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Life cycle assessment of photovoltaic electricity generation

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Abstract

The paper presents the results of a life cycle assessment (LCA) of the electric generation by means of photovoltaic panels. It considers mass and energy flows over the whole production process starting from silica extraction to the final panel assembling, considering the most advanced and consolidate technologies for polycrystalline silicon panel production. Some considerations about the production cycle are reported; the most critical phases are the transformation of metallic silicon into solar silicon and the panel assembling. The former process is characterised by a great electricity consumption, even if the most efficient conversion technology is considered, the latter by the use of aluminium frame and glass roofing, which are very energy-intensive materials. Moreover, the energy pay back time (EPBT) and the potential for CO_2 mitigation have been evaluated, considering different geographic collocations of the photovoltaic plant with different values of solar radiation, latitude, altitude and national energetic mix for electricity production.

Keywords: Life cycle assessment; Photovoltaic panels; Energy pay back time

1. Introduction

In these last years, energy-related problems are becoming more and more important and involve the rational use of resources, the environmental impact due to the emission of pollutants and the consumption of non-renewable resources. 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: they concern the increase of traditional plant and device efficiency [1,2], the diffusion of cogenerative systems, the study of innovative plant configurations, the use of not traditional fuels and of renewable resources. In this last context, solar energy is commonly considered as a very good solution, particularly for small distributed (household) thermal and/or electric energy production. 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 [3,4]. The public opinion, too, is particularly favourable to the use of solar energy, which seems to be completely clean and without any environmental impact. For these reasons, the capacity of photovoltaic power plants, converting solar energy directly to electricity, is increasing: in 10 years (1994–2004) it has grown by 16 times, +44.5% only in the last 2 years (2003–2004) [5].

While during the operation this technology can be considered almost absolutely clean, evaluating the production process of the panels is important in order to consider the emissions and the energy consumption during the whole panel life. For these reasons, only a deeper analysis can give a more correct basis to evaluate the real environmental sustainability of this kind of plants.

This paper presents the results of a life cycle assessment (LCA) [6,7] of the electric generation by means of photovoltaic panels. It takes into account mass and energy flows over the whole production process starting from silica extraction to the final panel assembling. The most advanced and consolidate technologies have been considered for the production of polycrystalline silicon panels, which are the most common nowadays in the market.

Abbreviations: EPBT, energy pay back time (year); ERF, energy return factor; GER, gross energy requirement (MJ/panel); GWP, global warming potential (kg CO_{2eq}/panel); PCM, potential for CO_2 mitigation (t CO_{2eq}/kWp); Mg-Si, metallurgic silicon; Sog-Si, solar-grade silicon.

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The operation of the panels has been analysed, too, in order to evaluate the annual electric production and so the energy pay back time (EPBT) and the potential for CO_2 mitigation (PCM) for different geographic collocations of the photovoltaic plant with different values of solar radiation. The different national energetic mix for electricity generation of each location has been considered, too.

In this way, the real energetic and environmental performance of a photovoltaic panel can be evaluated.

Table 1
Most important assumptions of the LCA

Silica into silicon transformation	Carbothermal
mg-SI into sog-Si transformation	UCC process
Casting and wafer production	Conventional casting process
Wafer area	$12.5 \times 12.5\,cm^2$
Wafer thickness	200 μm
Posterior metallisation	100%
Anterior metallisation	7%
EVA sheet thickness	0.5 mm
Module area	$0.65\,m^2$
Cells per module	36
Operation life	28 years
Module efficiency	16%

2. LCA goal and scope definition

The core of a photovoltaic plant is the solar cell converting the luminous energy into electricity by means of the photovoltaic effect, which consists in the generation of an electromotive force when the radiation reaches a semiconductor plate presenting a potential gap. Today, the semiconductor used for cells is almost always silicon: either monocrystalline, or polycrystalline or amorphous. Crystalline cells are the most common. For this reason a $0.65\,m^2$ panel of polycrystalline silicon produced using current and consolidate technologies has been chosen to define the "functional unit" [6–8] of the LCA. Its conversion efficiency has been assumed equal to 0.16 and its operation life equal to 28 years, as average values reported by many authors [9–11]. The most important assumptions are reported in Table 1. The production processes of the materials used during the cells' production process have been included in the analysis.

3. Inventory

The production process is schematised in Fig. 1. Nine different "unit operations" have been identified in the whole process.

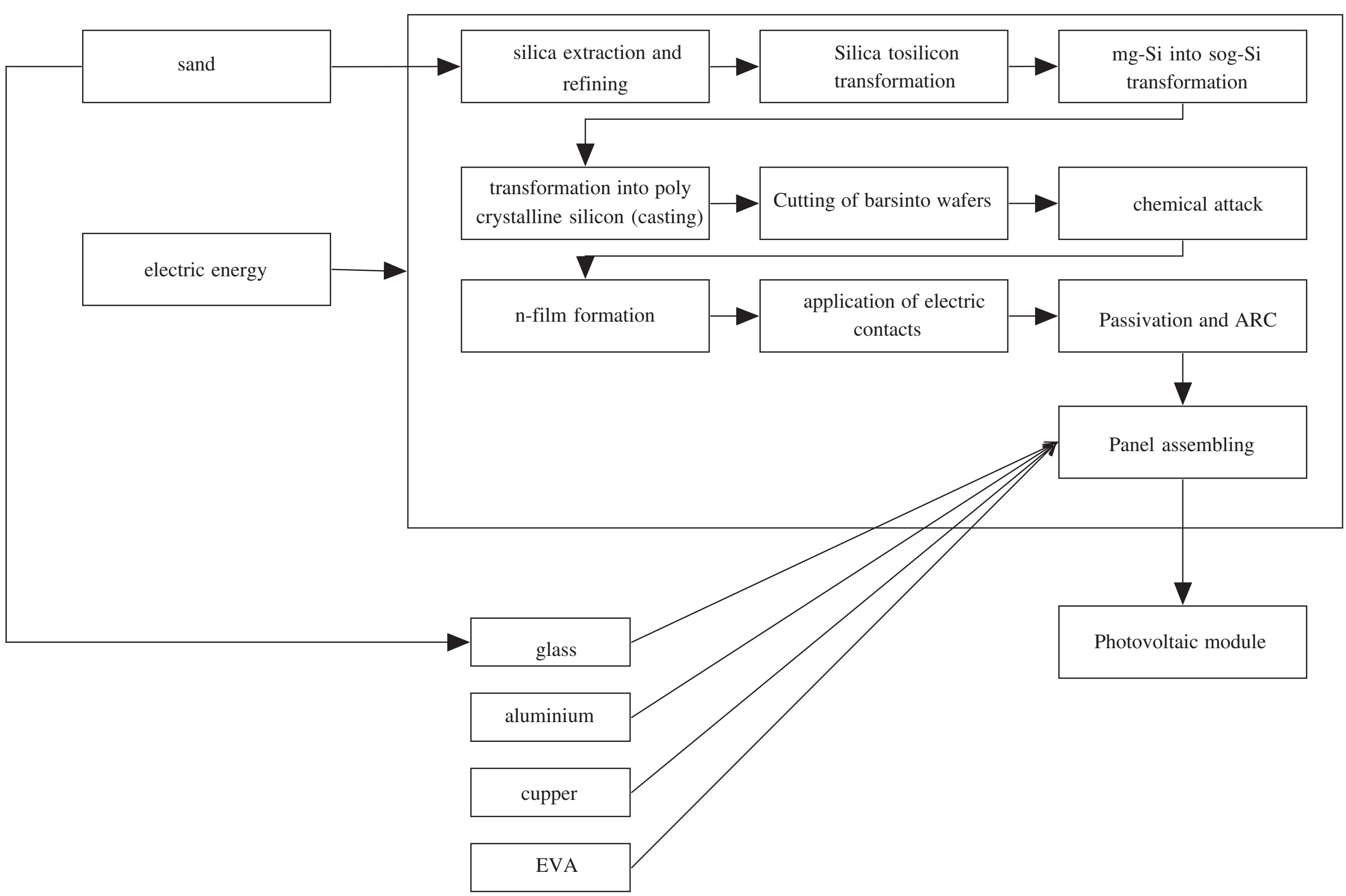

Fig. 1. Schematisation of the production process of a photovoltaic module.