# Sustainability Analysis of a 10 MW Solar Project in Andhra Pradesh using Life Cycle Assessment studies

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***Abstract*— India has started its journey to sustainability and other positive steps including increased taxes on carbon, fiscal policy measures to sustain afforestation, investment in public transport systems for cities, plans for a massive increase in renewable energies and the requirement of environmental clearances for large scale projects. The LCI data is the result of inventory analysis. LCA method is impossible to generalize due to complexity in data availability, assumptions, objects and accuracy. Hence, it is important for the operators and users to know the limitations and assumptions to be drawn from the LCA results. The analyses of the environmental impacts with different LCA methods have shown that it is quite important to include process specific emissions of the production chain. But not all possible emissions are investigated in India and data is not sufficient for analysis. A 10 MW plant with EPBT of 1-6 years can be estimated to have a range of 50-90 g-$CO_2$/kWhe from studies. It is necessary to evaluate all types of environmental impacts with different LCA methodologies if photovoltaic power plants shall be compared with other types of energy systems.**

***Index Terms*—EPBT, $CO_2$ emissions, LCA analysis, Sustainability.**

## 1) Introduction

An environmental management system implementation approach concerning the assessment of a product's overall environmental impact quantitatively is known as Life cycle assessment. Such evaluation involves $CO_2$ emissions during the whole life cycle of the product and energy requirements and the outcome is applicable in related environmental assessment. There is complexity in comprehending the outcome due to broad range of variable in a life cycle. The LCA analysis scheme and research consists of four stages. The stages are as follows [1].

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

The LCI data is the result of inventory analysis. LCA method is impossible to generalize due to complexity in data availability, assumptions, objects and accuracy. Hence, it is important for the operators and users to know the limitations and assumptions to be drawn from the LCA results [1]

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The key research feature in evaluating a photovoltaic system relates to the energy production. This differ the photovoltaic systems from other products. If a building developer explains new energy supply systems i.e., related to low carbon emissions and high energy efficiency from buildings, LCA can emphasize the potential of photovoltaic systems and materials that are useful.

A comparison of lifecycle GHG emissions for the different electricity generation methods are shown in table 1 [2]. Although the relative magnitude of GHG emissions between different generation methods is constant along studies, the absolute emission intensity fluctuates. It is because of variations in scope of the studies. Another factor impelling results is the definition of lifecycle like in some studies had considered waste management and treatment in the scope, while some neglected waste. Also these studies lead to a broader range in results and the most dominant is for solar power. This is mainly due to the rapid advancement of solar photovoltaic panels over the past decade. As the technology and manufacturing processes become more efficient, the lifecycle emissions of solar photovoltaic panels are continuing to reduce [2].

Table 1: Summary of intensity of lifecycle GHG emissions [2].

| Technology | Mean | Low | High |
|---|---|---|---|
| | Tonnes $CO_2$e/GWh | | |
| Lignite | 1054 | 790 | 1372 |
| Coal | 888 | 756 | 1310 |
| Oil | 733 | 547 | 935 |
| Natural Gas | 499 | 362 | 891 |
| Solar PV | 85 | 13 | 731 |
| Biomass | 45 | 10 | 101 |
| Nuclear | 29 | 2 | 130 |
| Hydroelectric | 26 | 2 | 237 |
| Wind | 26 | 6 | 124 |

Numerous LCA studies have been carried out for SPV systems and a wide range of results in EPBT and GHG emission estimation have been found. SPV system design is very dependent on the geographical location of the system since the amount of electricity generated varies with the irradiance and temperature [3]. A set of parameters is responsible for the variability in the performance of different installations.

## 2) Literature Review

Many researches have performed worldwide and papers are available in order to assess the feasibility and performance of variety of solar photovoltaic plants; to evaluate whether the photovoltaic power plant is feasible and viable choice to compensate the requirement of power in current and the future cases.

An LCA study was carried out for 50 $kW_p$ SPV system which is situated at Bazak (Bhatinda) in Punjab state of India [4].The energy pay-back time was found to be 1.85 years and the greenhouse gas emissions was evaluated as 55.7 *g*-$CO_2$/kWhe. These results have also been compared with the other solar photovoltaic electricity generation systems. This study had the more relevant conditions similar to the considered region in Andhra Pradesh.

The analyses of the environmental impacts with different LCA methods have shown that it is quite important to include process specific emissions of the production chain. But not all possible emissions are investigated in India and data is not sufficient for analysis [3].

A research review on LCA on photovoltaic modules showed the following results in which various studies of authors are considered and listed in the table 2.

Table 2: LCA of Crystalline PV Modules

| Author | Type of Cell | Energy required | EPBT (*years*) | GHG emissions (g-$CO_2$/kWhe) |
|---|---|---|---|---|
| Kato[5] | Mono | 4160-15520 | 8.9 | 61 |
| Kannan[6] | Mono | 2.2 MJ/kWh | 4.5 | 165 |
| Phylipsen & Alsema[7] | Multi | 1145 $kWh/m^2$ | 2.7 | NA |
| Ito[8] | Multi | NA | 2 | 12 |
| Pacca[9] | Multi | 4020 MJ/module | 7.5 | 72.4 |
| Jungbluth[10] | Multi | NA | 3-6 | 39-110 |
| Fthenakis & kim[11] | Multi, Mono | NA | 1.7-2.7 | 30-40 |
| Alsema[12] | Muti | 4200 $MJ/m^2$ | 2.5 | 46 |

The EPBT of a very large scale photovoltaic system would be 2.1-2.8 years, and the $CO_2$ emission rate would be 52-71 g$CO_2$/kWh [13].

Since the lifetime of PV systems generally exceeds 20 years, a low EPBT means that a system can recover the energy required to pay for itself more quickly. The figures for $CO_2$ emission rates are also much lower than those for fossil fuel plants.

## 3) METHODOLOGY

### *i) Energy Pay Back Time(EPBT)*

Andhra Pradesh state is considered in this work to see the sustainability of a 10 MW solar project. Two cases with mono crystalline modules-project A and PERC modules-project B are considered. EPBT is used in order to present the amount of energy consumed for a 10 MW solar project. Consumption of energy occurred during the following stages: construction of the plant, decommissioning, operation and maintenance of the plant.

For 10 MW solar project, we have considered only construction of the plant to calculate total primary energy required by the system throughout its life time.

The following formula is used to find number of years required for this 10 MW solar plant with energy generated though out its plant life and can be shown as equation below in years [14][15].

$$EPBT = \frac{\text{Total primary energy required by the sytsem through out its life cycle}}{\text{Annual primary energy generated by the system per year}}$$

### *ii) $CO_2$ Emissions*

The total life-cycle GHG emissions ($CO_{2eq}$) are generally estimated according to the full operational life cycle of each system from the commissioning of the plant to its full operation (cradle to grave). These emissions are found to vary widely within each technology. For the estimation of GHG emissions for the present study, life time of the project is considered to be 25 years. Estimation of GHG emissions is given by the equation below [3].

GHG Emissions Rate=

$$\frac{\text{Total } CO_2 \text{ emissions throughout its life cycle } (g-CO_{2eq})}{\text{Annual Power Generation } \left(\frac{kWh_e}{year}\right) \times \text{lifetime}(year)}$$

India does not have expensive life cycle data base currently available for general use so consequently we had referred to analysis undertaken in other countries having different conditions.

From recent studies in different countries, the photovoltaic systems carbon footprints are shown in table 3 [2].

Table 3: Carbon footprints of PV systems in various locations.

| Year | Author | Location | Life time (years) | GHG emissions (g-$CO_2$/kWhe) |
|---|---|---|---|---|
| 2008 | Ito et al., | China | 30 | 12.1 |
| 2007 | Pacca et al., | USA | 20 | 72.4 |
| 2005 | Hondo H | Japan | 30 | 53.4 |
| 2005 | Battisti and Corrado | Italy | 20 | 26.4 |
| 2005 | Souliotis et al., | Greece | 20 | 104.0 |

All photovoltaic-case scenarios of the similar studies conclude to carbon footprints that are certainly well below a value of 104 g $CO_2/kWh_e$, whereas if we compare to a the diesel power station considering only the power generation provides an emission of about 921.80 g $CO_2/kWh_e$ [2].

## 4) RESULTS AND DISCUSSIONS

Crystalline modules have good conversion efficiency but the required primary energy is high and corresponding GHG emissions are also high while thin film modules consume less energy due to low temperature production technologies but have very less efficiency than crystalline. Still, all of these together also is very less compared to other conventional source emissions (as high as $8.05 \times 10^2$ g/kWh) [16].

Total primary energy required for the 10 MW solar plant with project A plan throughout its plant life is 488,320,402.78 kWh.

Table 4: Total primary energy required for project plan A

| Sl.no. | Components | Energy required for 10 MW solar plant in $kWh_e$ |
|---|---|---|
| 1 | Polycrystalline PV module | $35\times10^7$ |
| 2 | Panel Frame (Alluminium) | $32.472\times10^6$ |
| 3 | Inverters | 5848402.78 |
| 4 | Mounting Structures | $10\times10^7$ |
| Total energy required | | 488,320,402.78 |

Total power generated by the system through its life time is 342,825,966.40 kWh. EPBT calculated for the 10 MW solar plant with project A plan is 1.42 years.

Total primary energy required for the 10 MW solar plant with project B plan throughout its plant life is 603,248,350.58 kWh.

Table 5: Total primary energy required for project plan B

| Sl.no. | Components | Energy required for 10 MW solar plant in kWh |
|---|---|---|
| 1 | Mono crystalline PERC PV module | 470,009,400 |
| 2 | Panel Frame (Alluminium) | 27,390,547.80 |
| 3 | Inverters | 5848402.78 |
| 4 | Mounting Structures | $10\times10^7$ |
| Total energy required | | 603,248,350.58 |

Total power generated by the system through its life time is 342,652,902.60 kWh.

EPBT calculated for the 10 MW solar plant with project B plan is 1.76 years.

By applying LCA tools, EPBT calculated for 10 MW solar plant with project A showed that EPBT for mono crystalline is 1.42 years, which is better compared to project B with an EPBT of 1.76 years. Both projects are sustainable as they have very less EPBT values for their life time of 25 years. It is found that most of energy is from PV modules production which can be addressed by manufacturers and produce less energy which can yield much lower values of EPBT for the project.

For a life time of 25 years and EPBT 1-6 years, we can estimate a rage of 50-90 g-$CO_2$/kWhe from studies. This range is predicted from various plants of similar conditions from the studies. Many production processes, especially for photovoltaic power are still under development in India. PERC modules can be considered along with crystalline module's emission as they require only few steps in manufacturing process that will need very less energy. So, for both project cases considered, we have similar emissions but it is entirely depending on the manufacturing processes.

## 5) Conclusion

According to life cycle studies from various plants regarding $CO_2$ emissions, reliable works have be used to estimate about 50 - 90 g-$CO_2$/kWhe of $CO_2$ emissions for similar condition plants in Andhra Pradesh. As the solar technology and manufacturing processes become more efficient, the lifecycle emissions of solar photovoltaic panels are continuing to reduce.

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