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Performance Investigation of Life Cycle Cost and CO_2 Emissions of the Solar PV System

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Abstract: With depletion of fossil fuel resources, the world is moving towards the use of non-conventional energy resources; among which the solar energy is pollution free and inexhaustible option. In this study, energy based analysis of photovoltaic (PV) system is analyzed for the climate of Madhav Institute of Technology and science, Gwalior, India and carbon credit is earned and calculated for the same. This analysis of PV system is done based on monthly performance of the system and life of 30 years. Embodied energy and Energy Payback (EPB) is also analyzed for calculation of reduction in CO_2 emission while generating of electrical energy.

Keywords: Solar energy, photovoltaic (PV) technology, CO_2 Analysis, Embodied energy and Energy Payback (EPB), Solar Thermal Technology.

I. INTRODUCTION

A. Solar Thermal Technology

Solar energy can directly be utilized by two technologies: Solar Thermal and Solar Photovoltaic. Solar thermal system provides thermal energy for various processes. In cold climate region it is used to heat air for comfort and hot water for washing, cleaning and other domestic use etc. many industrial survey shown 24% of heat in industry is used to heating fluid to a low temperature [1]. So solar energy is best suited for it. Even in high temperature heating significant amount of heat can be saved. Solar thermal energy is being used in drying, process industry etc.

As man became more civilized he discovered coal, oil and gas and started utilizing them to fulfillhis energy needs without realizing that their reserves are limited. With the increase in population the consumption of wood also increased resulting in denudation of forest The reserves of fossil fuels like coal, oil and gas ·also started decreasing resulting in increase in their prices and scarcity in countries where these fuels are not available [2]. Their large scale burning has created environmental problems for the mankind, animal world and for living beings today we cannot think of any activity without using energy from external sources in one form or the other. Energy has thus joined the rank of food and shelter, the two essential requirements for the existence of human race .As it has now been realized that the reserves of fossil fuels are limited, their large scale burning creates many ill effects on the natural environment, and without the use of energy from external sources we cannot think of any activity. Efforts are being made to search for new energy sources which are long lasting, easily available and are pollution free. Since solarenergy has all these qualities and human beings have been using this energy in different forms from the very beginning, intensive efforts are being made to utilize solar energy for various applications all over the world [3].

B. CO_2 Analysis For Solar PV System

Recent advancements in photovoltaic (PV) technology have been notable in terms of annual production capacity and life cycle environmental performances, which calls for timely updates of environmental indicators. The life-cycle greenhouse gas emissions, criteria pollutant emissions, and heavy metal emissions from four types of significant commercial PV systems: multicrystalline silicon, monocrystalline silicon, ribbon silicon, and thin-film cadmium telluride. This information is based on PV production data from 2004 to 2006. The life-cycle emissions of each PV system were calculated using typical power blends in Europe and the US throughout the fabrication of the components and modules. Thin-film cadmium telluride (CdTe) PV, the most recent generation of PV technology, produces modules with the least amount of energy and produces the fewest harmful air emissions [4]. Solar panels emit around 50g of CO_2 per kWh produced in its first few years of operation.

By the third year of having solar panels, most solar panels become carbon neutral. This is still roughly 20 times less than the carbon output of coal-powered electricity sources. The benefits of using solar energy have been campaigned repeatedly for a long time, and with a purpose. Utilizing it to generate power can greatly reduce the emissions of CO_2 by decreasing the demand for fossil fuels. This will minimize greenhouse gas emissions and can reduce our carbon footprint.

Fig.1 PV Solar setup on roof of MITS Gwalior

C. *Co_2 Analysis For Solar Stills*

Theoretical evaluation of carbon credits earned by various solar still designs in India in terms of CO_2 emission/mitigation. The experimental performance of the solar stills, as reported by numerous researchers, is used as the basis for numerical computation. Estimation of carbon credits that will benefit the country is done assuming a system life expectancy of 20 years, allowing for 250, 275, and 300 clear days annually. Accounting for carbon trading in the European market has also been done using return on investment based on life cycle cost analysis. With the present carbon trading rate of €2.10 per ton, it is discovered that the annual cash flow from carbon trading reduces the cost of producing distillate by Rs. 0.15 per liter. For the production of freshwater, reducing carbon dioxide (CO_2) footprint is a major challenge. Sunlight is a renewable energy source that creates freshwater and lowers CO_2 emissions. The purpose of this study is to look into the CO_2 emissions of solar stills [5]. The CO_2 footprint, CO_2 mitigation, carbon credit energy generation factor, and life cycle conversion efficiency are all calculated using the embodied energy analysis (LCCE). On a single basin, multi-slope solar still, the comparison is done. In the solar still, the multi-slope, a square-shaped pyramid, serves as a transparent medium. For testing purposes, two multi-slope solar stills were constructed. Solar stills installed on MITS Roof is shown in figure 2.

Fig.2 Solar stills installed on MITS Roof

D. CO_2 Analysis For Solar Dryer

The search for a future alternative energy source that is dependable, economical, and environmentally beneficial is underway. The best alternative for both energy security and protecting the planet from the environmental damage caused by the use of traditional fossil fuels appears to be solar energy. Given that drying consumes a large amount of energy, using solar energy will help cut traditional energy use by up to 27–80% and is the greatest approach to keep agricultural products from going bad. 1 Since ancient times, open sun drying has been the method of choice for drying agricultural products all throughout the world [6].

The technique of solar drying not only preserves the crops but also preserves the natural flavor, color, and other characteristics, increasing the market value of the finished goods. The solar greenhouse dryer essentially falls under the category of direct solar drying and is occasionally used in conjunction with a mixed mode solar drying system. It has been in use for the past 25 years to dry materials at low temperatures. A greenhouse is an enclosed structure that collects shorter wavelength sun energy [7]. Infrared radiation with long wavelengths from the sun is trapped within the greenhouse, raising its temperature. Low temperatures are great for drying vegetables and cash crops, and a greenhouse structure makes it simple to achieve this.

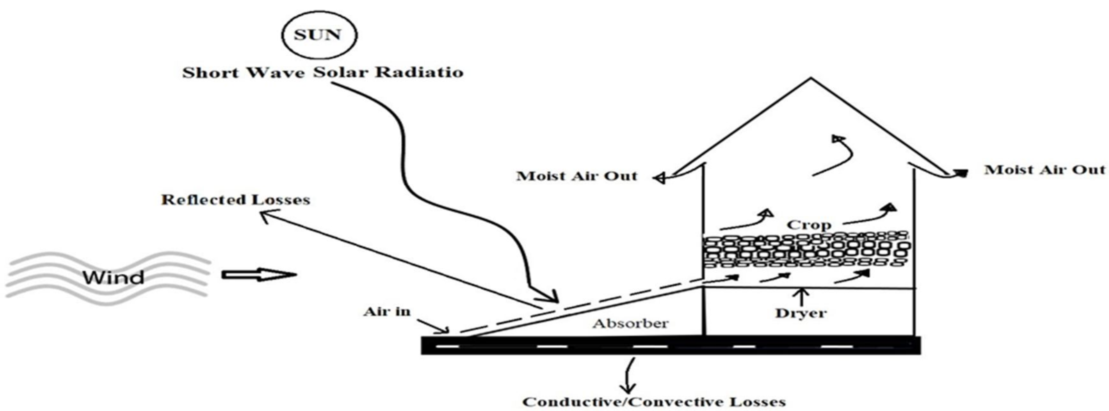

Fig.3 Solar Dryer

E. Economic Analysis

The economic analysis is generally carried out to evaluate the various cost associated with the developed system like annual cost of dryer, maintenance cost, cost of dried product per kg, and most importantly, the payback time. The drying cost of product per kg and payback time of the developed system is the key parameters that show the viability of developed system over other existing systems [8].

A typical inquiry concerning solar PV Is solar energy a good deal? or "What is the recompense?" Few people appreciate how complicated these issues really are. In order to obtain correct payback estimates, a number of assumptions and variables must be taken into consideration, including estimations of PV production, shading, the time value of money, electric rate structures, operations and maintenance, insurance, taxes, and incentives.

F. Environmental Analysis

The negative environmental effects of PV systems include land, water, pollution, hazardous materials, noise, and visual. Image result for environmental analysis for pv system Future PV system design trends emphasise enhanced design, sustainability, and recycling. Future laws can be well-supported by research to close the gaps and incentives to do so. The PV modules have to be exposed to the atmosphere under direct sunlight. Therefore, the performance and efficiency of the PV module are heavily influenced by environmental factors such as **irradiance, temperature, dust allocation, soiling, wind, shading, humidity** etc. However, despite the fact that using photovoltaic to generate power is more environmentally friendly than burning fossil fuels, multiple occurrences have connected the production of these gleaming examples of environmental virtue to a trail of chemical contamination [9].

G. How to Design and Install a Solar PV System

Today our modern world needs energy for various day to day applications such as industrial manufacturing, heating, transport, agricultural, lightning applications, etc. Most of our energy need is usually satisfied by non-renewable sources of energy such as coal, crude oil, natural gas, etc. But the utilization of such resources has caused a heavy impact on our environment. Also, this form of energy resource is not uniformly distributed on the earth. There is an uncertainty of market prices such as in the case of crude oil as it depends on production and extraction from its reserves. Due to the limited availability of non-renewable sources, the demand for renewable sources has grown in recent years [10].

Solar energy has been at the center of attention when it comes to renewable energy sources. It is readily available in an abundant form and has the potential to meet our entire planet's energy requirement. The solar standalone PV system as shown in fig 1 is one of the approaches when it comes to fulfilling our energy demand independent of the utility. Hence in the following, we will see briefly the planning, designing, and installation of a standalone PV system for electricity generation.

II. EXPERIMENTATION & OBSERVATIONS

Through the use of the well-known PV effect, SPV array turns solar energy into electricity. The experiment is carried out in Madhav Institute of Technology and Science Gwalior on October - December, 2022. The charge controller receives the electrical power generated by the array as output. The battery is connected to the load, then the PV array. The controller enhances the battery's functionality and lifespan by preventing overcharging. The battery receives the charge controller's output. This preserves the power generated by a solar electric system. Now the battery output is connected with inverter input. An inverter converts the DC electricity from This AC output of Inverter is now provided to the load connected with it.

Experimental Set Up:-

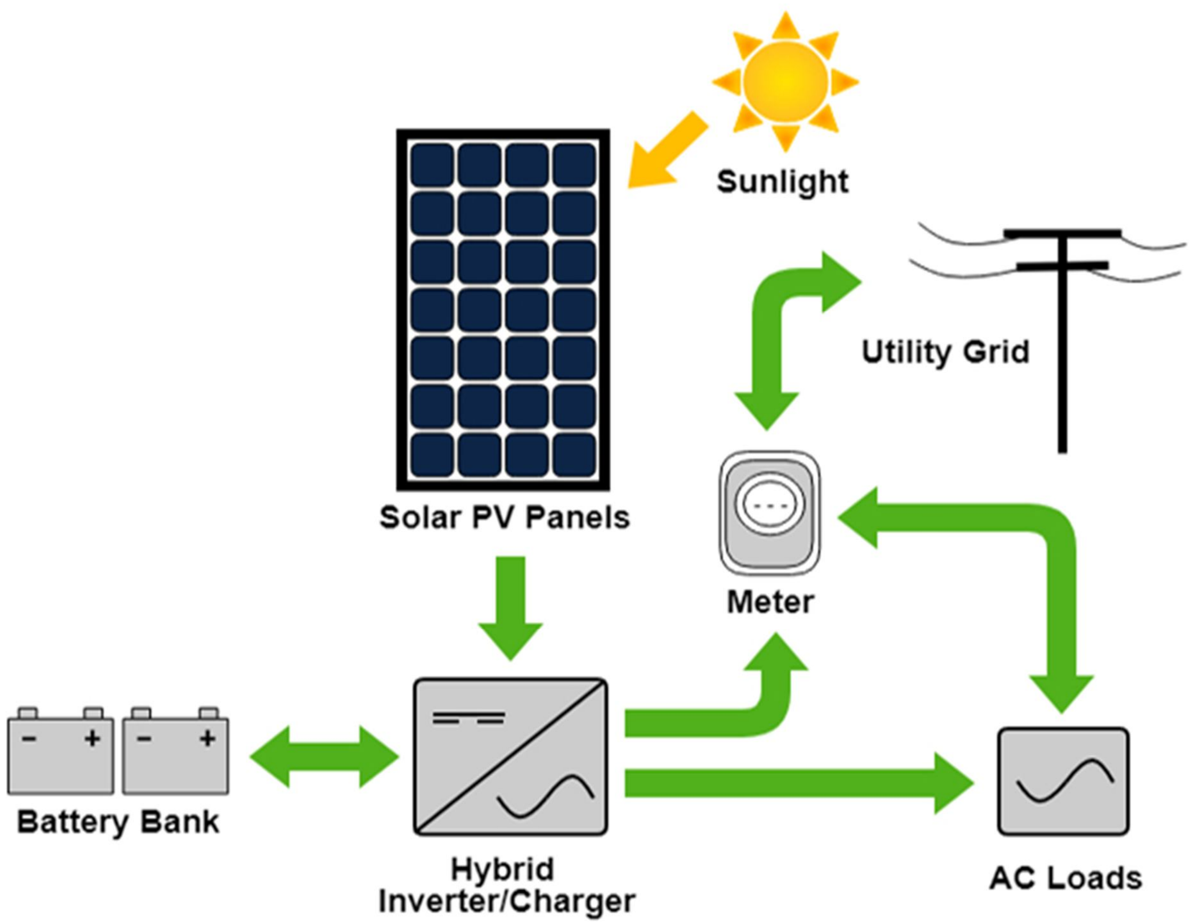

Fig 4 Sketch of PV Solar System

Fig 5 Photograph of PV panel and Battery – Inverter Arrangements

In any condition, if the PV system is not working properly to supply the load, due to some fault in system or in cloudy weather condition, then grid connected supply can be given to load by using the changeover switch. If in case grid connected supply is also not available, kerosene generator is provided for supplying the load.

III. RESULTS AND DISCUSSION

This thesis can be considered as an exploratory study for the feasibility of installing solar panels at Madhav Institute of Technology & Science Gwalior. The information that is gathered through literature reviews, case studies, field trips, and key informant interviews will be used to make recommendations about implementing photovoltaic solar system for the campus sustainability initiative. Several research techniques have been employed to ensure that sufficient information has been gathered to evaluate the feasibility of photovoltaic solar system at Madhav Institute of Technology & Science, Gwalior in terms of technological, economic, environmental, and social factors.

A. Data Collection

Intensity of solar rays varies during the day. It increases from morning to noon and reduces from noon to evening so intensity of sun radiation is measured in interval of one hour.
During measurement,
Average intensity during the day ($\bar{I}$) = 586.87 W/m^2
In every interval of one hour, the electrical power output is measured by measuring open circuit voltage and short circuit current, the total electrical energy generated by the PV array

$$E = 5.78 \text{ kWh. (Per day)}$$

Electrical power supplied to load will always be less than electrical power generated by PV array because of line losses. This can be calculated by considering efficiency of charge controller and inverter.
So, the total electrical energy provided to the load for one day, E per day:
E per day = E × Efficiency of charge controller × Efficiency of inverter E per day
= 5.78 × 0.95 × 0.95 = 5.22 kWh
Total electrical energy provided to the load for one year is calculated by considering the number of clear days in a year. Here we have considered 325 clear days for climate conditions of Gwalior, Madhya Pradesh, India.
E per year = E per day × No. of clear days E per year
= 5.22 × 325 E per year = 1695.25 kWh
So the yearly electrical energy output from the PV system is 1695.25 kWh (approximately).

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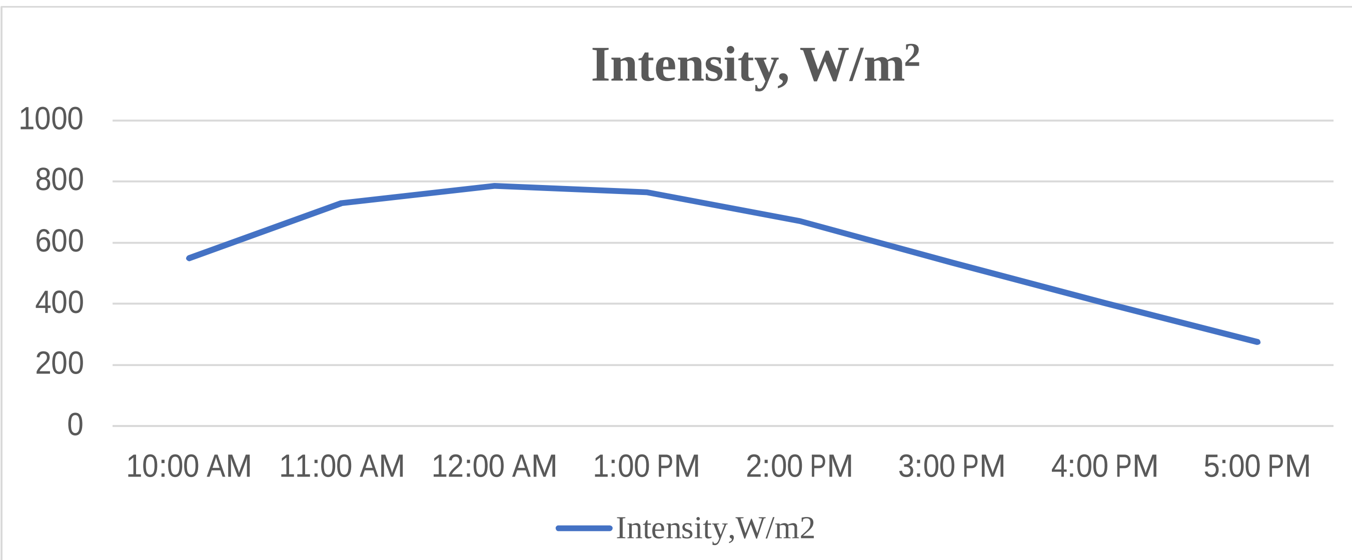
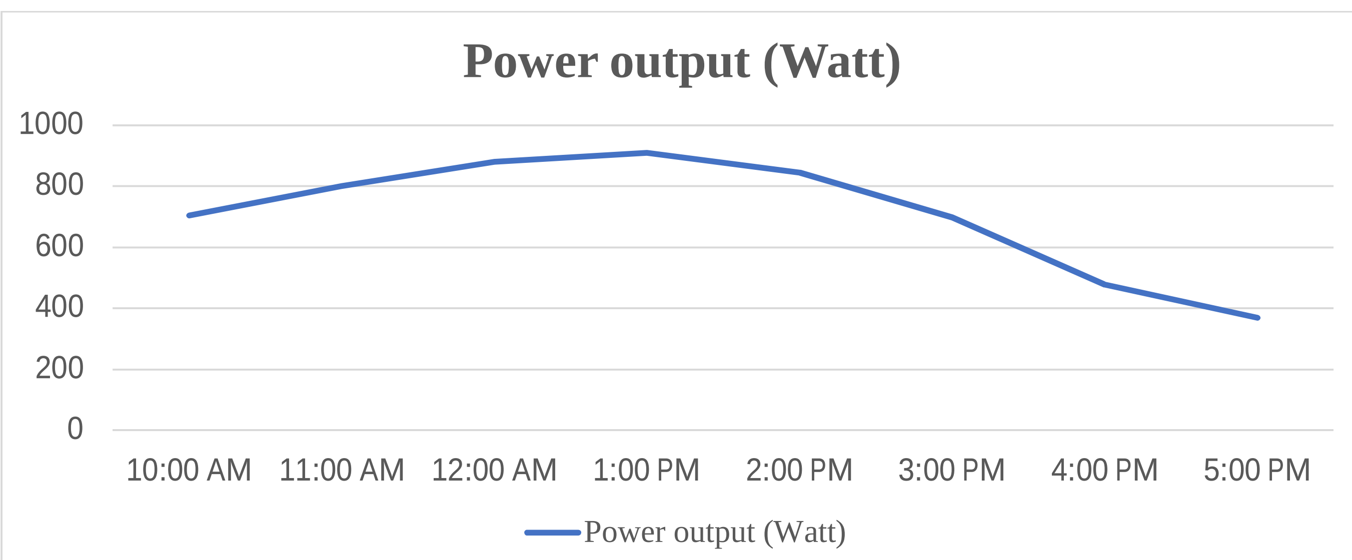
Table 1 Average hourly variation of SPV system parameters and electrical power output for three months. (October – December, 2022)

Time	Intensity, W/m^2	Short circuit current I_{sc} (Amp.)	Open circuit voltage, V_{oc} (Volt)	Power output (Watt)
10:00 AM	550	35.85	19.61	703.1
11:00 AM	730	41.20	19.43	800.5
12:00 PM	785	44.90	19.57	878.7
1:00 PM	764	46.85	19.38	908
2:00 PM	670	43.60	19.37	844.5
3:00 PM	535	35.81	19.46	696.8
4:00 PM	402	24.20	19.75	478
5:00 PM	275	19.25	19.17	369



Graph 1: Intensity (W/m^2) vs Time



Graph 2: Power output (Watt) vs Time

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Embodied Energy Consumption of PVsystem

As the embodied energy is the energy used in the fabrication practice and manufacturing of system so the embodied energy of solar system, which is used in our case study; is calculated by considering the total embodied energy (kWh) used in making of different components of solar system. It includes the energy used in material production, installation, maintenance and administration. This is shown in the TABLE 1 & 2.

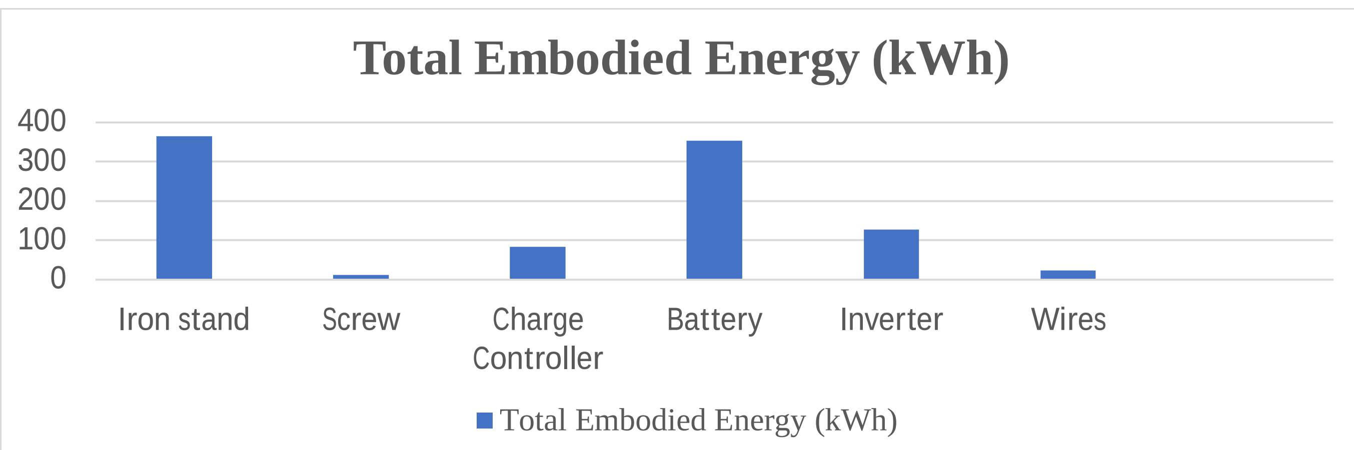
Table 1 Material production Energy (E_{mpe})

Material	Embodied Energy (kwh/m^2)	Total Area (m^2)	Total Embodied energy (kwh)
Silicon Purification process: Silicon production on metallurgical grade, silicon production on Electronic grade, Silicon crystal growth	665.00	7.35	4887.75
Solar Cell Production	123.00	7.35	904.05
Photovoltaic (PV) Module Lamination and Assembly: Steel infrastructure, Toddler (Ethyl vinyl acetate) production, production of Glass Sheet and Aluminum Frame, other materials	186.00	7.35	1367.1

Total material production (E_{mpe}) = 7158.9 kWh

Table 2 PV system installation energy (E_{inst})

Item	Embodied Energy	Total Weight	Total Embodied Energy(kWh)
Support structure:			
Iron stand	8.10 (kWh/kg)	45 kg	364.5 (kWh)
Screw	8.75 (kWh/kg)	1.250 kg	10.93 (kWh)
Charge Controller	212.00 (kWh/kW)	0.39 (kW)	82.68 (kwh)
Battery	48.00 (kWh/kW)	7.35 (m^2)	352.8 (kwh)
Inverter	212.00 (kwh/kW)	0.60 (kW)	127.2 (kWh)
Wires	3.09 (kWh/m^2)	7.35 (m^2)	22.72 (kWh)



Graph 3: PV system installation energy

Total material production energy (E_{inst}) = 960.83 kWh

Table 4 Energy used in maintenance (E_{main})

Item	Embodied Energy (kWh/m^2)	Total Area(m^2)	Total Embodied Energy (kWh)
Human labor	9.96	7.35	73.21

Table 5 Energy used in administration (E_{admin})

Item	Embodied Energy (kWh/m^2)	Total Area(m^2)	Total Embodied Energy (kWh)
Transportation	54.71	7.35	402.10

Total manufacturing energy (E_{mfg}) = E_{mpe} + E_{main}
= 7158.9 + 73.21
= 7232.11 kWh

Total material production energy (E_{inst}) = 960.83 kWh

Total energy used in administration (E_{admin}) = 402.10 kWh

Embodied energy is the summation of energy used in manufacturing, material production and administration.

Embodied energy (E_{in}) = E_{mfg} + E_{inst} + E_{admin}
= 7232.11 + 960.83 + 402.10
= 8595.04 kWh

B. Results Analysis and Discussions

1) Energy Pay Back Time

Energy payback time is the ratio of embodied energy (kWh) to the electrical energy generated (kWh/year) by the system-

T_{EPB} = Embodied Energy / Electrical Energy generated (yearly)

T_{EPB} = 8595.04 / 1695.25

T_{EPB} = 5 years

In 5 years, the solar system will recover the energy used in its fabrication, manufacturing and installation. For rest life time, system will provide energy gain.

2) Comparative Analysis of CO_2 Emission in PV Generator With Coal Based Plant

a) *PV System:* According to Tiwari and Nawaz [10] if electricity generated from coal based plant, an average CO_2 equivalent is 0.97 kg of CO_2 / kWh (approximately). This is calculated at source side.

There are no transmission and distribution losses in case of PV system and if the total life of PV system is considered as 30 years, yearly emission of CO_2 by each component can be evaluated as,

CO_2 emission per year = Embodied Energy × 0.97 / Life Time
= 8595.04 × 0.97 / 30
= 277.90 kg / year

b) *Coal Based Plant:* If electricity is generated from coal based plant, an average CO_2 equivalent is 0.97 kg. Of CO_2 / kWh (approximately).

However; in coal based thermal power plant, losses in transmission and distribution are 40% (approximately) so for a coal based power plant total CO_2 equivalent will be increased and this intensity for generation of electricity will now become 1.63 kg. CO_2 / kWh. At source side.

So, CO_2 emission per year = 1.63 × 1695.25
= 2763.25 kg/year

Reduction in CO_2 emission (when using PV system over coal based plant for the generation of electricity):
= 2763.25 – 277.90
= 2485.35 kg / year
= 2.48535 t CO_2 e

c) *Trading:* If the trading of reduction in CO_2 emission is @ € 21 per t CO_2 e (European climate exchange, 2008)

Then for the CO_2 emission reduction by PV system, which is considered in our case study, the annual profit becomes, 2.48535 × 21 × 81.58

= Rupees 4257.851 per (annual)

(Where € 1 = Rupees 81.58 on 12/041/2023)

For life time of 30 years it becomes, 4257.851 Rupees × 30

= 127735.53 (During lifetime)

IV. CONCLUSION

Based on this case study, the following conclusions have been drawn.

1) Embodied energy (E_{in}) of the installed PV system is 8595.04 kWh and EPBT of the system is 5.00 years.
2) Reduction in CO_2 emission; when using PV system against the coal-based plant for the generation of electricity is 2.48535t CO_2e and the monitory saving due to carbon credit is 127735.53 for life time of 30 years.
3) EPBT can be reduced if the output of system increased. For higher output from the PV system, it must operate under standard test conditions like higher solar insolation with solar cell temperature of 25ºC. Pay back of embodied energy can be reduced further with longer sun shine hours, more number of clear days e.g. Leh conditions in India.
4) The monitory savings due to carbon credit should also consider during economic analysis of PV system.

V. ACKNOWLEDGMENTS

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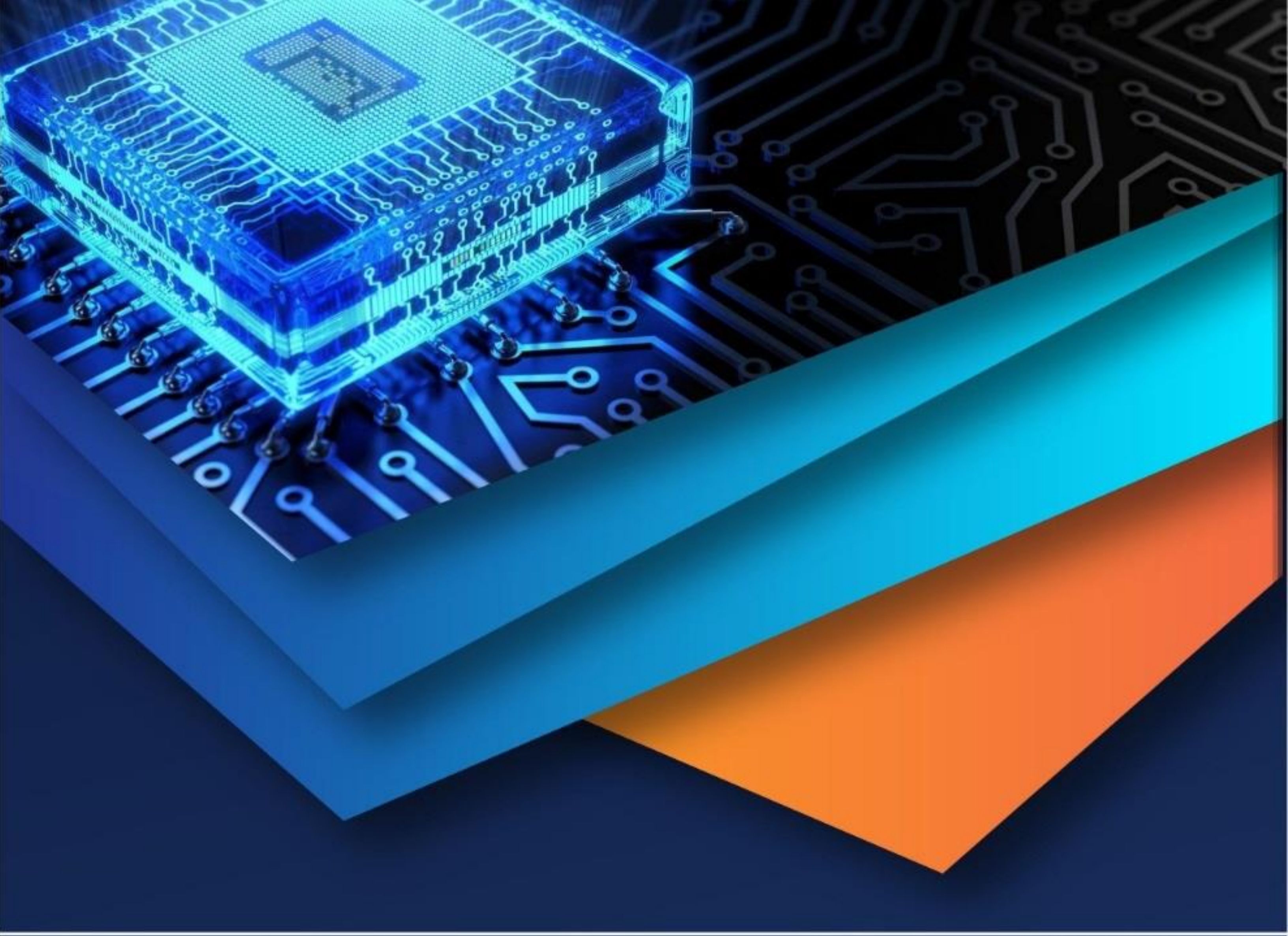

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