Life Cycle Assessment and Life Cycle Costing Analysis of Building Integrated PhotoVoltaics

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Abstract

The installation of Building Integrated PhotoVoltaics (BIPV) on building surfaces could provide environmental benefits, in particular in terms of GHG emissions reduction and primary energy demand decrease, and economic savings for the end-user. Comparative Life Cycle Analysis (LCA) and comparative Life Cycle Costing Analysis (LCCA) have been performed in the frame of the co-funded EU project CONSTRUCT-PV, in order to evaluate the environmental and economic impacts of the BIPV. The environmental footprints have been investigated through a so-called cradle to grave analysis, and the economic impacts have been examined from two different perspectives, the manufacturer’s one and the customer’s one. In order to make the comparison, a conventional system for the covering of the building surfaces has been selected, and the service to cover 1 square meter of building surface has been defined as functional unit.

1. Introduction

The project CONSTRUCT-PV, “Constructing buildings with customizable size PV modules integrated in the opaque part of the building skin” (FP7-ENERGY-2011-2, Grant Agreement No. 295981) involves 12 partners from 5 European countries, comprising 5 high-level R&D centres (Fraunhofer Institute for Solar Energy Systems, National Technical University of Athens, Scuola Universitaria Professionale della Svizzera Italiana, Ente Nazionale per le Nuove tecnologie, l’Energia e l’Ambiente and Technische Universitat Dresden), 2 SMEs (Un Studio and Advanced Management Solutions) and 5 LES (the project coordinator Ed. Zublin AG, D’Appolonia S.p.A., Meyer Burger AG, Tegola Canadese S.p.A. and SMA Solar Technology AG), leaders in the fields of PV technology and building construction.

The CONSTRUCT-PV main objective is to develop and demonstrate customizable, efficient and low cost BIPV for opaque surfaces of buildings, both roofs and façades. The idea is to utilise the BIPVs for covering the building surface, exploiting their twofold function: to cover the roof and, in the meanwhile, to produce electrical energy. The innovative aspect of the project consists therefore in the development of customized, efficient and low-cost BIPV modules (based on the most promising PV technologies, i.e. Metal Wrap Through and Hetero-Junction technology) to be integrated into opaque surfaces (like roofs) in buildings.

Two different BIPVs have been developed, one for the building roofs, the other one for the building façades. For each product, a comparative LCA and a comparative LCCA have been carried out in order to understand whether the substitution of the conventional systems, with the only function to cover the surface, through the bi-functional BIPV, could be a good choice from an environmental and economic point of view. The studies on the two products have been performed according to the same approach. As matter of example,
this paper reports the LCA and LCCA referred only to the BIPV to be installed on building roofs.

2. Goal and Scope

The paper assesses the environmental and economic impacts of the BIPV, which is a well-known technology. The purpose is to establish whether replacing the conventional covering systems with the BIPV is an eco-friendly and cost-effective choice.

The analyses do not support any business decisions.

The system has been divided into a foreground system and a background system under the specificity perspective. Processes in the background system (mining and transport of the raw materials) have not been inventoried with actual data from suppliers but included and evaluated on the basis of data taken from dedicated databases (GaBi Professional Database and Ecoinvent v 2.2). Processes in the foreground system (manufacturing, installation, use and disposal of the BIPV) have been instead inventoried based on data from the owners of the technologies.

The LCA has been performed according to the internationally recognized guidelines, i.e. “ILCD Handbook: General guide for Life Cycle Assessment – Detailed guidance”, and to specific standards, i.e. ISO 14040 and 14044. The boundary limits for the LCA include all the life cycle phases, from the manufacturing to the end-of-life steps, passing through the installation and use ones. This LCA study is classifiable in the situation C2 – Accounting, excluding interactions with other systems.

The LCCA has been made in accordance with the “SETAC Guidelines: Environmental Life Cycle Costing: A code of Practice” and ISO 15686-5:2008. Two different perspectives have been examined within the LCCA, the manufacturer’s one and the end user’s one.

The same functional unit has been selected for both the LCA and LCCA, i.e. the covering of 1 square meter of building roof. A conventional system available on the market for roofs covering has been appropriately selected by the project consortium. The conventional system is manufactured at industrial scale; therefore an industrial level production also for the BIPV has been estimated with the support of the manufacturers of the technologies, in order to make effective the comparison between the products.

2.1. Products description

The BIPV to be installed on roofs consists of two main components, a bituminous base manufactured by Tegola Canadese S.p.A. (“Bitumen” layer, Figure 1, lower part), and a PV module (“Glass” layer plus “Metal/Tedlar” layer, Figure 1, upper part) manufactured by Meyer Burger AG. The two parts are produced.
separately and then assembled through a hot coupling treatment. The BIPV is composed approximately at 30% by the bituminous base and at 70% by the PV module.

The “Prestige Ultimetal”, a metal covered bituminous base manufactured by Tegola Canadese S.p.A., has been selected as the conventional product for the comparison with the BIPV. The reasons leading to this choice are due to similar water-proofing features and data availability (data source: Tegola Canadese). The two products are installed in two different ways: the BIPV is installed through nails; the conventional product is installed through the application of a waterproofing membrane, with a gas torch.

A life span of 25 years and a disposal in landfill have been considered for both the products.

3. Life Cycle Inventory

The Life Cycle Inventory (LCI) is the LCA and LCCA phase that foresees a qualitative and quantitative identification and compilation of all inputs and outputs for a given product along its life cycle. The dedicated software GaBi 6 and a specific tool have been used, respectively, for the LCA and LCCA.

Information for performing the LCA and LCCA has been provided mainly by the products’ manufacturers, i.e. Tegola Canadese (for modelling the conventional product and the bituminous base of the BIPV) and Meyer Burger (for modelling the PV module of the BIPV).

In addition, two demo sites of BIPV prototypes have been built during the Construct-PV project and considered as reference for the LCA and LCCA inventory data and models, in particular with regard to the amount of electrical energy generated during the use phase. One demo site is located at Vittorio Veneto (Italy), in Tegola Canadese facilities, and the other one at Lugano (Switzerland), in SUPSI facilities (Figure 2).

Figure 2: Supsi (on the left) and Tegola Canadese (on the right) demo sites

4. Life Cycle Impact Assessment

The Life Cycle Impact Analysis (LCIA) is the LCA and LCCA phase that calculates the amount and significance of the environmental and economic impacts arising for the LCI.
Both environmental and economic results are hereinafter showed.

4.1. LCA results

Inputs and outputs identified in the LCI are assigned to impact categories and their potential impacts quantified according to characterization factors. The PEF (Product Environmental Footprint) recommendation (2013/179/EU) has been used as reference for impact assessment method. Fifteen indicators have been calculated.

The LCA results are reported in Table 1, related to the life cycle of the products and referred to the functional unit of the study, i.e. the covering of 1 square meter of building roof. In particular, regarding the BIPV, both the “impacts” of the manufacturing, installation and disposal steps (positive values), and the “savings” of the use step (negative values) are provided. As illustrated in the table, the total values associated to the entire life cycle are negative. The reason is associated to the production of electrical energy of the BIPV during the use phase: it does not only counterbalance the impacts generated by the other life cycle phases, but additionally provides a benefit, a so-called “avoided impact”.

<table>
<thead>
<tr>
<th>INDICATOR</th>
<th>BIPV</th>
<th>Conventional product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidification, accumulated exceedance [Moles of H+-Eq.]</td>
<td>3,75E-01, -5,23E+00, -4,86E+00</td>
<td>1,26E-01</td>
</tr>
<tr>
<td>Ecotoxicity for aquatic fresh water, USEtox [CTUe]</td>
<td>6,14E+02, -3,05E+01, 5,84E+02</td>
<td>3,62E+01</td>
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<tr>
<td>Freshwater eutrophication, EUTRENDE model, ReCiPe [kg P-Eq.]</td>
<td>2,18E-02, -6,42E-04, 2,11E-02</td>
<td>3,15E-03</td>
</tr>
<tr>
<td>Human toxicity cancer effects, USEtox [CTUh]</td>
<td>2,30E-06, -2,71E-07, 2,03E-06</td>
<td>4,05E-07</td>
</tr>
<tr>
<td>Human toxicity non-canc. effects, USEtox [CTUh]</td>
<td>4,30E-05, -3,62E-07, 6,80E-06</td>
<td>3,04E-06</td>
</tr>
<tr>
<td>Ionising radiation, human health effect model, ReCiPe [kg U235-Eq.]</td>
<td>4,02E+03, -2,41E+03, 1,61E+03</td>
<td>1,47E+03</td>
</tr>
<tr>
<td>IPCC global warming, incl biogenic carbon [kg CO2-Eq.]</td>
<td>4,65E+01, -9,91E+02, -9,44E+02</td>
<td>2,61E+01</td>
</tr>
<tr>
<td>Marine eutrophication, EUTRENDE model, ReCiPe [kg N-Eq.]</td>
<td>1,08E-02, -1,07E-01, -9,59E-02</td>
<td>3,51E-03</td>
</tr>
<tr>
<td>Ozone depletion, WMO model, ReCiPe [kg CFC-11-Eq.]</td>
<td>2,75E-06, -6,78E-07, 2,07E-06</td>
<td>1,78E-06</td>
</tr>
<tr>
<td>INDICATOR</td>
<td>BIPV</td>
<td>Conventional product</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
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<td>----------------------</td>
</tr>
<tr>
<td>Particulate matter/Respiratory inorganics, RiskPoll [kg PM2,5-Eq.]</td>
<td>3,34E-02</td>
<td>-3,15E-01</td>
</tr>
<tr>
<td></td>
<td>-3,48E-01</td>
<td>1,61E-02</td>
</tr>
<tr>
<td>Photochemical ozone formation, LOTOS-EUROS model, ReCiPe [kg NMVOC]</td>
<td>2,13E-01</td>
<td>-1,98E+00</td>
</tr>
<tr>
<td></td>
<td>-1,77E+00</td>
<td>1,12E-01</td>
</tr>
<tr>
<td>Resource Depletion, fossil and mineral, reserve Based, CML2002 [kg Sb-Eq.]</td>
<td>8,51E+01</td>
<td>-4,89E-04</td>
</tr>
<tr>
<td></td>
<td>8,51E+01</td>
<td>8,33E-03</td>
</tr>
<tr>
<td>Terrestrial eutrophication, accumulated exceedance [Mole of N-Eq.]</td>
<td>6,78E-01</td>
<td>-6,97E+00</td>
</tr>
<tr>
<td></td>
<td>-6,30E+00</td>
<td>1,97E-01</td>
</tr>
<tr>
<td>Total freshwater consumption, including rainwater, Swiss Ecocarcity [kg]</td>
<td>2,36E+01</td>
<td>-1,07E+03</td>
</tr>
<tr>
<td></td>
<td>-1,04E+03</td>
<td>1,90E+01</td>
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<tr>
<td>Primary energy demand from ren. and non ren. resources (gross cal. value) [MJ]</td>
<td>9,45E+02</td>
<td>-2,19E+04</td>
</tr>
<tr>
<td></td>
<td>-2,09E+04</td>
<td>7,16E+02</td>
</tr>
</tbody>
</table>

The environmental (in terms of kg of CO₂ eq.) and energetic (in terms of MJ) payback period have been calculated. As illustrated in Figure 3, the payback period is, in both cases, approximately, equal to 1 year.

![Environmental payback period](image)

**Figure 3: Environmental and energetic payback period**

Some indicators have been selected and reported in the following figures, since they are considered as the most representative ones for this study, using as reference the impact categories from EN 15804:2012, adding “Primary Energy Demand” and “Total Freshwater Consumption” (Figure 4).

Each graph illustrates the comparison between the impacts generated by the BIPV (in white colour with black lines) and those generated by the conventional product (in black colour). The impacts are given per each life cycle phase and referred to the functional unit. Some bars go under the axis of the abscissas and report negative values. The reason is again associated to the benefit provided by the production of electrical energy of the BIPV.
4.2. LCCA results

The inputs and outputs of the LCI have been associated to the cost information provided by the owners of the technologies.

The investment costs of the equipment (CAPEX) and the operative costs (OPEX) for the raw materials, utilities, personnel, equipment maintenance and waste treatment have been taken into account.

Two different points of view have been analysed, the manufacturer’s one and the end user’s one.

**Manufacturer’s point of view**

The investment and operative costs associated to the manufacturing phase have been considered in order to perform the cost analysis for the manufacturer for both the BIPV case and the conventional one.
For confidentiality reasons only the costs distribution will be provided within this document (Figure 5) and any costs will not be disclosed.

Figure 5: Costs distribution for the manufacturer (on the left: point of view of the manufacturer of BIPV; on the right: point of view of the manufacturer of the conventional product)

In general, the cost due to the manufacturing phase of the BIPV is higher than those of the conventional product. In particular, the manufacturing cost of the BIPV is 7 times higher than those of the conventional product. This is due to the fact that the BIPV is more complex from a structural point of view, being composed by two components, a bituminous base and a PV module. Indeed, the BIPV necessary for covering 1 square meter of roof weights almost three times the conventional product, composed by, practically, only by the bituminous base. For this reason, the costs for the manufacturer of BIPV are higher than those of the manufacturer of the conventional product.

**End user’s point of view**

The Cumulated Cash Flow Analysis for the end user of BIPV is provided in this section. An earning margin has been applied to the manufacturing cost of the BIPV manufacturer, in order to calculate a sale price for the end user.

The revenues due to the production of the electrical energy generated by the BIPV during the life span of 25 years have been calculated utilising an average price of the electrical energy for the medium household. In this way the “avoided costs for the electrical energy” from the end user point of view has been calculated. In addition the break-even point, i.e. the necessary period for the balance between costs and revenues, has been estimated. In particular, purchasing and installing the BIPV permits to the end-user to achieve revenues, after 10 years, differently from the conventional system that consists in a mere “cost” for the end user during its life span.

**5. Conclusions**

Generally, the installation of the BIPV in substitution of the selected conventional covering system for the building roof, i.e. the Prestige Ultimetal, seems a convenient choice both from an environmental and economic point of view.
Regarding the LCA results, the BIPV generates noticeable benefits compared to the reference system, in more than half indicators (8 on 15 impact categories), including the most important ones, i.e. the Primary Energy Demand and the Global Warming Potential. In particular, these benefits, calculated for the entire life cycles, achieved through the production of electrical energy by the PV part of the innovative solution, lets a huge impact reduction in terms of emissions of CO$_2$ eq. and Primary Energy Demand. The use phase, thanks to the electrical energy production is able to counterbalance, and in many cases overcome, the impacts generated by the other life cycle phases.

Regarding the LCCA, the results are promising for the end-user’s perspective. Indeed, the BIPV allows a significant economic saving through the production of electrical energy during the life span of the product. The break-even point is achieved after approximatively 10 years, permitting to the end user to completely counterbalance the initial investment cost and additionally achieve an economic saving during the course of the years.

Moreover, it shall be noted that the payback time related to the environmental impact (in terms of kg of CO$_2$ eq.) and to the energetic impact (in terms of MJ) is estimated at 1 year, approximately, while the economic break-even point is 10 years.

**ACKNOWLEDGEMENTS**

The Authors wish to thank Project Partners Tegola Canadese (Mr. Federico Cais), Meyer Burger AG (Mr. Christos Erban and Mr. Thomas Soederstroem), Ed. Zueblin AG (Mrs. Karoline, Fath, Robert Hecker), Scuola Universitaria Professionale della Svizzera Italia – SUPSI (Mr. Francesco Frontini), SMA Solar Technology AG (Mr. Joachim Laschinski) and Fraunhofer-gesellschaft zur foerderung der angewandten forschung e.v (Mrs. Heler Rose Wilson) for data providing. The result presented in this paper is part of the CONSTRUCT-PV project (http://www.constructpv.eu) co-funded by the European Commission in 7th FP, CP-IP 295981.

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