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Life Cycle Assessment of Rooftop Solar Photovoltaic System

Prashant Kaushik [1], Dr. Shishir Dixit [2], Prof. Shweta Kumari [3]

B. Tech. student, Electrical Engineering Department, MITS, Gwalior (M.P.), India[1]

Professor, Electrical Engineering Department, MITS, Gwalior (M.P.), India[2]

Professor, Electrical Engineering Department, MITS, Gwalior (M.P. India[3]

Abstract: The population of whole world is increasing, so the requirement of electricity is also increasing, that's why we have to produce more electricity. But the whole world is looking for clean environment and sustainable development and it is need also because of this we are going towards renewable energy sources for generation of electricity. Use of solar PV system is increasing in all over the world, because of its potential to reduce the energy consumption form traditional sources and to decrease the air pollution. Life cycle assessment (LCA) it is a study of impact on environment by technology or product in its whole life (form beginning to end of life). In this paper we did LCA on 100kw rooftop solar PV system. It is placed in MITS Gwalior (M.P.). We find out Embodied energy, energy payback time (EPBT). Total annual energy.

Keywords: LCA, (EPBT), Embodied Energy, Energy analysis, Annual energy.

I. INTRODUCTION

As every country in the world, including our India is progressing, natural resources are being used increasingly. Moreover, there is a lot of industrial activities like the setting up of industrial plants etc. Hence it is expected to see that the natural re-sources are depleting and thus it behoves us to start considering the possibility of recycling them as opposed to getting newer natural resources. Air, water and soil are very important part of our life. It's our duty to keep them clean and pure. These industrial activities are increasing because the world population is over 7.9 billion. Along with the population, the affluence and affordability is also increasing. 20 to 25 years back may be in mid 80sand early 90s, having just a TV in the house was considered luxury. But now multiple TVs became a commonplace commodity even in middle class houses. The cost of these electronics is now affordable so the de-mind of electricity is increasing. If we want the clean environment and sustainable development so we have to go with renewable sources of energy. Sun is the best renewable energy source to generate electricity. In 2005 Nawaz and Tiwari had evaluated the total embodied energy without battery replacement that was equal to 1380 kWh/m² and energy payback time (EPBT) that was equal to 13 years. But that system was off grid system. (Nawaz & Tiwari, 2005, #) had evaluated embodied energy without battery replacement and energy payback time (EPBT) for a rooftop system which were equal to 1380 kWh/m² and 13 years respectively. But the system for which they had evaluated embodied energy and EPBT was an off-grid system. [1] (Barnwal & Tiwari, 2008, #) in 2008 had estimated embodied energy, Energy pay-back time, energy production factor and life cycle conversion efficiency for a roof-top system which were equal to 249.04 kWh, 3.53 years, 2.84 and 0.1064 respectively.[2] In 2009, embodied energy, energy payback time, energy production factor and life cycle conversion efficiency of a stand-alone photovoltaic system was estimated by (Prabhakant & Tiwari, 2009, #) which were equal to 198166.89 kWh, 17.21 years, 1.99 and 0.22 respectively.[3] In 2014, an experimental study was conducted by (Sudan & Tiwari, 2014, #) for evaluation of energy matrices of the building by incorporating daylight concept for composite climate. In that experimental study energy payback time, energy production factor and life cycle conversion efficiency were estimated equal to 5.5 year, 9.09 and 0.17 respectively. [4] A case study was conducted by (Gupta & Tiwari, 2017, #) to study and analysis the integration of residential buildings with Photovoltaic systems. For an intensity of 450 W/m² and AT = 8°C.Energy payback time, Energy production factor and Life cycle conversion efficiency were estimated equal to 15.32 years, 19.58 and 0.47 respectively.[5] The analysis of the PV system has been performed under the same environmental Conditions likely solar irradiation, ambient temperature and wind speed, etc. Energy payback time (EPBT), energy production factor (EPF) and life cycle conversion efficiency (LCCE) of the PV system has been found to be 3.60 years, 0.27 and 0.0018 respectively. The unit cost of electricity of the PV system has been calculated as 9.85 INR/kW h for 5% interest rate and 30 years life span.[6]. In 2013 (Asif Ali, Aarif Zaheer and Osama Khan) did LCA on solar PV electricity generating system. Find the total annual units are 1013016 units, total cost in a year is 17221272Rs, total selling cost by plant in 25 year is 422610014.9 Rs.[7]. In 2019 (Anushka Pal and Jeff Kilby) in that study Life Cycle Assessment of multi-crystalline Photovoltaic (PV) panels, by considering environmental impacts of the entire life cycle

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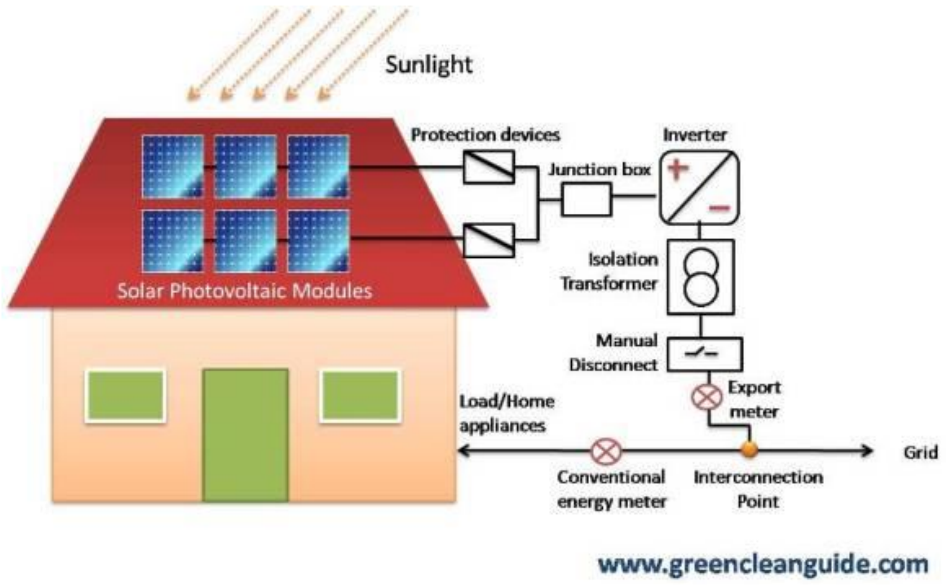
for any solar PV Systems. The overall manufacturing process of a solar PV panel ranging from silica extraction, crystalline Silicon ingot growth, wavering to module fabrication and packing of the solar PV panel. The results from this research showed that the module assembly and cell processing of the manufacturing process contributed towards the main environmental impacts of the life cycle of solar PV systems [8]. In 2016 (DB Singh, Al-Heal, Yadav and Tiwari) in that paper they did life cycle conversion efficiency for single slop and double slop passive solar still based on annual energy. That was is 1159.43, 1037 kWh and 108.4 kWh respectively.[9].

II. SYSTEM DESCRIPTION.

The system is placed in MITS (Gwalior). It is 100kW Rooftop PV system, this module supplied by Vikram Solar Pvt. Ltd. An effective area of each module is 1.919 m2and produces 320W peak power. The total effective area of the associated 308 number of modules in series/ parallel string combination is 591.052 m2. PV module is made of semiconductor material. When the sun radiation falls on the PV cells, its produces electricity by the photovoltaic effect. In this rooftop PV array, the power output of the PV is converted from direct current supply to alternating current supply by inverter. The three-phase commercial two inverters (50 kW) is used in the system. The inverter output terminals are connected to the common coupling point, and the common coupling point is connected to the load. There are two loads connected first hostel load is connected to 315 kVA transformer and second college load is connected to500 kVA transformer. Due to fault or cloudy weather conditions, if the roof top PV system is not able to supply the load, a change is made to the grid by a switch located at the common coupling point. Supplies are not available in the grid, so generators are used to supply. The load (single phase AC operated). This complete system is shown in figure.

This system is having total 308 number of PV modules. All rating of each module is as follows.

- The Peak power = 320 W.
- Module efficiency = 16.5%.
- Open circuit voltage = 46.6 V.
- Rated current = 8.5 A.
- Short circuit current = 9.04 A.
- Rated voltage = 37.84 V.



III. ENERGY ANALYSIS.

Our energy analysis researchers work with rooftop solar PV energy systems to provide information about efficiency, clean energy, reliability and sustainability of the system. By the energy analysis we are able to find that system is energy efficient or not and also, we can find (EPBT), and annual energy (kWh) generation of rooftop solar PV system.

A. THE ANNUAL ENERGY GENERATION of SYSTEM IN (kWh).

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We get data by software which is installed along with the system, for this energy analysis.in Table 1 shows energy generation by the system.

TABLE I . ANNUAL ELECTRICITY GENERATION

Date	Generation (kWh)
26.11.2019 – 13.01.2020	9574.02
13.01.2020 – 30.08.2020	92122.25
30.08.2020 – 29.09.2020	12313.45
29.09.2020 – 30.10.2020	9380.7
30.10.2020 – 26.11.2020	6768.1
	130158.52 (Total)

We find the total annual electricity generated by adding all data.
E per year = 130158.52 (kWh).

B. TOTAL EMBODIED ENERGY CALCULATION.

Embodied energy is the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself. The concept can be useful in determining the effectiveness of energy-producing or energy saving devices, or the "real" replacement cost of a building, and, because energy-inputs usually entail greenhouse gas emissions, in deciding whether a product contributes to or mitigates global warming. One fundamental purpose for measuring this quantity is to compare the amount of energy produced or saved by the product in question to the amount of energy consumed in producing it. The embodied energy is defined as the amount of power needed for all tasks related to the manufacture process, transportation to site and construction throw-out the whole life. A solar system embodied energy should be less as well as possible. If embodied energy is greater than output energy then system is not efficient. Energy used in making equipment and other supporting function (i. e. direct energy and indirect energy). The embodied energy of various materials used in the manufacture of solar panels is given below in Table 2.

TABLE I I. MATERIAL PRODUCTION ENERGY.

Material	Embodied Energy (kWh/m^2)	Total Area (m^2)	Total Embodied Energy (kWh)
Silicon Purification and	670.00	591.052	396004.85
Processing: Metallurgical grade silicon production, electronic grade silicon production, Silicon crystal growth			
Solar Cell Production	120.00	591.052	70926.25
PV Module Lamination and Assembly: Steel infrastructure, Ethyl vinyl acetate, Tedlar production, Glass Sheet production, Aluminium frame production, other materials	190.00	591.052	112299.9

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Total material production energy = 579230.59 kWh.

The embodied energies and weights of materials used in the supporting structure are shown below in Table 3

TABLE I I I . PV SYSTEM INSTALLATION ENERGY.

Item	Embodied Energy	Total Weight	Total Embodied Energy (kWh)
Support Structure: Iron stand Screw	7.70 (kWh/kg) 8.63 (kWh/kg)	1500 kg 40 kg	11550 (kWh) 345.2 (kWh)
Inverter	210.00 (kWh/kW)	100 kW	21000 (kWh)
Wires	3.00 (kWh/m^2)	591.052 m^2	1773.156 (kWh)

Total material production energy = 34668.356 kWh.

TABLE IV. ENERGY USE IN MAINTENANCE.

Item.	Embodied Energy (kWh/m^2)	Total Area (m^2)	Total Embodied Energy (kWh)
Human Labor	9.84	591.052	5815.96

TABLE V. ENERGY USED IN ADMINISTRATION.

Item.	Embodied Energy (kWh/m^2)	Total Area (m^2)	Total Embodied Energy (kWh)
Transportation	53.50	591.052	31621.282

Total manufacturing energy (E mfg.) = E mpe + E main
= 579230.96 + 5815.9
= 585045.99 kWh.
Total Material Production Energy = 34668.356 kWh.

Total energy used in administration = 31621.179 kWh.

Embodied energy (Ein) = 585046.92 + 34668.431 + 31621.199
Ein = 651336.499 kWh.

This contain the assessment of the overall energy consume to extract the raw material, manufacture a product or components, installation and maintain the component element whichever is being assessed.

IV. WHAT IS LCA

Life cycle assessment (LCA) is an approach to environmental management system implementation involving the quantitative evaluation of a product's overall environmental impact. Energy requirements and CO2 emissions throughout the whole life cycle of the product (including its manufacture, transport, use, disposal, etc.) are estimated in order to enable such evaluation, and the results can be used for related environmental assessment. However, since life cycle is related to a broad range of variables and is complicated, it is difficult to comprehend the exact significance of the results. Accordingly, it is very important to set a purpose for the evaluation. An LCA operator should implement research that matches the purpose and interpret the outcomes appropriately. The research and analysis scheme for LCA consists of the four stages shown in Fig. As follows: 1. goal and scope definition; 2. inventory analysis; 3. impact assessment; and 4. interpretation. The results of inventory analysis are referred to as life cycle inventory (LCI) data. LCA is applicable to any product or service, but its results are affected by objects, assumptions, data availability and accuracy. Hence, it is

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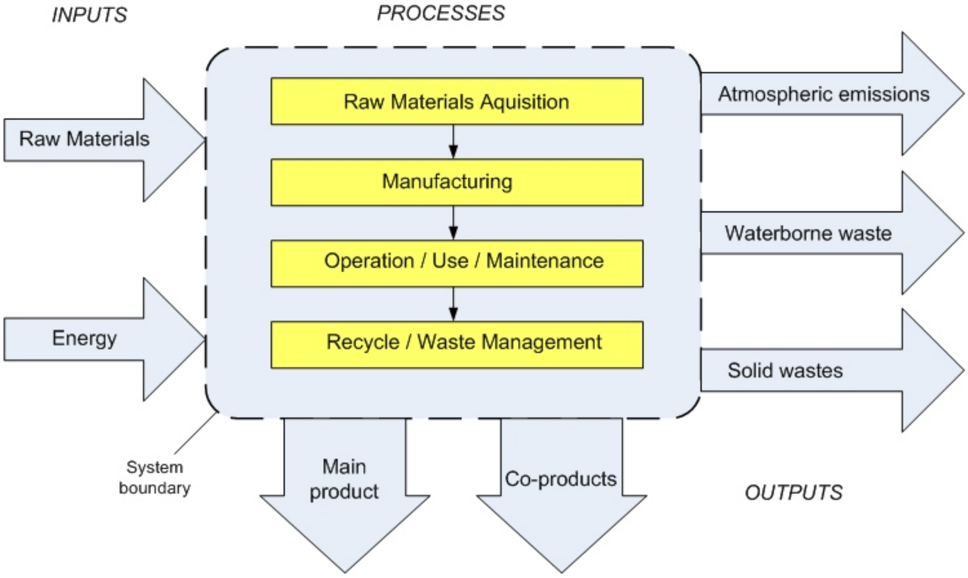
impossible to generalize the method in a very clear way. As a result, LCA operators and users must properly understand the limitations of LCA and the assumptions that can be drawn from its results. The essentials of LCA are standardized in ISO 14040 and ISO 14044, which stipulate the details and basic points of the approach.



FIGER.2. Block Diagram of Life Cycle Assessment.

V. LCA OF PV SYSTEM.

An LCA is performed to evaluate the life cycle energy usage and GHG emissions from electricity generation from a SPV system. A life time 25 years is considered for the SPV system. However, PV modules are expected to have longer life time according to manufacturer guarantee. India does not have yet expensive life cycle data base available for general use consequently, some data are available for energy as well as co2 emissions, much of the data used in this study were based on analysis undertaken in other countries. The life cycle of a solar power system is considered to be comprised of three phases, namely construction, operation and decommissioning. The complete methodology which is used here is summarized below:

1. Compilation of the material inventory for the total power system.
2. Compilation of the life cycle energy. It is an inventory of the energy inputs. The life cycle energy requirements should be considered initially as thermal and electrical energy separately and then converted to equivalent primary/electrical energy by using conversion efficiency.
3. Compilation of the life cycle GHG (Green House Gas) emissions which is estimated from each component of SPV system which is studied.
4. Estimation of the electricity generation by the PV system.
5. Estimation of environment indicators i.e., EPBT (Energy Pay Back Time) and GHG emissions.

This is the net energy productivity of the system with respect to the solar energy (radiation) over the life time of the system. The following methodology has been adopted for life cycle conversion efficiency Analysis of solar system.
For the complete analysis of solar system, the embodied energy, annual generation of energy and the LCCE analysis of the system is also done. The LCCE of the system mainly depends on embodied energy, total energy generation by system, solar input (radiation) and total life time of the system that is 25 years.

$$EPBT = \frac{Ein}{Eaout}$$

$$= \frac{651336.499}{130158.52} \quad [3]$$

$$EPBT = 5 \text{ years}$$

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$$EPF=\frac{Eaout}{Ein} \quad [5]$$

$$=\frac{130158.52}{651336.499}$$

EPF = 0.2 year

VI RESULT & CONCLUSION.

In this study we find out Energy Payback Time and Electricity Production Factor of the PV system is 5.0 years and 0.2 year respectively. Also, we found the embodied energy and solar input energy of the system is 651336.499 kWh and 789322.47 kWh respectively. The usually used four types of solar PV system had been reviewed with some latest PV technologies based on Life Cycle Assessment. The energy requirement, EPBT and GHG emissions have been estimated for mono-crystalline, poly-crystalline, amorphous and CdTe/CIS and other solar PV systems. For Crystalline modules have good conversion efficiency but the required primary energy is very high and corresponding EPBT and GHG emissions are also high while thin film modules consume less primary energy and have lower EPBT and GHG emission but the efficiency is low. A set of parameters is responsible for the variability in the performance of different installations. Aside from the level of incoming solar radiation, Life expectancy, BOS components, conversion efficiency, Cell Type, manufacturing process are some parameters on which it depends.

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