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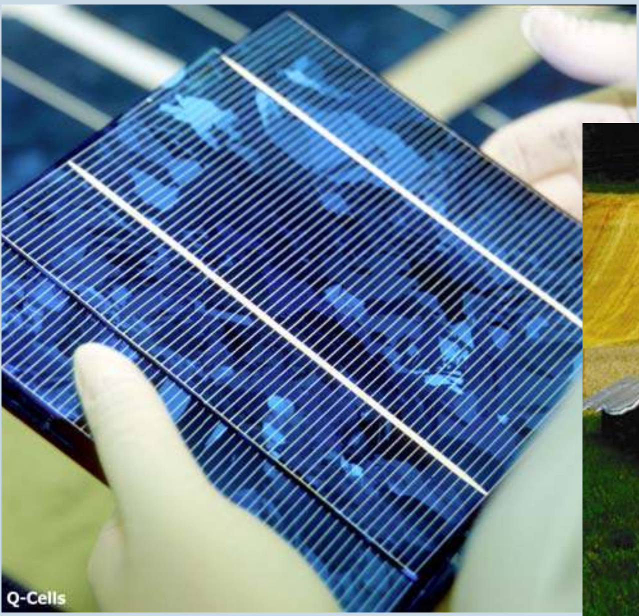
Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity


Q-Cells


Karlstadt Laudenbach, Germany (810 kW); Phoenix Solar

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T12-01:2009

INTERNATIONAL ENERGY AGENCY
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

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IEA PVPS Task 12, Subtask 20, LCA
Report IEA-PVPS T12-01:2009
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Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its member countries. The European Commission also participates in the work of the IEA.

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R & D Agreements established within the IEA. Since 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity.

The mission of the Photovoltaic Power Systems Programme is “to enhance the international collaboration efforts which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option”. The underlying assumption is that the market for PV systems is gradually expanding from the present niche markets of remote applications and consumer products, to the rapidly growing markets for building-integrated and other diffused and centralised PV generation systems. The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. By the end of 2007, twelve Tasks were established within the PVPS programme.

Task 12, with a length of 5 years (2007-2011) aims in fostering international collaboration in the areas of safety and sustainability which are crucial for allowing PV to grow to levels enabling a major contribution in the needs of the member countries and the world.

The overall objectives of Task 12 are to:

1. Quantify the environmental profile of PV in comparison to other energy technologies;
2. Define and address environmental health & safety and sustainability issues that are important for market growth;

The first objective of this task can be served with life cycle assessment (LCA) that describes energy, material and emission flows in all the stages of the life of PV. The second objective will be addressed with assisting the collective action of PV companies on defining material availability and product recycling issues and on communicating "lessons learned" from incidents or potential incidents in PV production facilities. The third objective (i.e., dissemination) will be accomplished by presentations to broad audiences, producing simple fact sheets documented by comprehensive reports, and engaging industry associations and the media in the dissemination of the information.

Within Task 12, Subtask 20 “Life Cycle Assessment” the targets are to quantify the environmental profile of electricity produced with PV systems (also compared to that of electricity from other sources of energy), to show the improvement trends of the PV environmental profile, and to assess the environmental profile of PV electricity with the help of "external" costs and other life cycle impact assessment methods.

This report has been prepared by Alsema Erik, Daniel Fraile, Rolf Frischknecht, Vasilis Fthenakis, Michael Held, Hyung Chul Kim, Werner Pölz, Marco Raugei, and Mariska de Wild Scholten. The editing has been done by Rolf Frischknecht. The support of the Swiss Federal Office of Energy is gratefully acknowledged.

Further information on the activities and results of the Task can be found at:

http://www.iea-pvps.org and http://www.iea-pvps-task12.org

Contents

1 Introduction

This document contains the methodology guidelines on how to perform life cycle inventory analysis and life cycle impact assessments of grid-connected photovoltaic electricity. It is based on the methodology guidelines drafted so far and it is extended according to the discussions on August 31, 2008 in Valencia.

2 Motivation and Objectives

National and regional energy policies ask for environmentally friendly electricity generating technologies. The PV industry is experiencing a rapid evolution. The availability of the most up-to-date PV performance and LCI data and of up-to-date weighted averages that accurately represent the mixture of options presently available or in operation in the country or region of study are key prerequisites for an adequate environmental assessment. The major motivation to carry out the work in the IEA PVPS Task 12, subtask 20 "LCA" is to supply the most recent and complete life cycle based information on PV components and systems. The major objectives of this subtask are:

- to prepare life cycle assessment studies, which reflect the current status in PV manufacturing, based on well-documented industry average and up-to-date LCI data and also on well-documented industry best cases (actual, existing systems). This work helps in the environmental evaluation of electricity supply systems both within solar photovoltaic electricity and across different energy carriers and resources used to produce electricity.
- to prepare life cycle assessment studies, which reflect the current status of PV systems in operation in a country or region. This work helps to quantify the contribution of solar electricity to the environmental impacts of a national or regional grid mix or of the grid mix of a utility.

3 Methodological Guidelines

All PV LCA studies should be elaborated according to the ISO standards 14040 and 14044. Deviations from the nomenclature, procedure and methodology compared to this standard for life cycle assessment should be clearly stated.

The following guidelines are structured into three main areas: Subchapter 3.1 contains recommendations regarding technical characteristics related to photovoltaic systems. Subchapter 3.2 contains aspects regarding modelling approaches in life cycle inventory analysis and life cycle impact assessment. Subchapter 3.3 contains aspects regarding reporting and communication.

3.1 Photovoltaics-specific aspects

3.1.1 Life expectancy

The recommended life expectancy used in life cycle assessment studies of photovoltaic components and systems differentiates between the components:

- Modules: 30 years for mature module technologies (e.g. glass-tedlar encapsulation), life expectancy may be lower for foil-only encapsulation;
- Inverters: 15 years for small size plants (residential PV); 30 years with 10% of part replacement every 10 yrs (parts need to be specified) for large size plants (utility PV, (Mason et al. 2006);
- Structure: 30 years for roof-top and façades and between 30 to 60 years for ground mount installations on metal supports. Sensitivity analyses should be carried out by varying the service life of ground mount supporting structures within the time span indicated.
- Cabling: 30 years
- Manufacturing plants (capital equipment): The lifetime may be shorter than 30 years, due to rapid technology development. No consensus on appropriate lifetime yet. [Discussions are ongoing]

The life time of structures and cabling will be re-examined in comparison with other power plant technologies, such as wind power plants.

3.1.2 Irradiation

The irradiation depends on the location and orientation of the modules. Depending on the goal of the study, two main recommendations are given:

- Analysis of industry average and best case systems:
  Assume for all systems on ground the irradiation on a latitude optimally oriented array plane (except when a specific system under study is laid out differently). Assume the same optimal orientation and tilt for roof top installations. No general assumption is possible with regard to façade installations. Case specific irradiation values shall be used when analysing façade installations.
- Analysis of the average of installed systems in a grid network:
  Use actual orientation and irradiation

See International Standard IEC 61724 for a description of irradiance (W/m^2) and irradiation ($kWh/m^2.yr$)

3.1.3 Performance ratio

The performance ratio (PR) depends on the kind of installation. The mean annual performance ratio shows an upward trend from 0.64 in 1991 to 0.74 in 2005.[1] In general the performance ratio increases with 1) decrease in temperature 2) monitoring the PV systems for early detection of defects. This means that well ventilated and large scale systems have a higher performance ratio.

It is recommended to use either site specific PR values or a default value of 75 % for roof-top and 80% for ground-mount latitude optimal installations (Fthenakis et al. 2008; Mason et al. 2006; Pfatischer 2008);

Use actual performance data (actual production per kWp) of installed technology whenever available or make reasonable assumptions which reflect actual performance data when analysing the average of installed systems in a grid network.

See International Standard IEC 61724 for definition of performance ratio.

3.1.4 Degradation

The degradation of the modules results in a reduction of efficiency over the life time. The following degradation rates are recommended:

- Mature module technologies: assume 80 % of the initial efficiency at the end of the 30 years life time. Assume linear degradation during these 30 years.
- Concentrated PV: [information about the degradation rate will be added when field data are available]

See Photon International market survey on solar modules for power guarantee values for all module models.

3.1.5 Back-up systems

For static LCA studies it is not considered necessary to include dedicated storage capacity or fossil-fuel generating capacity for the electricity that is fed into the grid by PV systems (no back-up capacity needed).

3.2 LCI/LCA modelling aspects

3.2.1 System modelling: static / prospective (attributional / consequential), electricity mix in background data, small versus large scale

The appropriate system model depends on the goal of the LCA. The following goals may be distinguished:

A) reporting of environmental impacts of PV currently installed in a utility's network (retrospective LCA)

B) choice of a PV electricity supplier, comparison of PV systems, or comparison of electricity generating technologies (short-term prospective LCA)

C) long-term energy policy, comparison of future PV systems or comparison of future electricity generating technologies (long-term prospective LCA)

The following recommendations apply on all goals:

- Depending on the goal and scope of the study, an attributional, decisional or

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[1] http://www.iea-pvps-task2.org/public/download/T2_Cost_and_Performance.pdf

consequential approach should be chosen (Frischknecht 2006). Up to now, most LCA use an attributional approach.

- The product system shall be divided into foreground and background processes. The following definition is proposed: Foreground processes are those on which the decision maker or product owner can directly have influence on. Background processes are all remaining processes of the product system at issue. [Discussions on the precise definition of background/foreground and its practical implementation are pending.]
- We recommend the use of the conventional process-based LCA developed by SETAC and standardised by the ISO.
- I/O or hybrid method: These approaches are not followed in this subtask. More experience in these approaches is needed before we recommend applying these methods.

The following recommendations apply on the two goals B) and C):

- Use the present average mix (i.e. Europe (EU 27, including Norway and Switzerland), US, Korea, China or Japan) when modelling current PV component production. Specify the year for which the data are valid.
- If the production of a material is bound to a certain country, a limited amount of companies or if the material production generally uses a specific type of electricity supply one may make an argued choice for a country or company specific electricity mix e.g. hydro power for Silicon feedstock production in Norway.
- Country or company specific cases must be clearly identified as such so that data are not unintentionally used for projections to different scales and regions.

The following recommendations apply on the goal C):

- Use an average future mix (i.e. Europe (EU 27, including Norway and Switzerland), US, Korea, China or Japan) when modelling future PV component production. Specify the year for which the data are intended to be valid.
- Adapt the performance of the power plants contributing to this future electricity mix.
- If the production of a material is expected to be bound to a certain country, a limited amount of companies or if the material production generally uses a specific type of electricity supply one may make an argued choice for a country or company specific electricity mix e.g. hydro power for Silicon feedstock production in Norway. However, in prospective analysis, one has to document the availability of country-specific resources to the projected scales. Country or company specific cases must be clearly identified as such so that data are not unintentionally used for projections to different scales and regions.
- Adapt the efficiency of material supply, transport and waste management services so that they represent a possible future state, consistent with the underlying energy policy scenario.

3.2.2 Functional unit and reference flow

The functional unit specifies the function based on which different PV technologies and other electricity generating technologies may be compared. It is recommended to use the ISO language and distinguish between “functional unit” and “reference flow”. The functional unit specifies the reference flow to enable comparisons. The functional unit is quantified with the reference flow such as the "kWh electricity" or the "m^2 laminate".[2]

- Comparison of PV technologies, module technologies and of electricity generating technologies in general (goal B):
  Use the kWh of electricity fed into the grid. In some cases the kWh supplied to low voltage customers may be used (it then shall include electricity transmission and distribution).
- Quantify the environmental impacts of a particular building (PV system is not the main focus in this kind of assessment):
  Square metre PV module is applicable for building applications. Square metre is not suited for comparisons of PV technologies because of differences in module and inverter efficiency and in performance ratio.
- Quantify the net energy gains achievable on a given roof (surface limitation): Square metre PV module.

The kWp may be used as the reference flow when quantifying the environmental impacts of module technologies. However, module technologies must not be compared on the basis of the nominal power (kWp) figures because the kWh fed to the grid may differ between the systems analysed.

The location, the module technology used, the voltage level and whether or not and how the transmission and distribution losses are accounted for should be specified.

3.2.3 System boundaries

This section defines the scope of the product system to be analysed. It gives guidance on what to include and what to exclude from the life cycle inventory analysis.

- The product system shall include the panel, the mounting system, the cabling, the inverter and all further components necessary for electricity production and supply to the grid.
- Include energy and material flows caused by manufacturing processes, climate control, ventilation, lighting for production halls, on-site emissions abatement and on-site waste treatments.
- Exclude commuting (transportation to and from work).

No consensus was reached on the items listed below. The following criteria may be used to decide whether or not to include those parts: similar depth of analysis when comparing power plant technologies; data availability; environmental relevance (according to ISO 14044).

- Whether or not administration, sales and distribution, and research and development should be included in the product system.
- If administration, sales and distribution, and research and development are included, try to keep their life cycle inventory information separate from manufacturing.
- If research and development are included, try to attribute their contributions to an appropriate sales volume regarding the component, on which R&D activities are spent. Use information from the respective business plans.
- If the inventory includes energy and materials that are not directly related to production (e.g. energy and material use for administration, research and

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[2] In all cases listed below, all balance of system (BOS) elements shall be included.

development), report on their impacts separately from "production-only" impacts in the interpretation phase of the LCA. If only aggregated data for production and office are available try to estimate office part and report on this separately.

- Examine the environmental impacts of PV production equipment, if data are available, as it may turn out to be relevant in certain cases (e.g. Mohr et al. 2007). If included, these impacts should be listed separately.

3.2.4 Modelling of allocation and recycling (including “Content of recycled aluminium”)

Multifunction processes (processes that produce several different products at the same time, e.g. off-grade silicon supply), recycling of materials (e.g. use of recycled aluminium) and use of waste heat (e.g. heat recovery in municipal waste incinerators) ask for consistent allocation rules. We recommend to follow the ISO standard 14044, Clause 4.3.4 "Allocation" (International Organization for Standardization (ISO) 2006).

3.2.5 Databases

The IEA PVPS Task 12 does not recommend any particular LCI database. Transparency of the documentation and availability of the unit process information and data are of utmost importance.

The Swiss partners committed themselves to implement the LCI data compiled within Task 12, Subtask 20 "LCA" into the ecoinvent database and thereby facilitate distribution of up to date and transparent LCA information on photovoltaics. This commitment is acknowledged and supported by the subtask 20 "LCA" partners.

3.2.6 Life cycle impact assessment, (including “Metrics”)

- Use category indicators, greenhouse gas emissions, cumulative energy demand, human toxicity, ecotoxicity, radionuclides emissions, nuclear waste generation, air pollutant emissions (NO_X, SO_2, PM10).

- (Abiotic) Resource Depletion:
  Existing impact assessment methods for resource depletion are considered problematic by some of the participants as they cannot be based on accurate data for scarce metals like indium, tellurium, gallium. One might use the cumulative exergy demand instead, which takes minerals into account, besides energy resources. [Discussions on this issue are ongoing.]

- Land use changes and water use are environmental challenges of growing importance. No decision taken yet and discussions on whether and how to include impact indicators on land use and water use are still ongoing.

- When using life cycle impact assessment methods that use impact pathway analysis to quantify environmental damage, be transparent about methodology and assumptions or clearly refer to the method and its version applied.

- If external cost is calculated, use generic damage factors generated by the NEEDS project. The NEEDS project in addition provides information on environmental impacts of the future supply of basic materials (steel, aluminium, copper, etc.), transport services (van and lorry) and electricity mixes (Frischknecht et al. 2007).

3.3 Reporting and communication

3.3.1 Key parameters to be reported

Clear communication is essential for transparency. The following aspects need to be reported:

- explicit goal of the study or investigation, including aspects such as static or prospective LCA (goal A), B) or C), current performance or large scale (future) development, etc.
- Name the commissioner of the study
- Intended purpose and audience
- Module efficiency
- Irradiation (kWh/(m^2.yr)) and performance data, including performance ratio (PR); describe if irradiation input is specified on horizontal or latitude tilt plane; describe in detail region and condition, e.g. X % for supersolar power plant installed in Spain, measured by continuous monitoring and reported in www.supersolar.org.
- Location of the PV plant (to be stated in the goal and scope description and during the interpretation of the LCA).
- Assumptions for production of major input materials, e.g. solar grade silicon
- Assumptions for system type, method of module mounting (for roof-top systems) and BOS components;
- Conversion factor from m^2 to kWp, For instance, 15 % module efficiency is equivalent to 150 Wp/m^2.

3.3.2 Reporting results (covering payback times and mitigation potentials)

- Adapt category indicators to audience: for policy makers only use selected (mid-point) impact categories, such as greenhouse gas emissions (GHG), cumulative energy demand (CED), acidification potential (AP), ozone depletion potential (ODP), or volume of radioactive waste.
- The indicators need to be described unequivocally. Cumulative energy demand (CED) for instance, requires a description of the method used to quantify CED. The impact category indicators need to be identified by specifying the underlying time horizon (e.g. with regard to global warming potential either 20, 100 or 500 years).
- Energy Pay-Back Time (EPBT):
  Describe the Cumulative Energy Demand method underlying the EPBT concept and specify the reference system, e.g. today European electricity mix, or national electricity supply mix. Specify the primary energy to electricity conversion factor and its reference and specify the energy contents of energy resources used to quantify the CED.
- Emission mitigation potentials: this may comprise climate change mitigation potential or high level nuclear waste mitigation potential (see e.g. Jungbluth et al. 2008). Give clear reference to the impact assessment method applied and specify the reference system, e.g. today European electricity mix, or national electricity supply mix.
- Since a major part of the environmental impacts of PV systems is due to emissions from the “background system”, (i.e. from electricity production and from the production of common materials like glass, aluminium, plastics, steel and the like), it

is recommended to separate “background” and “foreground” contributions to impact indicator results.

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