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Life cycle assessment of solar PV based electricity generation systems: A review

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ABSTRACT

Sustainable development requires methods and tools to measure and compare the environmental impacts of human activities for various products viz. goods, services, etc. This paper presents a review of life cycle assessment (LCA) of solar PV based electricity generation systems. Mass and energy flow over the complete production process starting from silica extraction to the final panel assembling has been considered. Life cycle assessment of amorphous, mono-crystalline, poly-crystalline and most advanced and consolidate technologies for the solar panel production has been studied.

Contents

1. Introduction

In these last decades, energy related problems are becoming more and more important and involves the rational use of resources, the environmental impact due to the emission of pollutants and the consumption of non-renewable resources [1]. With regard to energy systems, many projects aimed at the mitigation of these problems are being planned, also to fulfil the more and more restrictive environmental laws. Many countries have introduced policy to promote the installation of new renewable source plants in order to reach the Kyoto protocol targets, and often a specific mention to photovoltaic plants is reported [2,3].

Life cycle assessment (LCA) is a technique for assessing various aspects associated with development of a product and its potential impact throughout a product's life [4]. LCA stage includes definition of goal and scope, inventory analysis, impact assessment and interpretation of results as shown in Fig. 1 [5–7]. The goal and

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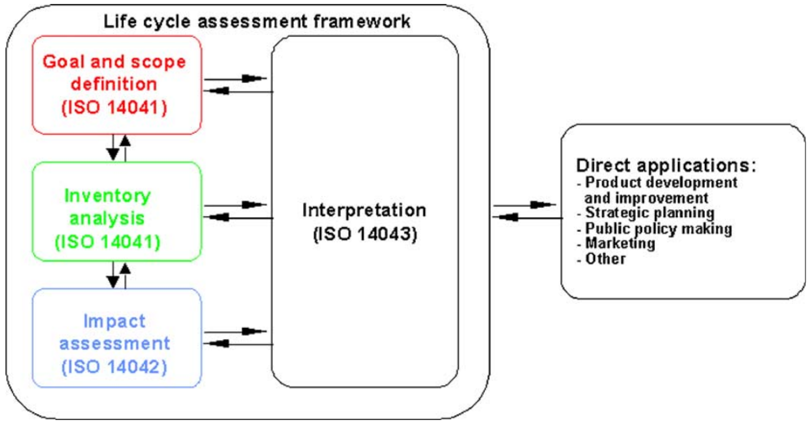

Fig. 1. Life cycle assessment framework [8].

scope definition describes the underlying question (objective), the system, its boundaries and the definition of a functional unit. The flows of pollutants, materials, resources are recorded in inventory analysis. These elementary flows (emissions, resource consumption, etc.) are characterize and aggregated for different environmental problems in impact assessment and finally conclusions are drawn in interpretation stage. LCA applications are comparisons of different product and systems, or different materials production or recycling methods. LCA can be used as a tool to detect potential for improvements with the aim to reduce impact on human health, environment and resource depletion.

Solar photovoltaic (PV) module converts solar energy directly into electricity and bring about environmental benefits such as greenhouse gas (GHG) and pollution reduction [9]. The PV industry has grown with an estimated 1.5 GW installed in year 2005. Most of this growth has come from European countries especially Germany and having grid-connected systems which was initially in the year 1990 were stand alone type [10]. The solar energy, which seems to be completely clean having no environmental impact but actually these systems also, emits greenhouse gases (GHG) emissions. In this paper a review has been done to estimate the environmental impacts of different solar PV based electricity generation systems using life cycle assessment technique.

2. Steps for fabrication of PV module

Silicon solar cells are perhaps the simplest and most widely used for space and terrestrial applications. The procedure for fabrication of mono-crystalline silicon solar PV module has been discussed in brief.

2.1. Purification of silicon

The silicon dioxide (SiO_2) is reduced to silica (Si) with carbon (C) in a large arc furnace. Further silicon is purified in the furnace by repeatedly pouring it and blowing with oxygen/chlorine mixture and finally solidifying it. This metallurgical grade is further purified for use in semi-conductor form. There are many different method exist to obtain solar-grade silicon (sog-Si). The most preferred one is the Siemens process in which metallurgical grade silicon is converted into a volatile compound which is condensed and then refined by fractional distillation.

2.2. Methods of growing silicon

There are several methods of growing single crystals of silicon from liquid, gas or solution such as: Czochralski technique, heat exchange method, dentritic web method, silicon on ceramic method, etc. [11].

2.3. Silicon wafers to silicon solar cells

The fabrication of solar cells from the single crystal silicon wafer involves many steps such as: surface preparation, dopants diffusion or junction formation, coating, etc. [12].

2.4. Module design

The individual cells are interconnected in series and parallel pattern for module fabrication. One module contains about 20–40 cells and each module may have three to five column of cells in series in such a way to get the desired output electrical characteristics. Since generally circular cells are produced but the packing density is not very high and about 15–20% of the module area remains uncovered. In case of square or hexagonal shaped cells better packing densities are obtained.

3. LCA of PV system

Photovoltaic (PV) technology is expected to be a leading technology to solve the issues concerning the energy and the global environment due to several advantages of the PV system.

3.1. LCA of amorphous PV systems

Schaefer and Hagedorn [13] carried out a comparative analysis of the surface and material requirements of different power stations. The accumulated energy consumption in the manufacturing and construction of PV electricity generation plants, CO_2 emissions caused by PV power generation and the energy amortization time or energy pay-back time (EPBT) were evaluated. The accumulated primary energy consumption for the construction of the photovoltaic power plants ranges from 13,000 to 21,000 kWh/kWp and represents the lowest threshold for the current state of the art. The life cycle CO_2 emission is 3.360 kg-CO_2/kWp for amorphous technology.

Alsema [14] studied the energy requirements and CO_2 emissions for the production of PV modules and BOS components of grid-connected PV systems. Thin film (amorphous) module and mono-crystalline (mc) silicon technologies were investigated and the energy pay-back period was found to be 2.5–3 years for rooftop installation and 3–4 years for multi-megawatt ground mounted system. The CO_2 emissions of the rooftop system were calculated as 50–60 g/kWh$_e$ now and probably 20–30 g/kWh$_e$ in the future.