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# Evaluation of technical improvements of photovoltaic systems through life cycle assessment methodology

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**Abstract**

Since solar energy systems feed on a 'clean' energy source, they do not produce polluting emissions during their operation. However, they carry the environmental weight of other phases in their life cycle. In order to analyze the energy and environmental profile of these systems, it is necessary to expand the system boundaries, taking into account also the 'hidden impacts' related to production, transportation and system disposal at the end of its technical life. Here, the life cycle assessment methodology is applied to derive a complete and extended energy and environmental profile of photovoltaic systems. As reference case, a conventional multi-crystalline building integrated system is selected, retrofitted on a tilted roof, located in Rome (Italy) and connected to the national electricity grid. Then improved configurations of the reference system are assessed, focusing on building integration issues and the operational phase (considering an experimental hybrid photovoltaic system with heat recovery). Environmental 'pay back times' of the assessed systems are then calculated for $CO_2$ equivalent emissions and embodied energy. All the analyzed configurations are characterized by environmental pay back times one order of magnitude lower than their expected life time (3–4 years vs. 15–30 years). Thanks to a wider exploitation of photovoltaic potential during its 'zero emission operation', these results are further lowered by photovoltaic hybrid systems (environmental pay back times, depending on heat recovery configuration, go down to 40–50% of the values calculated for the reference case).


## 1. Introduction

Solar energy systems feed on a 'clean' energy source and do not show polluting emissions during their operation. However, they carry the environmental weight of other phases in their life cycle. In order to

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**Nomenclature**

| | |
|---|---|
| BOS | balance of system |
| CED | cumulative energy demand |
| $CO_{2eq}$ PBT | '$CO_2$ equivalent' pay back time |
| $C_u$ | heat use coefficient (share of recovered heat delivered to the user) |
| DHW | domestic hot water |
| EPBT | energy pay back time |
| GWP | global warming potential |
| HRU | heat recovery unit |
| LCA | life cycle assessment |
| LHW | low heating value |
| mc-Si | multicrystalline silicon |
| PV | photovoltaic |
| PV/TH | photovoltaic/thermal |
| PBT | pay back time |

better analyze the energy and environmental profile of such systems, the system boundaries need to be expanded, taking into account also the 'hidden impacts' related to production, transportation and system disposal.

In this study, the life cycle assessment (LCA) analysis is applied to derive a complete and extended energy and environmental profile of photovoltaic systems.

Thanks to the LCA capability of pinpointing energy and environmental bottlenecks of the analyzed processes, it is possible to generate and evaluate improved system configurations. Focusing on the operational phase, in particular, the benefits of reduced material requirement for installation and improved energy performance through a wider exploitation of system potential are investigated.

In this paper, the main results of the above study are presented and discussed

## 2. Life cycle assessment

The LCA methodology allows to assess the potential environmental impacts of a product or service during its whole life cycle ('from the cradle to the grave').[1]

A LCA study is divided into the following steps:

1. Goal and scope definition.
2. Life cycle inventory.
3. Life cycle impact assessment.
4. Interpretation of results.

[1] LCA methodology is ruled by ISO (International Organization for Standardization) 14040 standards [1–4].

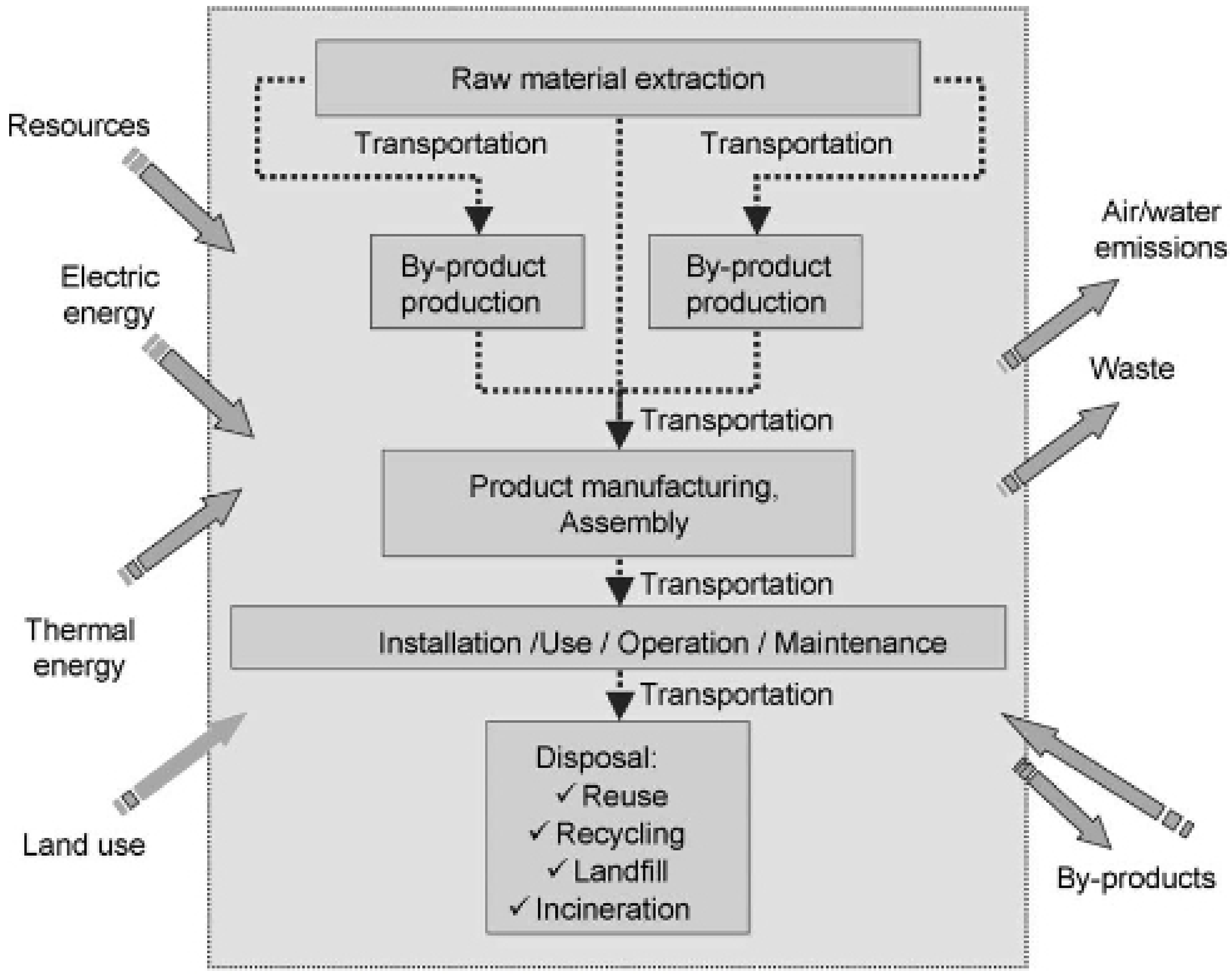


Fig. 1. Input and output data to be collected in the LCI phase.

In step 1 the goal of the study, its intended audience, and the main work hypotheses are defined. The key parameter to be fixed is the 'functional unit', i.e. the reference unit for which environmental impacts are calculated. The functional unit is related to the service offered by the product.[2] The geographical and time boundaries of the analysis are defined as well, underlining the phases excluded from the analysis (cut-off criteria).

In the life cycle inventory step, the environmental data for all the phases included in the study are collected. These data include raw resource and material consumption, electric and thermal energy use as well as air, water and soil emissions and by-products (Fig. 1).

When performing the life cycle impact assessment, the data collected in the previous step are grouped into aggregate indicators, such as greenhouse effect, primary energy consumption or solid waste production. To calculate these indicators, a relative weight factor is associated to every substance emitted or resource consumed. In the greenhouse effect indicator, for example, the weight factor for methane ($CH_4$) is 21; therefore, 1 kg of methane has the same effect as 21 kg of $CO_2$, the reference substance for this indicator.

In the last step, the results of the study are analyzed in detail and compared with the initial goals. The limits of the performed analysis, and consequently its applicability, are underlined. Some changes to the initial hyphoteses may be needed after the result of calculation, in order to obtain more useful, reliable and meaningful outputs.

[2] In the LCA study of an electricity production system, for example, the functional unit is a certain amount of electric energy delivered to the user (e.g. 1 kWh at low voltage, in Italy: 230 V).