fault is under voltage and the time of fault occur is in the daytime 1 pm to 3 pm.

4.18 Carbon emission balance

The CO_2 emissions balance for the grid-connected PV plant system is estimated during a lifetime of 25 years, as shown in Figure 4.16 which is from the simulation report produced by PVSYST.

CO_2 Emission Balance

Total: -7970.7 tCO_2

Generated emissions

Total: 8504.84 tCO_2

Source: Detailed calculation from table below

Replaced Emissions

Total: 615.6 tCO_2

System production: 6839.89 MWh/yr

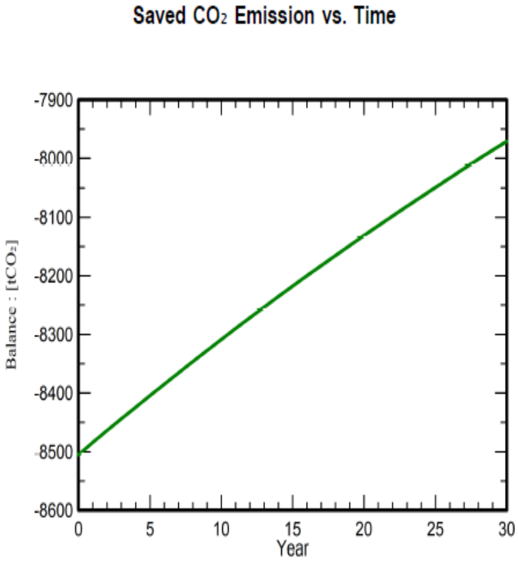
Grid Lifecycle Emissions: 3 gCO_2/kWh

Source: IEA List

Country: Nepal

Lifetime: 30 years

Annual degradation: 1.0 %



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	4964 kWp	8502627
Supports	0.02 kgCO2/kg	110320 kg	2208
Inverters	1.98 kgCO2/units	1.00 units	1.98

Figure 4.16: CO_2 emission balance

The overall CO_2 emissions from the plant were 8504.84 tons, which included emissions from manufacturing, operation, maintenance, and component disposal. Since hydropower is Nepal's main source of energy and its grid-connected energy sources only generate 3gCO_2/kWh (Ghimire, 2022). The substituted emissions based on electricity generation are 615.6 tons.

Nepal will earn $5 for each ton of decreased carbon dioxide emissions. For Nepal to get financing, they must either increase the amount of carbon stored in their forests or cut emissions. (Ghimire, 2022). Power plant can be benefited by the extra $3078 as an extra income.

4.19 Financial Analysis

Financial Analysis is done using MS excel and the major financial indicator was calculated. Sensitivity analysis is done for the different parameter like Initial cost, Interest rate, PPA rate and from that IRR, NPV, and payback period is calculated and presented in the graph and the result is analyzed. Financial key parameter for the analysis of the financial indicator has been shown in Table 4.7.

Table 4.7: Financial Parameter

Installed capacity	4 MW AC
Annual Energy Contract	6.93 GWh/year
PPA Rate	NRs. 7.3 per unit
Project life	25 years
Discount rate	11%
Debt	75% (NRs. 240 million)
Equity	25% (NRs. 80 million)
Corporate income tax	20%
Annual Depreciation	Straight line method
Loan Repayment Duration (Years)	10 years
Tax Holiday	
First 10 years	100% tax holiday
Next 5 years	50% off

Table 4.7 shows the financial parameter for the calculation of the financial parameters. Tariff rate was NRs. 7.3 per unit at the time of contract. Annual energy contract with NEA was 6.93 GWh and the project life was taken 25 years. The project was constructed with the Debt Equity ratio 75:25. The loan repayment duration was taken 10 years. Tax is implied according to the law of Nepal which was 20%. In the first 10

years of operation there will not any tax charge and next 5 years there will be 50% tax to be paid to the Nepal Government. From the criteria from the Table 4.7 the financial analysis is carried out and presented in the different financial indicators.

Initial cost of the project was 320 million Nepalese Rupee and the cost breakdown is presented in the Figure 4.17.

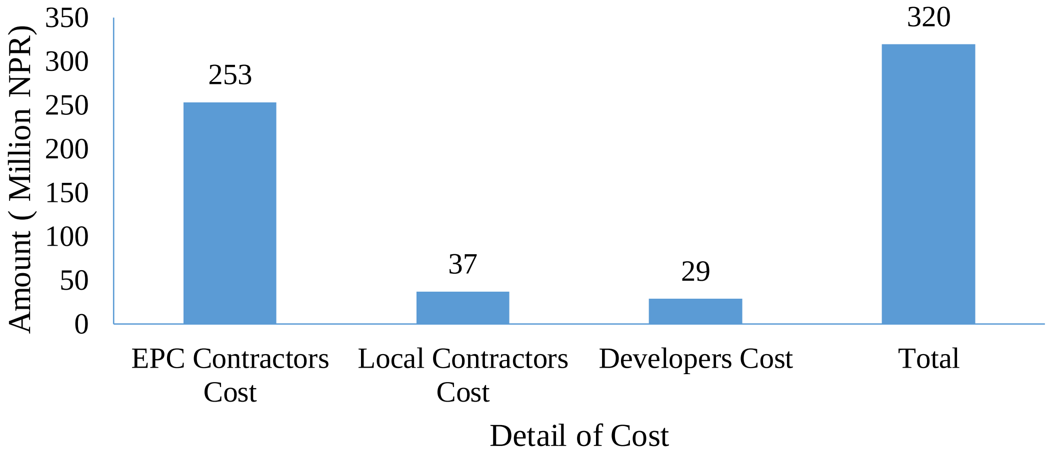


Figure 4.17: Cost Breakdown

From Figure 4.17, the total cost for the project is 320 million Nepalese rupees. 253 million was for the EPC contractors, 37 million for the local contractors and 29 million for the developers cost. It showed that the around 79.1% is for the EPC contract, 11.7% for local contract and 9.2% for developers cost. The installed capacity of the plant is 4 MW, so per megawatt cost is NRs. 80 million.

4.20 Major Financial Indicator

As per contract energy the major financial indicator NPV, IRR, Payback Period, B/C Ratio were calculated. Financial calculation result has been shown in Table 4.8.

Table 4.8: Major Financial Indicator

Particular	As per contract energy	As per Measured Energy
IRR of the Project	12.68%	10.20%
NPV (Nominal)	659,076,437	510,757,027
NPV (Discounted)	36,954,389	-17,276,374
Normal Payback Period (years)	7.07	8.39

Particular	As per contract energy	As per Measured Energy
Discounted Payback Period (years)	15.73	-
B/C Ratio (Nominal)	3.06	2.60
B/C Ratio (Discounted)	1.12	0.95
Equity IRR	18.77%	11.70%

As the first year energy was 9.48% less than the expected or contract energy and on next 10 months the trend was found 13.8% less than the expected. So the energy from next year will be less as per losses from this 22 months trend. So by assuming average 10% loss in the coming year financial indicator is calculated as actual energy generated from plant.

Financial analysis was shown that the plant is good as per contract energy and it has been seen that the plant is not good from the measured values as the energy was not meet as in contract with NEA. As per the contract energy, IRR of the project was 12.68% and Simple Payback Period was 7.08 years. Similarly, Discounted Payback period was 15.73 year. B/C Ratio was 3.06 and Equity IRR was 18.77%. But as per measured energy generation trend of 22 months the calculated financial indicator is different. So the new calculated financial indicator is at right side of the table. From the measured energy it was found that the IRR is 10.20%, Simple payback period will be 8.39 years, B/C ratio will be 0.95 and Equity IRR will be 11.70%.

As comparing the financial indicator between actual and contract energy from the plant it showed that the current scenario is not feasible to gain profit from the plant.

4.21 Energy loss in plant and financial analysis

In this study different percent of loss is considered to calculate the financial indicator which is shown in Table 4.9.

Table 4.9: Financial indicator with energy loss

Particulars	Percentage loss in energy						
	2%	3%	4%	5%	10%	11%	13%
IRR of the Project	11.37%	11.23%	11.08%	10.94%	10.20%	10.05%	9.75%

Particulars	Percentage loss in energy						
	2%	3%	4%	5%	10%	11%	13%
NPV (Nominal)	587,579,654	577,976,826	568,373,997	558,771,169	510,757,027	501,154,198	481,948,541
NPV (Discounted)	8,174,951	4,993,535	1,812,120	-1,369,296	-17,276,374	-20,457,789	-26,820,620
Normal Payback Period (years)	7.74	7.81	7.89	7.97	8.39	8.48	8.67
Discounted Payback Period (years)	21.60	22.87	24.16	25.64	33.59	35.30	38.85
B/C Ratio (Nominal)	2.84	2.81	2.78	2.75	2.60	2.57	2.51
B/C Ratio (Discounted)	1.03	1.02	1.01	1.00	0.95	0.94	0.92
Equity IRR	14.67%	14.29%	13.91%	13.54%	11.70%	11.34%	10.62%

In Table 4.9, 2%, 3%, 4%, 5%, 10%, 11%, 13% loss is considered. As increase in the loss IRR will be decrease and also the discounted NPV will be decrease, it will be negative if the loss is 5%. Discounted payback period will also increase as increasing the loss of energy. EIRR will also decrease as the benefit is low.

This shows that if the loss in the current scenario is more than 4% the plant is not feasible but the plant had 9.48% loss in previous year and in 10 months of next year it was 13.8%. So the loss will be minimize as possible to increase the energy generation and to gain profit from the project. As this was shown that the current scenario will not get the project in the benefit.

For the loss of 10% which is the current loss of the plant with the contract energy. With the 10% loss, financial indicator are not good for the solar project. As we taken the discount rate 11% so the IRR above 11% are only feasible for the profit from the plant. B/C ratio is also below the 1 if the energy loss is above 5%.Discounted NPV will be negative if the energy loss is 5 %.

As the losses was occurred in the plant, losses have to be minimize by adding solar panel or proper maintenance of the solar plant.

4.21.1 Energy loss and IRR

IRR was calculated in the different loss percentage will occur in the solar PV plant as shown in Figure 4.18.

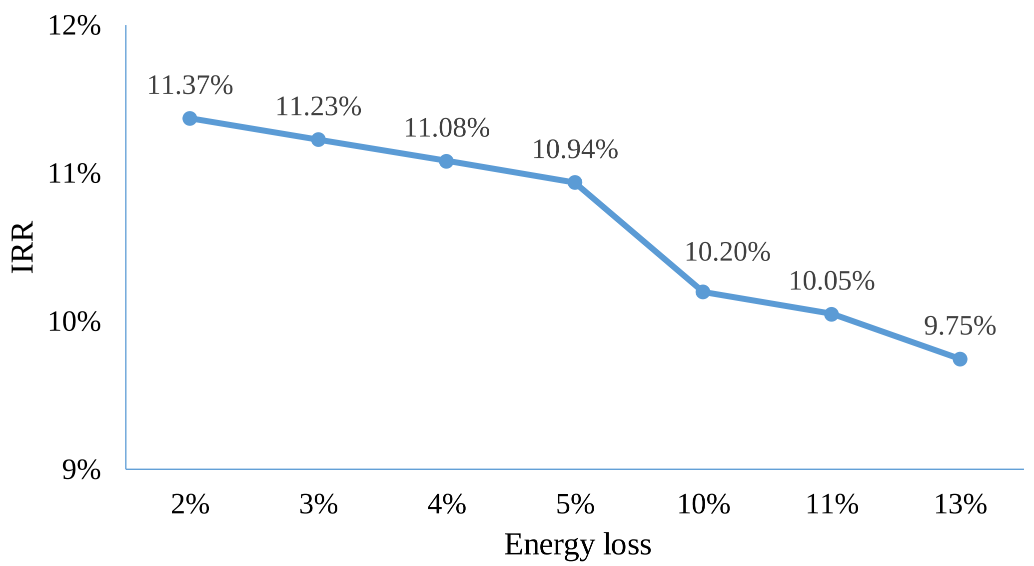


Figure 4.18: Variation of IRR with energy loss

From Figure 4.18, it is clear that if the energy loss is increased with compare to the contract energy the IRR will be decrease. At the 2% of energy loss from the contract energy, IRR will be 11.37% and if the energy will decrease then the IRR will be in decreasing pattern. The discount rate taken is 11% so from the above graph when the energy will decrease above 4 % then the financial indicator will be negative. To get the financial benefit from the plant the loss percent should not go beyond the 4% as per the current scenario. As per the 10% loss the IRR will be 10.20%. Increasing in the loss means low energy generation and hence revenue loss and the IRR will be lower than 11% which is taken discount rate.

4.21.2 Energy loss and payback period

Payback period was calculated in the different loss percentage will occur in the solar PV plant as shown in Figure 4.19.

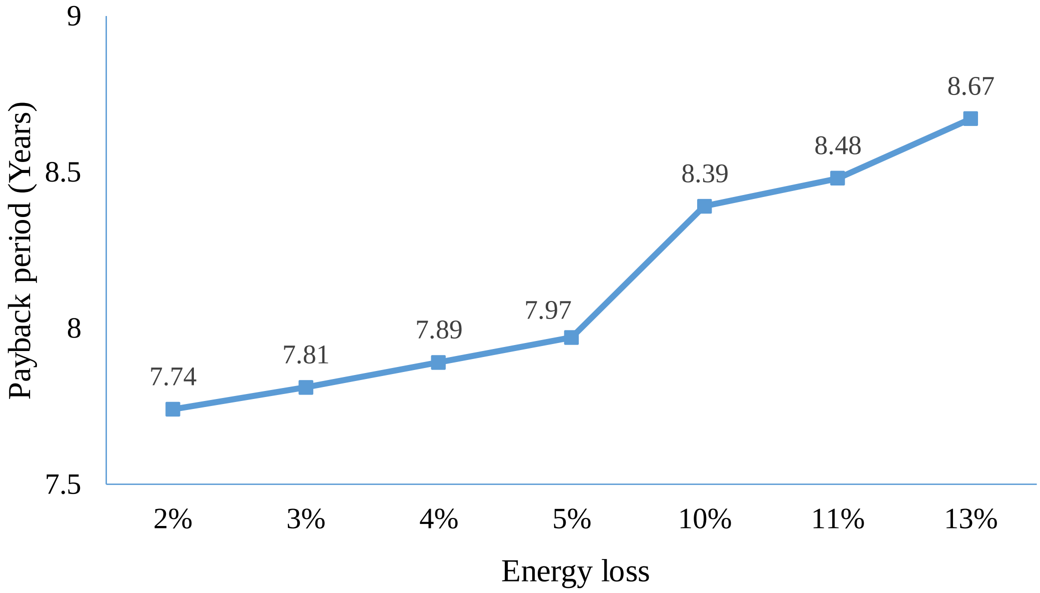


Figure 4.19: Variation of payback period with energy loss

From the Figure 4.19. It has shown that the payback period is increasing with increase in the energy loss. If energy loss is 2% then the payback period is 7.74 years and if the energy loss will increase the payback period will increase. If the current scenario with the energy loss which is 10% then the payback period will be 8.39 years. Similarly the payback period will increase with increase in energy loss. Payback period should be minimum as it indicates the return of investment at particular time period.

4.22 Sensitivity Analysis of the Solar PV Plant

Financial sensitivity analysis is carried out in this study by varying interest rate, Tariff rate, per megawatt cost. Sensitivity shows the plant is feasible or not if something unknown or uncertainty happen and also guide for the existing plant as well as the new plant.

4.22.1 Financial parameter when discount rate change

Financial indicator was calculated with the different discount rate and the result was presented in the Table 4.10.

Table 4.10: Financial Indicator when discount rate change

Discount Rate	9%	10%	11%	12%	13%
NPV Discounted (NRs.)	91,791,543.94	62,701,692.06	36,954,389.50	14,064,677.59	-6,371,430.52
Discounted Payback Period (years)	11.38	13.33	15.73	18.67	22.22

Table 4.10 shows the variation in discount rate and the NPV (Discounted) and the Discounted Payback period was calculated. The result from the calculation has been presented in the Figure 4.20.

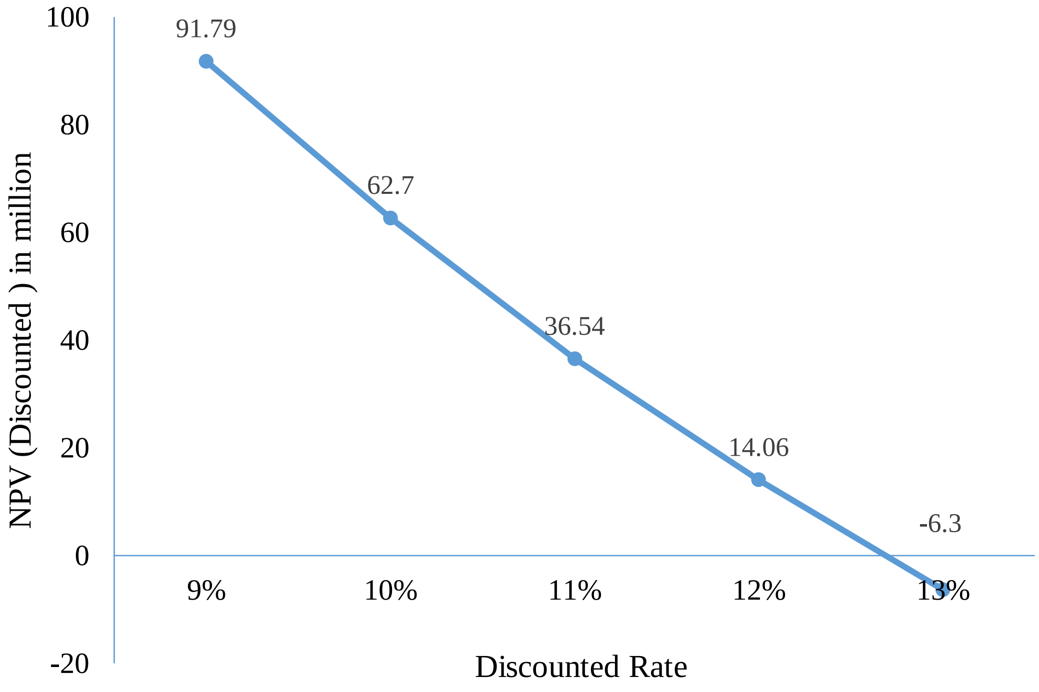


Figure 4.20: Variation of NPV with discount rate

In Figure 4.20, the NVP is declined with the increase in the discount rate. When the discount rate is 9% then the NPV (Discounted) is NRs. 91.79 million and when the discount rate is 13% the NPV (Discounted) is negative which was NRs. (-6.3) million. It is negative if the discount rate is beyond the 12.5%. Discount rate below 12.5% will be viable for the plant. If the discount rate will be more than 12.5% then the plant is in high risk for financial indicator as shown in the above graph where NPV will be negative.

4.22.2 Per Megawatt cost with the tariff rate

As per present project cost which was 80 million per megawatt then the financial indicator is calculated and presented in the Table 4.11.

Table 4.11: Financial Indicator with tariff change for 80 million per megawatt cost

NRs. 80 million per megawatt cost				
Particulars	NRs 5.94	NRs 6.5	NRs 7.30	NRs 8
IRR of the Project	9.33%	10.73%	12.68%	14.33%
NPV (Nominal)	459,817,562	541,865,363	659,076,437	761,636,138
NPV (Discounted)	-35,782,729	-5,832,144	36,954,389	74,392,607
Normal Payback Period (years)	8.94	8.07	7.08	6.39
Discounted Payback Period (years)	28.05	22.31	15.73	11.12
B/C Ratio (Nominal)	2.44	2.69	3.06	3.38
B/C Ratio (Discounted)	0.89	0.98	1.12	1.23
Equity IRR	9.66%	13.05%	18.77%	24.85%

The initial cost of the plant is NRs. 320 million which NRs. 80 million per megawatt. In this section the varying of the financial indicator is studied in different tariff rate. AS NEA has reduced the tariff rate to NRs. 5.94/kWh, so the study is carried out for the viable of the project if the per megawatt cost is NRs. 80 million and NRs. 100 million. First table shown that in the tariff rate of NRs.5.94 per unit the project is not good to invest and even in the NRs. 6.5 per unit. NRs.7.3 per unit is suitable as is in this solar plant. And if tariff rate is NRs.8 per unit then the financial indicator is positive.

Similarly, if the project cost is 100 million per megawatt then the financial indicator was presented in the Table 4.12.

Table 4.12: Financial Indicator with tariff change for 100 million per megawatt cost

NRs. 100 million per megawatt				
Particulars	NRs 5.94	NRs 6.5	NRs 7.30	NRs 8
IRR of the Project	6.55%	7.84%	9.49%	10.88%
NPV (Nominal)	384,389,326	472,297,674	589,508,748	692,068,450

NPV (Discounted)	-133,888,697	-103,856,296	-63,813,107	-28,775,316
Normal Payback Period (years)	11.27	10.09	8.86	8.01
Discounted Payback Period (years)	49.76	41.19	32.05	25.61
B/C Ratio (Nominal)	1.96	2.18	2.47	2.73
B/C Ratio (Discounted)	0.67	0.74	0.84	0.93
Equity IRR	4.00%	6.32%	9.68%	12.98%

This shows that the plant is not suitable even in the tariff rate of NRs.8 per unit if the initial investment is NRs. 100 million per megawatt. As per above table it showed that the IRR will be less than the discount rate. And also the Discounted NPV will be negative. Payback period will be also high.

4.23 Levelized Cost of Energy (LCOE)

Levelized Cost of Energy was calculated as per measured data and contract energy with reference to the different discount rate and the result has been presented as shown in Figure 4.21.

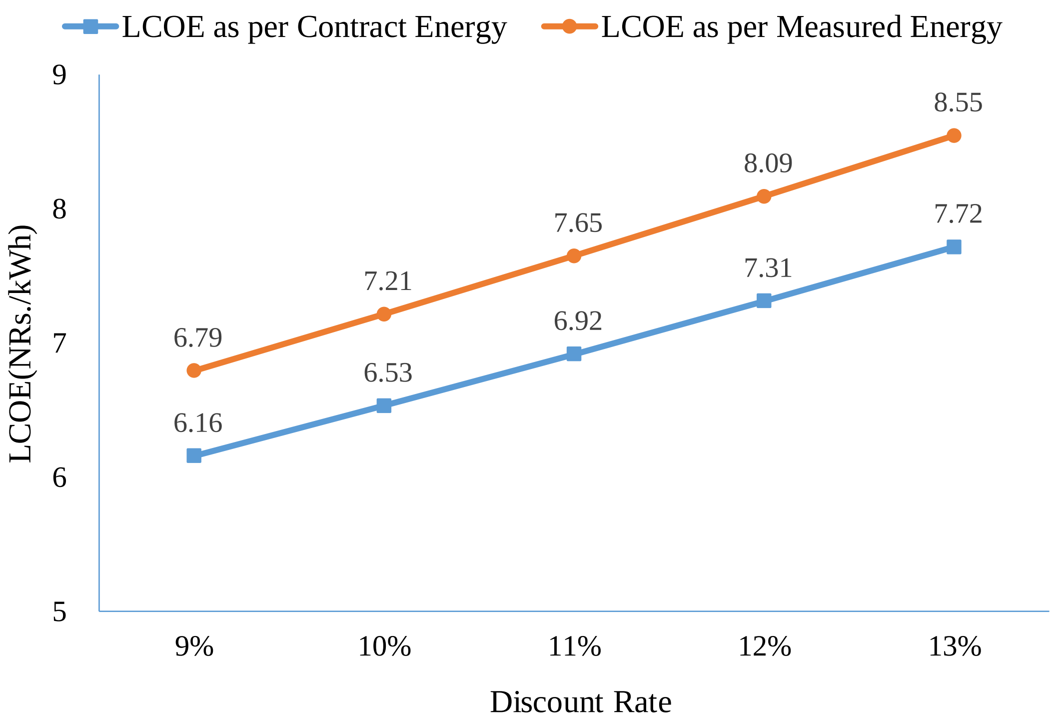


Figure 4.21: Variation of LCOE with discount rate

For this project for the lifetime 25 years, LCOE was calculated NRs.7.65/kWh as per calculated with the discount rate of 11%. And similarly per measured energy generation, LCOE was found NRs.6.92/kWh obtained with the 11% of discount rate.

Figure 4.21 shows the relation of Discount rate and the LCOE. As Discount rate will increase, LCOE will also increase. In 9% of discount rate the LCOE will be NRs. 6.16/kWh and NRs. 6.79/kWh respectively for Contract and measured energy. Similarly, the LCOE increase with increase in the Discount rate. If the discount rate is 13% then the LCOE will be NRs. 7.72/kWh and NRs. 8.55/kWh for the contract and measured energy. As per current tariff rate, discount rate should be minimum to gain the profit from the project.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Following conclusions has been made from the study

- Yearly 6269 MWh Energy was supplied to national grid. Among them the highest was in Falgun and Baisakh which was 624 MWh. Lowest energy generation was in the month of Poush and the actual energy of the poush month is 366 MWh.
- As per measured data from the plant, highest PR value was found in Kartik month which was 0.802 and lowest in the month of Magh which was 0.600. The annual PR was found 0.695.
- In month of Falgun, the CUF was found high which is 21.67% and lowest was in Poush which was 12.71%.
- The CUF of the plant was found 17.89% and the Performance Ratio was found 0.695 annually. The CUF of contract energy was 19.77%. CUF of measured data was found low as compared to the contract energy. Also PR of Contract energy was 0.77 and PR was found low as compare to measured PR which was only 0.695.
- As per simulated data, yearly energy generation was 6840 MWh which was varies from 510 MWh to 656 MWh. Similarly CUF varies from 16.59% to 22.78% and annual CUF was found 19.52%. Performance ratio also varies from 0.669 to 0.992 and annual PR was found 0.848.
- The actual energy generated in the 1st year from the plant was 6269 MWh and the contract energy was 6926 MWh. Energy fed to grid was 657 MWh less than the contract in the PPA, which was found 9.48% less.
- Final Yield of the plant was 3.46 kWh/kWp/day per measured data and per simulated data it was found 3.78 kWh/kWp/day.
- IRR is 12.68%, NPV is NRs. 659 million, simple payback period is 7.07 years, and discounted payback period is 12.60 years for the contract energy but as per actual energy generated from the plant, IRR is 10.20%, NPV is NRs.510 million, simple payback period is 8.39 years according to financial parameters from the analysis.

- LCOE was found NRs. 6.92/kWh and NRs. 7.65/kWh for the contract energy and actual energy generated from the plant respectively.

5.2 Recommendations

Following are the recommendations from this study.

- This is one-year analysis. One year study doesn't give the exact analysis, if the data is taken more than one year or throughout the plant operation then the study will have the better result. For better research work more than one year data is to be implied in the future research for the better and exact analysis.
- As per tariff rate the plant is satisfactory but the tariff rate of new solar plant is reduced to NRs. 5.94 per unit. It has to be studied once by the NEA.
- The data is simulated for the particular Solar Panel and Inverter, if we choose another Panel and Inverter It will be the different result as we have done in the installed instrument.
- Growing in the field of energy, the solar PV Technology is dominating other renewable solar plant. Research in similar field is required for the future.
- Cleaning of Solar module is done effectively and modern cleaning equipment is to be installed.
- By current scenario the plant is in loss so internal fault is to be minimize. If the plant have more than 4% loss as compared to contract energy the plant will not be in profit.

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APPENDIX A: Energy generation from Solar PV Plant till Jestha 2080

Year-Month	Energy Delivered (MWh)
2078-Bhadra	515
2078-Ashoj	534
2078-Kartik	533
2078-Mangsir	468
2078-Poush	366
2078-Magh	375
2078-Falgun	624
2078-Chaitra	566
2079-Baisakh	624
2079-Jestha	592
2079-Ashar	570
2079-Shrawan	503
2079- Bhadra	526
2079-Ashwin	546
2079-Kartik	524
2079-Mangsir	412
2079-Poush	282
2079-Magh	351
2079- Falgun	455
2079- Chaitra	620
2080-Baisakh	545
2080-Jestha	669
Total	11199

APPENDIX B: Contract Energy

Month / Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Baisakh	785838	770122	765886	761674	757485	753319	749176	745056	740958	736883	732830	728799
Jestha	741954	727115	723116	719139	715184	711250	707338	703448	699579	695731	691904	688099
Ashadh	677717	664162	660509	656876	653263	649670	646097	642543	639009	635494	631999	628523
Shrawan	623180	610716	607357	604017	600695	597391	594105	590837	587587	584355	581141	577945
Bhadra	601371	589343	586102	582878	579672	576484	573313	570160	567024	563905	560804	557720
Ashwin	575468	563959	560857	557772	554704	551653	548619	545602	542601	539617	536649	533697
Kartik	549027	538046	535087	532144	529217	526306	523411	520532	517669	514822	511990	509174
Mangsir	502990	492931	490220	487524	484843	482176	479524	476887	474264	471656	469062	466482
Poush	499205	489221	486530	483854	481193	478546	475914	473296	470693	468104	465529	462969
Magh	516317	505990	503207	500439	497687	494950	492228	489521	486829	484151	481488	478840
Falgun	647856	634899	631407	627934	624480	621045	617629	614232	610854	607494	604153	600830
Chaitra	744537	729646	725633	721642	717673	713726	709801	705897	702015	698154	694314	690495
Total (kWh)	**7465458**	**7316150**	**7275911**	**7235893**	**7196096**	**7156516**	**7117155**	**7078011**	**7039082**	**7000366**	**6961863**	**6923573**

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
724791	720805	716841	712898	708977	705078	701200	697343	693508	689694	685901	682129	678377
684314	680550	676807	673085	669383	665701	662040	658399	654778	651177	647596	644034	640492
625066	621628	618209	614809	611428	608065	604721	601395	598087	594798	591527	588274	585038
574766	571605	568461	565334	562225	559133	556058	553000	549959	546934	543926	540934	537959
554653	551602	548568	545551	542550	539566	536598	533647	530712	527793	524890	522003	519132
530762	527843	524940	522053	519182	516326	513486	510662	507853	505060	502282	499519	496772
506374	503589	500819	498064	495325	492601	489892	487198	484518	481853	479203	476567	473946
463916	461364	458826	456302	453792	451296	448814	446346	443891	441450	439022	436607	434206
460423	457891	455373	452868	450377	447900	445437	442987	440551	438128	435718	433322	430939
476206	473587	470982	468392	465816	463254	460706	458172	455652	453146	450654	448175	445710
597525	594239	590971	587721	584489	581274	578077	574898	571736	568591	565464	562354	559261
686697	682920	679164	675429	671714	668020	664346	660692	657058	653444	649850	646276	642721
6885493	**6847623**	**6809961**	**6772506**	**6735258**	**6698214**	**6661375**	**6624739**	**6588303**	**6552068**	**6516033**	**6480194**	**6444553**

APPENDIX C: Actual and Contract energy comparison

Year-Month	Energy Delivered (MWh)	Contract Energy (MWh)	Deviation in Energy (MWh)	Loss energy percent
78-Bhadra	514.63	557.50	-43	-7.69
78-Ashoj	533.82	533.81	0	0.00
78-Kartik	532.78	509.36	23	4.60
78-Mangsir	467.79	466.14	2	0.35
78-Poush	366.11	463.16	-97	-20.95
78-Magh	375.03	479.23	-104	-21.74
78-Falgun	624.16	601.25	23	3.81
78-Chaitra	566.16	690.81	-125	-18.04
79-Baisakh	624.16	729.35	-105	-14.42
79-Jestha	591.72	688.53	-97	-14.06
79-Ashar	570.10	629.04	-59	-9.37
79-Shrawan	502.89	577.75	-75	-12.96
79- Bhadra	525.55	557.50	-32	-5.73
79-Ashwin	546.47	533.81	13	2.37
79-Kartik	523.61	509.36	14	2.80
79-Mangsir	412.47	466.14	-54	-11.51
79-Poush	281.59	463.16	-182	-39.20
79-Magh	351.29	479.23	-128	-26.70
79- Falgun	455.41	601.25	-146	-24.26
79- Chaitra	619.65	690.81	-71	-10.30
80-Baisakh	544.93	729.35	-184	-25.28
80-Jestha	668.82	688.53	-20	-2.86
Total	11199.15	12645.06	-1445.91	-11.43

APPENDIX D: Comparison of Actual, Contract and Simulated energy

Month	PPA Contract Energy (MWh)	Simulated Energy (MWh)	Actual Energy Delivered to Grid (MWh)
2078-Bhadra	558	556	515
2078-Asoj	534	554	534
2078-Kartik	509	570	533
2078-Mangsir	466	553	468
2078-Poush	463	543	366
2078-Magh	479	546	375
2078-Falgun	601	620	624
2078-Chaitra	691	656	566
2079-Baisakh	729	621	624
2079-Jestha	689	589	592
2079-Asadh	629	510	570
2079-Srawan	578	522	503
Year	6926	6840	6269

APENDIX E: Detail Cost Breakdown

S.N.	Details of Cost	Amount (NPR)
A	EPC Contractors Cost	240,000,000
1	Solar PV Modules* and accessories	122,000,000
2	BOS Equipment	118,000,000
2.1	Inverter and Accessories	17,280,000
2.2	Mounting Structure and accessories	55,745,000
2.3	Combiner box and accessories	2,016,000
2.4	UPS, LT ACDB, UPS DB and Lighting DB	1,280,000
2.5	Inverter Duty Transformer and Accessories	9,005,600
2.6	33 kV ICOG Panel, isolator, LA and Accessories	5,533,000
2.7	CCTV, SCADA, Weather Monitoring Station & Accessories	4,800,000
2.8	Earthing & Fire Fighting System	1,030,400
2.9	Lightning Protection ESE	1,600,000
2.10	Illumination System	1,120,000
2.11	HDPE Pipes, Cable, connectors and Accessories	7,250,000
2.12	Energy meter	1,520,000
2.13	Bay at NEA Sub-Station	3,820,000
3	Miscellaneous	6,000,000
B	Local Contractors Cost	39,867,501
1	All Civil Works, Land Leveling, Fencing & Control House	25,000,000
2	Equipment Site Handling Cost	1,167,501
3	All Erection Works	4,500,000
4	Transmission Line	9,200,000
C	Developer's Cost	40,132,500
1	Project Design & Drawing Works	750,000
2	Land Lease/Purchase	12,050,000
3	DPR & IEE Preparation Cost	1,020,000
4	Construction License and other Fee	620,000
5	Custom & Duties	2,880,000
6	Bank Fee & LC Charges	2,212,500
7	IDC	4,000,000
8	Project Management Cost	3,600,000
9	Staff Quarter	3,500,000
10	Project Insurance	700,000
11	Land Reclamation & Structure Dismantling	1,500,000
12	Social Mitigation Expenses	1,400,000
13	Miscellaneous Cost	5,900,000
D	Grand Total (A+B+C)	320,000,001
	AC Capacity (MW)	4
	Cost per MW (NRs. crore)	8

APPENDIX F: Financial Analysis with Contract Energy

Financial Analysis

Base Case

Installed Capacity	4.00	MW
Sellable Energy	6.93	GWh/year

Equity	25%	80,000,000
Debt	75%	240,000,000
Total Financial Cost	100%	320,000,000
Annual Depreciation		St. Line Method
Start of Construction		
COD		
Discount Rate (%)		11%

PARAMETERS

Average Energy Price per kWh	7.30	
Increment in Energy Price	0%	For the First 5 years of Operation
Interest Capitalization During Construction	6	Months
Interest on Long Term Debt	11%	To be Financed by Banks
Loan Repayment Duration (Years)	10	Years after COD
Financial Analysis (Years)	25	Years after COD

Corporate Tax (%)	20%
Bonus and Welfare Fund	2%
Tax Holiday	
First 10 years	100% tax holiday
Next 5 years	50% off

Revenue Royalty	
Up to 15 years	
After 15 years	
Capacity Royalty (Rs/kW)	
Up to 15 Years	
After 15 Years	
O&M as % of Revenue	
O&M as % of Total Cost	
O&M Escalation	

Results

Year	Project Cost		Energy Revenue	Incentive from Govt	Penalty	O & M Cost	Capacity Royalty	Revenue Royalty	Land Lease	Total Operating Cost	Gross Operating Profit	Depreciation	Profit before Interest & Tax	Interest on Debt	Profit Before Tax	Bonus and Welfare Fund	Corporate Tax	Profit After Tax	Loan Repayment	Net Cash flow	Net Cash flow available for Equity	Cumulative Equity Cash Flow
	Equity	Debt																				
0	50,500,000	151,500,000																		(202,000,000)	(50,500,000)	(50,500,000)
1			52,528,554	-	4,334,894	4,000,000	-	-	640,000	8,974,894	43,553,660	12,800,000	30,753,660	16,170,000	14,583,660	291,673	-	14,291,987	12,000,000	15,091,987	15,091,987	(35,408,013)
2	29,500,000	88,500,000	51,477,989		-	4,080,000	-	-	659,200	4,739,200	46,738,789	12,800,000	33,938,789	22,154,741	11,784,048	235,681	-	11,548,367	11,825,147	12,523,220	(16,976,780)	(52,384,793)
3			51,194,863		-	4,161,600	-	-	678,976	4,840,576	46,354,287	12,800,000	33,554,287	23,269,507	10,284,780	205,696	-	10,079,084	12,642,769	10,236,315	10,236,315	(42,148,478)
4			50,913,288		-	4,244,832	-	-	699,345	4,944,177	45,969,111	12,800,000	33,169,111	21,820,377	11,348,734	226,975	-	11,121,759	14,091,899	9,829,860	9,829,860	(32,318,618)
5			50,633,268		-	4,329,729	-	-	720,326	5,050,054	45,583,214	12,800,000	32,783,214	20,205,146	12,578,068	251,561	-	12,326,507	15,707,130	9,419,376	9,419,376	(22,899,242)
6			50,354,778		-	4,416,323	-	-	741,935	5,158,259	45,196,519	12,800,000	32,396,519	18,404,775	13,991,745	279,835	-	13,711,910	17,507,501	9,004,409	9,004,409	(13,894,833)
7			50,077,830		-	4,504,650	-	-	764,193	5,268,843	44,808,987	12,800,000	32,008,987	16,398,043	15,610,944	312,219	-	15,298,725	19,514,233	8,584,492	8,584,492	(5,310,341)
8			49,802,403		-	4,594,743	-	-	787,119	5,381,862	44,420,541	12,800,000	31,620,541	14,161,297	17,459,244	349,185	-	17,110,059	21,750,979	8,159,080	8,159,080	2,848,739
9			49,528,494		-	4,686,638	-	-	810,733	5,497,370	44,031,124	12,800,000	31,231,124	11,668,172	19,562,951	391,259	-	19,171,692	24,244,104	7,727,589	7,727,589	10,576,328
10			49,256,089		-	4,780,370	-	-	835,055	5,615,425	43,640,664	12,800,000	30,840,664	8,889,283	21,951,381	439,028	-	21,512,354	27,022,993	7,289,360	7,289,360	17,865,688
11			48,985,176		-	4,875,978	-	-	860,106	5,736,084	43,249,092	12,800,000	30,449,092	-	30,449,092	608,982	2,984,011	26,856,099	30,120,403	9,535,696	9,535,696	27,401,384
12			48,715,757		-	4,973,497	-	-	885,910	5,859,407	42,856,350	12,800,000	30,056,350	-	30,056,350	601,127	2,945,522	26,509,701	33,572,841	5,736,859	5,736,859	33,138,244
13			48,447,819		-	5,072,967	-	-	912,487	5,985,454	42,462,365	12,800,000	29,662,365	-	29,662,365	593,247	2,906,912	26,162,206	-	38,962,206	38,962,206	72,100,449
14			48,181,355		-	5,174,427	-	-	939,862	6,114,288	42,067,067	12,800,000	29,267,067	-	29,267,067	585,341	2,868,173	25,813,553	-	38,613,553	38,613,553	110,714,002
15			47,916,351		-	5,277,915	-	-	968,057	6,245,972	41,670,379	12,800,000	28,870,379	-	28,870,379	577,408	2,829,297	25,463,674	-	38,263,674	38,263,674	148,977,676
16			47,652,809		-	5,383,473	-	-	997,099	6,380,572	41,272,237	12,800,000	28,472,237	-	28,472,237	569,445	5,580,558	22,322,233	-	35,122,233	35,122,233	184,099,910
17			47,390,720		-	5,491,143	-	-	1,027,012	6,518,155	40,872,565	12,800,000	28,072,565	-	28,072,565	561,451	5,502,223	22,008,891	-	34,808,891	34,808,891	218,908,801
18			47,130,074		-	5,600,966	-	-	1,057,822	6,658,788	40,471,286	12,800,000	27,671,286	-	27,671,286	553,426	5,423,572	21,694,288	-	34,494,288	34,494,288	253,403,089
19			46,870,862		-	5,712,985	-	-	1,089,557	6,802,542	40,068,320	12,800,000	27,268,320	-	27,268,320	545,366	5,344,591	21,378,363	-	34,178,363	34,178,363	287,581,451
20			46,613,077		-	5,827,245	-	-	1,122,244	6,949,489	39,663,588	12,800,000	26,863,588	-	26,863,588	537,272	5,265,263	21,061,053	-	33,861,053	33,861,053	321,442,505
21			46,356,708		-	5,943,790	-	-	1,155,911	7,099,701	39,257,007	12,800,000	26,457,007	-	26,457,007	529,140	5,185,573	20,742,294	-	33,542,294	33,542,294	354,984,798
22			46,101,752		-	6,062,665	-	-	1,190,589	7,253,254	38,848,498	12,800,000	26,048,498	-	26,048,498	520,970	5,105,506	20,422,023	-	33,222,023	33,222,023	388,206,821
23			45,848,195		-	6,183,919	-	-	1,226,306	7,410,225	38,437,970	12,800,000	25,637,970	-	25,637,970	512,759	5,025,042	20,100,169	-	32,900,169	32,900,169	421,106,990
24			45,596,027		-	6,307,597	-	-	1,263,095	7,570,692	38,025,335	12,800,000	25,225,335	-	25,225,335	504,507	4,944,166	19,776,662	-	32,576,662	32,576,662	453,683,652
25			45,345,254		-	6,433,749	-	-	1,300,988	7,734,737	37,610,517	12,800,000	24,810,517	-	24,810,517	496,210	4,862,861	19,451,445	-	32,251,445	32,251,445	485,935,097

APPENDIX G: Financial Analysis with Actual Energy generated

Cost-Benefit Analysis

Nominal											Discount Rate		11%	Discount Rate		10.20%
Year	Penalty	O&M	Land Lease	Royalty	Bonus & Welfare	Tax	Total Cost	Benefit	Cash Flow	Cumulative	DF	Cash Flow	Cumulative	DF	Cash Flow	Cumulative
0							320,000,000		(320,000,000)	(320,000,000)	1.0000	(320,000,000)	(320,000,000)	1.000	(320,000,000)	(320,000,000)
1	#######	4,000,000	640,000	-	156,427	-	9,131,321	45,766,255	36,634,934	(283,365,066)	0.9009	33,004,445	(286,995,555)	0.9074	33,244,205	(286,755,795)
2	-	4,080,000	659,200	-	91,131	-	4,830,331	44,250,487	39,420,156	(243,944,911)	0.8116	31,994,283	(255,001,273)	0.823	32,460,814	(254,294,981)
3	-	4,161,600	678,976	-	63,880	-	4,904,456	44,104,101	39,199,645	(204,745,266)	0.7312	28,662,442	(226,338,830)	0.747	29,291,644	(225,003,337)
4	-	4,244,832	699,345	-	85,940	-	5,030,117	43,861,530	38,831,413	(165,913,852)	0.6587	25,579,455	(200,759,375)	0.678	26,330,879	(198,672,459)
5	-	4,329,729	720,326	-	111,302	-	5,161,356	43,620,293	38,458,937	(127,454,916)	0.5935	22,823,507	(177,935,868)	0.615	23,664,643	(175,007,815)
6	-	4,416,323	741,935	-	140,347	-	5,298,606	43,380,383	38,081,777	(89,373,138)	0.5346	20,360,073	(157,575,795)	0.558	21,263,778	(153,744,037)
7	-	4,504,650	764,193	-	173,498	-	5,442,341	43,141,793	37,699,452	(51,673,686)	0.4817	18,158,258	(139,417,537)	0.507	19,101,998	(134,642,039)
8	-	4,594,743	787,119	-	211,227	-	5,593,089	42,904,518	37,311,429	(14,362,258)	0.4339	16,190,418	(123,227,119)	0.460	17,155,611	(117,486,428)
9	-	4,686,638	810,733	-	254,060	-	5,751,431	42,668,556	36,917,126	22,554,868	0.3909	14,431,819	(108,795,301)	0.417	15,403,263	(102,083,165)
10	-	4,780,370	835,055	-	302,583	-	5,918,008	42,433,876	36,515,867	59,070,735	0.3522	12,860,322	(95,934,979)	0.379	13,825,696	(88,257,470)
11	-	4,875,978	860,106	-	473,288	2,319,112	8,528,484	42,200,490	33,672,006	92,742,741	0.3173	10,683,566	(85,251,413)	0.344	11,568,976	(76,688,494)
12	-	4,973,497	885,910	-	466,180	2,284,280	8,609,866	41,968,385	33,358,518	126,101,259	0.2858	9,535,226	(75,716,187)	0.312	10,400,476	(66,288,018)
13	-	5,072,967	912,487	-	459,042	2,249,306	8,693,802	41,737,554	33,043,752	159,145,012	0.2575	8,509,237	(67,206,950)	0.283	9,348,810	(56,939,208)
14	-	5,174,427	939,862	-	451,874	2,214,182	8,780,344	41,507,985	32,727,641	191,872,653	0.2320	7,592,643	(59,614,306)	0.257	8,402,378	(48,536,830)
15	-	5,277,915	968,057	-	444,674	2,178,904	8,869,551	41,279,691	32,410,140	224,282,793	0.2090	6,773,860	(52,840,446)	0.233	7,550,731	(40,986,099)
16	-	5,383,473	997,099	-	437,442	4,286,927	11,104,942	41,052,652	29,947,710	254,230,503	0.1883	5,638,920	(47,201,526)	0.211	6,331,290	(34,654,809)
17	-	5,491,143	1,027,012	-	430,174	4,215,708	11,164,037	40,826,867	29,662,830	283,893,333	0.1696	5,031,783	(42,169,742)	0.192	5,690,648	(28,964,161)
18	-	5,600,966	1,057,822	-	422,871	4,144,132	11,225,790	40,602,317	29,376,527	313,269,860	0.1528	4,489,385	(37,680,357)	0.174	5,114,111	(23,850,050)
19	-	5,712,985	1,089,557	-	415,529	4,072,186	11,290,258	40,379,003	29,088,745	342,358,605	0.1377	4,004,870	(33,675,488)	0.158	4,595,314	(19,254,736)
20	-	5,827,245	1,122,244	-	408,149	3,999,857	11,357,495	40,156,924	28,799,429	371,158,035	0.1240	3,572,106	(30,103,382)	0.143	4,128,522	(15,126,213)
21	-	5,943,790	1,155,911	-	400,727	3,927,128	11,427,556	39,936,067	28,508,511	399,666,546	0.1117	3,185,605	(26,917,777)	0.130	3,708,564	(11,417,649)
22	-	6,062,665	1,190,589	-	393,263	3,853,979	11,500,496	39,716,412	28,215,916	427,882,462	0.1007	2,840,460	(24,077,317)	0.118	3,330,780	(8,086,869)
23	-	6,183,919	1,226,306	-	385,755	3,780,399	11,576,378	39,497,973	27,921,594	455,804,056	0.0907	2,532,280	(21,545,037)	0.107	2,990,974	(5,095,895)
24	-	6,307,597	1,263,095	-	378,201	3,706,370	11,655,263	39,280,742	27,625,479	483,429,535	0.0817	2,257,139	(19,287,898)	0.097	2,685,361	(2,410,534)
25	-	6,433,749	1,300,988	-	370,599	3,631,873	11,737,209	39,064,701	27,327,492	510,757,027	0.0736	2,011,524	(17,276,374)	0.088	2,410,534	0

IRR of the Project	10.20%
NPV (Nominal)	510,757,027
NPV (Discounted)	(17,276,374)
Normal Payback Period (yrs)	8.39
Discounted Payback Period (yrs)	33.59
B/C Ratio (Nominal)	2.60
B/C Ratio (Discounted)	(0.95)
Equity IRR	11.70%

B/C Ratio or PI = (NPV + Initial Cash Outlay)/Initial Cash Outlay

APPENDIX H: Levelized Cost of Energy (LCOE) Calculation

Year	DF	Cash Flow	Cumulative	DF	Contract Energy	Cumulative
0	1.0000	320,000,000	320,000,000	1.000		-
1	0.9009	9,131,321	328,226,416	0.901	6269350	5,648,063
2	0.8116	4,830,331	332,146,821	0.812	6061711	10,567,883
3	0.7312	4,904,456	335,732,917	0.731	6041658	14,985,491
4	0.6587	5,030,117	339,046,411	0.659	6008429	18,943,429
5	0.5935	5,161,356	342,109,424	0.593	5975383	22,489,528
6	0.5346	5,298,606	344,942,275	0.535	5942518	25,666,641
7	0.4817	5,442,341	347,563,625	0.482	5909835	28,513,163
8	0.4339	5,593,089	349,990,614	0.434	5877331	31,063,492
9	0.3909	5,751,431	352,238,991	0.391	5845008	33,348,451
10	0.3522	5,918,008	354,323,222	0.352	5812860	35,395,650
11	0.3173	8,528,484	357,029,167	0.317	5780889	37,229,829
12	0.2858	8,609,866	359,490,219	0.286	5749094	38,873,155
13	0.2575	8,693,802	361,728,997	0.258	5717473	40,345,486
14	0.2320	8,780,344	363,765,991	0.232	5686025	41,664,614
15	0.2090	8,869,551	365,619,766	0.209	5654752	42,846,482
16	0.1883	11,104,942	367,710,740	0.188	5623651	43,905,372
17	0.1696	11,164,037	369,604,524	0.170	5592722	44,854,080
18	0.1528	11,225,791	371,320,074	0.153	5561961	45,704,071
19	0.1377	11,290,258	372,874,490	0.138	5531370	46,465,617
20	0.1240	11,357,495	374,283,205	0.124	5500949	47,147,921
21	0.1117	11,427,556	375,560,146	0.112	5470694	47,759,229
22	0.1007	11,500,496	376,717,886	0.101	5440604	48,306,927
23	0.0907	11,576,378	377,767,777	0.091	5410681	48,797,636
24	0.0817	11,655,263	378,720,070	0.082	5380924	49,237,284
25	0.0736	11,737,209	379,584,023	0.074	5,351,329	49,631,185
NPV (Discounted) (NRs,)			379,584,023			
Energy (Discounted) (kWh)			49,631,184			
LCOE (NRs./kWh)			7.65			

APPENDIX I: Twenty five years energy generation pattern

Year	Expected Energy (MWh)	Energy Delivered (MWh)	Simulated Energy (MWh)
1	6926	6269	6840
2	6787	6062	6801
3	6750	6042	6771
4	6713	6008	6738
5	6676	5975	6701
6	6639	5943	6658
7	6603	5910	6610
8	6566	5877	6560
9	6530	5845	6509
10	6494	5813	6458
11	6459	5781	6412
12	6423	5749	6371
13	6388	5717	6331
14	6353	5686	6293
15	6318	5655	6257
16	6283	5624	6226
17	6249	5593	6198
18	6214	5562	6169
19	6180	5531	6136
20	6146	5501	6097
21	6112	5471	6042
22	6079	5441	5970
23	6045	5411	5889
24	6012	5381	5798
25	5979	5351	5699
Total	159924	143197	158534

APPENDIX J: Simulation Results from PVSYST

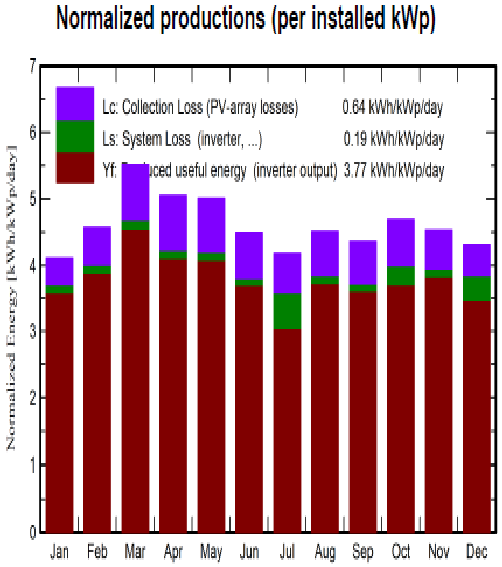
Main results

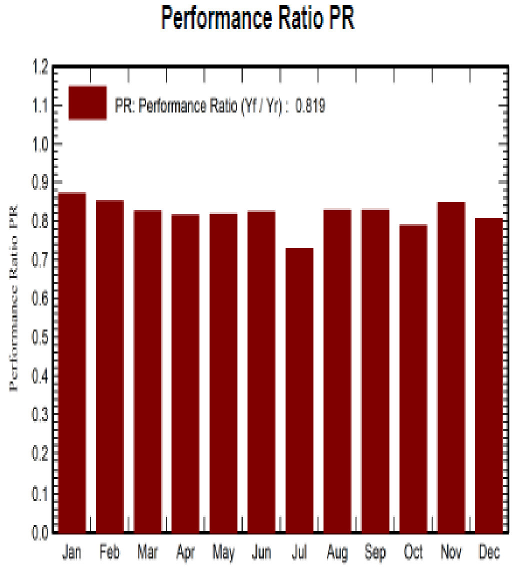
System Production

Produced Energy (P50) 6839.89 MWh/year   Specific production (P50) 1378 kWh/kWp/year   Perf. Ratio PR 81.86 %

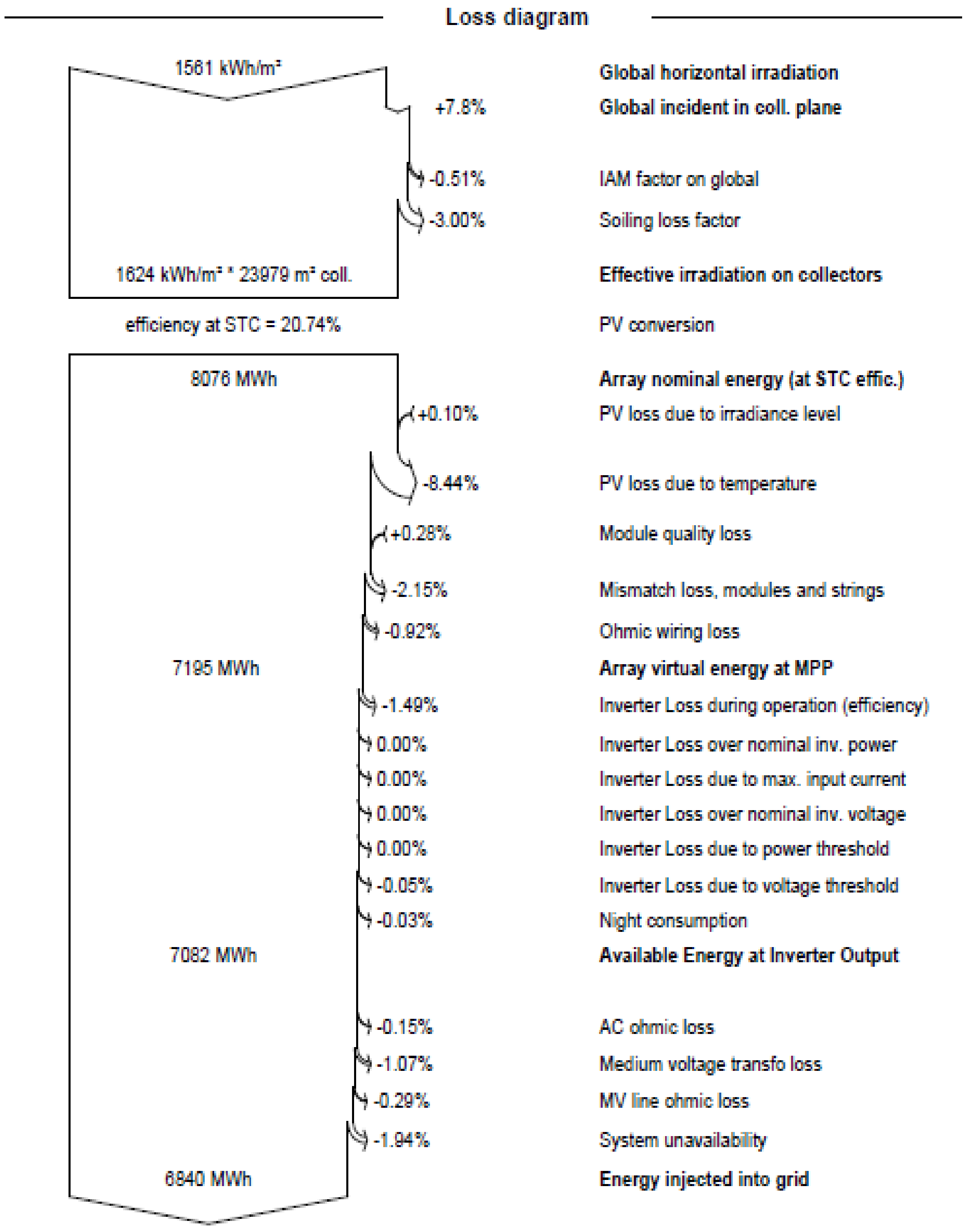
Produced Energy (P75) 6606.82 MWh/year   Specific production (P75) 1331 kWh/kWp/year

Produced Energy (P90) 6396.58 MWh/year   Specific production (P90) 1288 kWh/kWp/year





Month	$Glob_{Hor}$	$Diff_{Hor}$	T (amb)	GlobInc	$Glob_{EFF}$	Earry	Egrid
	kWh/m^2	kWh/m^2	(°C)	kWh/m^2	kWh/m^2	MWh	MWh
January	102.2	49.2	14.5	127.5	123.1	569	551
February	110.9	60.0	19.4	128.0	123.6	558	541
March	156.1	76.9	25.1	170.8	164.9	721	700
April	148.3	87.6	29.7	151.5	146.2	631	612
May	158.6	100.5	31.4	155.2	149.7	647	629
June	140.1	93.8	31.0	134.6	129.8	567	550
July	134.7	91.1	29.8	129.8	125.1	552	469
August	141.2	89.8	29.7	139.9	134.9	593	575
September	125.3	76.5	28.7	130.9	126.2	554	537
October	129.0	65.6	26.6	145.5	140.5	616	570
November	110.8	52.0	21.4	135.8	131.2	589	571
December	104.0	47.9	16.3	133.6	128.9	593	534
Year	1561.2	890.9	25.3	1683.1	1624.3	7192	6840


Loss diagram
1561 kWh/m²
Global horizontal irradiation
+7.8%
Global incident in coll. plane
-0.51%
IAM factor on global
-3.00%
Soiling loss factor
1624 kWh/m² * 23979 m² coll.
Effective irradiation on collectors
efficiency at STC = 20.74%
PV conversion
8076 MWh
Array nominal energy (at STC effic.)
+0.10%
PV loss due to irradiance level
-8.44%
PV loss due to temperature
+0.28%
Module quality loss
-2.15%
Mismatch loss, modules and strings
-0.92%
Ohmic wiring loss
7195 MWh
Array virtual energy at MPP
-1.49%
Inverter Loss during operation (efficiency)
0.00%
Inverter Loss over nominal inv. power
0.00%
Inverter Loss due to max. input current
0.00%
Inverter Loss over nominal inv. voltage
0.00%
Inverter Loss due to power threshold
-0.05%
Inverter Loss due to voltage threshold
-0.03%
Night consumption
7082 MWh
Available Energy at Inverter Output
-0.15%
AC ohmic loss
-1.07%
Medium voltage transfo loss
-0.29%
MV line ohmic loss
-1.94%
System unavailability
6840 MWh
Energy injected into grid

Aging Tool

Aging Parameters

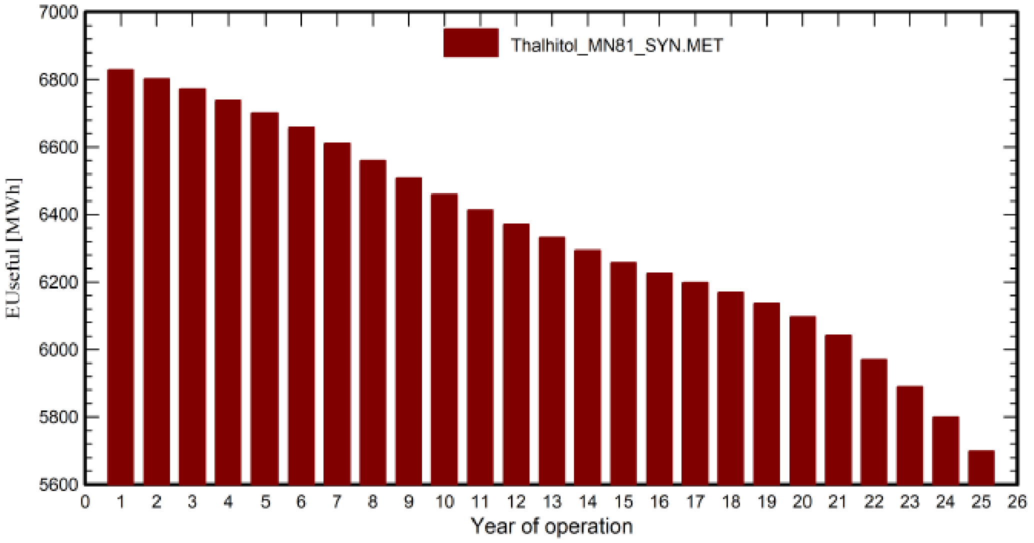
Time span of simulation	25 years		
Module average degradation		**Mismatch due to degradation**	
Loss factor	0.4 %/year	Imp RMS dispersion	0.4 %/year
		Vmp RMS dispersion	0.4 %/year

Meteo used in the simulation

Thalhitol MN81 SYN

Years reference year

Useful out system energy



Performance Ratio