Renewable Energy 61 (2014) 2–6

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

Environmental impacts of large-scale grid-connected ground-mounted PV installations

Antoine Beylot [a,*,1], Jérôme Payet [a,1], Clément Puech [b,2], Nadine Adra [b,2], Philippe Jacquin [c,3], Isabelle Blanc [d,4], Didier Beloin-Saint-Pierre [d,4]

[a] CYCLECO, 1011 Avenue Léon Blum, 01500 Ambérieu-en-Bugey, France
[b] Transénergie, 3D, allée Claude Debussy, 69130 Ecully, France
[c] PHK Consultants, 17 bis rue Jean-Marie Vianney, 69130 Ecully, France
[d] MINES ParisTech, Center for Energy and Processes, Rue Claude Daunesse BP 207, 06904 Sophia Antipolis Cedex, France

ARTICLE INFO

Article history:
Received 2 January 2012
Accepted 16 April 2012
Available online 27 June 2012

Keywords:
Environmental impacts
LCA
PV installations

ABSTRACT

This study characterizes the environmental performances of large-scale ground-mounted PV installations by considering a life cycle approach. The methodology is based on the application of the existing international standards of Life Cycle Assessment (LCA). Four scenarios are compared, considering fixed-mounting structures with (1) primary aluminum supports or (2) wood supports, and mobile structures with (3) single-axis trackers or (4) dual-axis trackers. Life cycle inventories are based on manufacturers' data combined with additional calculations and assumptions. Fixed-mounting installations with primary aluminum supports show the largest environmental impact potential with respect to human health, climate change and energy consumption. The climate change impact potential ranges between 37.5 and 53.5 g CO_2 eq/kWh depending on the scenario, assuming 1700 kWh/m^2 yr of irradiation on an inclined plane (30°), and multi-crystalline silicon modules with 14% of energy production performance. Mobile PV installations with dual-axis trackers show the largest impact potential on ecosystem quality, with more than a factor 2 of difference with other considered installations. Supports mass and composition, power density (in MWp/acre of land) and energy production performances appear as key design parameters with respect to large-scale ground-mounted PV installations environmental performances, in addition to modules manufacturing process energy inputs.

1. Introduction

PV systems deployment and solar energy use are developing rapidly in Europe. In particular, Austria, Switzerland, Germany, France, Italy and the Netherlands experienced a two to four-fold increase in their annual installed photovoltaic power in 2009 [1]. Large-scale PV systems (>500 kWp) represent a lower share of the photovoltaic power production compared to small scale systems (<3 kWp). However, their market is showing a dramatic increase in number of installations. In France a 90% increase was observed between the 2nd and 1st trimesters 2010 for installations of power superior to 500 kWp, compared to a 38% increase for small scale installations [2].

In this context of rapid development, the issue of PV systems environmental impacts characterization has been intensively addressed and discussed. While several initial publications underlined the higher external environmental costs of PV compared to those of nuclear energy and natural-gas-fuel power plants [3,4], new LCA databases have been built to comply with the improvements in PV systems [5,6]. They highlighted the photovoltaic potential for a low carbon energy supply and the environmental benefits of PV as opposed to fossil-fuel based energy [7,8]. LCA data currently consider solar cells, panels and installation equipments production in the supply chain of different technologies. Up to now, most studies have focused on module technologies and small scale installations. They exposed the key parameters for environmental performances of PV installations, when focusing on greenhouse gas

* Corresponding author. Present address: BRGM, BP 6009, 3 av. C. Guillemin, 45060 Orléans Cedex, France. Tel.: +33 (0)2 38 64 31 18.
E-mail addresses: a.beylot@brgm.fr (A. Beylot), jerome.payet@cycleco.eu (J. Payet), c.puech@transenergie.eu (C. Puech), n.adra@transenergie.eu (N. Adra), philippe.jacquin@phkconsultants.com (P. Jacquin), isabelle.blanc@mines-paristech.fr (I. Blanc), didier.beloin-saint-pierre@mines-paristech.fr (D. Beloin-Saint-Pierre).
[1] Tel.: +33 (0)2 38 64 31 18.
[2] Tel.: +33 (0)4 72 86 04 17.
[3] Tel.: +33 (0)4 78 33 36 14.
[4] Tel.: +33 (0)4 93 95 75 13.

0960-1481/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2012.04.051

emissions and primary energy use as environmental indicators: irradiation intensity received by PV installations, modules manufacturing electricity use and its corresponding fuel mix and PV technology [9–12]. However, only few evaluations of large-scale PV installations can be found in the literature [13,14].

This study aims at characterizing the environmental impacts of large-scale grid-connected ground-mounted PV installations (5 MWp), considering one module technology (mc-Si) with different structures and types of supports (fixed-mounting or mobile). The results highlight key parameters related to large-scale PV systems environmental performances on a life cycle perspective. Impacts on climate change and energy consumption are considered as indicators for the environmental assessment together with human health and ecosystem quality indicators. Recommendations are finally given to enable stakeholders in the field of large-scale PV systems to minimize the environmental impacts of future installations.

2. Methodology

This Life Cycle Assessment (LCA) study was performed in compliance with the ISO standards 14040 and 14044 [15,16] and followed the provisions of the International Reference Life Cycle Data System (ILCD) Handbook [17].

2.1. Scope of the study

The Functional Unit is defined as the kWh of electricity produced by a large-scale grid-connected ground-mounted PV installation (5 MWp), considering 1700 kWh/m^2 yr of irradiation on an inclined plane (30°) and 30 years of life expectancy.

The system boundaries are described in Fig. 1. They include the manufacturing of core infrastructures (modules, mounting system, cabling, inverters, transformers), the manufacturing of complementary infrastructures (wire fences, control centers and road to access the plant), the plant installation (excavation and track construction), the use phase and the decommissioning (excavation, modules and structures end-of-life). Recycled waste material is assumed to substitute for primary produced material, without considering any correction factor.

Four grid-connected ground-mounted PV installations are compared in the study. Their differentiating key features are detailed in Tables 1 and 2. The multi-crystalline silicon (mc-Si) PV technology is chosen for every scenario. Consequently, only the type of structure and its related system energy production differentiate the scenarios.

Life cycle impact assessment is performed with the use of the IMPACT 2002+ method (v2.04) [18]. The results focus on four damage impact categories: climate change, resources, human health and ecosystem quality. The temporary carbon storage in bio-based goods (wood supports in one scenario) is taken into account in compliance with ILCD provisions, i.e. by considering "−0.01 kg CO_2-equivalents" per 1 kg of CO_2 and 1 year of storage/delayed emissions.

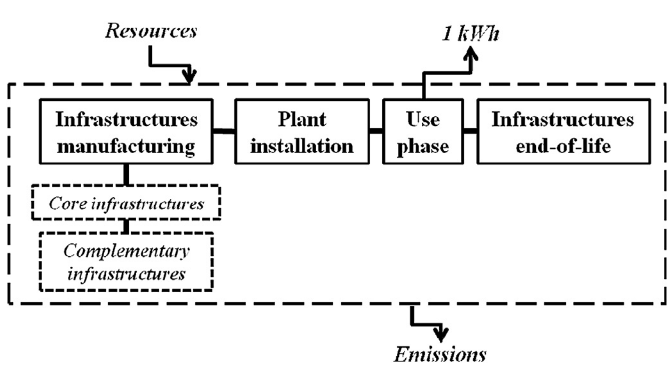

Fig. 1. Scheme of system boundaries.

Table 1
Scenarios key features.

Scenarios	1	2	3	4
Module technology	mc-Si	mc-Si	mc-Si	mc-Si
Structure key features	Fixed-mounting Primary aluminum supports	Fixed-mounting Wood-based supports	Mobile Single-axis trackers	Mobile Dual-axis trackers

2.2. Inventory

The inventory distinguishes between:

- foreground processes, corresponding to PV systems parameters, land occupation and electricity use and generation, for which specific data have been used.
- upstream and downstream processes, corresponding to materials extraction and transformation, PV modules fabrication, materials and products transport, electricity production mix, infrastructures end-of-life, for which semi-specific or generic data have been used. Ecoinvent v2.0 [19] was used as the reference database for semi-specific data.

2.2.1. PV installations electricity production

Energy efficiency of the PV modules is set to 14%, with an average performance ratio of 0.855 for the system. The increase in production thanks to mobility is respectively set to 5% for Scenario 3 considering single-axis trackers and to 32.5% for Scenario 4 considering dual-axis trackers, based on average manufacturers' data. The corresponding electricity generated over the 30 years installation life-time is given in Table 2 for the 4 scenarios.

2.2.2. Infrastructures

Data on infrastructures of large-scale PV installations have been either directly collected or calculated from manufacturers' data, as detailed in Table 3. Ten 500 kW inverters are necessary for each PV installation, assuming 10 years of life expectancy (i.e. 30 inverters over each installation life-time), and five 1 MW transformers, considering 30 years of life expectancy.

2.2.3. Key additional assumptions

In the absence of specific or semi-specific data for plant building operations (track construction), for engines composition (used in

Table 2
Energy production in scenarios.

Scenarios	1	2	3	4
Increase in production due to mobility	–	–	5% (Average data from a Spanish supports manufacturer)	32.5% (Average data from an Italian supports manufacturer)
Electricity production over 30 years (in GWh)	218.0	218.0	228.9	288.9