Chapter 3

LIFE CYCLE ASSESSMENT OF SOLAR MODULES

The chapter outlines the life cycle assessment of the solar photovoltaic panels. Life cycle analysis is done for the cradle to the grave trip of the panels. It includes the different types of solar panels and the balance of the system. LCA helps in the establishment of environmental understanding of the particular solar panels.

3.1. Introduction

The production of electricity is a significant contributor to the worldwide emissions of greenhouse gases and the associated environmental effects. To quantify the environmental effects of human activity on a variety of items, such as goods, services, etc., sustainable development requires methods and instruments. The life-cycle analysis method is an essential instrument for assessing a technology or product's environmental profile from conception through disposal. As material and energy flows are frequently intertwined and divergent emissions into the environment may occur at distinct life-cycle stages, such life-cycle analyses of energy systems are crucial. Due to its potential to lower traditional energy use and air pollution, photovoltaic systems are a technology for the production of electricity from renewable sources that is expanding quickly.

3.2 Life Cycle Assessment

It is possible to define LCA as a method for examining and evaluating the environmental implications of a material, product, or service over the course of its full life cycle. LCA takes into account all characteristics or features of the natural environment, human health, and resources (ISO 2005). The compilation and evaluation of the inputs, outputs, and potential environmental consequences of a product system over its life cycle is thus described by ISO14040 as the LCA. (ISO 2006).

The entire life cycle evaluation of the PV technology is analyzed for further designation as an ecologically friendly technology. Solar energy use turned out to be a highly tempting choice. The traditional sources of energy have not been able to keep up with the world's growing economy and population. In addition, there has been a rise in greenhouse gas emissions, which is harming the ecosystem. Therefore, in order to meet energy demands and stop environmental damage, a sustainable energy source is very necessary.

The whole life cycle includes the procedures involved in manufacturing, assembling, processing photovoltaic system components, transporting needed materials, installing and furnishing the solar PV system, and eventually disposing of the product when it has been fully utilized. Thus, the life cycle evaluation is shown. Through this, a precise and accurate analysis is created that takes into account every aspect of the environment, from production to the energy payback period.

Electricity generation adds greatly to overall greenhouse gas emissions and their environmental effect. Methods and instruments for measuring the environmental consequences of human activities for diverse items such as goods, services, and so on are required for sustainable development. Life-cycle analysis is a useful method for assessing a product's or technology's environmental profile from cradle to grave. Such life-cycle analyses of energy systems are critical, particularly because material and energy flows are frequently intertwined, and divergent emissions into the environment might occur at several life-cycle stages.

Photovoltaic systems are a technique for producing electricity from renewable sources that are quickly expanding due to their promise to reduce energy consumption from traditional sources while also lowering air pollution. During the operational period, there are no emissions and only solar electricity is used. However, it should be remembered that, when considering the whole life cycle of a plant, photovoltaic systems, like any other methods of power production, produce emissions, particularly during the manufacturing stage and component installation. In this study, the environmental burden of a photovoltaic power generating system over its life cycle as measured by energy payback time and greenhouse gas emissions is compared to the state of the art using a life cycle assessment

Life cycle assessment is done to study environmental repercussions involved throughout fabrication, positioning, and knocking down conditions. LCA is described as the collection and analysis of all needed inputs during the course of a technology's lifespan. Three components make up LCA:

1) Design & outlook

2) Reservoir assay

3) Effect analysis

The whole layout of the LCA may be formed as shown in Fig.3.1 based on these components.

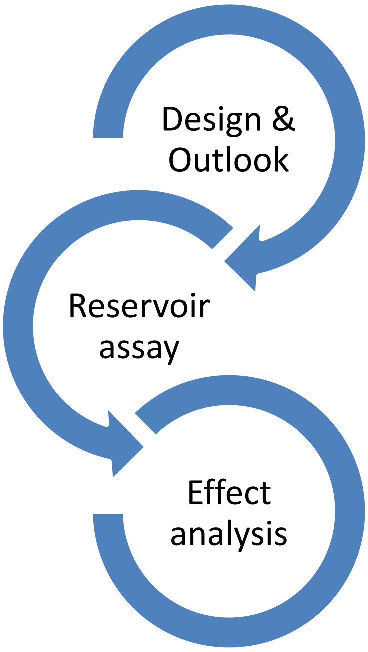

Fig. 3.1 Outline of Life Cycle Assessment

The production stage, from cradle to gate, and the end stage, from cradle to grave, are taken into account in the design and viewpoint of LCA. Therefore, LCA makes assumptions about all phases of the product's life cycle. The life cycle assessment of the PV technology covers every aspect, from the procurement of raw materials to the assembly process to the operating phase. The extraction of raw materials for input is the subject of the reservoir essay. The cost of all the input and output phases of the solar panel life cycle are also included, as well as the cost of transportation. The whole evaluation of the solar panels is incorporated into the effect analysis (Deng et al., 2019).

The raw material flow method analyses all of the inputs from the environment and all of the outputs flowing to different other sources including air, water, and land. The effect analysis takes into account factors such as acidification, eutrophication, loss of water resources, ozone depletion, human toxicity, and climate change (Arora et al., 2018). Three factors are regarded as life cycle indicators: air emissions, water consumption, and land use. All environmental characteristics are looked at. LCA examines the environmental impact of products from cradle to grave, from the procurement of raw materials to the product's manufacture, usage, and maintenance, and ultimately to the management of the product's end-of-life, whether via reuse, recycling, or reduction. The analysis of input in terms of energy assures that solar energy is a clean energy source. The operating duration is considered to be between 27 and 30 years, making solar energy more ecologically benign than fossil fuels.

An extensive analysis of the different inputs and outputs of the solar PV systems is conducted using the Life Cycle Assessment methodology. However, given the rising concern about climate change, a more sustainable and environmentally friendly approach to reducing greenhouse gas emissions is essential. The effectiveness of current PV technologies will be assessed, and its implications for the environment, human health, and social and economic factors will be carefully examined and social and economic aspects will be analyzed in depth. Energy-related issues have become increasingly relevant in recent decades, involving the efficient use of resources, the environmental effect owing to pollutant emissions and the usage of non-renewable resources. As a result, there is an urgent need to develop renewable energy technologies, particularly photovoltaic, to address the concerns of energy scarcity and environmental pollution. PV technology, which generates electricity directly from solar energy, consumes no fossil fuels and emits no greenhouse gases (GHG) during operation. As a result, it seems to be perfectly clean and has no environmental impact.

However, during some stages of its life cycle, such as solar cell manufacturing processes, PV module assembly, the balance of system (BOS) production, material transportation, PV system installation and retrofitting, and system disposal or recycling, it consumes a significant amount of energy and emits some GHG. When sunlight strikes PV materials, photons of a specific wavelength cause electrons to flow through the materials, resulting in direct current (DC) power. Commercial PV materials include amorphous silicon, multi-crystalline silicon, mono-crystalline Silicon, Cadmium Telluride (CdTe), Copper Indium Diselenide (CIS), and thin film technologies are examples of commercial PV materials.

A typical PV system comprises the PV module and the balance of system (BOS) components for mounting the PV modules and converting the generated electricity to the appropriate magnitude of alternative current (AC) electricity for use in the power grid. A technique called life cycle assessment is used to measure and examine the energy consumption and environmental effects associated with the development of commodities over the course of their life cycles.

The LCA stage involves aim and scope formulation, inventory analysis, impact assessment, and outcome interpretation. The description of purpose and scope specifies the underlying issue (objective), the system, its boundaries, and the definition of a functional unit. Inventory analysis records the fluxes of contaminants, commodities, and resources. In the impact assessment step, these elementary fluxes (emissions, resource consumption, etc.) are characterized and aggregated for various environmental concerns, and eventually, conclusions are reached in the interpretation stage. Photovoltaics have relatively high environmental impacts compared to other technologies, 10 and 2.5 times higher than the GHG emissions of the nuclear-fuel cycle for each country, and 45 and 23 percent of those of combined cycle natural-gas power generation in the same country, according to informational publications for decision-makers in the European Community (European Commission, 2003) and Australian Coal Industry Association Research Program (ACARP), 2004. This work examines the necessary energy and environmental impact for main Si and Thin Film type PV module technologies, as well as certain newer innovations, through an evaluation of their energy payback period and GHG emissions.

3.3. LCA of PV System

3.3.1. LCA of Mono Crystalline PV System:

Evaluated the total energy need of a mono-Si PV module ranging from 4160 to 15520 MJ/m^2, and the EPBT and GHG emission rate for the mono-Si PV system was CO_2-eq./kWh, respectively, under 1427 kWh/m^2/yr. irradiation (Kato et al., 1998). Energy requirements of crystalline silicon PV modules ranged between 5300 and 16,500 MJ/m^2 for mono-Si modules (Alsema & Nieuwlaar, 2000a). A life cycle assessment of a distributed 2.7 kWp solar PV system and discovered that the life cycle energy usage was 2.2 MJ/kWh, and the projected EPBT and GHG emissions were 4.5 years and about 165g- CO_2/kWh (Kannan et al., 2006). Investigated a 300 kW PV facility near Austin using a single-axis tracker. The total embodied energy (emission) was 16.5 GWh, with 280 g-CO_2eq/kWh life cycle CO_2 emissions (Kreith et al., 1990). The total process energy and embodied energy of materials in mono-Si modules were 2742 kWh/kWp and 2857 kWh/kWp, respectively, with a 4.1-year EPBT(Knapp & Jester, 2001). Calculated the embodied energy for the manufacture of crystalline silicon PV modules and BOS components and determined that the embodied energy for open field and roof-top PV systems was 1710 and 1380 kWh/m^2, respectively, with an EBPT of 7-26 years (Nawaz & Tiwari, 2006).

3.3.2. LCA of Multi Crystalline PV System

Multi-Si PV systems have about the same conversion efficiency as mono-Si systems but consume less energy during their lifetime. As a result, multi-Si systems may have a shorter EPBT and lower GHG emissions rate than mono-Si systems. In 1995, the life cycle evaluation of a multi-Si PV module was investigated. The embodied energy need was determined to be 1145 kWh/m^2 and the EPBT to be 2.7 years, with module efficiency and performance ratios of 13% and 0.75, respectively (Phylipsen & Alsema, 1995). LCA is completed for a grid-connected PV system. Ito investigated the feasibility of a 100 MW large-scale PV project in the Gobi Desert with a module efficiency of 12.8%. According to the data, the plant's EPBT and CO_2 emission rate was less than 2 years and 12 g CO_2-eq./kWh, respectively (Ito, 2011). Investigated the life-cycle assessment of multi-crystalline modules with BOS, inverter, and transportation. One module's production required 1000 Mega Joule of primary embodied energy in materials and 3020 Mega Joule of process energy (Pacca et al., 2007).

3.3.3. LCA of a-Si PV System

Due to low-temperature production processes, thin film PV modules utilize less material and energy over the course of their lifetime than crystalline silicon modules while having a lower conversion efficiency as a result manufacturing procedures. As a result, there will be reduced EPBT and GHG emissions. (Lewis & Keoleian, 1997) performed a case study on the manufacture of amorphous PV modules. The overall process energy was around 491 MJ/m^2(Mega joule per meter square), whereas the embodied energy was 864 and 1990 MJ/m^2 for low and high energy use, respectively.

The EPBT for a-Si frame modules was 8.1 and 4.5 years, respectively, for high and low energy consumption. By employing frameless modules, this energy may be lowered to 386 and 640 MJ/m^2. Energy analysis studies of thin film PV modules from six studies on a-Si modules and three studies on CdTe modules were also reviewed. The author presented the best approximation that a-Si and CdTe thin film frameless modules' energy needs range from 600 to 1500 MJ/m^2 and estimated the EPBT of a grid-connected system was less than two years with 1700 kWh/m^2/yr irradiation.

3.3.4. LCA of CdTe and CIS PV System

The first solar cell based on CdTe and CdS was announced in 1972, with a 6 percent efficiency. Since then, the cell has improved significantly, and a peak efficiency of 16.5 percent has been reported. According to (Kato et al., 1998) the total primary energy needed for generating the CdS and CdTe PV module was around 1803 MJ/m^2 at 10 MW/yr. and 1272 MJ/m^2 at 100 MW/yr. According to the findings, the EPBT of a PV system ranged from 1.7 (10 MW/yr. scale) to 1.1 years (100 MW/yr.), and the lifetime CO_2 emission rate ranged from 14 (10 MW/yr.) to 9 g CO_2-eq./kW h (100 MW/yr.). (Ito et al., 2003) investigated the life cycle analysis of a 100MW PV system employing CdTe and CIS solar cell modules in the Gobi Desert.

The life cycle CO_2 emissions are 15.6 and 16.5 g CO_2 eq/kWh, respectively. Hynes performed a life cycle study on two types of CdTe thin film modules that were created using distinct deposition processes (Hynes et al., 1994). The overall energy needs were 992.52 and 1187.7 MJ/m^2, respectively, and the corresponding EPBTs were 5-11 and 6-13 months, with a 10 percent efficiency. (Raugei et al., 2007) performed a comparison of CdTe and CIS modules to crystalline modules. The EPBT of CdTe and CIS PV modules was 0.5 and 1.9 years, respectively, and their life-cycle GHG emission rates were 17 and 70 g CO_2-eq./kWh.

However, if the BOS components are included, the EPBT and GHG emissions increase to 1.5 and 2.8 years, respectively, and 48 and 95 g CO_2-eq./kW. Examined necessary primary energy as 350-650 MJ/m^2 (process energy) and 300-400 MJ/m^2 (material energy), with an EPBT of 3.2 years for CdTe modules with a module efficiency of 6% and irradiation of 1000 W/m^2 (Alsema & Nieuwlaar, 2000b). EPBT is 1.8 and GHG is

46 g CO_2-eq./kWh for 11 percent efficiency for very large-scale PV systems deployed in the desert, according to (Ito et al., 2010).

3.4 Conclusion

Based on Life Cycle Assessment, the four most common types of solar PV systems were compared to some of the most recent PV technologies. The energy requirements, EPBT, and GHG emissions for mono-crystalline, poly-crystalline, amorphous, CdTe/CIS, and other solar PV systems have been calculated. Crystalline modules have a high conversion efficiency but a high needed primary energy and related EPBT and GHG emissions, whereas thin film modules use less primary energy and have lower EPBT and GHG emissions but have poor efficiency. The heterogeneity in the performance of different installations is caused by a set of factors. Aside from the amount of incoming solar radiation, additional characteristics to consider are life expectancy, BOS components, conversion efficiency, cell type, and manufacturing method.

The three stages of the PV LCA methodology's analysis are: 1) Production 2) Practical 3) Put an end to existence. From an environmental standpoint, the manufacturing phase has a greater impact since it involves a variety of compounds in all phases of matter that might damage human health. Due to fire risks, the utility phase may potentially increase the hazardous pollutants that already impact the land. The waste buildup occurs at the end-of-life phase. During the production process, utility phase, and end-of-life phase, harmful gaseous emissions are emitted into the environment. Additionally, the impact is assessed in relation to the environment while taking into account not just the production process but also the resource use.

The disposal and end-of-life plots for the c-Si and CdTe panels are fully interpreted. When solar PV modules reach the end of their useful lives, recycling them is crucial for preserving the components that were previously utilized. The difficulties that arise during the process, such as a lack of garbage collecting locations and appropriate recycling technology, obscure recycling. The material from PV modules will eventually be recycled due to a lack of enough supply. Recycling solar panels can assist in reducing resource waste. The usually used four types of solar PV systems 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. Crystalline modules have good conversion efficiency but the required primary energy is very high and corresponding EPBT and GHG emissions are also high thin film modules consume less primary energy and have lower EPBT and GHG emissions but the efficiency is low. The heterogeneity in the performance of different installations is caused by a set of parameters. Aside from the amount of incoming solar radiation, it is dependent on life expectancy, BOS components, conversion efficiency, cell type, and manufacturing method.

Solar energy is equally crucial to humans, animals, and plants. Solar energy is hailed as an unlimited source of energy that is free of pollution and noise. Solar photovoltaic technology offers a technologically realistic answer to society's existing health and environmental confusion caused by its reliance on fossil fuel-based electricity generation. Solar energy is now economically feasible in many applications and will continue to grow as production scales up.