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Assessing the prospective environmental impacts of photovoltaic systems based on a simplified LCA model

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1. Introduction

The increasing electricity demand and the limited fossil energy resources require the development of new energy policies, based on more environment-friendly electricity-production technologies. The use of photovoltaic (PV) systems has been increasing a lot these last years, and this growth will probably continue. Although the environmental impacts of PV systems are small during their operating phase, they are more significant during their fabrication and recycling phases. These impacts must thus be assessed over the complete life time using life cycle analysis (LCA). However, LCA requires the collection of a large amount of data and is thus time-consuming. Besides, LCA results found in the literature corresponding to the photovoltaic energy pathway show a large variability, reflecting the heterogeneity of systems and their modeling within this energy pathway. An analysis based on 57 estimates found in 23 peer-reviewed studies revealed that the environmental performances related to climate change (defined by the ratio of the impacts related to climate change and the electricity production over the life cycle) range between 1 to 218 gCO₂eq/kWh [1].

These two points limit the use of LCA to assess the environmental impacts of one electricity-production technology. To address these issues, Padey *et al.* [2] developed a generic methodology that accounts for the heterogeneity of systems within one energy pathway and provides its related environmental impacts with a limited data and time investment. It is based on the definition of a simplified parameterized model estimating the environmental performances of a set of systems (composing an energy pathway) as a function of their key parameters. This methodology first characterizes the environmental profile of one energy pathway, by setting a reference LCA model. The latter generates the environmental impacts distribution, representative of the potential configurations for the studied pathway, by taking into account the different sources of variability (technological, geographical, methodological, ...). The sources of variability explaining most of the environmental performances variability are identified as key parameters using global sensitivity analysis. A simplified model function of these identified parameters is then defined to estimate the environmental performances of the set of studied systems.

This method was first applied to study the current environmental performances related to climate change of onshore wind power electricity pathway in Europe [2]. Here, we apply and extend this generic methodology to assess the prospective environmental performances of photovoltaic systems.

2. Materials and methods

2.1. Characterization of the considered PV systems

The considered PV systems in this study are characterized as follows:

- Technological characterization : mono- and polycrystalline technologies; thin-film technologies
- Spatial characterization : worldwide
- Temporal characterization : existing and future installations, in order to develop a prospective tool
- Methodology: ecoinvent database v2.2 and climate change characterization based on IPCC and Cumulative Energy Demand.

Following the methodology described in [2], the potential sources of variability associated with these characterizations are then identified and described by intervals and probability distributions. Among others, one potential source of variability is the manufacturing origin of the considered PV modules. For the existing PV systems (case of the thin-film technology CdTe) installed in France, the current manufacturing origin is described in Table 1. However, this characterization could possibly change in the future, and this may significantly impact the environmental performances of the energy pathway.

Manufacturing origin	Germany	Malaysia	Norway	Switzerland	Spain
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Current characterization	22%	78%	0%	0%	0%
Prospective characterization	0%	0%	33.33%	33.33%	33.33%

Table 1: Characterization of the parameter related to the manufacturing origin of thin-film PV installed in France (current situation). The prospective characterization corresponds to an arbitrary but possible scenario for the future.

2.2. Adaptation of the methodology for a prospective use

The methodology described in [2] is adapted to investigate whether possible future changes in the parameters characterizations could lead to significant modifications of the environmental performances. In this aim, a new parameter is defined and characterized by two (or more) states: the current state and the future state(s) with a given probability distribution between the different states.

In the example of the manufacturing origin of PV systems based on the thin-film technology CdTe, a new parameter “manufacturing scenario” defines the distribution of manufacturing countries to be used to simulate the environmental performances of these new systems. It is characterized with values for the current state (second line of Table 1) and for the future state (third line of Table 1); the two states being considered as equally likely.

Using the reference LCA model, the distribution of the environmental performances is simulated. Global sensitivity analysis is used to determine whether the new parameter linked to the current and prospective states induces a significant part of the performances variance. A new simplified model can then be constructed to assess the prospective impacts of the considered energy pathway.

3. Results and discussion

The prospective environmental performances related to climate change and cumulative energy demand of PV systems are assessed for systems characterized as in section 2.1. In this abstract, we only provide results for thin-film PV system based on the CdTe technology and located in France. We also consider that the “manufacturing origin” is the only parameter characterization acting future scenario (as given in Table 1).

The environmental performances related to climate change ($Perf_{CC}$), in gCO_2eq/kWh , are defined as follows :

$$Perf_{CC} = \frac{Im \text{ pacts}_{systems}}{EP} ; EP \text{ being the electricity production } EP = \eta . OR . PR . S . Irr . LT . Lo , \text{ where } \eta \text{ is the efficiency}$$

of the PV system, OR a factor linked to the system orientation, PR the performance ratio (characterizing the total efficiency of the system), S the PV module surface, Irr the irradiance, LT the life time, and Lo a factor describing the efficiency loss function of the PV module age.

The distribution of these climate change performances is simulated. A global sensitivity analysis, based on Sobol indices [3], shows that the parameter “manufacturing scenario” explains more than 25% of variance of the climate change performances, it is the second most influencing parameter (after the irradiance Irr explaining more than 30% of the variance). Thus, the changes in the manufacturing origin parameter induce a significant modification of the performances and must be taken into account in the simplified model. The latter is then derived as a function of the irradiance Irr and the manufacturing scenario:

$$Perf_{CC} = \begin{cases} 0.4 + 52700 / Irr & \text{for actual systems} \\ -0.6 + 42498 / Irr & \text{for future systems} \end{cases}$$

A limitation of this methodology is that it can only be used to investigate the influence on the performances of changes in the parameters distributions, but not the influence of a major technology breakthrough.

4. Conclusions

The methodology developed by [2] is adapted to assess the prospective environmental performances of PV systems based on a simplified model. Accessing the prospective impacts of an energy pathway using a simplified model can help decision makers in the establishment of new energy policies; since it facilitates the investigation of where to produce and with which type of energy as well as where to install new energy-production technologies aiming at minimizing the environmental impacts.

5. References

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