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Life Cycle Analysis to estimate the environmental impact of residential photovoltaic systems in regions with a low solar irradiation

Ruben Laleman [a,*], Johan Albrecht [a,1], Jo Dewulf [b,2]

[a] Ghent University, Faculty of Economics and Business Administration, Tweekerkenstraat 2, B9000 Ghent, Belgium
[b] Research Group ENVOC, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

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ABSTRACT

Photovoltaic installations (PV-systems) are heavily promoted in Europe. In this paper, the Life Cycle Analysis (LCA) method is used to find out whether the high subsidy cost can be justified by the environmental benefits. Most existing LCAs of PV only use one-dimensional indicators and are only valid for regions with a high solar irradiation. This paper, however, presents a broad environmental evaluation of residential PV-systems for regions with a rather low solar irradiation of 900–1000 kWh/m^2/year, a value typical for Northern Europe and Canada. Based on the Ecoinvent LCA database, six Life Cycle Impact Assessment (LCIA) methods were considered for six different PV-technologies; the comprehensive Eco-Indicator 99 (EI 99) with its three perspectives (Hierarchist, Egalitarian and Individualistic) next to three one-dimensional indicators, namely Cumulative Energy Demand (CED), Global Warming Potential (GWP) and the Energy Payback Time (EPT).

For regions with low solar irradiation, we found that the EPT is less than 5 years. The Global Warming Potential of PV-electricity is about 10 times lower than that of electricity from a coal fired plant, but 4 times higher when compared to a nuclear power plant or a wind farm. Surprisingly, our results from the more comprehensive EI 99 assessment method do not correlate at all with our findings based on EPT and GWP. The results from the Individualist perspective are strongly influenced by the weighting of the different environmental aspects, which can be misleading. Therefore, to obtain a well-balanced environmental assessment of energy technologies, we recommend a carefully evaluated combination of various impact assessment methods.

Contents

* Corresponding author. Tel.: +32 9 2644209.
E-mail addresses: Ruben.laleman@ugent.be (R. Laleman), Johan.albrecht@ugent.be (J. Albrecht), Jo.dewulf@ugent.be (J. Dewulf).
[1] Tel.: +32 9 2643510.
[2] Tel.: +32 9 264 59 49; fax: +32 9 264 62 43.

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1. Introduction

Photovoltaic (PV) technologies are strongly supported in most developed countries, even in regions with a low solar irradiation such as Northern Europe. From a cost-efficiency perspective, this practice could be challenged for obvious reasons. When gas powered and nuclear electricity plants produce electricity at a production cost of some €75 per MWh, the diffusion of residential PV-installations with a production cost of some €300 to €450 per MWh in regions with a low solar irradiation [1] risks becoming extremely expensive. More and more authors recommend the immediate and drastic reduction of production subsidies (feed-in tariffs or green certificates) for solar technologies [2]. But can the support for PV-technologies also be challenged from a broad environmental perspective? Are there strong sustainability gains from investing in PV in regions with little sunshine? To answer the latter question, we perform a Life Cycle Impact Assessment (LCIA) for privately owned roof top PV-systems in regions with a low solar irradiation.

Table 1 presents some cities in regions with a low, moderate, and high solar irradiation. The data illustrates that investing in PV-systems in the south of Spain or California is much more interesting compared to Belgium, Germany or the U.K.

The analysis in this paper concerns regions with an irradiation of 900–1000 kWh/m^2/year, such as Belgium, the U.K., Germany and Sweden. Multiple Life Cycle Impact Assessment (LCIA) methods are compared to obtain a broad perspective on the environmental impact of residential PV-systems in those regions. All our calculations are based on the Ecoinvent (v2.0) database.

The LCA of PV-systems has been a subject of many articles, but in most cases, these assessments are limited to one-dimensional indicators such as Global Warming Potential (GWP), Cumulative Energy Demand (CED) and Energy Payback Time (EPT) [6–8]. PV is booming in countries such as Germany but unfortunately, only a few authors consider regions with low irradiation for their LCA. For example, Jungbluth [9] and Jungbluth et al. [10] have studied PV-systems in Switzerland, assuming an average horizontal irradiation of 1117 kWh/m^2/year, which is still some 15% more compared to the U.K., northern Germany and Belgium.

In this study, we want to contribute to the existing literature by comparing the results from the one-dimensional indicators, such as CED, EPT and GWP, with the Eco-Indicator 99 (EI 99) method for regions with a low irradiation (950 kWh/m^2/year). All the results are evaluated in detail and compared with data found in the literature. The goal is to obtain a very broad, nuanced and clear picture of the environmental impact of a residential PV-system.

Six different types of PV-systems will be evaluated: Cadmium Telluride (CdTe), $CuInSe_2$ (CIS), ribbon Si, multi crystalline Si (multi c-Si or poly c-Si), mono crystalline Si (mono c-Si) and amorphous (a-Si). Especially the new technologies such as CdTe and other thin film cell types have steep learning curves. The energy cost of thin film PV-cells is already comparable to that of crystalline systems [8] and has recently (end 2008) dropped to 1$/W [11]. According to Raugei and Frankl [8], the conversion efficiency is now at a satisfying 10–11% and could theoretically increase up to 16–17%.

In the next section, we present a brief overview of the different LCIA methods that were used. In Sections 3 and 4, the environmental impact of various PV-types is evaluated. We conclude by linking our findings to the existing literature and by discussing the value added of the EI 99 method. Table 2 gives an overview of the LCIAs used, and the technologies that have been analyzed.

Table 1
Horizontal irradiation in the EU, US and Canada (in kWh/m^2/year).

Low irradiation (kWh/m^2/year)		Moderate irradiation (kWh/m^2/year)		High irradiation (kWh/m^2/year)	
Brussels	960	Istanbul	1320	Seville	1700
Cologne	967	Bordeaux	1300	Cyprus	1750
London	980	Turin	1340	Malta	1770
Stockholm	940	Minneapolis (MN)	1430	San Francisco (CA)	1715
Vancouver	1100	Seattle (WA)	1200	Los Angeles (CA)	1788

Source: EU: [3]; US [4]; Canada [5].

Table 2
Overview of content of the paper and the used LCIA methods.

Unit	LCIA	Subject of research
3 kWp PV-system	CED, EPT, GWP, EI 99	CdTe/CIS/ribbon Si/multi c-Si/mono c-Si/a-Si
1 kWh electricity	GWP, EI 99	PV (multi c-Si) compared to fossil based energy