Interactive Web-Service for Environmental Multi-Criteria Life Cycle Assessment of Photovoltaic Systems Worldwide

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INTERACTIVE WEB-SERVICE FOR ENVIRONMENTAL MULTI-CRITERIA LIFE CYCLE ASSESSMENT OF PHOTOVOLTAIC SYSTEMS WORLDWIDE

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ABSTRACT: Photovoltaic (PV) technologies constitute a leading renewable energy source with a worldwide installed capacity of 135 GW in 2013 that may increase to nearly 4700 GW in 2050. To achieve this production level while minimizing environmental impacts, decision makers must rely at national level on relevant technological, economic and planning aspects which are highly geographically dependent. The access to performance data is a critical issue in the decision-making process and determines the successful development of efficient PV systems. For this reason, a new interactive tool is proposed here to provide the users with easy-to-use data and maps for the solar irradiation and screening level environmental results of representative PV technologies. The calculation procedures account for the geographic location and the PV system layout (installation, orientation and inclination angles). The tool has a worldwide coverage with a multi-criteria scope, both in terms of the numerous technological scenarios and of the wide range of environmental indicators. Moreover, the user is given the possibility to compare the PV environmental performance to the corresponding country electricity mix environmental footprint.

Keywords: Photovoltaic, Web-Service, environmental performance, solar irradiation data, IEA PVPS Task 12, OGC standards.

1 INTRODUCTION

Photovoltaic (PV) technologies constitute a leading renewable energy source in the context of energy transition [1,2]. The worldwide installed capacity is expected to increase from 135 GW in 2013 to nearly 4700 GW in 2050 [2]. Although PV systems rely on sunlight, which is an extensive renewable source, and cause nearly no emissions during the use (power generation) phase, other processes over the production chain corresponding to materials extraction, components' manufacturing, transport and end-of-life management should be computed to quantify the environmental costs over the whole life cycle of the panels [3,4]. To achieve the worldwide production target while maintaining a low level of environmental impacts in the upstream and downstream stages, techno-economic and planning criteria affecting the theoretical generation potential of PV systems need to be included. Geographically-dependent factors that may alter the PV power production and, thus, the environmental performance should also be taken into account [5,6].

The access to detailed data that support the decision-making process is essential to enhance the development of more efficient PV systems [6]. With the aim of contributing to the supply of accessible information, we propose an interactive online tool to provide the users with easy-to-use data and maps for the solar irradiation and environmental performance results at screening level of representative PV technologies, according to a Life Cycle Assessment (LCA) approach. This tool was developed in the framework of Task 12 of the Photovoltaic Power Systems Program (PVPS) established by the International Energy Agency (IEA). The calculation procedures account for the geographic location and the PV system layout, namely installation, orientation and inclination angles. The tool has a worldwide coverage with a muti-criteria scope, both in terms of the numerous technological scenarios [7,8] and the wide range of environmental indicators [9-11]. Moreover, the user is given the possibility to compare the PV environmental performance to the corresponding country electricity mix, inventoried according to treeze Ltd. [12].

2 PURPOSE OF THE WORK

The aim of this work is to propose an easy-to-use interactive tool to assess the environmental footprint of current and prospective representative PV systems at screening level accounting for its geographic location. To enlarge the audience and to ease their access, the tool is available online [http://viewer.webservice-energy.org /project_iea/]. The geo-localized environmental performances provided by our tool are compared with the environmental footprint of the national electricity mix on the same methodological background to allow decision makers to position the environmental interest of PV systems.

3 APPROACH

Although renewable sources, and particularly PV systems, exhibit remarkably lower emissions and better environmental performances than fossil sources during their utilization, their impact during manufacturing and installation as well as end-of life management phases should be quantified to assess their sustainability [1-4].

Life cycle assessment (LCA) is one of the main tools recommended for the environmental evaluation of emerging technologies such as PV systems [3,4,13]. LCA is a standardized methodology that aims at assessing the potential environmental impacts of processes over their whole life cycle from the extraction and processing of raw materials to the use and end-of life stages. The environmental impacts are quantified by classifying the emitted substances into specific impact categories and converting their values into reference units through sets of characterization factors [14].

Environmental performances for energy systems are expressed as the ratio of their environmental impacts issued from LCA, over the produced energy along their life time (Eq. 1). For PV systems, the environmental impacts are calculated according to the methodological guidelines, published in the framework of the IEA PVPS Task 12 [9]. The quantification of multi-annual mean of surface solar global irradiations enables determining the total energy production at a specific location over a given life time.

$$\text{Environ perform} = \frac{\text{Total impact over lifetime}}{\text{Generated electricity}} \quad (1)$$

The developed tool allows obtaining the environmental performances of PV systems in the form of a Web-client invoking a Web-Service that combines algorithms for the calculation of PV life cycle impacts and annual solar irradiation [6]. The Web-Service is based on representative life cycle inventories developed within IEA PVPS program [7,8]. The expected electric yearly production of the PV systems has been computed from the freely available solar irradiation NASA SSE database (https://eosweb.larc.nasa.gov/sse). More precisely, the 1°x1° worldwide maps of multiannual (22 years) average of monthly global and diffuse irradiations have been used to compute the expected yearly global irradiations on the tilted plane corresponding to the PV systems applying the same algorithm used for the NASA SSE database itself which corresponds to the RETScreen method [15].

After obtaining the annual irradiation for a given location, our tool computes the total electricity generated over the whole life cycle of the PV system, as well as the environmental performance, and provides the results to the user.

Regarding the range of results provided by the tool, the Web-client has been developed to propose an interactive user interface matching the foreseen request from the users. The tool offers the user the possibility to obtain multi-criteria LCA results including diverse impact categories of widespread impact assessment methodologies such as ILCD 2011 Midpoint+, Cumulative Energy Demand, IMPACT 2002+, IPCC 2013 and USETox among others [9-11].

3 SCIENTIFIC INNOVATION AND RELEVANCE

This Web-Service is the first tool to propose a worldwide coverage of environmental performance of PV systems. It is developed using a state of the art interoperable and open standards Web-Service framework from the Open Geospatial Consortium (OGC), namely Web Processing Service (WPS). It combines the latest updated life cycle inventories, published in 2015 by the IEA Task 12, and the solar irradiation database compiled from the worldwide NASA SSE database for a wide range of inclinations and orientations. A new Web-client based on a previously developed version [6] is proposed for the user to compare the PV performance to the national LCA electricity mix from the WPS. The implemented LCA categories cover a wide range of environmental issues.

4 RESULTS

To obtain the environmental performance for a specific impact category, the user needs to make a choice for the following parameters:

(1) the PV technology,
(2) the type of system (power output and mounting),
(3) the techno-economic context,
(4) the performance ratio,
(5) the orientation and inclination,
(6) the PV lifetime and
(7) the environmental impact assessment method and impact category.

Figure 1 shows the cascading menu developed to facilitate the selection of the parameters.

a)

b)

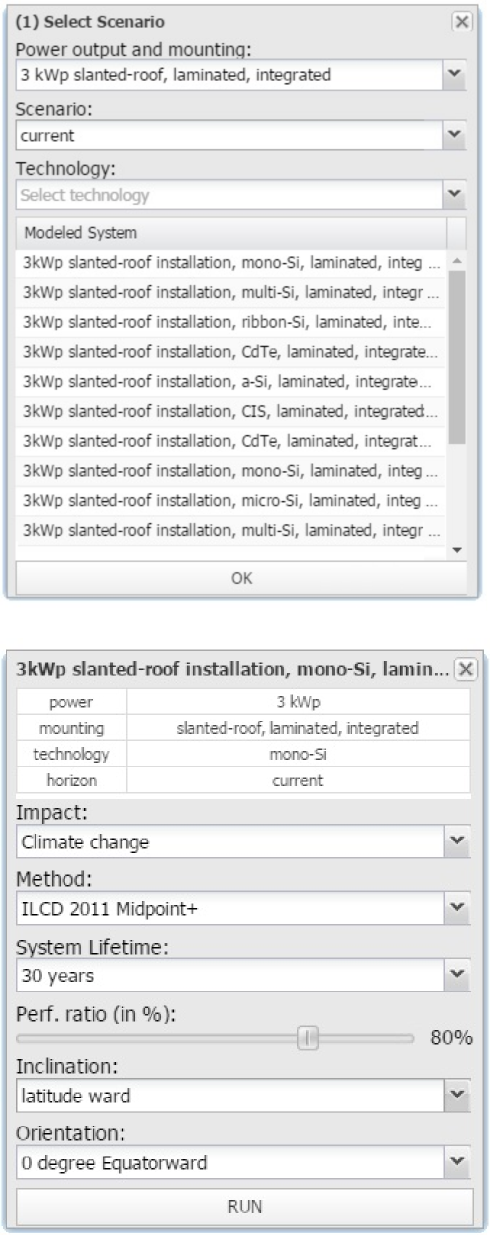

Figure 1: Web-Service cascade menu for the selection of: a) PV technology, mounting and techno-economic context and b) impact assessment method, category, and energy production conditions including the performance ratio, the lifetime, the inclination and the orientation.

The interactive Web-client allows the user to investigate many different technological scenarios for representative 3kWp or 570kWp systems (Figure 2) combined with different options of installations, orientation and inclination. The techno-economic context is taken into account by selecting either "current" or "prospective" scenarios, following the scenarios defined by IEA PVPS Task 12 [7-8].

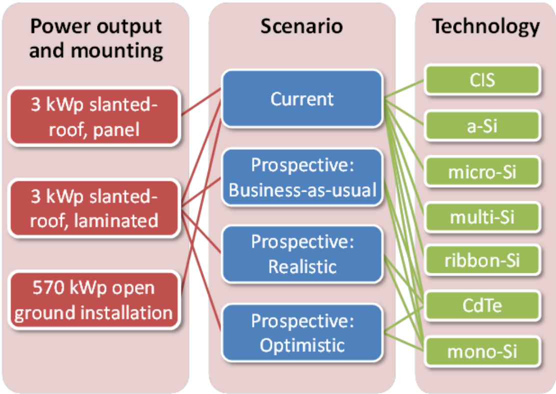

Figure 2: Available production scenarios provided by the Web-Service represented by links between boxes.

After the user's selection of the requested parameters, the Web-Service provides worldwide maps of LCA results at screening level for the selected impact category. By clicking on a specific location on the map the user get for this location: the latitude, the longitude, the mean annual solar irradiation, the environmental impact over the whole life cycle, the performance as impact per kWh, the environmental footprint of the corresponding country electricity mix for an equivalent level of energy production and the relative difference between the local PV environmental performance minus the performance of the country electricity mix. The user can export those data for further processing with the "export" button.

An illustration of the environmental performance for a specific representative PV is given in Figure 3, obtained by operating the Web-Service http://viewer.webservice-energy.org/project_iea/.

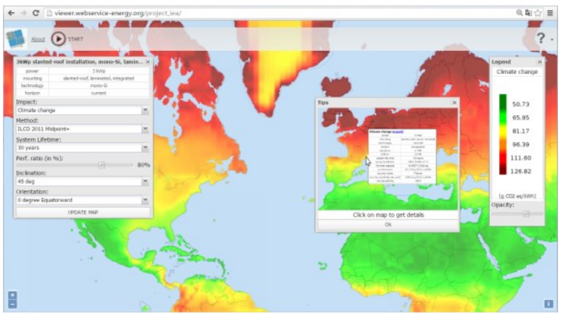

Figure 3: Worldwide map of climate change (ILCD 2011 Midpoint + method) obtained from the Web-Service for 3 kWp slanted-roof laminates of current CdTe technology with a 30-year lifetime at 45° inclination and south orientation.

LCA practitioners can process the environmental results provided by the Web-Service to carry out three types of comparative environmental analyses:

1. A given technology A vs another technology B: Figure 4 shows the comparison of the existing laminate technologies for the impact categories of climate change (equivalent to carbon footprint), non-renewable cumulative energy demand and human toxicity (cancer effects) according to ILCD 2011 Midpoint+ method.

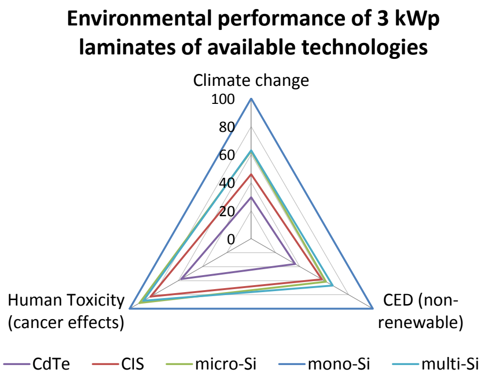

Figure 4: Comparative environmental performance of 3 kWp laminates of current PV technologies available in the Web-Service, operating at 45° inclination and south orientation

2. The current vs prospective techno-economic context for a given technology: Three prospective techno-economic contexts are provided for mono-Si and CdTe laminates. The business-as-usual scenario estimates the future context by considering the continuation with current policies and no additional goals. The realistic scenario corresponds to a situation in which energy policies would give a relatively high priority to the empowering of renewable energy policies. The optimistic scenario considers the implementation of ambitious energy policies and high development of efficient renewable energy technologies.

The environmental benefits of mono-Si prospective scenarios in the three selected categories are depicted in Figure 5. According this figure, the business-as-usual scenario may lead to limited impact reductions ranging between 10% and 20%, whereas the realistic scenario involves significant improvements from 35% to nearly 50% and the optimistic scenario may allow higher reductions, between 40% and 60%.

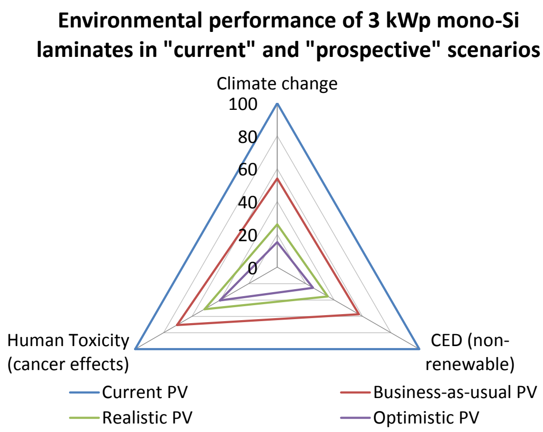

Figure 5: Comparative environmental performance of current and prospective 3 kWp mono-Si laminates operating at 45° inclination and south orientation.

3. A given technology vs the current country electricity mix: In Figure 6, we propose the comparison of PV and country mix environmental performances in different countries and geographic locations. The locations were selected to represent the extreme environmental performances within each country. As shown in Figure 6, the comparative results of the climate change for the mono-Si laminates and the corresponding country electricity mix are highly dependent on the geographical location and the specific characteristics of each national grid. Thus, the differences are rather limited in the case of France due to the low carbon emissions associated with the high percentage of nuclear energy and low production from fossil fuels. On the contrary, countries with a high percentage of electricity coming from fossil sources, such as Germany or US, exhibit a remarkably lower impact on climate change of the PV systems than that of the country mix.

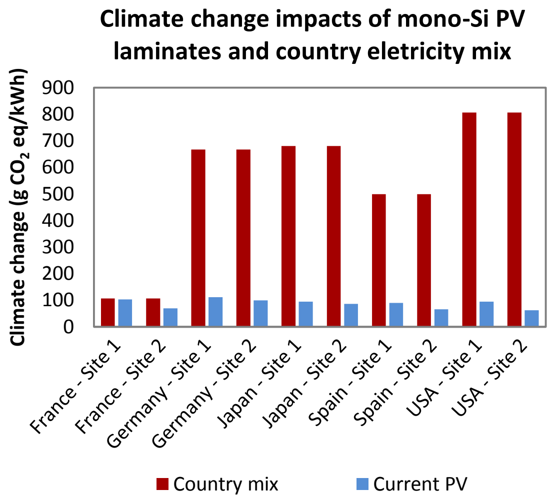

Figure 6: Comparative environmental performance of current 3 kWp mono-Si laminates operating at 45° inclination and south orientation with respect to country electricity mix.

5 CONCLUSIONS

We developed an easy-to-use interactive Web-Service based on current OGC standards to provide environmental data on existing PV technologies. The tool offers accessible and adapted information to support decision-making processes.

Analyzing the differences of the PV performance of the available technologies and providing comparisons with respect to the performance of the corresponding national electricity mix open the way to understand the positioning of PV mix relying on a multi-criteria assessment. Easy and open access to this key information is essential to feed the debate on energy transition.

6 ACKNOWLEDGMENTS

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