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ECONOMIC EVALUATION OF PV MICROGRID

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Declaration by the Guide

This is to certify that **Mr. Ganesh Nandkumar Jadhav**, a student of MBA (Power Management), SAP ID **500049574** of UPES has successfully completed this dissertation report on **"Economic Evaluation of PV Mrcrogrid"** under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analyzed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfillment for the award of degree of **Master of Business Administration (MBA) (Power Management)**.

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Abstract

Solar photovoltaic (PV) power systems for both utility as well as roof mount applications growing rapidly in India. Solar power plants in India till date are mostly ground-mounted power plants. Due to initiative of Ministry of New and Renewable Energy, Government of India, many projects are coming up with rooftop solar PV installation. Most of the utility scale PV power plants are typically in the scale of 5 MW in size and connected to the electrical grid. The objective of this study is to present the economical evaluation of residential and commercial 100 KW roof top solar PV power ranging from 5 to 15kW and 25 to 100kW respectively. Economical feasibility of renewable energy is presented using Net Present Value (NPV), Return on Investment (ROI) and Internal Rate of Return (IRR) in many cases. In this report, financial analysis has been performed with Levelized Cost of Energy (LCOE), Pay Back Period (PBP) and Emission Reduction Benefit (EBP). Standard financial procedures have been used and the sensitivity parameters studied, mainly focusing on discount rate, inflation rate and sell back rate. The feasibility analysis results were discussed and presented in the conclusions. Keywords: Solar rooftop PV, Economic Evaluation,LCOE, PBP, EBP, Microgrid.

Chapter 1

Introduction

1.1 Overview of Power Sector

Growth of Power sector is key to the economic development of the country as it facilitates development across various sectors of the economy, such as manufacturing, agriculture, commercial enterprises and railways. Since independence the power sector in India has grown considerably. However, the enactment of Electricity Act, 2003, has brought in revolutionary changes in almost all the areas of the sector. Through this Act a conducive environment has been created to promote private sector participation and competition in the sector by providing a level playing field. This has led to significant investment in generation, transmission and distribution areas. Over the years the installed capacity of Power Plants (Utilities) has increased to 3,26,833 MW as on 31.3.2017 from a meagre 1,713 MW in 1950. Similarly, the electricity generation increased from about 5.1 Billion units in 1950 to 1,242 BU (including imports) in the year 2016- 17. The per capita consumption of electricity in the country has also increased from 15 kWh in 1950 to about 1,122 kWh in the year 2016-17. Regional grids have been integrated into a single national grid with effect from 31.12.2013 thereby providing free flow of power from one corner of the country to another through strong inter regional AC and HVDC links. As a result, the all India peak demand (MW) not met as well as energy (MU) not supplied have registered steady decline. The peak not met and energy not supplied were 1.6 % and 0.7 % respectively during the year 2016-17. [1]

1.2 Background

1.2.1 Perspective of National Electricity Policy

National Electricity Policy stipulates that the National Electricity Plan would be for a short-term framework of five years while giving a 15-year perspective and would include [1]:

- Short-term and long term demand forecast for different regions
- Suggested areas/locations for capacity additions in generation and transmission keeping in view of the economics of generation and transmission, losses in the system, load centre requirements, grid stability, security of supply,quality of power including voltage profile, etc.; and environmental considerations including rehabilitation and resettlement
- Integration of such possible locations with transmission system and development of national grid including type of transmission systems and requirement of redundancies;
- Different technologies available for efficient generation, transmission and distribution.
- Fuel choices based on economy, energy security and environmental considerations.

This policy suggest that cost of electricity and environment consideration should brought together, which leads to use of renewable sources.

1.2.2 Tariff Policy 2016

The Central Government has notified the revised Tariff Policy vide Gazette notification dated 28.01.2016 in exercises of powers conferred under section 3(3) of Electricity Act, 2003. The Tariff Policy has been evolved in consultation with the State Governments, the Central Electricity Authority (CEA), the Central Electricity Regulatory Commission and various stakeholders. The objectives of this Tariff Policy are to [1]:

1. Ensure availability of electricity to consumers at reasonable and competitive rates;
2. Ensure financial viability of the sector and attract investments;
3. Promote transparency, consistency and predictability in regulatory approaches across jurisdictions and minimize perceptions of regulatory risks;
4. Promote competition, efficiency in operations and improvement in quality of supply;
5. Promote generation of electricity from renewable sources;
6. Promote hydroelectric power generation including Pumped Storage Projects (PSP) to provide adequate peaking reserves, reliable grid operation and integration of variable renewable energy sources;
7. Evolve a dynamic and robust electricity infrastructure for better consumer services;
8. Facilitate supply of adequate and uninterrupted power to all categories of consumers;
9. Ensure creation of adequate capacity including reserves in generation, transmission and distribution in advance, for reliability of supply of electricity to consumers.

The Tariff Policy 2016 is also giving importance to power generation through renewable energies.

1.2.3 Grid Connected Rooftop Solar Program

As a part of Intended Nationally Determined Contributions (INDCs), India has committed to increase the share of installed capacity of electric power from non-fossil-fuel sources to 40% by 2030. Solar energy is one of the main source to accomplish the target of 40% of electric power from non-fossil-fuel. Government of India has set the target of achieving 100 GW of solar power capacity in the country by the year 2022 of which 40 GW to be achieved from rooftop solar (RTS) [2].

The rooftop solar (RTS) plant is a system installed mainly on the roof of a building and includes installations on open contiguous land within the area of premises wherein valid and live electricity connection has been provided by the concern Distribution utilities/companies (DISCOMS). Typically, 1(one) kWp RTS plant requires about 10 sq. m area. The Solar power so generated can then be used either for captive consumption of the premises or can be fed into the grid and be adjusted in the electricity bill. Net-metering regulations notified by respective State Electricity Regulatory Commissions (SERCs) provide a legal framework for such adjustment. RTS plants help DISCOMs in reducing transmission and distribution losses as power consumption and generation are co-located. These Plants are also useful in tackling day time peak load as solar generation profile matches such peak loads during the day.

The Government, on 30th December 2015, approved a program "Grid Connected Rooftop and Small Solar Power Plants Programme" for installation of 4,200 MW RTS plants in the country by year 2019-20, of which 2,100 MW was through CFA and balance 2,100 MW was without CFA. The RTS projects sanctioned under this Program are under implementation by State Nodal Agencies (SNAs), Solar Energy Corporation of India (SECI), Public Sector Undertakings (PSUs) and other Government Agencies (GAs) [2].

The Government, on 19th February 2019 approved Phase-II of Grid Connected Rooftop and Small Solar Power Plants Programme for achieving cumulative capacity of 40 GW RTS plants by 2022. In Phase-II, it has been decided to implement the programme by making the DISCOMs and its local offices as the nodal points for implementation of the RTS programme. DISCOMs will play a key role in expansion of RTS as DISCOMs are having direct contact with end user and they provide approval for installation, manage the distribution network and also have billing interface with rooftop owner [2].

Aims and Objectives [2]: The key objectives of the programme are:

1. To promote grid connected RTS in all consumer segments, viz., residential, institutional, social, Govt., commercial, industrial etc.

2. To bring DISCOMs at forefront as key drivers for rapid deployment of RTS.

3. To create awareness, capacity building, human resource development, etc.

4. To promote sustainable business models.

5. To create additional RTS capacity of 38000 MW in the country by 31.12.2022 out of which a capacity of 4000 MW in residential sector with Central Financial Assistance and 34000 MW in other sectors (i.e., Social, Government, educational, PSUs,Statutory /Autonomous bodies, Private Commercial, Industrial Sectors etc.) by suitably incentivizing DISCOMs

6. To promote domestic manufacturing of solar cells and module

According to this program promoted by MNRE India, roof top solar PV installation at residential and commercial complex will start increasing.

1.3 Need for Research

To evaluate the economic and environmental performance of the solar PV Microgrids, investigation of typical PV Microgrid installed on the roof of a building is analyzing its operation mode and benefit to consumer, utility and society with the real operation data. The NPV and IRR systems of economic evaluation do not reflect about emission reduction. Hence new economic index must be introduced for economic evaluation of PV Microgrid. Levelized energy cost (LEC), emission reduction benefits (ERB) and payback period (PBP) are selected for economic evaluation as economic indices. This gives economic scheduling and optimized model of PV Microgrid with impact of emission reduction.

1.4 Research Hypothesis

In last few decade, Photovoltaic(PV) systems have experienced remarkable growth, due to the rapid growth of the global PV industry, the continued expansion of the industrial scale, and the significant decrease of the PV module price. It brings us not only direct economic benefits but also indirect benefits such as energy saving, emission reduction, loss reduction, reliability improvement, and deferral of grid construction, etc. The economic evaluation on Microgrid should not be limited to its finance only. Net contributions of PV Microgrid to the national economy and whole society must be evaluated. In the aspect of optimal allocation of PV Microgrids, some analytical methodologies have been presented for the optimal implementation. This study proposes, new method for economic evaluation of PV Microgrid with case study.

In Microgrid there are different distributed energy recourses such as wind, solar, biomass, micro-turbine. Due to large availability and attractive government policies, solar PV Microgrid is proven to be best for investment. Hence its economical analysis must be carried out with new indices. To quantitatively evaluate the economic and environmental performances of the PV Microgrids based on local energy prices, photovoltaic array generating capacity and other data in the project, three indexes are introduced here: Levelized Energy Cost (LEC), Emission Reduction Benefit (ERB) and Payback Period (BPP).

Chapter 2

Literature Review

2.1 Introduction

Following are the major areas to reach upto research hypothesis which may be categories as broad and narrow area of research:

1. Microgrid Power System (Broad area)
2. Renewable energy in Microgrid and challenges (Broad area)
3. Solar rooftop design and implementation (Narrow area)
4. Economic evaluation using different indices (Narrow area)

2.1.1 Microgrid Power System (Broad area)

Many believe the electric power system is undergoing a profound change driven by a number of needs. There's the need for environmental compliance and energy conservation. This transformation will be necessary to meet environmental targets, to accommodate a greater emphasis on demand response (DR), and to support plug-in hybrid electric vehicles (PHEVs) as well as distributed generation and storage capabilities [3]. According to US department of energy, distributed generation is the use of small-scale power generation technologies located close to the load being served, capable of lowering costs, improving reliability, reducing emissions and expanding energy options [4]. New trends of the development of microgrids are including higher renewable energy integration, multi energy forms, multi-level architecture, demand side management, generalized storage. These trends make microgrid be more economic, efficient and green, but also bring new challenges [5].

2.1.2 Renewable energy in Microgrid and challenges (Broad area)

The impact of microgrid and distributed energy challenges are discussed in [6] and its impact study is give in [7]. Major challenges in implementation of distributed generation in microgrid are stability, protection, architecture design, operation strategies, converter designed and most importantly complex economics.Although the construction costs of microgrid are higher, it is economic to invest in microgrid in view of its social benefits in improving reliability, energy saving and emission reduction, environmental protection and deferral of investment in transmission and distribution grids [8–10].

2.1.3 Solar rooftop design and implementation (Narrow area)

Total solar PV generation is 16% of total RES installed capacity as on 30.03.2016 and it is expected to grow further with tremendous rate due to different policies to promote solar PV generation [11]. Comprehensive benefits analysis and economic evaluation of Microgrid [12] shows the importance of economic evaluation and its process.

Economic evaluation of PV Microgrid must be carried out before implementation the project. There are some researches on the economic evaluation of PV Microgrid to understand different affecting parameters to the investment in [12–17]. Besides, the economic return of grid-connected photovoltaic system is investigated in a global view in [18]. The performance and economic evaluation of photovoltaic power generation projects in different countries are discussed in [19–21]. Reduction of voltage drop and power system loss can be obtained with the PV system installed to provide the dispersed generation for the local loads. However, the PV system penetration is limited due to the violation of voltage variation introduced by the large intermittent PV power generation is discussed in [22].

2.1.4 Economic evaluation using different indices(Narrow area)

However, most papers are mainly concentrated in the net present value (NPV) [21, 23] and the internal rate of return (IRR) [24]. It shows that there is less research carried out which focus on the economic evaluation of the emission reduction benefits of PV Microgrids, especially for the non counter current systems. Economic performances of microgrids with SS-PVs specifically for industries by comprehensively considering three indexes of LEC, ERB, and PBP and using real operation data of the microgrid and optimal simulation results are discussed in [25]. Economic feasibility of a residential solar microgrid connected to the distribution system without any energy storage system is carried out in [26]. These all papers are giving importance to levelized cost of energy (LCOE), pay back period (PBP) and emission reduction benefits (ERB) than net present value (NPV) [21,23] and the internal rate of return (IRR) in economic evaluation of grid conneceted solar PV based microgrid system.

2.2 Factor Critical to Success of Study

In order to be able to realistically model the variations in market prices and fluctuations in full load hours (FLH) within respective technologies, upper and lower price limits are indicated. These limits are chosen based on a technology cost analysis of individual components, market and literature research as well as latest reports from current power plants. It should be noted that market prices are often based on applicable feed-in tariffs and are therefore not always in free competition. Characteristics of individual technologies that cannot be mapped into LCOE, such as the advantages of easily integral storage, the number of FLH, decentralized power generation, capacity for follow-up operation and time of day availability, have not been taken into account. The technologies are evaluated and compared based on standard market financing costs and historically proven learning curves.

To evaluate economics of solar PV based microgrid connected to microgrid on the basis of new indices levelized cost of energy (LCOE), pay back period (PBP) and emission reduction benefits (ERB), following parameters must be known before:

1. **Type of renewable energy available**
2. **Specific investment cost** for the construction and installation of power plants with upper and lower limits; determined based on current power plant and market data
3. **Local condition** with typical irradiation and wind conditions for different locations and full load hours (FLH) in the energy system
4. **Operating and maintenance cost** during the power plant?s operational life time
5. **Lifetime of the plant** for which plant is working in good condition
6. **Financing condition** earnings calculated on the financial market and maturity periods based on technology-specific risk surcharges and country specific financing conditions taking into account the respective shares of external and equity-based financing.

2.3 Summary

Decarbonisation and transformation of the energy system are associated with both technical and economic efforts. The cost of current and future power generation is heavily dependent on the cost of expanding and operating power plants. The costs of renewable energy technologies in particular have changed dramatically in recent years. This development is driven by technological innovations such as the use of less-expensive and better- performing materials, reduced material consumption, more efficient production processes, increasing efficiency as well as automated mass production of components. For these reasons, the aim of this study is to analyze the current and future cost situation as transparently as possible in the form of LCOE, PBP and ERB.

Chapter 3

Research Design, Methodology and Plan

3.1 Introduction

Decarонisation and transformation of the energy system are associated with both technical and economic efforts. The cost of current and future power generation is heavily dependent on the cost of expanding and operating power plants. The costs of renewable energy technologies in particular have changed dramatically in recent years. This development is driven by technological innovations such as the use of less-expensive and better- performing materials, reduced material consumption, more efficient production processes, increasing efficiency as well as automated mass production of components. For these reasons, the aim of this study is to analyze the current and future cost situation as transparently as possible in the form of LCOE.

3.2 Research Plan

Research plan for this study is given below:

1. Analysis of the current situation and the future market development of photovoltaic (PV) in India
2. Economic modeling of technology-specific LCOE for PV installations at residential and Commercial site on the basis of common market financing costs
3. Assessment of the different technology and financial parameters based on sensitivity analyzes of the individual technologies
4. Forecast the future LCOE of renewable energy technologies using learning curve models and market growth scenarios
5. Analysis of the current situation and future market development of photovoltaic solar power plants for locations with favorable solar irradiance.
6. Analysis of electricity generation costs of PV storage systems

3.3 Historical Development of Renewable Energy Technology

3.3.1 Global Review

The visualisation shows the global production of renewable energy over the long-term. As we see, historical production of renewable energy has been dominated by traditional biomass the burning of wood, forestry materials and agricultural waste biomass. Although implemented at smaller scales for thousands of years, across a range of countries, hydropower output did not feature at large production scales with pumped storage development until the 1920s.

Today, traditional biofuels remain the largest source of renewables, accounting for 60-70 percent of the total. Traditional biomass remains the dominant fuel source for cooking & heating across many low-income households. The World Bank reports that only 7 percent of the worlds low-income households have access to clean fuels and technologies for cooking; the average share in Sub-Saharan Africa was 13 percent; and approximately one-third in South Asia. Among the remaining renewable technologies, hydropower remains dominant, accounting for approximately one-quarter of renewable consumption.

Renewable technologies with exception to traditional biomass are often termed 'modern renewables'. These include hydropower, solar, wind, geothermal and modern biofuel production (including modern forms of waste-to-biomass conversion). The change and mix of modern renewable consumption over the last 50 years is shown in the Fig.3.1. This is measured in terawatt-hours per year and can be viewed across a range of countries and regions.

Globally, the world produced approximately 5.9 TWh of modern renewable energy in 2016. This represents a 5 to 6-fold increase since the 1960s. Here we see that hydropower remains the dominant form of modern renewables consumption, accounting for almost 70 percent. Despite absolute growth in production, hydropowers share is, however, declining as other renewable technologies grow.

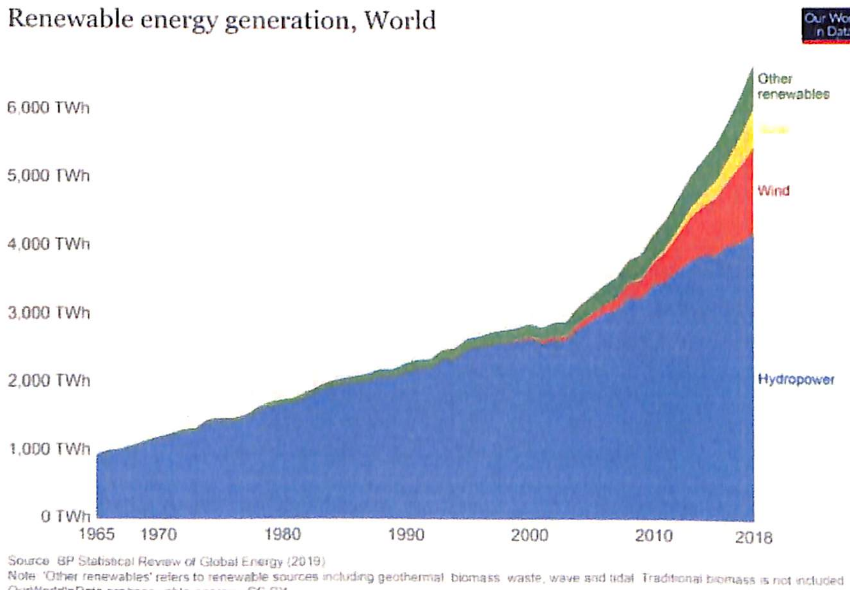


Figure 3.1: Global renewable energy consumption

Globally, the world produced approximately 585 TWh through solar PV generation in 2018 which was negligible in 2000 (see Fig.3.2). This shows significant change in solar PV applications in last decade. In Asia pacific region, the growth in renewable energy is recorded 300 to 350% in last 20 years. It shows large potential of solar PV projects in India also [27].

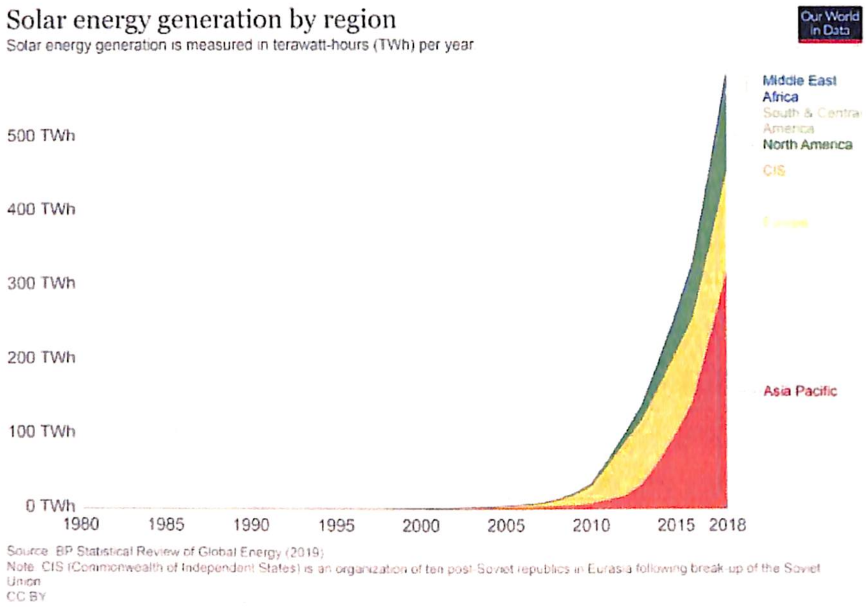


Figure 3.2: Solar energy generation by region

3.3.2 National Review

India is one of the countries with the largest production of energy from renewable sources. As of 2019, 35% of India's installed electricity generation capacity is from renewable sources, generating 17% of total electricity in the country.

Coal power currently represents the largest share of installed capacity at just under 194 GW. Total installed capacity as of 30 June 2019 (see Fig.3.3), for grid connected power in India stood at a little under 358 GW [28].

The fast growing renewable energy sources under the responsibility of the Ministry for New and Renewable Energy exceeded the installed capacity of large hydro installations (see Fig.3.4) [29]. This figure is targeted to reach 175 GW by 2022.

The 2022 electrical power targets include achieving 227GW (earlier 175 GW) of energy from renewable sources - nearly 113 GW through solar power, 66 GW from wind

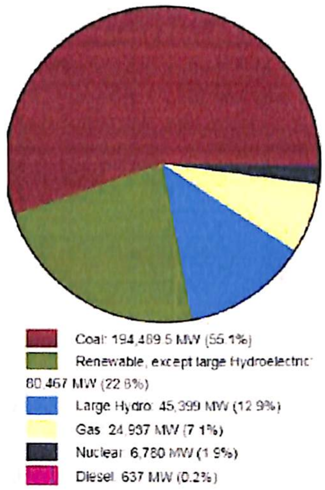


Figure 3.3: Installed grid power capacity from all sources in India as of 30 June 2019

power, 10 GW from biomass power, 5GW from small hydro and 31GW from floating solar and offshore wind power. The bidding process for the further additional 115 GW or thereabouts to meet these targets of installed capacity from January 2018 levels will be completed by the end of 2019-2020. The government has announced that no new coal-based capacity addition is required beyond the 50 GW under different stages of construction likely to come online between 2017 and 2022. With the expansion of renewable power generation capacity, the outstanding payment dues from the power purchasers are also increasing due to their weak purchasing capacity.

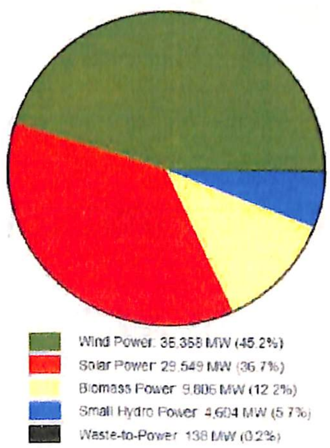


Figure 3.4: Installed grid interactive renewable power capacity in India as of 30 June 2019 (excluding large hydro)

3.4 Input Data for Calculation of Levelized Cost of Energy(LCOE)

3.4.1 Size and cost of solar PV system

For PV, the upper and lower limits for the installation cost are differentiated according to the system sizes of small rooftop systems up to 15 kWp, large rooftop systemy up to 1000 kWp and ground-mounted PV systems. By using these costs, the LCOE for each point of time for investment and construction are calculated. The financial lifetime of PV is set to 25 years. Longer lifetimes and operation of PV are also reported by the plant monitoring in different countries.

To calculate cost of rooftop solar PV, Solar Rooftop Calculator from MNRE site is used. The deatils are given in Table 3.1

Table 3.1: Size and cost of solar PV system

Parameter	Solar Rooftop			Source
	1-10kW	11-100kW	101kW-500kW	
Cost (Rs kW)	60000	55000	53000	MNRE calculator
Lifetime (yrs)	25	25	25	Own Assumption
Share of Debt (%)	70	70	70	MNRE calculator
Share of Equity (%)	30	30	30	MNRE calculator
Average solar irradiation (W sq.m)	1266.52	1266.52	1266.52	MNRE calculator
Average generation (units kWp day)	5	5	5	MNRE calculator
O & M cost (Rs year kW)	6600	5500	5300	Own assumption
Replacement cost (Rs) (after 20 yrs)	60000	55000	53000	Own Assumption

3.4.2 Cost of energy from grid

In Maharashtra, electricity is distributed though Maharashtra State Electricity Distribution Company Ltd. (MAHADISCOM). After analyzing the electricity bills for residential and commercial consumers, the rate of electrical energy from grid is given in Table 3.2

Table 3.2: Cost of energy from grid

Type of Consumer	Grid Power Price (Rs/kWh)	Grid Power Price (Rs/kWh)
Residential	8	2.8-3.2
Commercial	14	2.8-3.2

3.4.3 Load Profile

To determine economic evaluation, it is necessary to input the data for average energy consumed per day. Table 3.3 gives average energy consumed per day by residential and commercial consumer.

Table 3.3: Load Profile

Type of consumer	Energy consumed (units/day)	Peak Demand (kw)	Peak month
Residential	10	2.06	January
Commercial	80	13.47	January

Daily and yearly average load curve for residential consumer is given in Fig.3.5 and Fig.3.6

Daily and yearly average load curve for commercial consumer is given in Fig.3.7 and Fig.3.8

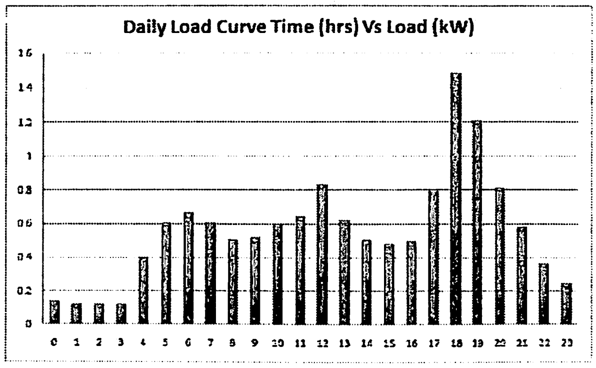


Figure 3.5: Daily load curve (Residential)

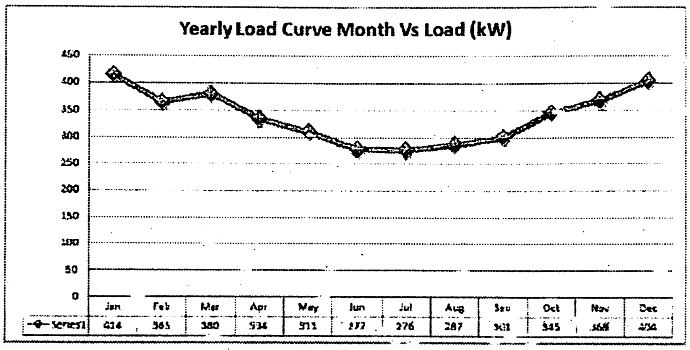


Figure 3.6: Yearly load curve (Residential)

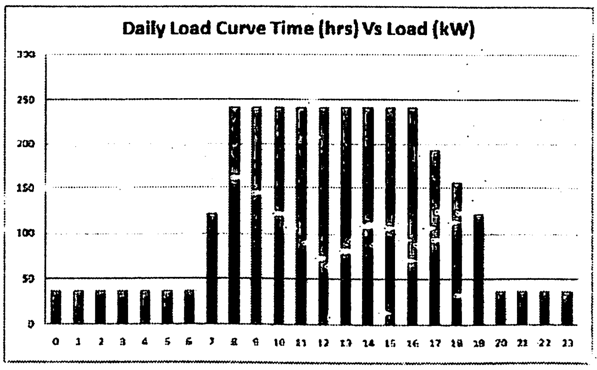


Figure 3.7: Daily load curve (commercial)

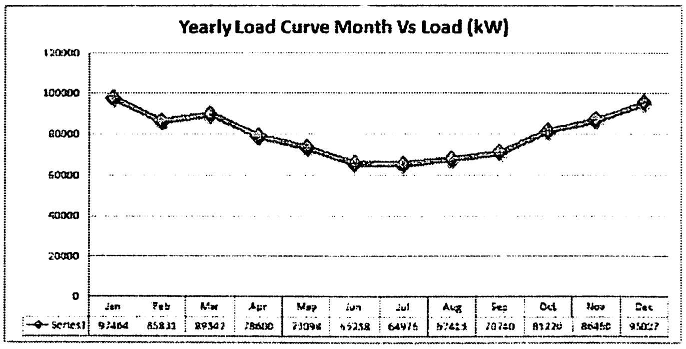


Figure 3.8: Yearly load curve (commercial)

3.5 Levelized Cost of Energy (LCOE)

To calculate LCOE, following assumptions are made

1. Nominal discount rate is considered 4%, 6%, 8%.
2. Expected inflation is considered 0%, 2%, 4%.
3. Selback rate of energy is considered Rs.2.8/unit,Rs.3.0/unit,Rs.3.2/unit.

The LCOE is calculated using HOMER software.

3.5.1 Calculation of LCOE

HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system.

Type: Output Variable

Units: $ kWh

Symbol:COE

To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served, using the following equation:

$$COE = \frac{C_{ann,tot} - C_{boiler}H_{served}}{E_{served}} \tag{3.1}$$

where $C_{ann,tot}$ = total annualized cost of the system [Rs/yr]

C_{boiler}= boiler marginal cost [Rs/kWh]

H_{served} = total thermal load served [kWh/yr]

E_{served}= total electrical load served [kWh/yr]

The second term in the numerator is the portion of the annualized cost that results from serving the thermal load. In systems, such as wind or PV, that do not serve a thermal load (Hthermal=0), this term is zero.

The COE is a convenient metric with which to compare systems, but HOMER does not rank systems based on COE.

3.5.2 Annualized Cost

The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component.

HOMER calculates annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor, as in the following equation:

$$C_{ann} = CRF(i, R_{proj})C_{NPC}) \tag{3.2}$$

where: C_{NPC} = the net present cost [Rs]

i = the annual real discount rate [%]

R_{proj} = the project lifetime [yr]

$CRF()$= a function returning the capital recovery factor

The annualized cost serves as a useful metric for comparing the costs of different components because it measures their relative contribution to the total net present cost. It allows for a fair cost comparison between components with low capital and high operating costs (such as diesel generators) and those with high capital and low operating costs (such as PV arrays or wind turbines).

The annualized costs of each system component and of the system as a whole appear on the Cost Summary tab of the Simulation Results window.

3.5.3 Net Present Cost (NPC)

The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each Component in the system, and of the system as a whole.

3.5.4 Annual Real Discount Rate

The real discount rate is used to convert between one-time costs and annualized costs. HOMER calculates the annual real discount rate (also called the real interest rate or interest rate) from the "Nominal discount rate" and "Expected inflation rate" inputs. HOMER uses the real discount rate to calculate discount factors and annualized costs from net present costs. HOMER uses the following equation to calculate the real discount rate:

$$i = \frac{i' - f}{1 + f} \tag{3.3}$$

where i = real discount rate

i' = nominal discount rate (the rate at which you could borrow money)

f = expected inflation rate

3.5.5 Capital Recovery Factor

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{3.4}$$

where:i = real discount rate

N = number of years.

3.6 Site Selection

For installation of solar rooftop PV system, two sites has been considered. For residential, we choose my own apartment, whose terrace area is approximately 3200 sq.ft. Approximately 50% area of the terrace (3200/2=1600 sq.ft) can be utilized to install solar rooftop upto 13.8kW as per calculation from solar rooftop calculator by MNRE, India.

Similarly For commercial, we choose my own institute, where approximately we can utilize 1000 sq.m. area to install solar rooftop upto 100kW as per calculation from solar rooftop calculator by MNRE, India.

3.7 Procedure Followed for Economic Evaluation of solar rooftop PV

Following steps are carried out for economic evaluation of solar rooftop PV.

- Selection of site for solar rooftop PV installation.
- Load survey of particular premises.
- Calculation of solar PV generation potential.
- Survey of current supply system.
- Feeding all data to HOMER software
- Analysis of data with sensitivity parameters such as sellback cost, inflation rate, discount rate.
- Select optimized design on the basis of LCOE, PBP and ERB.

Chapter 4

System Description, Result and Analysis

4.1 System Description: Case-I Residential Project

Input Summary

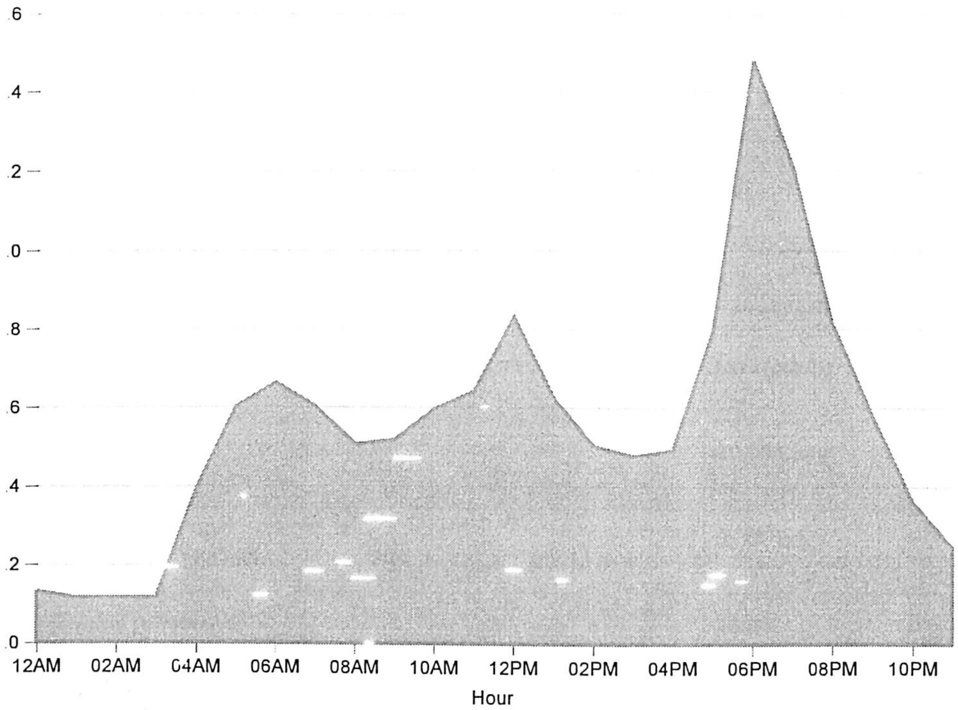
Project title	Gokuldham Residency Apartment, Audumbar Nagar Nashik
Author	Ganesh N Jadhav
Notes	

Project Location

Location	217, Sagar Township, Ayodhya nagari, Nashik, Maharashtra 422003, India
Latitude	20 degrees 1.25 minutes North
Longitude	73 degrees 49.58 minutes East
Time zone	Asia/Kolkata

Load: Electric 1

Data source	Synthetic
Daily noise	10%
Hourly noise	20%
Scaled annual average	10.000 kWh/d
Scaled peak load	2.0585 kW
Load factor	0.2024



Microgrid Controller: HOMER Cycle Charging

Quantity	Capital	Replacement	O&M
1	₹0.00	₹0.00	₹0.00

Minimization strategy	Economic
Setpoint state of charge	80
Allow multiple generators to operate simultaneously	Yes
Allow systems with generator capacity less than peak load	Yes
Allow diesel off operation	Yes

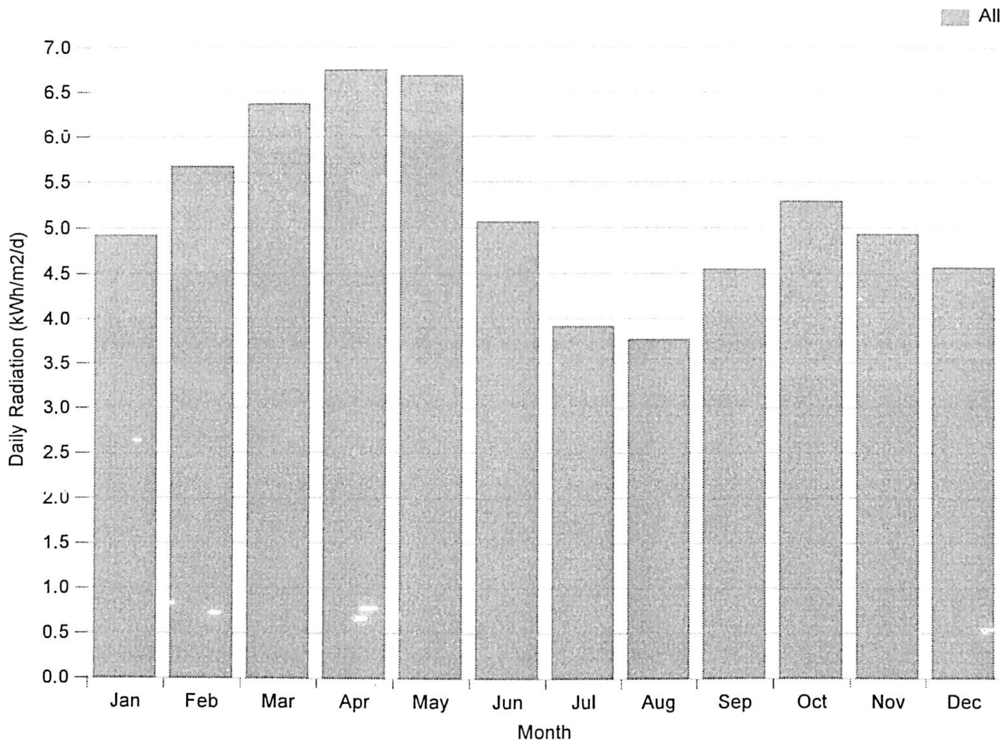
PV:Generic flat plate PV

Size	Capital	Replacement	O&M

Sizes to consider	0,5,7.5,10
Lifetime	20 yr
Derating factor	80%
Tracking system	No Tracking
Slope	20.021 deg
Azimuth	0.000 deg
Ground reflectance	20.0%

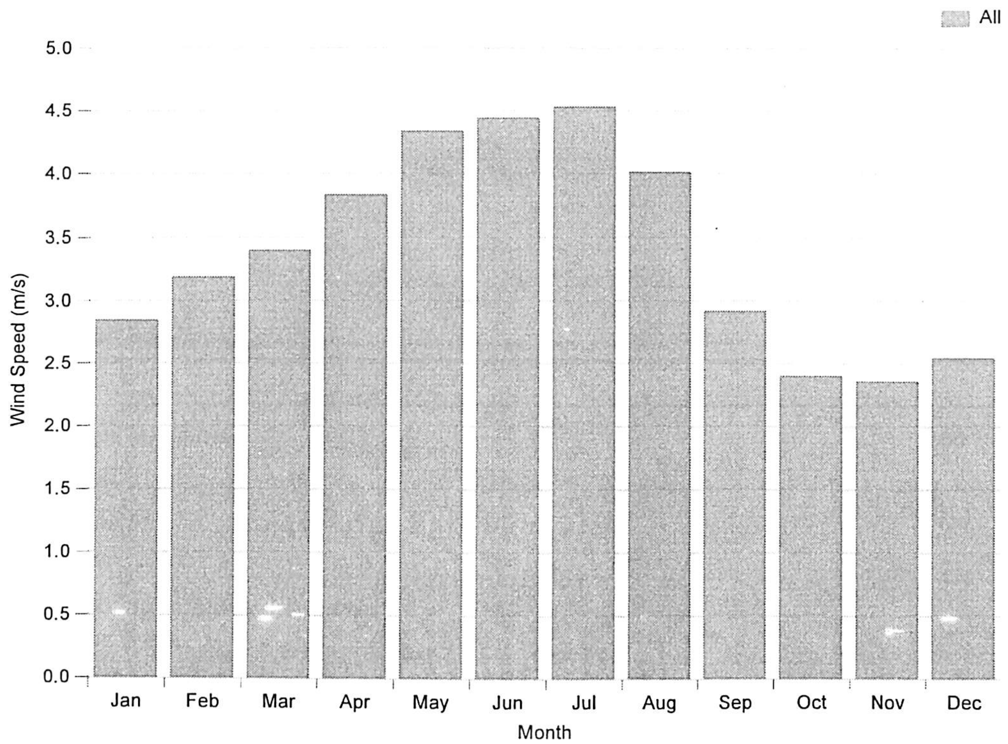
Solar Resource

Scaled annual average	5.19 kWh/m2/d



Wind Resource

Scaled annual average	3.39



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Fuel: Diesel

Price	₹ 70.00/L
Lower heating value	43.2 MJ/kg
Density	820.00 kg/m3
Carbon content	88.0%
Sulfur content	0.4%

Economics

Annual real interest rate	0%
Project lifetime	25 yr

Capacity shortage penalty	₹0/kWh
System fixed capital cost	0
System fixed O&M cost	0

System control

Timestep length in minutes	60
Multi-Year enabled	No
Allow systems with multiple generators	Yes
Allow systems with multiple wind turbine types	No
Battery autonomy threshold	2
Maximum renewable penetration threshold	50
Warn about renewable penetration	Yes

Optimizer

Maximum simulations	10000
System design precision	0.01
NPC precision	0.01
Minimum spacing	0
Focus factor	100.002981445635
Optimize category winners	Yes
Use base case	No

Emissions

Carbon dioxide penalty	₹ 0/t
Carbon monoxide penalty	₹ 0/t
Unburned hydrocarbons penalty	₹ 0/t
Particulate matter penalty	₹ 0/t
Sulfur dioxide penalty	₹ 0/t
Nitrogen oxides penalty	₹ 0/t

Constraints

Maximum annual capacity shortage	5
Minimum renewable fraction	0
Operating reserve as percentage of hourly load	10
Operating reserve as percentage of peak load	0
Operating reserve as percentage of solar power output	80
Operating reserve as percentage of wind power output	50

4.2 System Description: Case-II Commercial Project

Input Summary

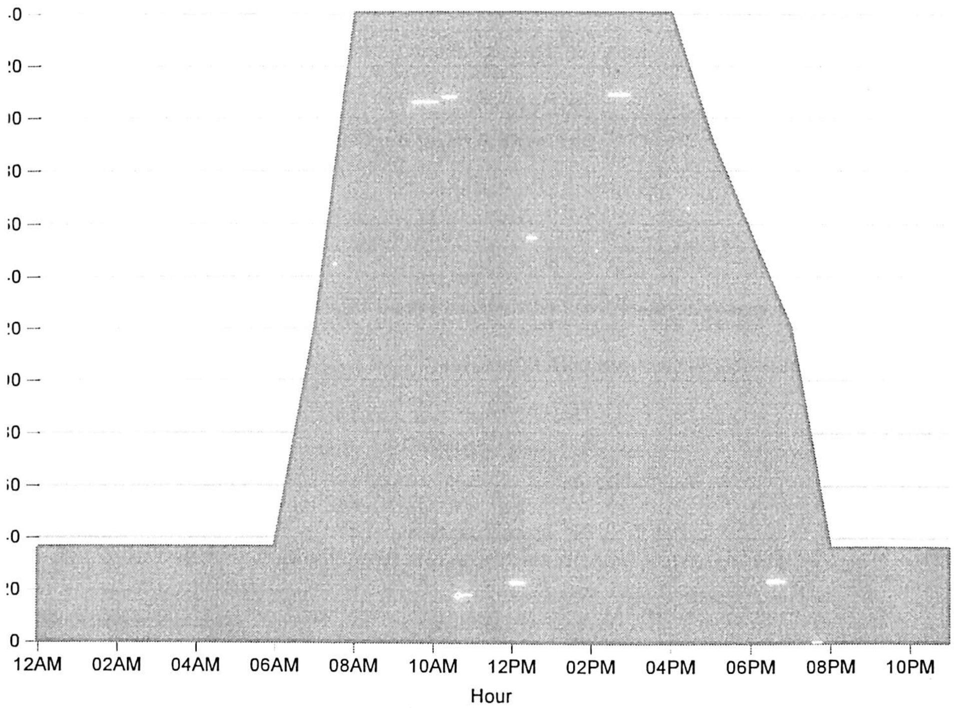
Project title	K.K. Wagh Institute of Engineering Education and Research, Nashik
Author	Ganesh N. Jadhav
Notes	

Project Location

Location	K.K. Wagh Building, Mumbai Agra Rd, Durga Nagar, Nashik, Maharashtra 422006, India
Latitude	20 degrees 0.82 minutes North
Longitude	73 degrees 49.38 minutes East
Time zone	Asia/Kolkata

Load: Electric1

Data source	Synthetic
Daily noise	10%
Hourly noise	20%
Scaled annual average	80.000 kWh/d
Scaled peak load	13.4664 kW
Load factor	0.2475



Microgrid Controller: HOMER Cycle Charging

Quantity	Capital	Replacement	O&M
1	₹0.00	₹0.00	₹0.00

Minimization strategy	Economic
Setpoint state of charge	80
Allow multiple generators to operate simultaneously	Yes
Allow systems with generator capacity less than peak load	Yes
Allow diesel off operation	Yes

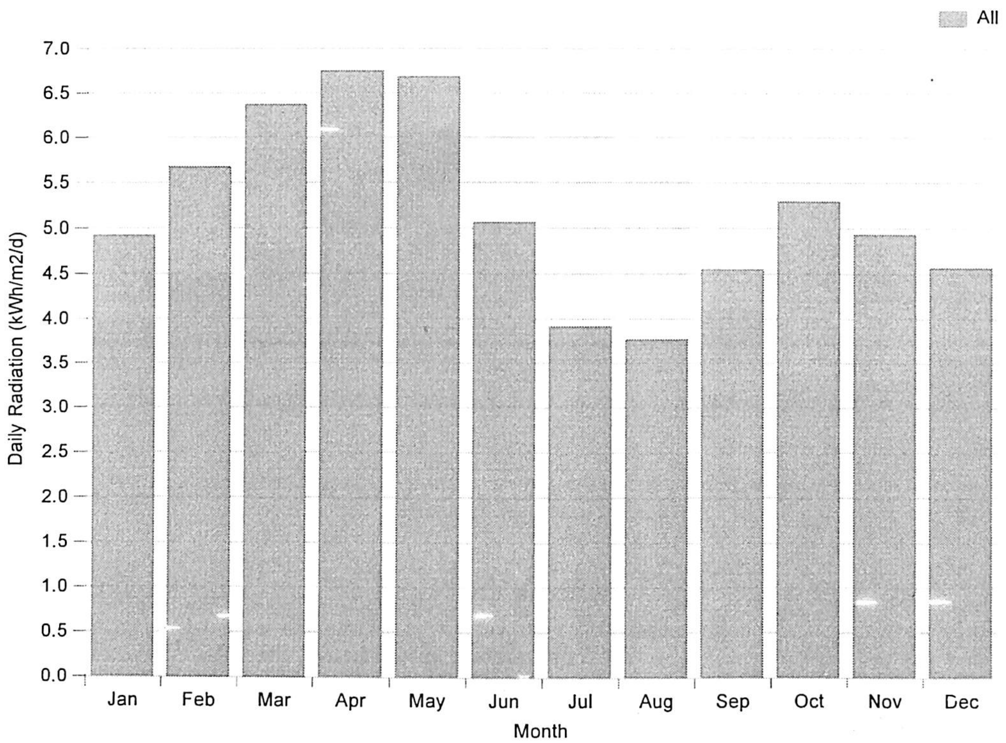
PV:Generic flat plate PV

Size	Capital	Replacement	O&M

Sizes to consider	0,25,50,75,100
Lifetime	20 yr
Derating factor	80%
Tracking system	Horizontal Axis, monthly adjustment
Slope	20.014 deg
Azimuth	0.000 deg
Ground reflectance	20.0%

Solar Resource

Scaled annual average	5.19 kWh/m2/d



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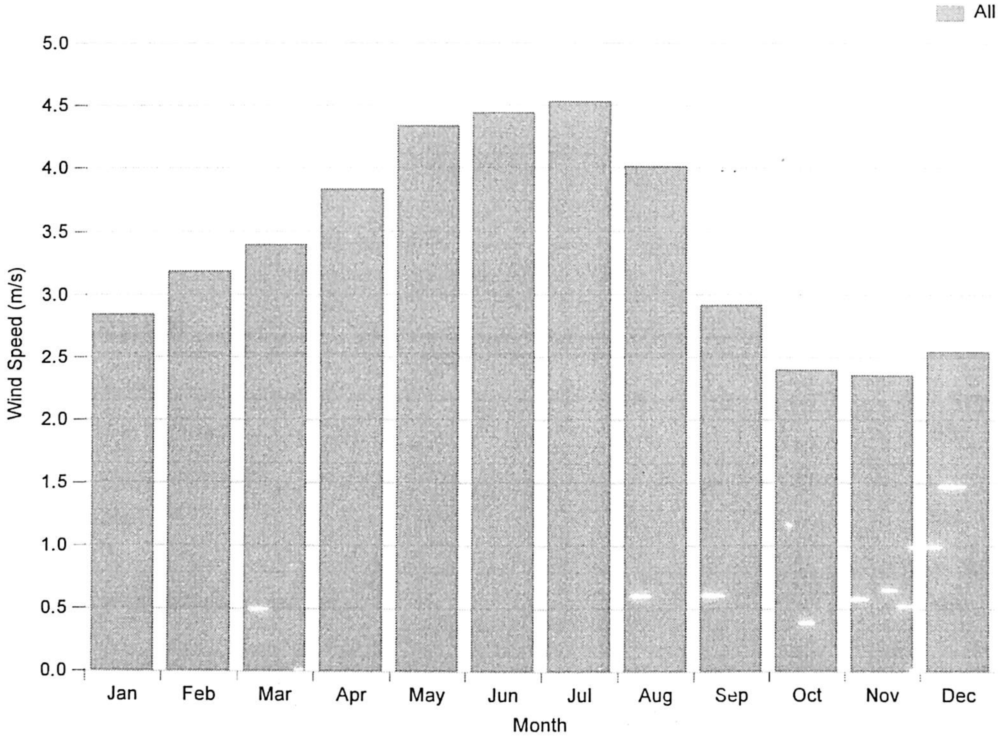
Wind Resource

Scaled annual average	3.39



Fuel: Diesel

Price	₹ 70.00/L
Lower heating value	43.2 MJ/kg
Density	820.00 kg/m3
Carbon content	88.0%
Sulfur content	0.4%

Economics

Annual real interest rate	4%
Project lifetime	25 yr

Capacity shortage penalty	₹0/kWh
System fixed capital cost	0
System fixed O&M cost	0

System control

Timestep length in minutes	60
Multi-Year enabled	No
Allow systems with multiple generators	Yes
Allow systems with multiple wind turbine types	Yes
Battery autonomy threshold	2
Maximum renewable penetration threshold	55
Warn about renewable penetration	Yes

Optimizer

Maximum simulations	10000
System design precision	0.01
NPC precision	0.01
Minimum spacing	0
Focus factor	50
Optimize category winners	Yes
Use base case	No

Emissions

Carbon dioxide penalty	₹ 0/t
Carbon monoxide penalty	₹ 0/t
Unburned hydrocarbons penalty	₹ 0/t
Particulate matter penalty	₹ 0/t
Sulfur dioxide penalty	₹ 0/t
Nitrogen oxides penalty	₹ 0/t

Constraints

Maximum annual capacity shortage	5
Minimum renewable fraction	0
Operating reserve as percentage of hourly load	10
Operating reserve as percentage of peak load	0
Operating reserve as percentage of solar power output	80
Operating reserve as percentage of wind power output	50

4.3 Result:Case-I Residential Project

After inputting data to HOMER software, simulation is carried out for different situations given in Table 4.1

Table 4.1: Different cases for which simulations are carried out Y: Feasible N: Not Feasible

Configuration: 5kW PV+ Grid									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Discount Rate									
Inflation Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	Y	Y	Y	Y	Y	Y	Y	Y	Y
4%	Y	Y	Y	Y	Y	Y	Y	Y	Y
6%	Y	Y	Y	Y	Y	Y	Y	Y	Y
8%	Y	Y	Y	Y	Y	Y	Y	Y	Y
Configuration: 7.5kW PV+ Grid									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Discount Rate									
Inflation Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	Y	Y	Y	Y	Y	Y	Y	Y	Y
4%	Y	Y	Y	Y	Y	Y	Y	Y	Y
6%	Y	Y	Y	Y	Y	Y	Y	Y	Y
8%	Y	Y	Y	Y	Y	Y	Y	Y	Y
Configuration: 10kW PV+ Grid									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate									
Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	Y	Y	Y	Y	Y	N	Y	Y	N
4%	Y	Y	Y	Y	Y	Y	Y	Y	Y
6%	Y	Y	Y	Y	Y	Y	Y	Y	Y
8%	Y	Y	Y	Y	Y	Y	Y	Y	Y

The simulation result report generated by HOMER for 10kW PV+Grid,Discount Rate=8%, Inflation Rate=4%, Sellback rate=Rs.3.2 kWh is given below.

HOMER Pro

System Simulation Report

File: Residential.homer

Author: Ganesh N Jadhav

Location: 217, Sagar Township, Ayodhya nagari, Nashik, Maharashtra 422003, India (20°1.2'N, 73°49.6'E)

Total Net Present Cost: ₹362,159.30

Levelized Cost of Energy (₹/kWh): ₹1.27

Notes:

Sensitivity variable values for this simulation

Variable	Value	Unit
Sellback Rate	3.20	₹/kWh
ExpectedInflationRate	4.00	%
NominalDiscountRate	8.00	%

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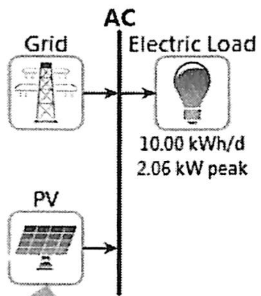
Table of Contents

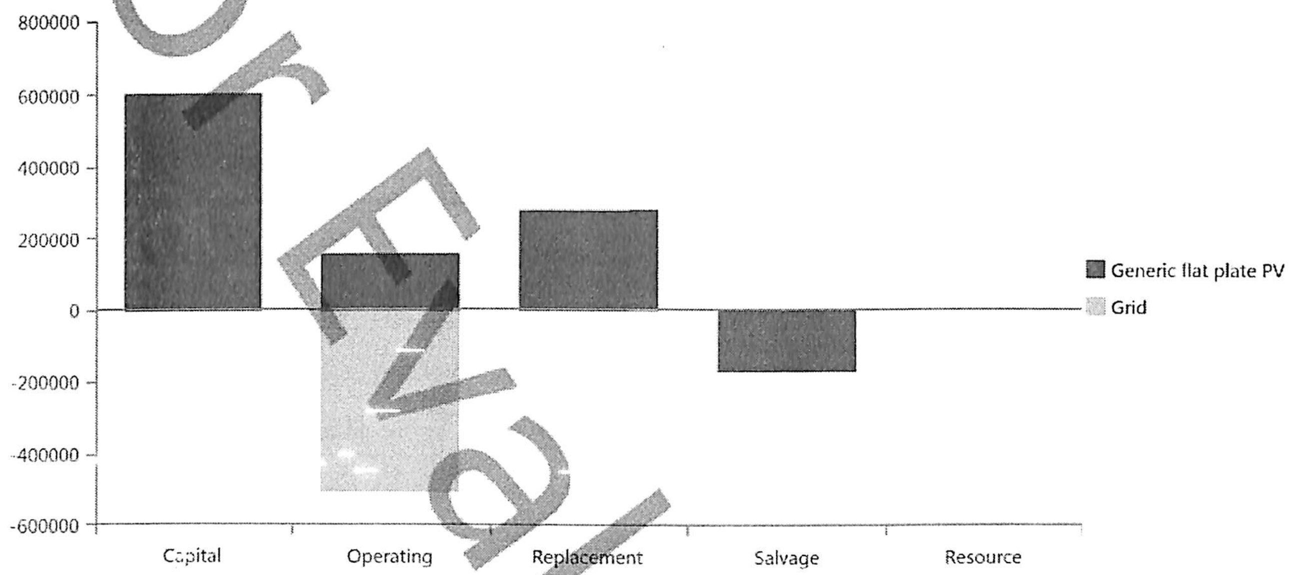
System Architecture

Component	Name	Size	Unit
PV	Generic flat plate PV	10.0	kW
Grid	Grid	10.0	kW
Dispatch strategy	HOMER Cycle Charging		

Schematic



Cost Summary



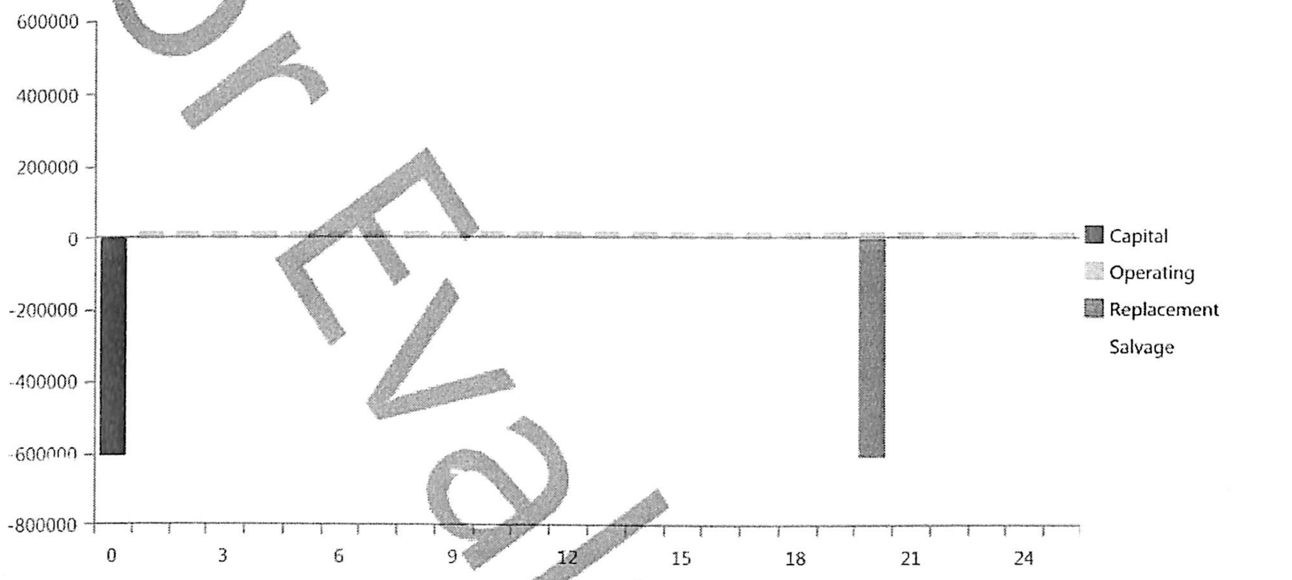
Net Present Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic flat plate PV	₹600,000	₹158,792	₹282,061	-₹175,167	₹0.00	₹865,686
Grid	₹0.00	-₹503,527	₹0.00	₹0.00	₹0.00	-₹503,527
System	₹600,000	-₹344,735	₹282,061	-₹175,167	₹0.00	₹362,159

Annualized Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic flat plate PV	₹37,785	₹10,000	₹17,763	-₹11,031	₹0.00	₹54,517
Grid	₹0.00	-₹31,710	₹0.00	₹0.00	₹0.00	-₹31,710
System	₹37,785	-₹21,710	₹17,763	-₹11,031	₹0.00	₹22,807

Cash Flow


600000
400000
200000
0
-200000
-400000
-600000
-800000
0
3
6
9
12
15
18
21
24
Capital
Operating
Replacement
Salvage


600000
400000
200000
0
-200000
-400000
-600000
-800000
0
3
6
9
12
15
18
21
24
Generic flat plate PV
Grid

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Electrical Summary

Excess and Unmet

Quantity	Value	Units
Excess Electricity	0	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

Production Summary

Component	Production (kWh/yr)	Percent
Generic flat plate PV	16,202	90.2
Grid Purchases	1,762	9.81
Total	17,964	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	3,650	20.3
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	14,314	79.7
Total	17,964	100

PV: Generic flat plate PV

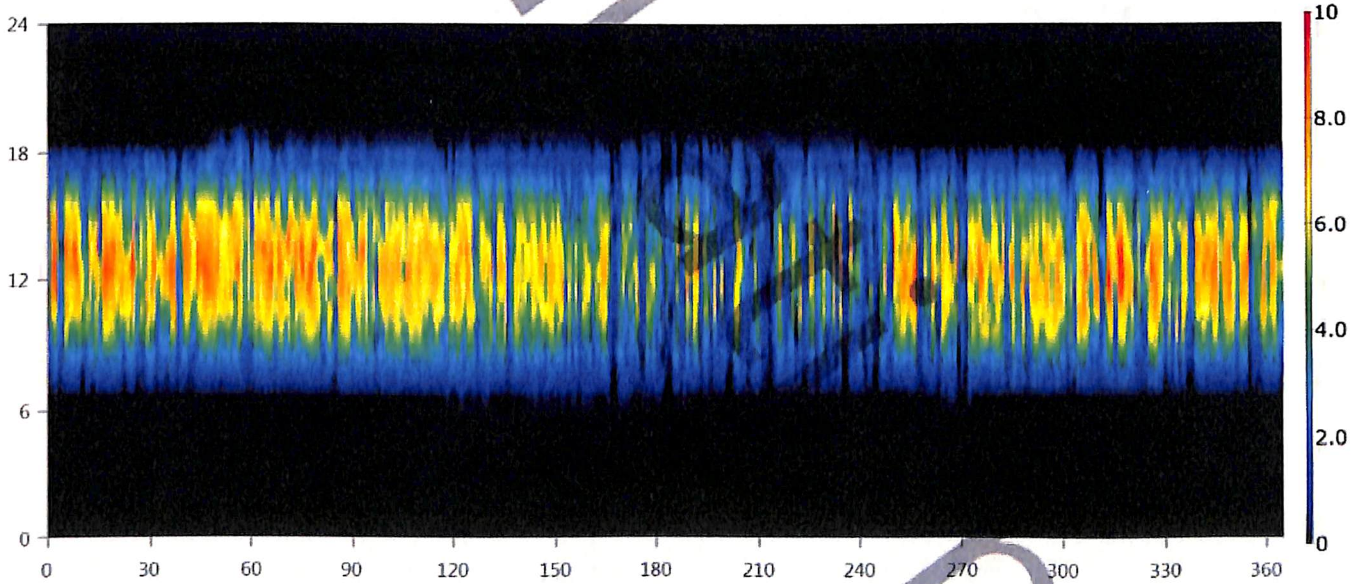
Generic flat plate PV Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	9.89	kW
PV Penetration	444	%
Hours of Operation	4,407	hrs/yr
Levelized Cost	3.36	₹/kWh

Generic flat plate PV Statistics

Quantity	Value	Units
Rated Capacity	10.0	kW
Mean Output	1.85	kW
Mean Output	44.4	kWh/d
Capacity Factor	18.5	%
Total Production	16,202	kWh/yr

Generic flat plate PV Output (kW)



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Grid: Grid

Grid rate: Demand 1

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	0	0	0	2.06	₹0.00	₹0.00
February	0	0	0	1.75	₹0.00	₹0.00
March	0	0	0	1.55	₹0.00	₹0.00
April	0	0	0	1.43	₹0.00	₹0.00
May	0	0	0	1.29	₹0.00	₹0.00
June	0	0	0	1.20	₹0.00	₹0.00
July	0	0	0	0.967	₹0.00	₹0.00
August	0	0	0	1.13	₹0.00	₹0.00
September	0	0	0	1.50	₹0.00	₹0.00
October	0	0	0	1.59	₹0.00	₹0.00
November	0	0	0	2.05	₹0.00	₹0.00
December	0	0	0	1.81	₹0.00	₹0.00
Annual	0	0	0	2.06	₹0.00	₹0.00

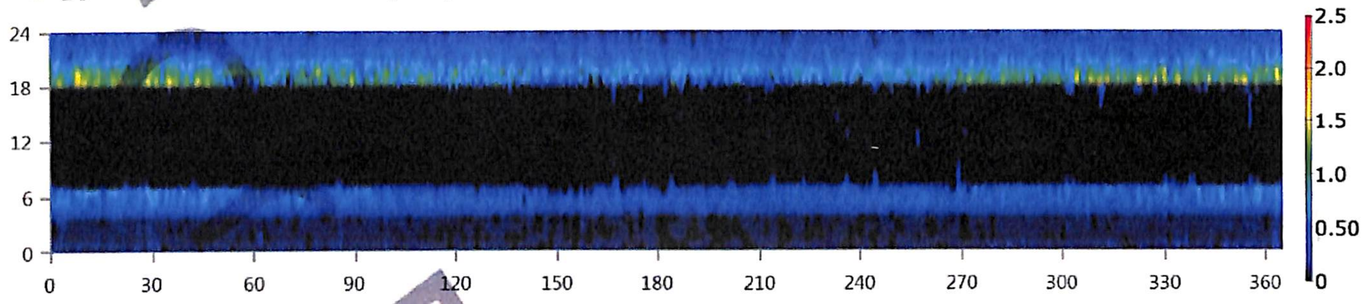
Grid rate: Rate 1

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	191	1,358	-1,167	0	-₹2,820	₹0.00
February	157	1,329	-1,172	0	-₹2,996	₹0.00
March	163	1,514	-1,351	0	-₹3,541	₹0.00
April	143	1,429	-1,286	0	-₹3,427	₹0.00
May	122	1,370	-1,248	0	-₹3,405	₹0.00
June	110	966	-856	0	-₹2,210	₹0.00
July	109	761	-652	0	-₹1,562	₹0.00
August	121	746	-625	0	-₹1,419	₹0.00
September	134	972	-838	0	-₹2,040	₹0.00
October	154	1,308	-1,154	0	-₹2,955	₹0.00
November	170	1,289	-1,119	0	-₹2,765	₹0.00
December	187	1,270	-1,083	0	-₹2,568	₹0.00
Annual	1,762	14,314	-12,552	0	-₹31,710	₹0.00

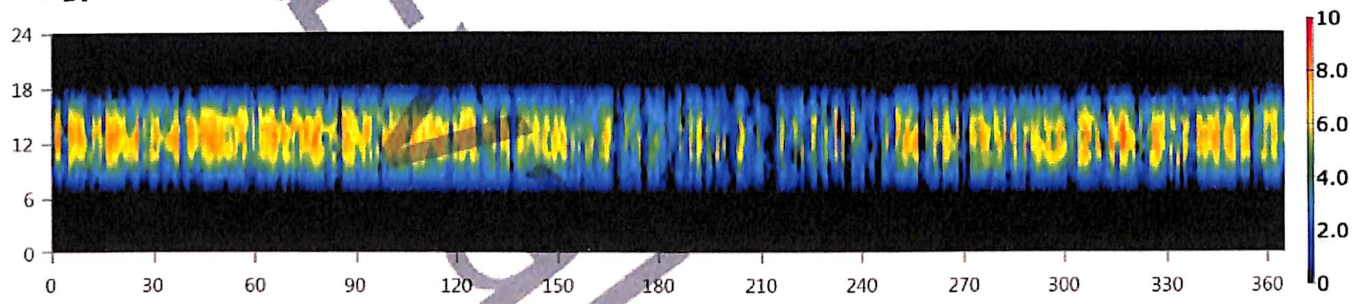
Grid rate: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	191	1,358	-1,167	2.06	-₹2,820	₹0.00
February	157	1,329	-1,172	1.75	-₹2,996	₹0.00
March	163	1,514	-1,351	1.55	-₹3,541	₹0.00
April	143	1,429	-1,286	1.43	-₹3,427	₹0.00
May	122	1,370	-1,248	1.29	-₹3,405	₹0.00
June	110	966	-856	1.20	-₹2,210	₹0.00
July	109	761	-652	0.967	-₹1,562	₹0.00
August	121	746	-625	1.13	-₹1,419	₹0.00
September	134	972	-838	1.50	-₹2,040	₹0.00
October	154	1,308	-1,154	1.59	-₹2,955	₹0.00
November	170	1,289	-1,119	2.05	-₹2,765	₹0.00
December	187	1,270	-1,083	1.81	-₹2,568	₹0.00
Annual	1,762	14,314	-12,552	2.06	-₹31,710	₹0.00

Energy Purchased From Grid (kW)



Energy Sold To Grid (kW)



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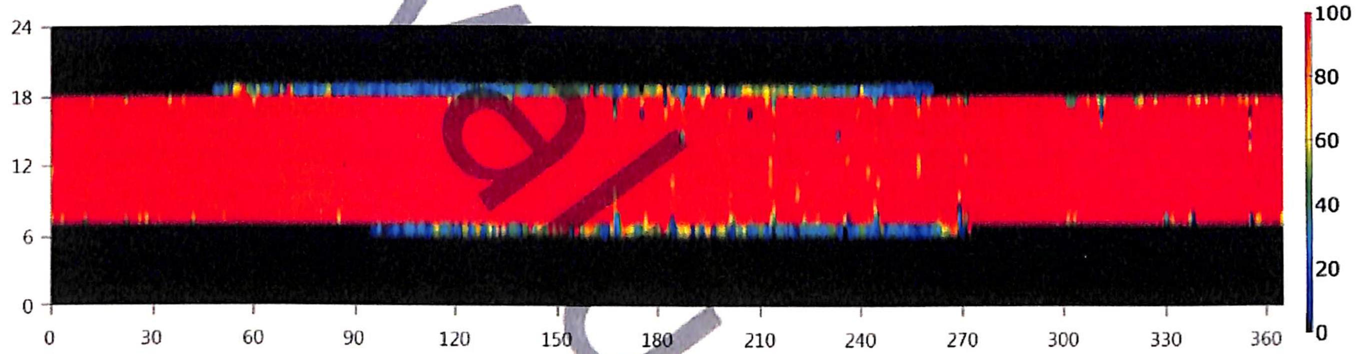
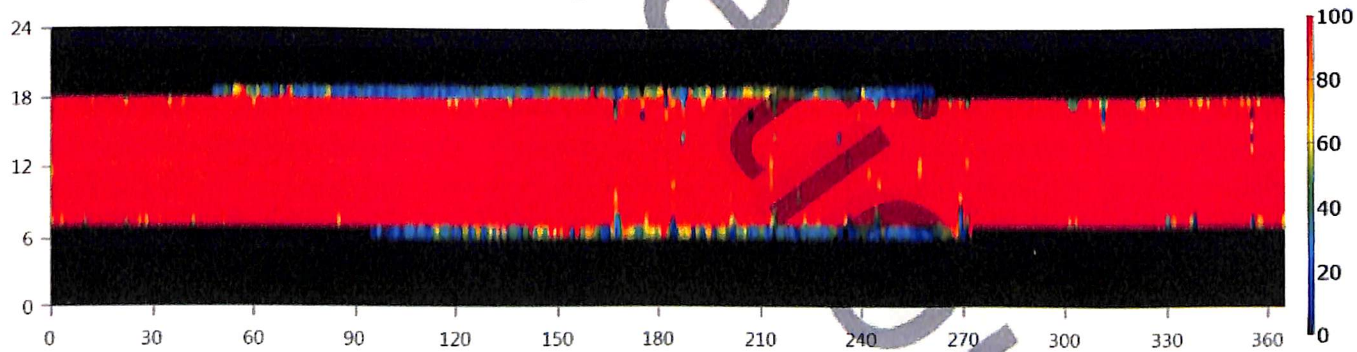
Renewable Summary

Capacity-based metrics	Value	Unit
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%
Energy-based metrics	**Value**	**Unit**
Total renewable production divided by load	90.2	%
Total renewable production divided by generation	90.2	%
One minus total nonrenewable production divided by load	100	%
Peak values	**Value**	**Unit**
Renewable output divided by load (HOMER standard)	100	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

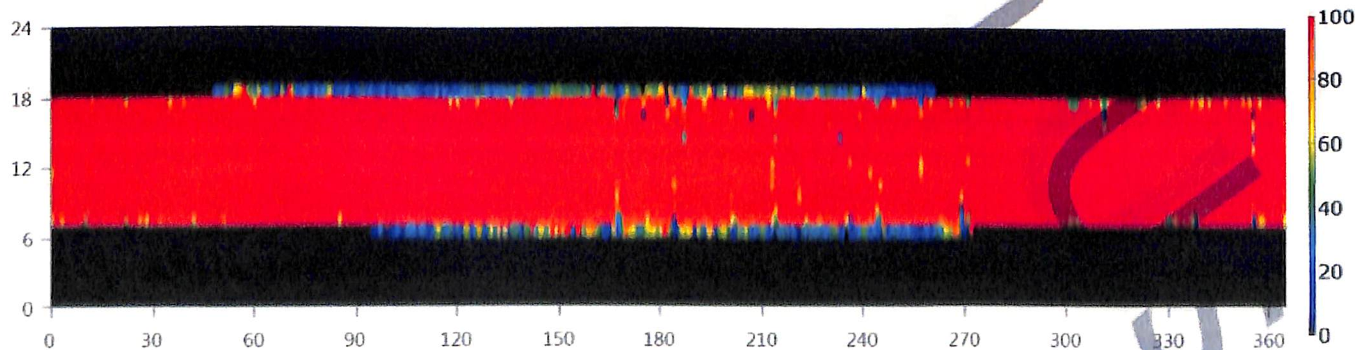
Instantaneous Renewable Output Percentage of Total Generation



Instantaneous Renewable Output Percentage of Total Load



100% Minus Instantaneous Nonrenewable Output as Percentage of Total Load



HOMER Pro

Compare Economics

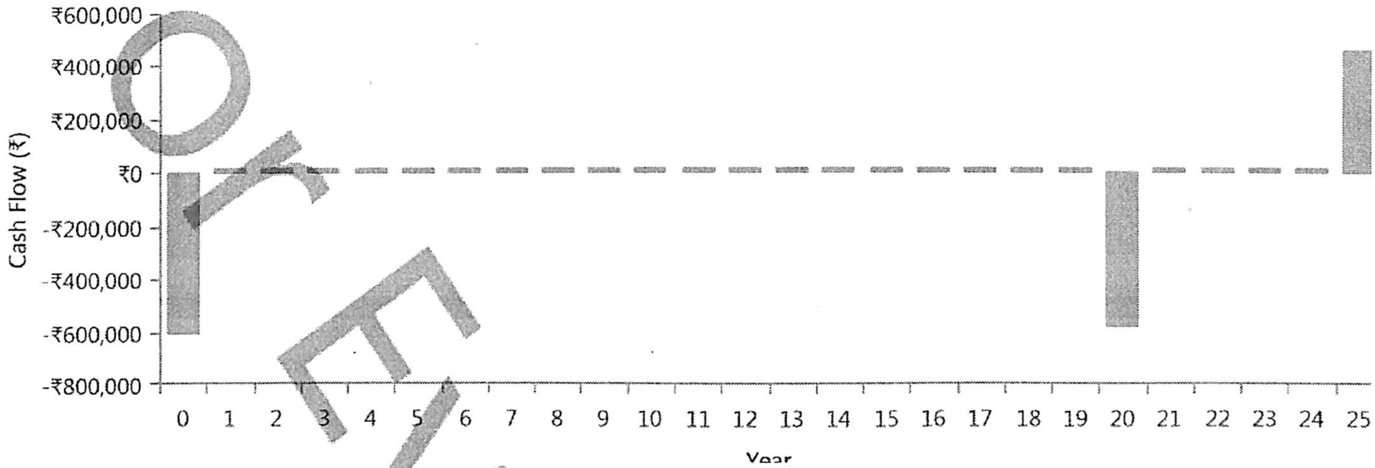
IRR (%):**5.42**

Discounted payback (yr):**11.8**

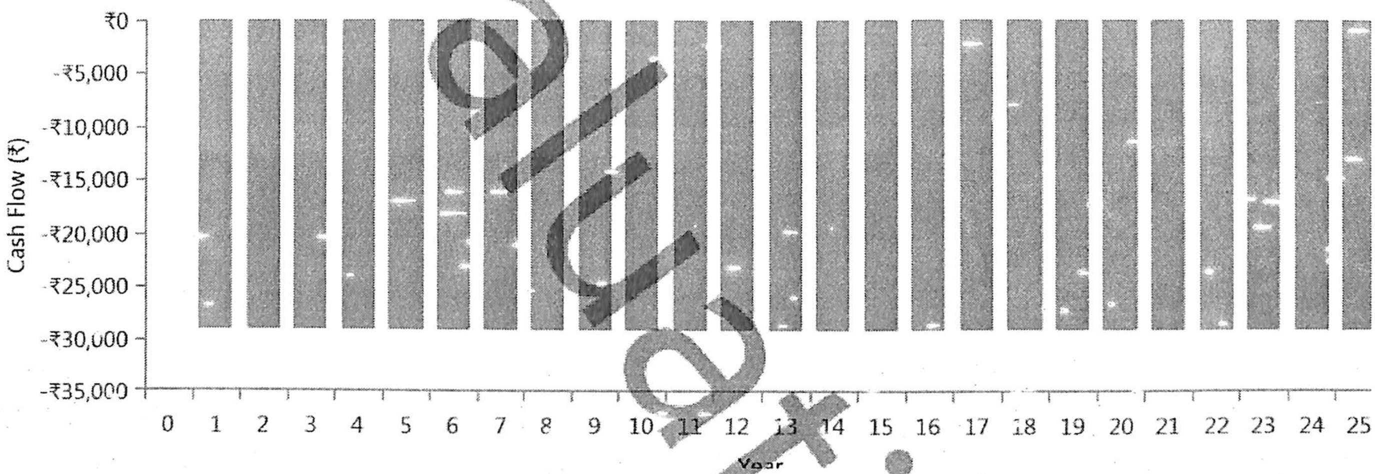
Simple payback (yr):**11.8**

	Base Case	Current System
Net Present Cost	₹463,674	₹362,159
CAPEX	₹0.00	₹600,000
OPEX	₹29,200	-₹14,978
LCOE (per kWh)	₹8.00	₹1.27
CO2 Emitted (kg/yr)	2,307	1,113
Fuel Consumption (L/yr)	0	0

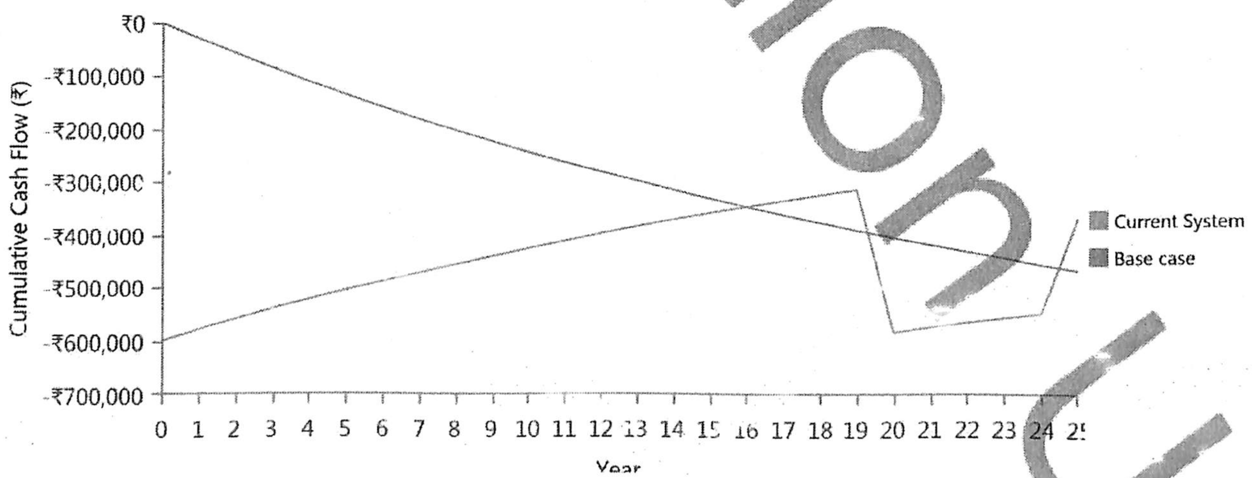
Current Annual Nominal Cash Flows



Base Case Annual Nominal Cash Flows



Cumulative Discounted Cash Flows



Such results are simulated in HOMER for all possible cases. The result of LCOE for different capacity with sensitivity variables discount rate, inflation rate are presented in Table 4.2.

Table 4.2: Levelized cost of energy (LCOE) for case-I

5kW PV+ Grid- LCOE									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate / Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	1.731	1.3829	1.0545	1.6043	1.2561	0.9277	1.4775	1.1293	0.801
4%	2.4898	2.093	1.731	2.363	1.9662	1.6043	2.2362	1.8394	1.4775
6%	2.9029	2.4741	2.0858	2.7762	2.3473	1.9591	2.6494	2.2205	1.8323
8%	3.3413	2.8779	2.459	3.2145	2.7512	2.3322	3.0878	2.6244	2.2055
7.5kW PV+ Grid- LCOE									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate / Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	1.1159	0.7427	0.3908	0.9682	0.5951	0.2431	0.8205	0.4474	0.0955
4%	1.9291	1.5038	1.1159	1.7814	1.3561	0.9682	1.6337	1.2084	0.8205
6%	2.3719	1.9123	1.4962	2.2242	1.7646	1.3485	2.0765	1.6169	1.2008
8%	2.8418	2.3451	1.8961	2.6941	2.1974	1.7484	2.5464	2.0197	1.6008
10kW PV+ Grid- LCOE									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate / Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	0.7802	0.3937	0.0292	0.6209	0.2344	-	0.4615	0.075	-
4%	1.6225	1.182	0.7802	1.4631	1.0226	0.0209	1.3038	0.8633	0.4615
6%	2.0811	1.6051	1.1741	1.9218	1.4457	1.0147	1.7624	1.2863	0.8554
8%	2.5678	2.0534	1.5884	2.4084	1.894	1.429	2.2491	1.7347	1.2696

Discussion: The simulated result reported in Table.4.2, shows that, LCOE decreases with increase in, sellback rate and inflation rate. LCOE increase with increase in discount rate. As solar PV capacity increases, similar trend is observed, but LCOE is decreases with decreases in solar PV capacity. This increases capital, operation and maintenance cost of the system. Increase in solar PV rating, increases share of renewable energy. Now government is buying renewable energy at Rs.2.80/unit or kWh. If government or electricity boards increase sell back rate, then investment in solar rooftop by residential consumer start increasing.

The result of ROI, IRR and PBP for different capacity with sensitivity variable sell back rate are presented in Table 4.3.

Discussion: Calculated values of ROI and IRR increase with increases in rating of solar PV and increase with sell back rate. But these indices have no effect of inflation

Table 4.3: ROI, IRR and PBP for different configuration and sell back rate case-I

Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
	ROI	IRR	PBP	ROI	IRR	PBP	ROI	IRR	PBP
Configuration	(%)	(%)	(yrs)	(%)	(%)	(yrs)	(%)	(%)	(yrs)
5kW PV+Grid	4	6.1	11.14	4.4	6.7	10.64	4.8	7.3	10.18
7.5kW PV+Grid	3	4.8	12.46	3.5	5.4	11.78	3.9	6.1	11.18
10kW PV+Grid	2.5	4	13.28	3	4.7	12.49	3.5	5.4	11.79

and discount rate. PBP calculations also shows that it increases with solar PV capacity and decreases with sell back rate. Hence LCOE index is better indication of economic evaluation along with PBP.

The result of CO2 emission for different capacity of solar PV are presented in Table 4.4.

Table 4.4: CO2 emission for different capacity of solar PV

Configuration	CO2 emission (kg/yr)	reduction in CO2 (%)
Grid	2306.8	–
5kW PV+Grid	1181.617	48.78
7.5kW PV+Grid	1139.517	50.60
10kW PV+Grid	1113.407	51.73

Discussion: The result shows that CO2 emission decreases with increase in capacity of solar PV. It has no effect of inflation rate, discount rate and sell back rate. Almost 50% reduction in CO2 emission is reported with installation of solar PV at residential consumer.

4.4 Result: Case-II Commercial Project

After inputting data to HOMER software, simulation is carried out for different situations given in Table 4.5 Different cases for which simulations are acrried out Y: Feasible N: Not Feasible

Table 4.5: Different cases for which simulations are carried out Y: Feasible N: Not Feasible

Configuration: 25kW PV+ Grid									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate									
Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	Y	Y	Y	Y	Y	Y	Y	Y	Y
4%	Y	Y	Y	Y	Y	Y	Y	Y	Y
6%	Y	Y	Y	Y	Y	Y	Y	Y	Y
8%	Y	Y	Y	Y	Y	Y	Y	Y	Y
Configuration: 50kW PV+ Grid									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate									
Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	Y	Y	Y	Y	Y	Y	Y	Y	Y
4%	Y	Y	Y	Y	Y	Y	Y	Y	Y
6%	Y	Y	Y	Y	Y	Y	Y	Y	Y
8%	Y	Y	Y	Y	Y	Y	Y	Y	Y
Configuration: 75kW PV+ Grid									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate									
Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	Y	Y	Y	Y	Y	Y	Y	Y	Y
4%	Y	Y	Y	Y	Y	Y	Y	Y	Y
6%	Y	Y	Y	Y	Y	Y	Y	Y	Y
8%	Y	Y	Y	Y	Y	Y	Y	Y	Y
Configuration: 100kW PV+ Grid									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate									
Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	N	N	N	Y	Y	N	Y	Y	N
4%	N	N	N	Y	Y	Y	Y	Y	Y
6%	N	N	N	Y	Y	Y	Y	Y	Y
8%	N	N	N	Y	Y	Y	Y	Y	Y

The simulation result report generated by HOMER for 10kW PV+Grid,Discount Rate=8%, Inflation Rate=4%, Sellback rate=Rs.3.2 kWh is given below.

HOMER Pro

System Simulation Report

File: Commercial.homer

Author: Ganesh N. Jadhav

Location: K.K. Wagh Building, Mumbai Agra Rd, Durga Nagar, Nashik, Maharashtra 422006, India (20°0.8'N, 73°49.4'E)

Total Net Present Cost: ₹7,296,096.00

Levelized Cost of Energy (₹/kWh): ₹2.75

Notes:

Sensitivity variable values for this simulation

Variable	Value	Unit
Diesel Fuel Price	100	₹/L
Sellback Rate	3.00	₹/kWh
ExpectedInflationRate	4.00	%
NominalDiscountRate	6.00	%

HOMER Pro

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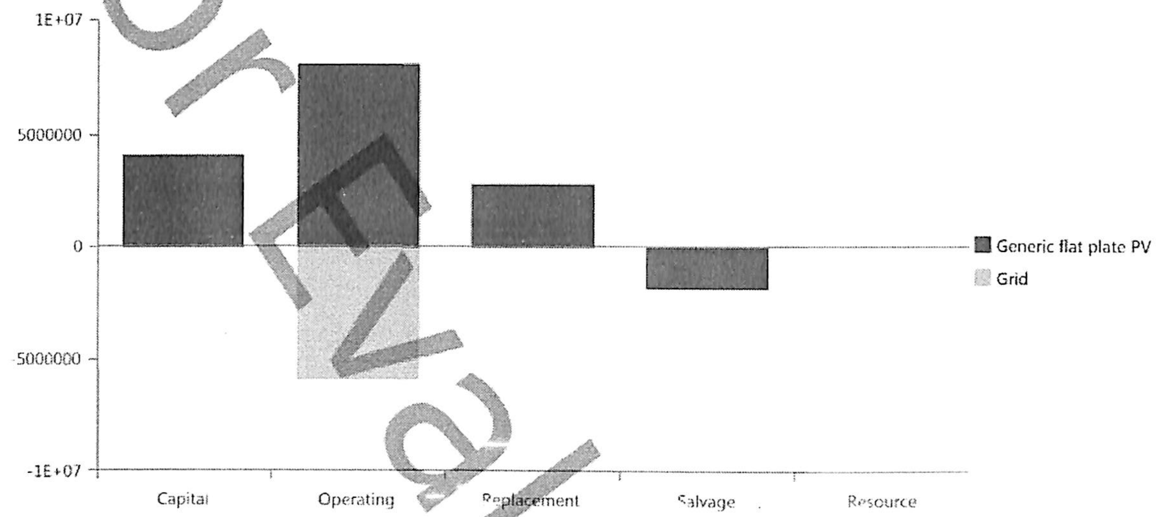
Cost Summary



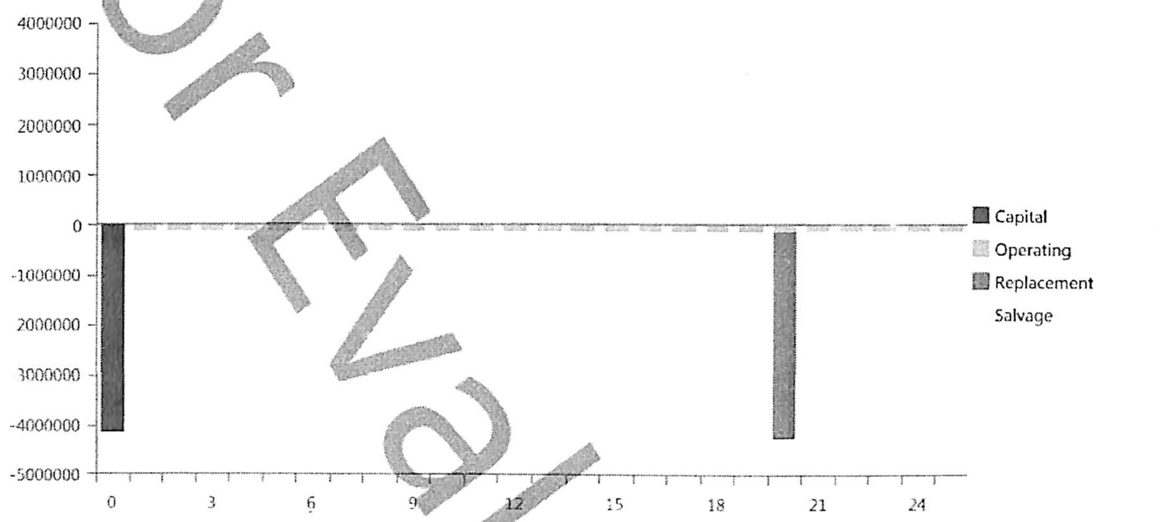
Net Present Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic flat plate PV	₹4.13M	₹8.13M	₹2.82M	-₹1.92M	₹0.00	₹13.1M
Grid	₹0.00	-₹5.85M	₹0.00	₹0.00	₹0.00	-₹5.85M
System	₹4.13M	₹2.27M	₹2.82M	-₹1.92M	₹0.00	₹7.30M

Annualized Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic flat plate PV	₹209,381	₹412,500	₹143,050	-₹97,541	₹0.00	₹667,390
Grid	₹0.00	-₹297,047	₹0.00	₹0.00	₹0.00	-₹297,047
System	₹209,381	₹115,453	₹143,050	-₹97,541	₹0.00	₹370,343

Cash Flow



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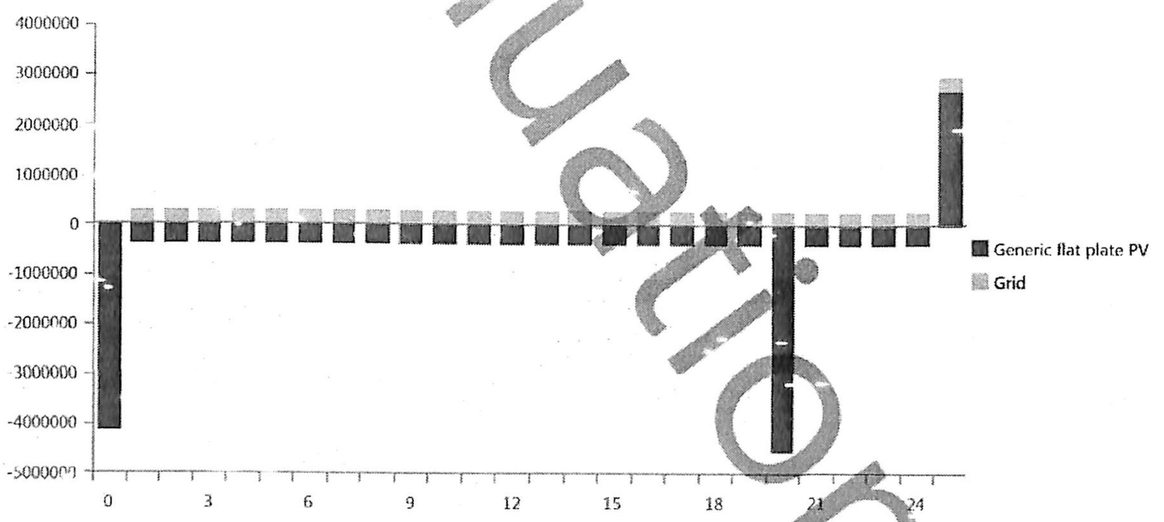
Capital
Operating
Replacement
Salvage



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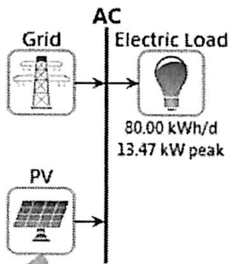
12
15
18
21
24
Generic flat plate PV
Grid

HOMER Pro

System Architecture

Component	Name	Size	Unit
PV	Generic flat plate PV	75.0	kW
Grid	Grid	200	kW
Dispatch strategy	HOMER Cycle Charging		

Schematic



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Electrical Summary

Excess and Unmet

Quantity	Value	Units
Excess Electricity	0	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

Production Summary

Component	Production (kWh/yr)	Percent
Generic flat plate PV	128,216	95.3
Grid Purchases	6,289	4.68
Total	134,505	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	29,200	21.7
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	105,305	78.3
Total	134,505	100

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PV: Generic flat plate PV

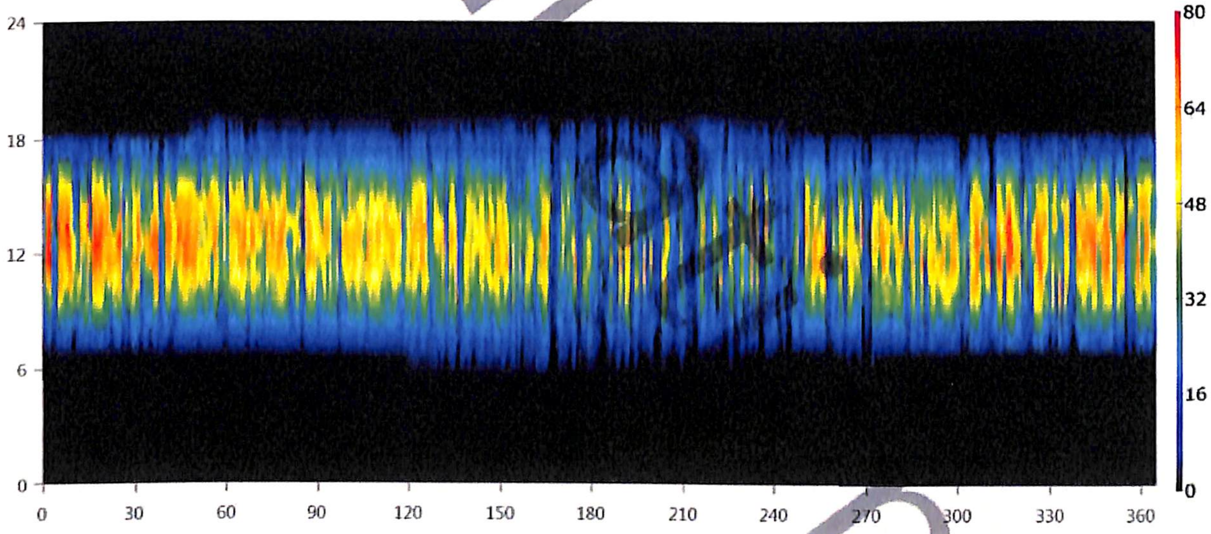
Generic flat plate PV Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	79.8	kW
PV Penetration	439	%
Hours of Operation	4,407	hrs/yr
Levelized Cost	5.21	₹/kWh

Generic flat plate PV Statistics

Quantity	Value	Units
Rated Capacity	75.0	kW
Mean Output	14.6	kW
Mean Output	351	kWh/d
Capacity Factor	19.5	%
Total Production	128,216	kWh/yr

Generic flat plate PV Output (kW)



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Grid: Grid

Grid rate: Demand 1

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	0	0	0	8.07	₹0.00	₹0.00
February	0	0	0	6.88	₹0.00	₹0.00
March	0	0	0	5.72	₹0.00	₹0.00
April	0	0	0	4.91	₹0.00	₹0.00
May	0	0	0	4.78	₹0.00	₹0.00
June	0	0	0	5.23	₹0.00	₹0.00
July	0	0	0	5.31	₹0.00	₹0.00
August	0	0	0	6.27	₹0.00	₹0.00
September	0	0	0	7.91	₹0.00	₹0.00
October	0	0	0	6.23	₹0.00	₹0.00
November	0	0	0	7.59	₹0.00	₹0.00
December	0	0	0	7.12	₹0.00	₹0.00
Annual	0	0	0	8.07	₹0.00	₹0.00

Grid rate: Rate 1

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	710	10,527	-9,816	0	₹0.00	₹0.00
February	546	9,739	-9,192	0	₹0.00	₹0.00
March	555	10,518	-9,963	0	₹0.00	₹0.00
April	459	10,098	-9,639	0	₹0.00	₹0.00
May	380	10,431	-10,052	0	₹0.00	₹0.00
June	383	7,498	-7,116	0	₹0.00	₹0.00
July	381	5,706	-5,325	0	₹0.00	₹0.00
August	466	5,280	-4,814	0	₹0.00	₹0.00
September	498	6,688	-6,190	0	₹0.00	₹0.00
October	573	9,118	-8,545	0	₹0.00	₹0.00
November	635	9,666	-9,031	0	₹0.00	₹0.00
December	703	10,036	-9,332	0	₹0.00	₹0.00
Annual	6,289	105,305	-99,016	0	-₹297,047	₹0.00

Grid rate: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	710	10,527	-9,816	8.07	₹0.00	₹0.00
February	546	9,739	-9,192	6.88	₹0.00	₹0.00
March	555	10,518	-9,963	5.72	₹0.00	₹0.00
April	459	10,098	-9,639	4.91	₹0.00	₹0.00
May	380	10,431	-10,052	4.78	₹0.00	₹0.00
June	383	7,498	-7,116	5.23	₹0.00	₹0.00
July	381	5,706	-5,325	5.31	₹0.00	₹0.00
August	466	5,280	-4,814	6.27	₹0.00	₹0.00
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December	703	10,036	-9,332	7.12	₹0.00	₹0.00
Annual	6,289	105,305	-99,016	8.07	-₹297,047	₹0.00

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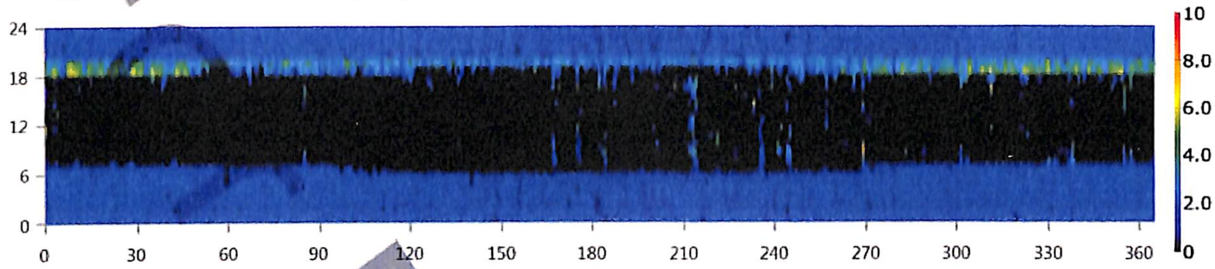
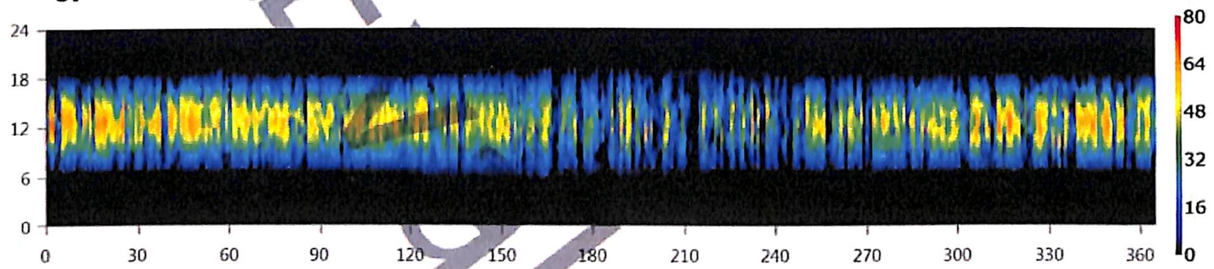
Energy Purchased From Grid (kW)



Energy Sold To Grid (kW)



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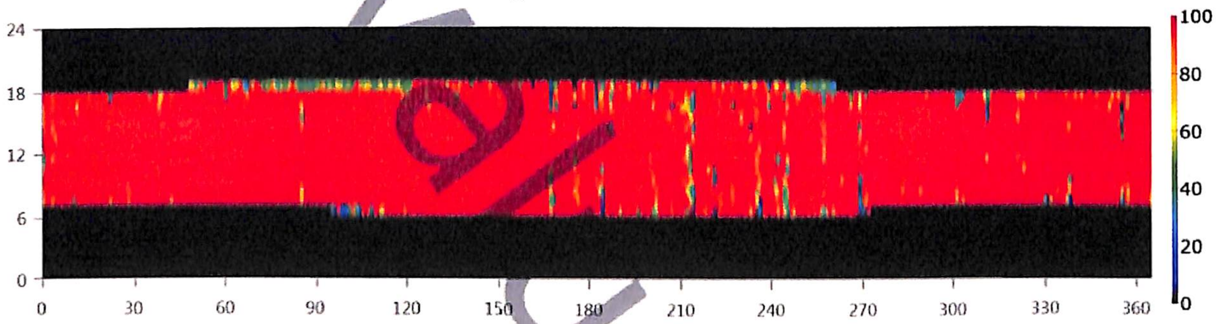
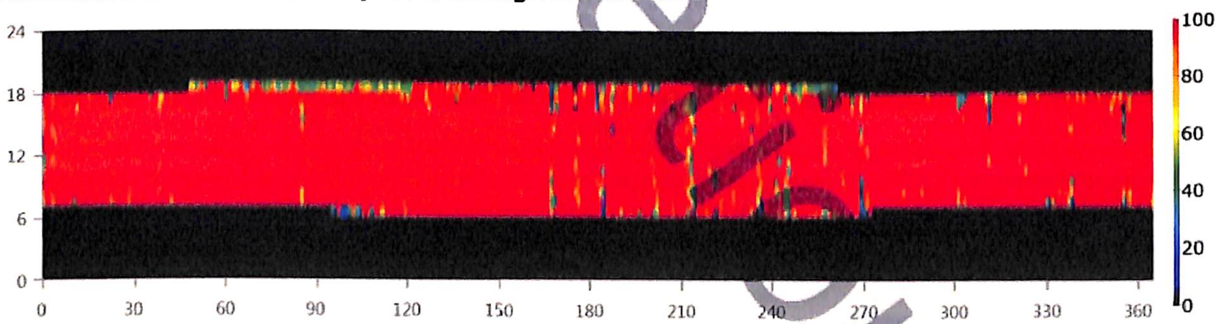
Renewable Summary

Capacity-based metrics	Value	Unit
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%
Energy-based metrics	**Value**	**Unit**
Total renewable production divided by load	95.3	%
Total renewable production divided by generation	95.3	%
One minus total nonrenewable production divided by load	100	%
Peak values	**Value**	**Unit**
Renewable output divided by load (HOMER standard)	100	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

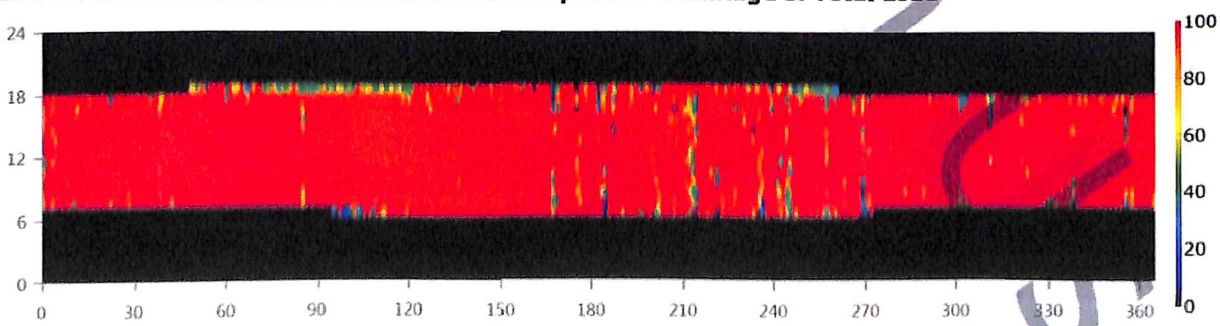
Instantaneous Renewable Output Percentage of Total Generation



Instantaneous Renewable Output Percentage of Total Load



100% Minus Instantaneous Nonrenewable Output as Percentage of Total Load



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Compare Economics

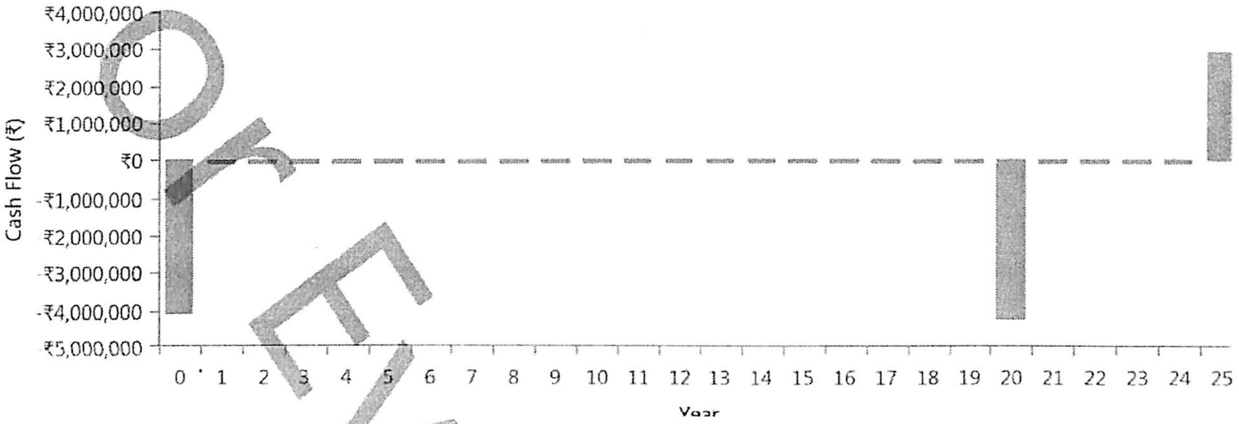
IRR (%):**3.38**

Discounted payback (yr):**N/A**

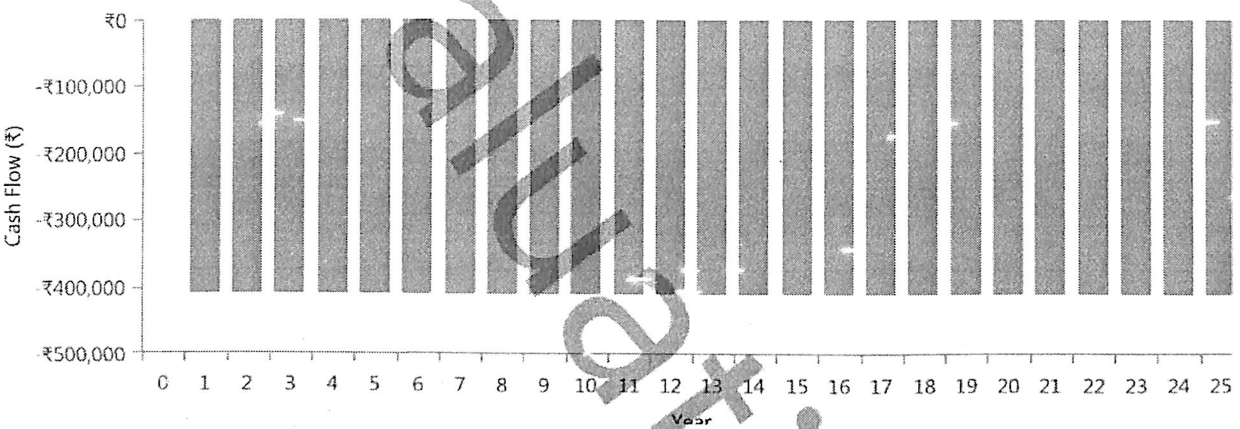
Simple payback (yr):**14.1**

	Base Case	Current System
Net Present Cost	₹8.05M	₹7.30M
CAPEX	₹0.00	₹4.13M
OPEX	₹408,800	₹160,962
LCOE (per kWh)	₹14.00	₹2.75
CO2 Emitted (kg/yr)	18,454	3,975
Fuel Consumption (L/yr)	0	0

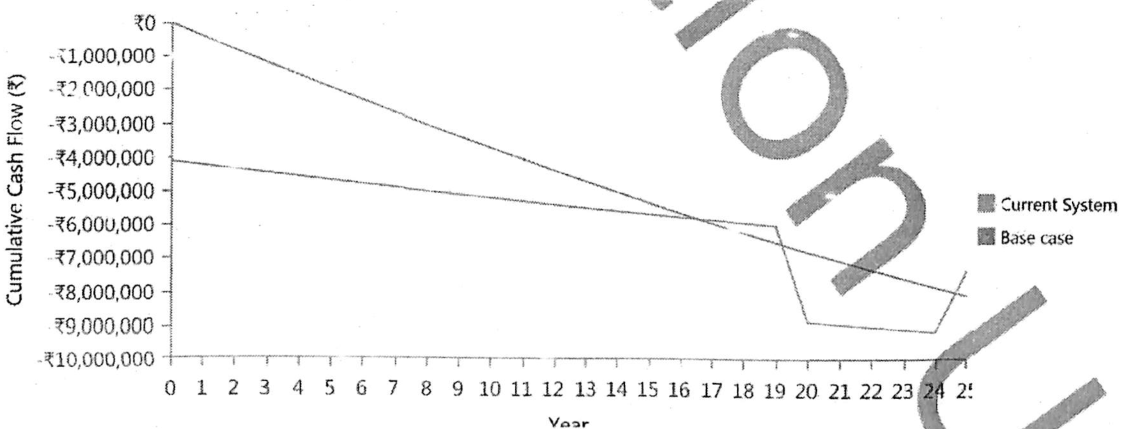
Current Annual Nominal Cash Flows



Base Case Annual Nominal Cash Flows



Cumulative Discounted Cash Flows



Such results are simulated in HOMER for all possible cases. The result of LCOE for different capacity with sensitivity variables discount rate, inflation rate are presented in Table 4.6.

Table 4.6: Levelized cost of energy (LCOE) for case-II

25kW PV+ Grid- LCOE									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate / Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	3.276141	2.966496	2.674475	3.223445	2.913801	2.621779	3.17075	2.861105	2.569084
4%	3.950933	3.598011	3.276141	3.898237	3.545316	3.223445	3.845542	3.49262	3.17075
6%	4.318361	3.936969	3.591673	4.265666	3.884274	3.538978	4.21297	3.831578	3.486283
8%	4.708247	4.296131	3.923573	4.655552	4.243435	3.870877	4.602856	4.19074	3.818182
50kW PV+ Grid- LCOE									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate / Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	2.760996	2.416345	2.091311	2.639092	2.294441	1.969407	2.517188	2.172538	1.847503
4%	3.512074	3.119254	2.760996	3.39017	2.99735	2.639092	3.268266	2.875446	2.517188
6%	3.92104	3.490531	3.112199	3.799136	3.374627	2.990295	3.677232	3.252723	2.368392
8%	4.355002	3.896296	3.48162	4.233099	3.774393	3.359716	4.111195	3.652489	3.237813
75kW PV+ Grid- LCOE									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate / Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	2.538989	2.184112	1.849434	2.391759	2.036882	1.702204	2.244529	1.889652	1.554973
4%	3.312352	2.907877	2.538989	3.165122	2.760647	2.391759	3.017892	2.613417	2.244529
6%	3.733454	3.296349	2.900613	3.586223	3.149118	2.753383	3.438993	3.001888	2.606153
8%	4.180293	3.707976	3.280996	4.033062	3.560716	3.133765	3.885832	3.413516	2.986535
100kW PV+ Grid- LCOE									
Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
Inflation Rate / Discount Rate	0%	2%	4%	0%	2%	4%	0%	2%	4%
0%	2.419138	2.059487	1.720306	2.258927	1.899276	1.560094	2.098715	1.739064	1.399883
4%	3.202907	2.79299	2.419138	3.042695	2.632778	2.258927	2.882483	2.472566	2.098715
6%	3.629673	3.186687	2.785628	3.469461	3.026476	2.625417	3.30925	2.866264	2.465205
8%	4.082524	3.603853	3.171128	3.922312	3.443641	3.010916	3.7621	3.283429	2.850705

Discussion: The simulated result reported in Table.4.6, shows that, LCOE decreases with increase in, sellback rate and inflation rate. LCOE increase with increase in discount rate. As solar PV capacity increases, similar trend is observed, but LCOE is decreases with decreases in solar PV capacity. This increases capital, operation and maintenance cost of the system. Increase in solar PV rating, increases share of renewable energy.

Now government is buying renewable energy at Rs.2.80/unit or kWh. If government or electricity boards increase sell back rate, then investment in solar rooftop by commercial consumer start increasing. The result also shows that LCOE can not be calculated for 100kW solar PV capacity with sell back rate of Rs.2.8/kWh.

The result of ROI, IRR and PBP for different capacity with sensitivity variable sell back rate are presented in Table 4.7.

Table 4.7: ROI, IRR and PBP for different configuration and sell back rate case-II

Sellback Rate	Rs.2.8/kWh			Rs.3/kWh			Rs.3.2/kWh		
	ROI	IRR	PBP	ROI	IRR	PBP	ROI	IRR	PBP
Configuration	(%)	(%)	(yrs)	(%)	(%)	(yrs)	(%)	(%)	(yrs)
25kW PV+Grid	17.5	22	4.45	17.7	22.2	4.41	17.9	22.5	4.37
50kW PV+Grid	5.6	8.3	9.44	6	8.9	9.09	6.4	9.4	8.76
75kW PV+Grid	1.6	2.6	15.08	2.1	3.4	14.06	2.6	4.1	13.17
100kW PV+Grid	-0.4	–	–	0.2	0.3	24.95	0.7	1.1	17.6

Discussion: Calculated values of ROI and IRR increase with increases in rating of solar PV and increase with sell back rate. But these indices have no effect of inflation and discount rate. PBP calculations also shows that it increases with solar PV capacity and decreases with sell back rate. Hence LCOE index is better indication of economic evaluation along with PBP. Calculation of ROI, IPR and PBP is infeasible for 100kW solar PV capacity with Rs.2.80/kWh sell back rate.

The result of CO2 emission for different capacity of solar PV are presented in Table 4.8.

Discussion: The result shows that CO2 emission decreases with increase in capacity of solar PV. It has no effect of inflation rate, discount rate and sell back rate. Almost 70 to 80% reduction in CO2 emission is reported with installation of solar PV at commercial

Table 4.8: CO2 emission for different capacity of solar PV

Configuration	CO2 emission (kg/yr)	reduction in CO2 (%)
Grid	18454.4	–
25kW PV+Grid	5464.047	70.39
50kW PV+Grid	4331.269	76.53
75kW PV+Grid	3974.609	78.46
100kW PV+Grid	3794.834	79.44

consumer.

As per scheme of grid solar rooftop PV launched by Ministry of New and Renewable energy, Government of India,30% subsidy on capital cost is given to project. With this subsidy, LCOE and PBP will further reduced.

Chapter 5

Conclusion

The method of Levelized Cost of Electricity (LCOE) allows a comparison of power plants with different generating and cost structures. The LCOE results from the comparison of all costs, which arise throughout the lifetime of the power plant for the construction and operating of the plant, with the sum of the generated amount of energy throughout the life cycle. The underlying idea is that the generated electricity implicitly corresponds to the revenue from the sale of this energy. Thus, the further this income is in the future, the lower the associated present value.

The LCOE represents a comparative calculation on a cost basis and not a calculation of feed-in tariffs. These can only be calculated by adding further influencing parameters. As calculation of LCOE does not take into account the value of the electricity produced within an energy system in a given hour of the year, it is to be emphasized that this method is an abstraction of reality aiming at making different power plants comparable. The method is not suitable for determining the profitability of a specific plant. For this purpose, a financial calculations, which takes into account all income and expenditure with a cash flow model must be carried out.

The LCOE can be used to support decision-making. It should be noted that the LCOE is a cost-based figure and does not include revenues.

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[1] "National electricity plan," Government of India, Ministry of Power, CEA, Tech. Rep., Jan 2018.

[2] "Guidelines on implementation of phase ii of grid connected rooftop solar programme for achieving 40 gw capacity from rooftop solar by the year 2022," Govenment of India, Ministry of New and Renewable Energy, Tech. Rep., Aug 2019.

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