Applied Energy 111 (2013) 505–514

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Life Cycle Assessment of a Building Integrated Concentrated Photovoltaic scheme

Karim Menoufi *, Daniel Chemisana, Joan I. Rosell

University of Lleida, C/Pere de Cabrera s/n, 25001 Lleida, Spain

HIGHLIGHTS

- A gap is found in literature regarding the LCA studies of BICPV schemes.
- The BICPV scheme installed has significantly lower environmental impact compared to the conventional widely used BIPV ones.
- Some design improvements are foreseen within the installed BICPV scheme components.

ARTICLE INFO

Article history:
Received 8 February 2013
Received in revised form 11 April 2013
Accepted 14 May 2013
Available online 7 June 2013

Keywords:
Life Cycle Assessment (LCA)
Building Integrated Concentrated Photovoltaics (BICPV)
Life Cycle Impact Assessment (LCIA)
Environmental impact
Concentrated photovoltaics
Reflectors

ABSTRACT

A Life Cycle Assessment (LCA) study of a Building Integrated Concentrated Photovoltaic (BICPV) scheme at the University of Lleida (Spain) is conducted. Assumptions for representing a real building are considered, and a comparison to a hypothetical conventional Building Integrated Photovoltaic (BIPV) scheme is established. The Life Cycle Impact Assessment (LCIA) is performed using the EI99 methodology, which is considered to be the reference. In addition, the environmental impact is re-evaluated using the EPS 2000 methodology. The results show a significant extent of the environmental benefits gained using the BICPV schemes. Some differences in the components impact contribution percentages are noticed between the EI99 and the EPS 2000 methodologies. Nevertheless, both methodologies coincide in the conclusion of the significant environmental impact reduction reached from replacing the conventional BIPV schemes with the BICPV ones. Recommendations for future work and system improvements are discussed as well.

1. Introduction

Although the photovoltaic (PV) technology is one of the vital renewable energy trends [1], it is associated with some environmental concerns. The production of PV cells is accompanied by a high rate of emissions during manufacturing, and consequently causes a high impact on the environment. This impact can be induced whether in a direct way (process emissions) or in an indirect way (fossil fuels consumed during manufacturing). Furthermore, the PV industry utilizes a variety of chemicals, where many of which are relatively toxic to the human health and the environment [2–5].

In spite of those facts, the PV technology market is growing rapidly, especially for Building Integrated applications (BIPV). The building integration schemes are gaining a world wide acceptance. This is due to the savings that can be achieved in building materials during construction, and simultaneously reducing the environmental load during the operational phase through replacing the fossil fuels resources. In addition, the integration of PV into buildings permits the use of various PV technology types, which are characterized by their flexibility and reduced thickness. This means that fewer amounts of PV materials are used in comparison to the quantities used in the assembly of the conventional ground mounted PV systems. Therefore, these whole innovative solutions mainly aim at reducing the overall environmental burdens caused by both the building sector and the PV industry during the construction and operational phases [6–8].

On the subject of further reducing the environmental burdens, several research works have shown that the use of the concentrating technology can be energetically beneficial. This is because a concentrating system mainly consists of simple lenses or reflectors, which are especially fabricated and designed to focus the solar radiation on smaller PV cell areas in different concentration ratios depending on the application. Such types of schemes contribute significantly in reducing the amount of materials and energy used in PV cells fabrication [9–15]. Hence, Life Cycle Assessment (LCA) studies are essential in the PV domain, in correlation with the

* Corresponding author. Tel.: +34 973003572; fax: +34 973003575.
E-mail address: kmenoufi@macs.udl.cat (K. Menoufi).

0306-2619/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2013.05.037

building industry, due to the high environmental impact induced from various components specifically during the assembly/production stage [16–21].

Several studies of LCA about PV systems can be found in literature. These studies have used various LCA indicators, such as the Energy Payback Time, which has been the principal interest for most of the corresponding LCA articles [22–35]. Other studies have been interested in investigating different related environmental aspects of PV systems, such as the exergy analysis [36–39]. A fewer number of studies is found to be interested in conducting LCA of PV systems using various developed LCIA methodologies: The RECIPE methodology [40], the Eco-Indicator 99 (EI99) methodology [41–43], and the Eco-Scarcity methodology [43].

Within this framework of LCA studies, it is found that a wide range of PV technologies has been considered. This includes single-crystalline, poly-crystalline, and thin film; installed within different schemes, whether integrated in buildings, ground mounted or applied for large scale power plants [22–55]. Novel technology concepts of PV have been considered as well, such as quantum dot PVs [56], micromorph systems [57] and nano-crystalline materials [58]. Regarding the concentrating technology, which is the main interest of the present work, it is noticed that all the surveyed studies are mainly directed at the high concentration applications [59–70].

Hence, in this regard, it is concluded that three gaps in the surveyed literature are found:

- Variety of LCA indicators: The Energy Payback Time is the most dominant.
- LCA studies of Building Integration Concentrated Photovoltaics (BICPV) schemes.
- The relative impact of a PV system/facade with respect a whole building (in case of BIPV studies)

In the regard of the first gap, evaluating the Energy Payback Time, and consequently working on finding solutions to reduce it through increasing the operational efficiency, is not sufficient. High dependence on the Energy Payback Time as the sole environmental indicator of a specific system does not provide a comprehensive environmental performance prospective, as this criterion does not take into consideration the instantaneous impact that is induced during the assembly stage [71]. Therefore, through using the LCIA methodologies, and by focusing on the assembly stage, the explication of the temporal resolution of the environmental impact can be clearly spotted (i.e. the impact of a certain quantity of emissions of a specific substance on the environment during a period of 1 month is worse than the impact of the same amount of emissions spread throughout the whole year). Furthermore, some studies have shown that in the future, as more PV systems will be installed, the energy mix itself will be mostly powered by PV systems. This will make the Energy Payback Time indicator no longer viable for providing the best guidance for the environmental performance improvements of PV systems [72–73].

The second gap highlighted is the lack of LCA studies of BICPV schemes, as it has been found that all of the related case studies are interested in high concentration applications specified for large scale power plants.

Finally, the third gap is about the whole system analysis. Most of the LCA studies of BIPV schemes are concerned with the environmental impact of the PV system corresponding components (The PV panel, PV cells, encapsulations, etc.) without taking into consideration the environmental impact of the PV system with respect to the whole building installation.

Therefore, for the purpose of contributing in reducing these gaps, the present research examines the environmental performance of a BICPV scheme through LCA. This study emphasizes the assembly stage, taking into consideration the impact of the Concentrating Photovoltaic (CPV) system with respect to the whole installation. Furthermore, the study is conducted using a widely used methodology (EI99), and then the impact is re-assessed using the EPS 2000 methodology.

2. Case study

A BICPV scheme assembled and tested at the Applied Energy Research Centre (CREA) at the University of Lleida (Spain) is described and studied. In addition, in order to present more representative results, a comparative study with a conventional BIPV system is performed.

2.1. The building model

In order to be able to represent a BICPV scheme of relatively small scale and wattage requirements in a realistic manner, a typical widely known Mediterranean building design is assumed. This type of building design has been used in several studies [74–78]. Nevertheless, in the present case study, such construction assumption is highly dependent on the data provided by Bribian et al. [76]. This data includes a wide range of information about building materials, concerning the recommended dimensions, mass and mass per unit volume. The assumed building model ($3.51 \times 2.11 \times 2.05$ m) is built on a precast concrete base. The walls are composed of bricks (solid and hollow), a layer of expanded polystyrene insulation, and the finishing is done with plaster and cement mortar. The roof is mainly based on a light weight precast concrete block, and its overall construction comprises layers of expanded polystyrene, asphalt, plaster, cement mortar, and the external finishing is done with concrete roof tiles. The north façade is made of the materials of the side walls, in addition to a wooden door.

2.2. The BICPV system

The integrated concentrating system is composed of 22 flat coated reflectors ($2 \times 0.16 \times 0.006$ m), with a maximum achieved concentration ratio of 10× (suns). This scheme is to represent the installation of the reflectors as windows blinds (Fig. 1). A steel

Fig. 1. The reflectors facade: during the installation of the concentrating PV façade at the Applied Energy Research Centre (CREA) at the University of Lleida (Spain). The tracking system is noticed on the left.