International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 2, February - 2014

# Study & Life Cycle Review of Solar PV Systems: an Example of a 25kwp Distributed Solar PV System in Bhopal

Manvendra Singh Thakur[1,] Miss Savita Vyas[2] Anurag Gour[3]
1. M.Tech Scholar School of Energy Technology, UTD, RGPV Bhopal INDIA
2. Assistant Professor School of Energy Technology, UTD, RGPV Bhopal INDIA
3. Assistant Professor School of Energy Technology UTD, RGPV Bhopal INDIA

***Abstract*-In life cycle review (LCR) of solar PV systems, energy payback time (EPBT) is the normally used pointer to validate its primary energy use. However, EPBT is a utility of competing traditional energy sources with which electricity generation from solar PV system is compare, and amount of electricity produced from the solar PV system, which changes with solar irradiation and local ambient conditions. Consequently, it is more suitable to use location - specific EPBT for major decision-making in solar PV power generation planning and commissioning. LCR and life cycle cost benefit analysis are performed for a 25 kW$_p$ mono-crystalline solar PV system operating in RCVP Noronha Academy of Administration Bhopal Madhya Pradesh. Coordinates: 23°12′24″N 77°25′37″E**

**This paper evaluates different parameters from a life cycle perspective that affect climate change mitigation. The primary objectives are to quantify the different life cycle effects on resulting greenhouse gas (GHG) emissions for electricity produced by mc-Si panels for grid-connected systems in Bhopal Madhya Pradesh. The study considers the effects of energy efficiency measures, location of production, installation, building-integrated options, and climatic effects.**

***Keywords: life cycle, monocrystalline PV, climate change mitigation.***

## 1. INTRODUCTION

This paper presents a review of life cycle assessment (LCA) of solar PV based electricity generation systems. Life cycle assessment of amorphous, mono-crystalline, poly-crystalline, thin film is most superior and secures technologies for the solar panel production has been studied. This paper includes various EPBT analysis of the PV system with reference to an oil fired power generation plant and greenhouse gas (GHG) emissions and their installation costs are compared. This paper proposes that however the cost of electricity generation is high in solar PV power plant, but it has some benefit also as per the global environment is concern.

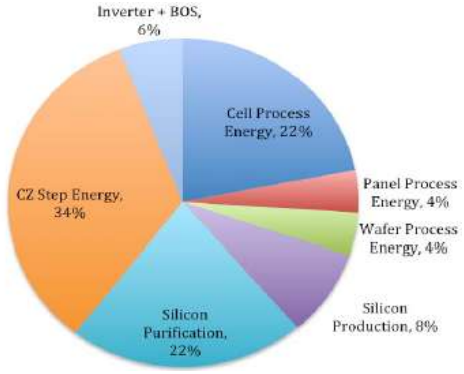
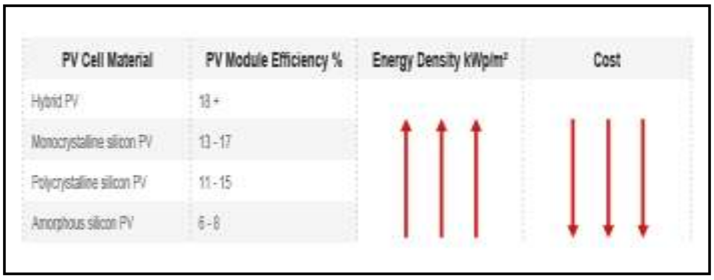


Fig 1 The sharing of personified energy requirements for mc-Si PV array power plant

In this paper, we present major life cycle impact parameter (e.g., energy payback time and life cycle emissions) of solar PV technologies for which detailed data are available. This paper also includes the life cycle list data that were the building block of the reported LCR results. Fig 1 shows the distribution of embodied energy requirements for mc-Si PV power plant



| PV Cell Material | PV Module Efficiency % | Energy Density KWp/m² | Cost |
|---|---|---|---|
| Hybrid PV | 18 + | ↑↑↑ | ↓↓↓ |
| Monocrystalline silicon PV | 13 - 17 | | |
| Polycrystalline silicon PV | 11 - 15 | | |
| Amorphous silicon PV | 6 - 8 | | |

Fig: 2 Comparison of different PV cells

### *1.1. Basics of PV solar Cell*

1.2. The PV cells are basic elements of PV generation system. Analysis of PV cells is basis for researching maximum power point tracking control algorithm. The electric generation principle of PV cells comes from PV effect, which of its physic structure is similar to PN junction in diodes. When the sun light shines on PV cells, PN junction can produce voltage. The power of one PV cell is very small. It is necessary for PV array to get greater power by connecting large number of PV cells in series. The equivalent circuit of PV cells is given in Fig.3

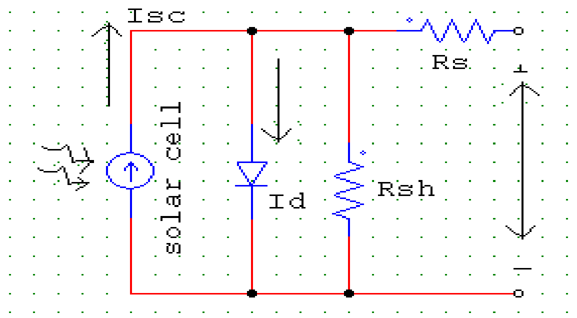


Fig. 3PV Cell equivalent electrical circuit

In an Ideal solar cell

$$J = J_0 \left(exp\frac{qV}{nKT} - 1\right) - J_{ph} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The open circuit voltage is

$$V_{oc} = \frac{nKT}{q} Ln\left(\frac{J_{ph}}{J_o} + 1\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The short circuit is:

$$J_{sc} = -J_{ph} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

### 1.3. *PV Cell and Module Ratings*

- **Standard Test Conditions (STC)**

In order to compare solar cells on a like for like basis a set of Standard Test Conditions (STC) has been defined. The conditions are normal irradiance of 1000w/m$^2$, cell temperature 25 °C & Air Mass =1.5

- **Air Mass**

The receiving surface corresponding to AM 1.5 is defined as an inclined plane at 37° tilt (the average latitude in the USA) toward the equator, facing the sun. In this case, the surface normal points to the sun, at an elevation of 48.81°, its zenith angle, above the horizon.

- **Rated Power**

Rated Power is the maximum power generated measured in (Wp or kWp) by the solar cell or solar module under the Nominal Test Conditions.

### 1.4. *PVcell Performance Characteristics*

The PV Cell VI graph shows reveals that by incident of constant solar irradiance the generated output voltage of a cell falls, to provide more current.

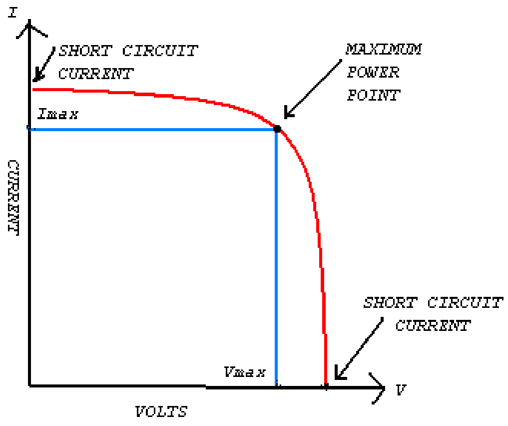


Fig: 4 solar cell Array VI Charctestics curve

The Fill Factor (FF) is defining as the ratio between the power at the maximum power point and the product of the open circuit voltage and short circuit current. It is typically better than 75% for good quality solar cells.

$$FF = \frac{Pmax}{P_T} = \frac{I_{mp} \cdot Vmp}{Isc \;\; Voc} \ldots\ldots\ldots\ldots (4)$$

## 2. LIFE CYCLE ASSESSMENT OVERVIEW

The life-cycle for preparing photovoltaic cell starts from the extraction of raw materials from the material supplied and ends by disposing or recycling of the PV components (Figure 5)

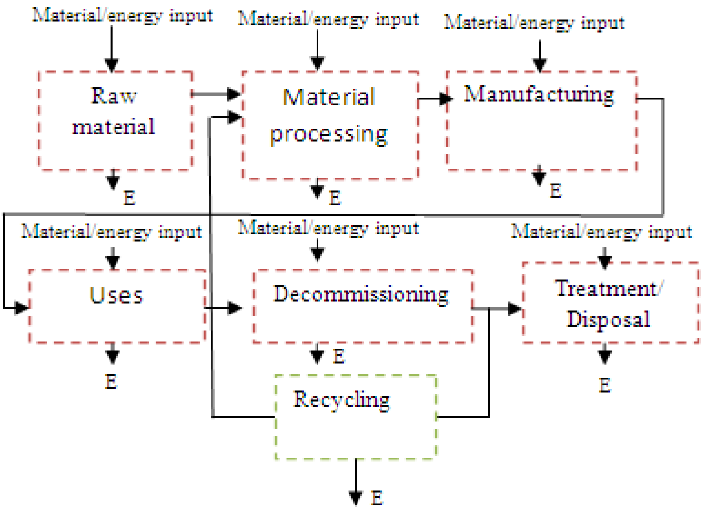


Fig: 5 Life cycle flow diagram of preparing PV Cell

The Basic or raw material consist of those for balance-of-system and encapsulations components and the material required for mounting structures. The manufacture of a bulk silicon PV device is divided into several steps, that is, wafer, cell, and module. In the wafer stage, solar-grade polycrystalline or single-crystal silicon ingots are sliced into 0.2 mm thick wafers.

During the cell stage, a p-n junction is formed by dopant diffusion and electric circuit is created by applying and sintering metallization pastes.

Plant Specification for 25 $kW_p$ mono-crystalline solar PV system operating in RCVP Noronha Academy of Administration Bhopal Madhya Pradesh, shown in table 1

| Particulars | Solar Power Plant |
|---|---|
| Capacity | 25 KWp |
| Type | Roof Top |
| Units | 1 Unit |
| Uses | Battery backup system for existing electrical appliances |
| Scope of Supply | Includes Solar PV module,Inverter,Battery |
| Solar panel wattage | 60 Wp X 90 No's |
| Battery Rating | 12 V 1500Ah X 50 |
| Power Saving PM | 1500 units |
| Money saved PM | Rs ,9950/- |
| Not in Scope | Civil work, conduit material ,wiring |
| Technical Support | MPUVN Bhopal |
| Cost | 52.00 Lack<br>Central subsidy 15.00L<br>State subsidy 10.40L |
| Area required | 3750 sqft |

Table 1: Specification of solar PV plant

## 2.1. *Life Cycle Assessment Indicators and Interpretation*

### *2.1.1 Primary Energy Demand*

This is the cumulative primary energy demand throughout the life cycle of a PV system. Primary energy is defined as the energy personified in natural resources or that we get from nature of natural resources that has not undergone any anthropogenic conversion and needs to be converted and transported to become usable energy [1].

### *2.2 Energy Payback Time*

Energy payback time is defined, as the period required by renewable energy power plant system to produce the equal quantity of energy (in terms of primary energy equivalent) that was used to generate by the system itself. Energy payback for roof top PV power plant or standalone system is shown in fig 6

$$(EPBT)=(Emat+Emanuf+Etrans+Einst+EEOL)/((Eagen/nG)EO\&)$$

Where,

**Emat:** Primary energy demand to produce materials comprising PV system

**Emanuf:** Primary energy demand to manufacture PV system

**Etrans:** Primary energy demand to transport materials used during the life cycle

**Etrans:** Primary energy demand to transport materials used during the life cycle

**Einst:** Primary energy demand to install the system

**EEOL:** Primary energy demand for end-of-life management

**Eagen:** Annual electricity generation

**EO&M:** Annual primary energy demand for operation and maintenance

**nG:** Grid efficiency, the average primary energy to electricity conversion efficiency at the demand side.

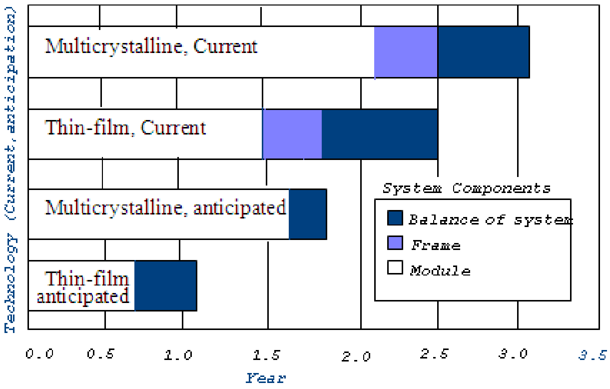


Fig: 6 Payback of energy investment for Rooftop PV system

### *2.3 Return on Energy Investment (ROEI)*

The conventional way of calculating the Return on Energy Investment of PV is as follows:

***EROI = lifetime / EPBT = T· ((Eagen/nG) – $E_{O\&Mr}$)/ (Emat+Emanuf+Etrans+Einst+EEOL)***

We noted that sometimes the EROI is computed without the prior conversion of the generated electricity into its primary energy-equivalent, resulting to an EROI lower by a factor of 1/nG than the EROI calculated by the recommended equation above.

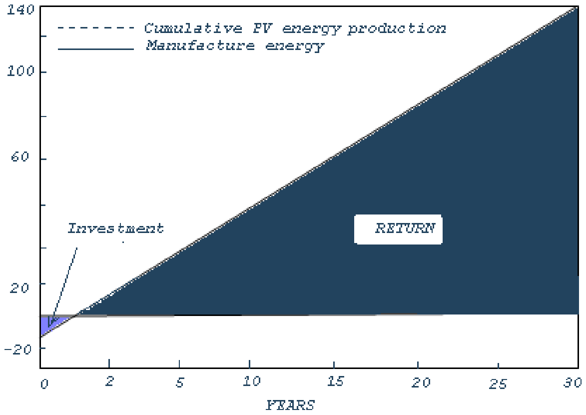


Fig: 7 Cumulative Net Clean Energy Payoff for solar PV system

It is mandatory to specify the approach on which the calculation is based (total or nonrenewable energy) and thus keep the transparency and traceability of the calculated EROI.Energy return payoff for a solar PV system is shown in fig 5.

| **Parameter** | **Value** |
|---|---|
| **Solar Irradiation** (kWh/$m^2$/yr) | 1,700 \| 2,400 |
| **System Lifetime** | 30 years |
| **Crystalline Silicon Module Efficiency** | |
| Mono-crystalline | 14.0% |
| Multi-crystalline | 13.2% |
| **Thin Film Module Efficiency** | |
| Amorphous silicon (a-Si) | 6.3 % |
| Cadmium telluride (CdTe) | 10.9% |
| Copper indium gallium diselenide (CIGS) | 11.5% |
| **Performance Ratio** | |
| Ground-Mounted | 0.80 |
| Rooftop | 0.75 |

Table 2: Different Solar PV Array Parameter for Calculation of Life Time

| **Cell Type:** | **Mono-crystalline** |
|---|---|
| **Cell Arrangement:** | 90 (9x 10) |
| **Dimensions:** | 64.5 x 38.7 x 1.57in (1638 x 982 x 40mm) |
| **Weight:** | 44.1 lbs (20kg) |
| **Front Cover:** | Tempered glass |
| **Frame Material:** | Anodized aluminum alloy |
| **Standard Packaging (Modules per Pallet):** | 24 pcs |

Table 3: Mechanical data for the specified solar PV power plant site

### *2.4 Establishing Baseline emission*

One important consideration for life cycle assessments conducted in India is the verification and evaluation of baseline emissions. Often the studies that span a series of 10-30 years assume the electricity generation mix may remain constant. However, both the electricity mix and emissions will likely change over the next thirty years. Therefore, assessments should incorporate predictive modeling to estimate the future electricity generation mix. Another issue arises when studies assume that all electricity produced by solar electricity will replace electricity generated by a conventional source. However, with expected electricity demand to increase, it is unclear how much the electricity supply will increase and therefore whether solar will supplement the current electricity or displace the production of marginal electricity sources. These issues all affect the amount of GHG emissions offset by generating solar electricity and create different life cycle assessment results

## 3. SIMULATION RESULTS FOR DIFFERENT SOLAR PV TECHNOLOGIES

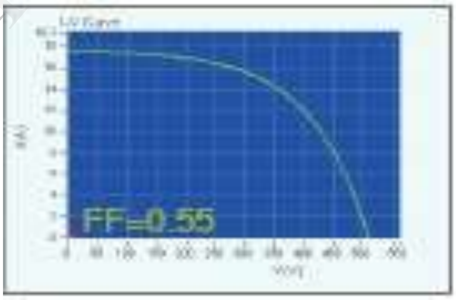


Fig: 8 Thin Film PV Array

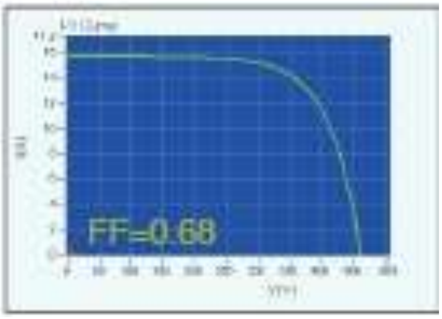


Fig: 9 Standards Crystalline Array

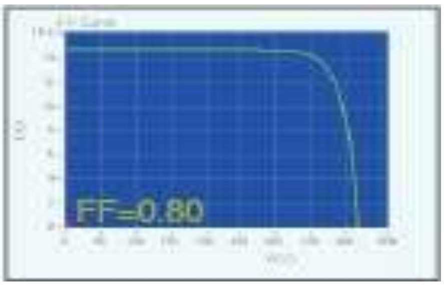


Fig: 10 High Efficiency Crystalline

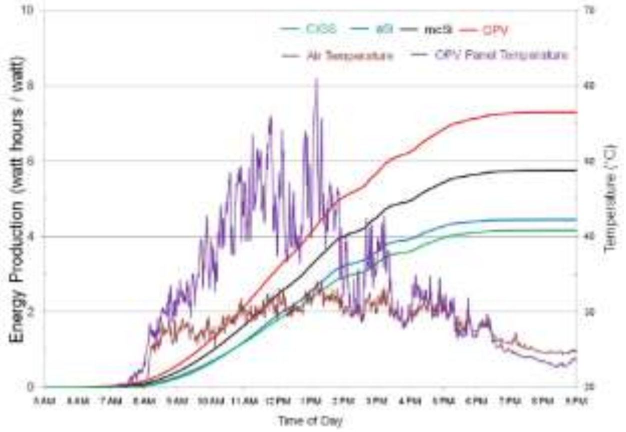


Fig: 11 Electrical energy [production curve for different solar PV technologies

## CONCLUSION

An assessment of renewable energy technologies for their potential to decrease GHG emissions requires careful analyses of all the stages in the life of the fuels and devices. Quantifying such emissions in both present-day and prospective contexts is dominant for comparing the environmental profiles of different electricity-generation options. GHG emissions in the lifecycles of solar electric and nuclear-fuel- technologies vary, depending on the efficiencies of upstream energy, local conditions, and other assumptions. Previous studies showing nuclear technology to have a clear GHG advantage over PV are greatly outdated; the emissions from the life cycles of the two cycles are comparable under today's average Asian country Conditions. In addition, GHG emissions during the life cycle of PV are lower than those from a biomass direct-firing cycle and an order of magnitude lower than those from coal, petroleum and natural gas burning. Established trends in the PV cycles of current PV technologies are expected to keep further reducing emissions in the solar-electric cycle.

## REFRENCES

1. Varun, Bhat IK, Prakash, R, LCA of renewable energy for electricity generation – a review, Renewable and Sustainable Energy Reviews 13 (2009) 1067-1073.
2. Mermoud A, Roecker C, Bonvin J, PVSYST Version 4.37 (2009).
3. [3] Razykov TM, Ferekides CS, Morel D, Stefanakos E, Ullal HS, Upadhyaya HM, Solar photovoltaic electricity: Current status and future prospects, Solar Energy 85 (2011) 1580-1608.
4. [4] Jungbluth N, Stucki, M, Flury K, Frischknecht R, Busser, S, Life Cycle Inventories of Photovoltaics, ESU-Services, Ltd., Swiss Federal Office of Energy (2012).
5. [5] Pacca S, Sivaraman D, Keoleian GA, Parameters affecting the life cycle performance of PV technologies and systems, Energy Policy 35 (2007) 3316-3326.
6. [6] LDK, the World's Largest Manufacturer of Solar Wafers,http://www.ldksolar.com/pro_wafer_mon.php, Accessed July 2012.
7. [7] Pizzini S, towards solar grade silicon: Challenges and benefits for low cost photovoltaics, Solar Energy Materials & Solar Cells 94 (2010) 1528-1533.
8. [8] R. Dones; R. Frischknecht, "Life Cycle Assessment of Photovoltaic Systems: Results of Swiss Studies on Energy Chains."Appendix B-9, Report Number 97072, 1997.
9. [9] J. M. Mason, V. M. Fthenakis, T. Hansen and H.C. Kim, Energy Pay-Back and Life Cycle CO2 Emissions of the BOS in an Optimized 3.5 MW PV Installation. Prog. Photovoltaic: Res. Appl. 14, 2006, pp.179-190.
10. [10] V. M. Fthenakis and H.C. Kim "Energy Use and Greenhouse Gas Emissions in the Life Cycle of CdTe Photovoltaics," Mater. Res. Soc. Symp. Proc. 0895-G03-06.1, 2006.