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ENERGY PAY BACK PERIOD AND CARBON PAY BACK PERIOD FOR SOLAR PHOTOVOLTAIC POWER PLANT

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ABSTRACT

In this paper, we have investigated the entire life-cycle assessment of polycrystalline silica module system, the energy requirement of PV modules and balance of the systems and calculated the Energy Pay-Back period for systems. Based on the past study, life cycle inventory data have been collected for this study. The detail investigation has made for the existing Roof top Solar PV Power plant at Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu. Results are reported in the form of Energy Pay Back period, CO_2 emission per KWh, CO_2 emission reduction and Carbon Payback Period.

Key words: Solar energy, Polycrystalline PV cell, Life cycle assessment, Energy pay back period, Carbon pay back period.

INTRODUCTION

Electricity has been a preferred form for energy consumption and has consistently registered a higher growth rate than other forms of energy. Increased consumption of electric power is more intimately bound up with economic development on the one hand and increased emission of pollutants on the other hand. Establishment of new industries, plants, commercial complexes and expansion of the capacity for consumer goods industries to feed its ever increasing population has led to a considerable increase in the consumption of electricity in India and, consequently, the emission levels of CO_2. Besides, with government plans for rural electrification and electricity to all, the demand for electricity is sure to increase at an astonishing rate. In India, Power sector is contributing 65% of the total CO_2 emission[1].

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Table 1 shows the data as June 2013, the installed capacity of power plant in fuel wise. The coal is dominating in the power production and contributing 57% of the entire power production. The renewable energy is contributing in the next level of power production in India[2].

Table 1: Source wise installed capacity of power plant

Fuel	MW	Contribution %
Total thermal	155968.99	68.19
Coal	134,388.39	58.75
Gas	20,380.85	8.91
Oil	1,199.75	0.52
Hydro	39,788.40	17.39
Nuclear	4,780.00	2.08
Renewable energy	28,184.35	12.32
Total	2,28,721.73	100

We are in the position to accelerate the development of advance clean energy technology in order to address the global challenges of energy security. Power being produce from the natural resource (renewable energy) is the one of the alternative method. From the renewable energy Solar Photovoltaic is a key technology option to realize the shift to a decarbonised energy supply and is projected to emerge as an attractive alternative for renewable energy technology. India is having large potential to generate the electricity form solar radiation.

India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun. The India Meteorological Department maintains a nationwide network of radiation stations, which measure solar radiation, and also the daily duration of sunshine. In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 KWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million GWh of energy per year. The highest annual global radiation is received in Rajasthan and northern Gujarat. For example, assuming the efficiency of PV modules were as low as 10%, this would still be a thousand times greater than the domestic electricity demand projected for 2015[3,4].

Because of its location between the Tropic of Cancer and the Equator, India has an average annual temperature that ranges from 25-27.5°C. This means that India has huge solar potential. Photovoltaic (PV) cells have a low efficiency factor, yet power generation systems using photovoltaic materials have the advantage of having no moving parts. The efficiency of solar photovoltaic cells with poly crystal silicon is about 13-17%. High efficiency cells with concentrators are being manufactured, which can operate with low sunlight intensities[5].

Jawaharlal Nehru National solar mission will be carried out in three phases and aims to do the following: to create a policy frame work deployment of 20,000 MW by 2022; to add 1,000 MW of grid solar power by 2013, and another 3,000 by 2017. The scheme also aims at strengthening indigenous manufacturing capability, and achieving 15 million sq. meters solar thermal collector area by 2017 and 20 million by 2022[6].

The total installed capacity of grid interactive renewable power, which was 27294 MW as on Jan' 2013. Fig. 1 is shown contribution of renewable energy in India. The share of solar in grid interactive renewable power still accounts to nearly five percent in the overall energy mix[7].

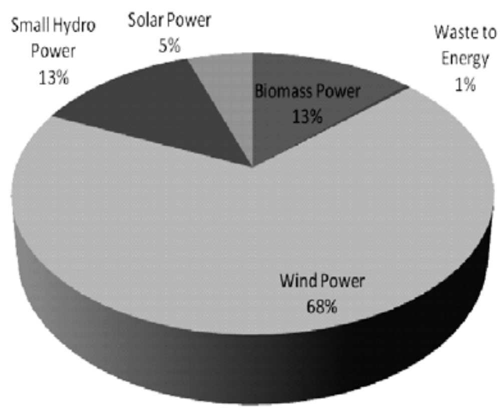

Fig. 1: Source wise installed capacity of renewable energy system

The solar mission, which is part of the National Action Plan on Climate Change, has been generated and other uses with ultimate objective of making solar energy competitive with fossil-based energy options. Solar electricity generation is given attention because it is the largest renewable energy resource with abundant reserves and the technology is friendly to the environment when compared with electricity generation by fossil fuels. The electricity from a solar cell system was found to give higher impact value than those of wind turbine and hydro, but lower than those of fossil fuel power plants[8].

From various life-cycle studies for photovoltaic systems, which range between 28.3 g/KWh to 317 g/KWh[9] and CO_2 equivalent values ranged from 23 g/KWh to 180 g/KWh[10]; the estimated payback time ranged from 0.7 to 11.8 years. Variations in the results can be for a range of factors, such as the quantity and grade of silicon, module efficiency and lifetime, as well as irradiation conditions.

Muanjit et al.[11] took for his studies 500 KWp solar power plant in Thailand. Two types of solar cell for the power plant, multi crystalline silicon (m-Si) solar cell and thin film amorphous silicon (a-Si) solar cell, are considered[11]. LCA results of the solar cell power plant in Switzerland using the new eco-invent database found that important environmental impacts were not directly related to the energy use of the solar energy electricity generation but the impacts occurred at its module production[3] as the assessed results in the Netherlands[6] and the USA[12] also show. In Japan and Thailand, the numerical environmental total standard (NETS) method and LCA technique has been applied to study the environmental impacts of the power plant systems. In multi crystalline silicon (m-Si) solar cell power generation system, the largest impact was at the manufacturing process of the array field due to natural resource (i.e. silicon and aluminum) consumption[13].

The energy requirement of present day crystalline silicon modules vary considerably; between 2400 and 7600 MJ/m^2 for the multi crystalline (mc-Si) technology and between 5300 and 16500 MJ/m^2 for single-crystalline (sc-Si) technology[14-17]. Partly, these differences can be explained by different assumptions for process parameters like wafer thickness and wafering losses. Silicon purification process required 900-1700 MJ/Kg and Czochralsky process require 500-2400 MJ/Kg. Primary crystalline step require 2400MJ/Kg of energy[18].

The present work analyzes the entire life-cycle of some selected PV system; in order to identify best opportunities for reducing CO_2 emissions, calculate the Energy payback period and carbon Payback period.

Methodology

LCA of the solar cell power plant

The life cycle assessment is based on the ISO 14040 standard, and includes a goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation. LCA has been used in many industries since the early 1990's to gage the environmental impact of the entire life cycle of a product including manufacture, use, and disposal. LCA is based on an inventory of the inputs of the raw materials, capital goods, factories, transportation, and energy and fuels needed to create a product. Fig. 2 shows the life cycle stages. The input, modification, and emissions of energy and materials are known as process flows.

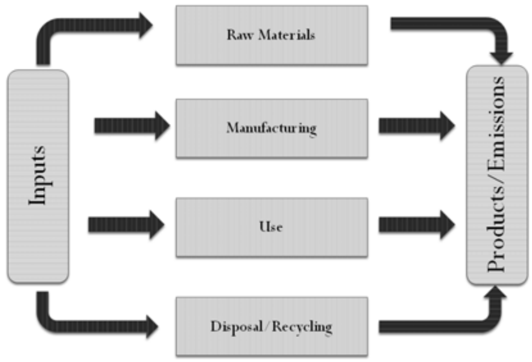

Fig. 2: Stage wise life cycle assessments

A detailed life cycle inventory of crystalline silicon modules for polycrystalline silicon feedstock purification, crystallization, wafering, cell processing and module assembly with the current status of technology. Here studied the system complexity, and material involved and power consumption of the production of solar module. Fig. 3 shows a block diagram for process steps in the production of the Poly-Si PV module. A crucible process was adapted for the Solar cell production, which is continuously cast in ingots with electromagnetic casting technology. The ingots are then cut into wafers using multi- wire saws. Several PV cells are laminated in EVA between a glass and a Tedlar sheet and finally aluminum frames are added.

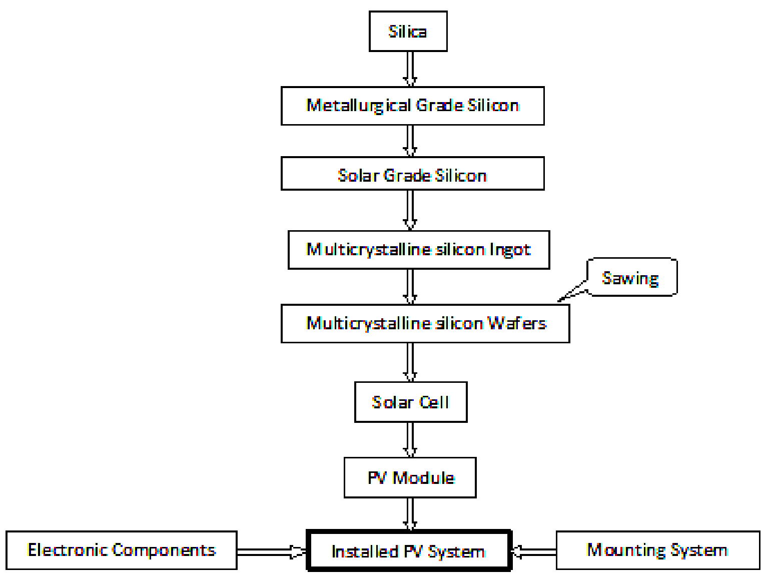

Fig. 3: Block diagram of process steps in production of Poly crystalline Module

Description of the system

In this study, we have considerd the Roof Top Solar PV power plant located at Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu. The detail of the site is given in the Table 2.

Table 2: Specification of 11 KW solar PV power plant

Description	m-Si solar model
Model	124 W
Model dimension	662 x 1482 mm
Model weight	13 Kg
Open circuit voltage (V_{oc})	21.20 V
Short circuit current (I_{sc})	8.20 A
Voltage at peak power point (V_{mp})	17.0 V
Current at peak power point (I_{mp})	7.3 A
Maximum system voltage	1000 V
Normal operating temperature	25^{o}C
Standard test	IEC 61215 and IEC 61730
No of solar panel	88
No. of battery	48

Life cycle inventory

Based on the LCA of 11KW solar plant, the result has been discussed as three categories: Material inventory, Energy inventory and Carbon inventory. Regarding the solar power plant, the foremost important environmental impact will arise during manufacturing of the solar panel and battery. On the other hand, the operational stage does not contribute significantly to the environmental impacts. Several life cycle studies exist for the solar power plant of various capacities. The available studies are differing in their scope and climatic condition; however show the dominant influence of the material production on the environmental performance of solar power plants.

Material inventory

Based on the available data, the material inventory for solar power plant is divided into three components: solar panel (PV cell and frame), supporting structure and battery.

Table 3 shows the data, in which battery consume more amount lead and lead oxide material[11].

Table 3: Material inventory

Material	Total weight (Kg)
Solar panel	
Silicon cell	105.6
Glass	572
Aluminium	440
EVA	17.6
Copper	8.8
Total	**1144**
Supporting structure	
MS angle	1240
Total	**1240**
Lead acid battery	
Lead	672
Lead oxide	940.8
Polypropylene	268.8
Sulfuric acid	268.8
Water	430.08
Glass	53.76
Antimony	26.88
Other	26.88
Total	**2688**
Grand total	**5072**

Energy inventory

The energy consumption of the solar plant is expressed as KWh of energy consumed for manufacturing of system. It includes the energy consumed in the recycling phase. Table 4 shows the detailed power consumption as material wise. Solar panel is consuming

30.48 MWh of energy for the manufacturing[11].

Table 4: Energy inventory

Process	Total energy consumption (KWh)
Solar panel	
High purity silicon production	11348.70
m-Si wafer production	1853.50
Solar cell production	2336.40
m-Si module assembly	1811.70
Aluminium production	8632.80
Glass production	2913.90
EVA production	1079.10
Copper production	53.90
Tedlar production	453.20
Total	**30483.20**
Supporting structure	
MS angle	**4534.11**
Lead acid battery	
Lead	4176.49
Lead oxide	3329.95
Poly propulene	5656.05
Sulfuric acid	3.15
Glass	299.66
Glass fiber	346.48
Total	**13811.77**
Grand total	**48829.09**

Carbon inventory

Among the various environmental impacts, this paper considers the carbon emission from various activities in the life cycle of the solar power plant. Table 5 describes the carbon emission in the various stages of solar power plant. The maximum carbon emission is accounted in the manufacturing of solar panel. Nearly 5.5 tons of carbon has emitted in the manufacturing of batteries[11].

Table 5: Carbon inventory

Process	Carbon emission (Kg)
Solar panel	
m-Si module production	447.92
Aluminum production	5478.00
Glass production	162.80
EVA production	39.60
Copper production	57.20
Tedlar production	202.40
Total	**6387.92**
Supporting structure	
MS Angle	942.40
Lead acid battery	
Lead	739.20
Lead Oxide	1005.89
Polypropylene	1370.88
Sulfuric acid	1720.32
Glass	602.11
Glass Fiber	102.14
Total	**5540.54**
Grand Total	**12870.86**

RESULTS AND DISCUSSION

Electricity generation capacity

The average radiation at site is 4.73 $KWh/m^2/d$. Based on that; average electricity production per year from the solar PV plant is 22.8 MWh. The overall electricity production of site is 570 MWh during its lifetime Table 6.

The following assumption has been made for the calculation -

Efficiency of the PV module -17.38%

Losses in DC circuit - 3%

Converter Efficiency - 92%

Losses in AC circuit - 3%

Life time - 25 years

Table 6: Life time electricity production of the 11 KW project

Capacity (kw)	Average radiation (KWh/m^2/d)	Total area of PV panel	Electricity generation per year (MWh)	Life time of plant	Life time electricity production (MWh)
11	4.73	86.34	22.8	25	570

Energy pay back period

The energy consumption of 11 KW solar power plant is 48829 MW per turbine. This is nothing but the energy consumed in the life cycle of solar plant. The energy intensity of the 11 KW plant for this sit condition is 0.086. The energy payback period for the above capacity solar plant is 2.14 year (Table 7). The energy pay back period can be calculated using the equation (2).

$$\text{Energy intensity} = \frac{\text{Total input energy (KWh)}}{\text{Life time electricity production (KWh)}} \qquad \ldots(1)$$

$$\text{EPBP} = \frac{\text{Energy consumed by solar plant (MWh)}}{\text{Energy produced by solar plant per year (MWh)}} \qquad \ldots(2)$$

Table 7: EPBP for the 11 KW solar plant

Capacity (KW)	Electricity generation per year (MWh)	Life time electricity production (MWh)	Electricity consumed by plant (MWh)	Energy intensity	EPBP (Year)
11	22.8	570	48.83	0.086	2.14

Carbon payback period

Carbon intensity is nothing but, the carbon emission associated with the manufacturing, operation and decommissioning of the wind turbine per unit of electricity production over the life time. The simplified equation is given below.

$$CO_2 \text{ Intensity} = \frac{\text{Life cycle } CO_2 \text{ emission (g of } CO_2)}{\text{Life time electricity generation (KWh)}} \quad \ldots(3)$$

Carbon Pay Back Period is nothing but, a measure of how long a CO_2 mitigating process needs to run to compensate the CO_2 emitted to the atmosphere during the life cycle stage. CPBP for the 11 KW solar plant is 73 days (Table 8).

$$CPBP = \frac{\text{Life cycle } CO_2 \text{ emission}}{\text{Gross } CO_2 \text{ emission avoided per year}} \times 365 \quad \ldots(4)$$

Table 8: Carbon pay back period for the 11 KW solar plant

Life cycle CO_2 emission (Kg)	Life time electricity production (MWh)	CO_2 intensity (Kg/MWh)	Carbon intensity of coal based power plant (Kg/MWh)	Carbon reduction by solar power plant (Kg/MWh)	Gross CO_2 reduction per year	CPBP (days)
12870.86	570	22.58	941	918.42	20939.97	224.35

CONCLUSION

The present paper gives the result of carbon reduction in the Roof Top Solar PV power plant at Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu. Energy intensity of the solar plan is 0.086. Energy Pay back Period for this system is 2.6 years. Carbon intensity for the solar plant is estimated as 22.58 Kg/MWh.The carbon emission for the total life cycle was estimated at 9.8 tons. The carbon payback period for the 11 KWh roof top plant is 224 days.

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