# A Prospective Mapping of Environmental Impacts of Large Scale Photovoltaic Ground Mounted Systems Based on the CdTe Technology at 2050 Time Horizon

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**A PROSPECTIVE MAPPING OF ENVIRONMENTAL IMPACTS OF LARGE SCALE PHOTOVOLTAIC GROUND MOUNTED SYSTEMS BASED ON THE CDTE TECHNOLOGY AT 2050 TIME HORIZON**

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ABSTRACT: Environmental performances of PV systems are likely to evolve in the future due to significant technological improvements of the systems, to less energy intensive manufacturing processes as well as a shift towards less carbon-intensive energies for electricity mix. In spite of the complexity to estimate these changes with accuracy, projections are available based on scenarios representing different levels of improvements. Based on these scenarios, prospective environmental impacts and electricity production of large scale PV systems are assessed. This paper focuses on GHG performance of large scale photovoltaic ground mounted systems based on the Cadmium Telluride (CdTe) technology. We compare the current (2011-2013) and prospective (at 2050 time horizon) GHG performance of such PV systems under different scenarios accounting for technological improvements, future electricity mixes, and module manufacturing origin. A significant decrease in GHG performance is to be found for the prospective scenarios compared to the current situation ranging from 50 up to 80% depending on the scenarios. Prospective technological improvement seems to induce more uncertainties than prospective electricity mixes involved in manufacturing the modules.
Keywords: Life Cycle Assessment, CdTe, large-scale ground-mounted installation, Environmental Effect

## 1 INTRODUCTION

Worldwide annual photovoltaic (PV) power generation is projected to be multiplied nearly by a factor of 200 from 2010 to 2050 in the utility sector, going from 8 TWh to 1498 TWh [1]. This increase should contribute to the reduction in greenhouse gases (GHG) emissions related to electricity generation. This reduction is required to limit the observed climate change due to the anthropogenic activity [2]. Although GHG emissions of PV systems are close to zero during their utilization, GHG are emitted upstream (system manufacturing and installation) and downstream (end-of-life). Assessing the environmental impact related to these GHG emissions, combined with an evaluation of the life time electricity production, allows a comparison between different renewable energies or between different PV systems. This performance evaluation must be made using a life cycle approach, such as life cycle assessment (LCA). LCA studies of PV systems have pointed parameters mostly influencing the environmental performances of PV systems, such as the irradiation, or the electricity mix used in manufacturing processes [3], [4], [5].

Environmental performances of PV systems are likely to evolve in the future, due to significant technological improvements of the systems themselves, of the manufacturing processes, which are foreseen to become less costly in energy, and due to the shift in the electricity mix toward less carbon-intensive sources of energy. In spite of the complexity to estimate these changes with accuracy, projections are available based on different scenarios representing different levels of improvements. Based on these scenarios, prospective environmental impacts and electricity production of large scale PV systems can be assessed. The prospective electricity production depends on technological improvements, but also on the available solar resource related to the system localization. Assessing these prospective performances helps knowing in which proportion and where PV systems should be developed to maximize the electricity production while minimizing their environmental impacts.

This paper focuses on GHG performance of large scale photovoltaic ground mounted systems based on the Cadmium Telluride (CdTe) technology. We compare the current (2011-2013) and prospective (at 2050 time horizon) GHG performance of such PV systems under different scenarios accounting for technological improvements, future electricity mixes, and module manufacturing origin.

## 2 METHODS

To investigate the current and prospective GHG performance of PV systems, a parameterized LCA model is built. The main characteristics of this model are the following:

- Technological scope: 5MWp PV installation, ground-mounted with modules based on CdTe.
- Geographical scope: Europe.
- Temporal scope: 2011-2013 period and 2050 time horizon.
- Methodological scope: The GHG performance is defined by the ratio of the global warming impact of the system (in $gCO_2eq$) to the electricity produced over the life cycle (in kWh). The global warming impact is assessed with the global warming potential with a time horizon of 100 years (GWP 100yr) from the IPCC 2007 [2].

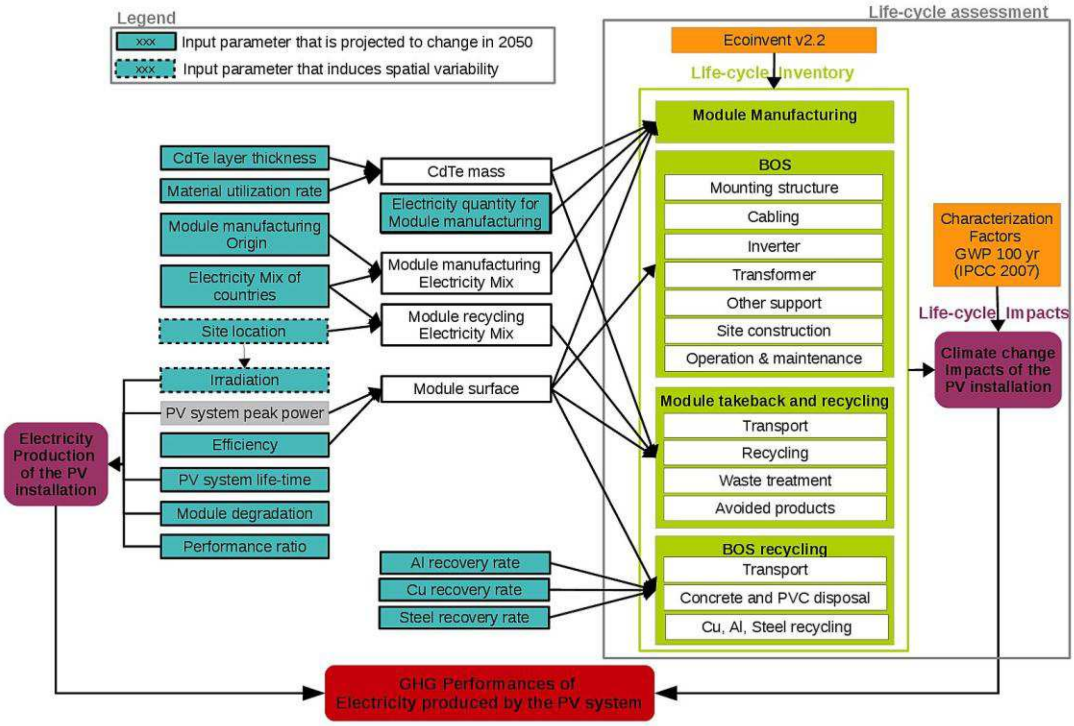


**Figure I:** parameterized LCA model of large-scale ground mounted PV systems based on CdTe

**Table I:** Parameters of the parameterized LCA model, and their current (2011-2013) and prospective values (around 2050).

| **Parameter** | **Current value** | **Prospective value** |
|---|---|---|
| CdTe layer thickness (µm) | 3<br>[6] | BAU:2 REAL:1 OPT:0.1<br>[6] |
| Material Utilisation rate (%) | 55<br>[7] | BAU:70 REAL:85 OPT:99<br>[7] |
| Module Manufacturing origin | Germany, US, Malaysia | Germany, US, Malaysia, China |
| Electricity mix ($gCO_2eq/MJ$) | values for 2013 [8] | IEA scenarios for 2035: S1, S2, S3<br>[9] |
| Site location | Europe | |
| Irradiation ($kWh/m^2/yr$) | Helioclim 3 database (2011-2013) [10] | |
| Module efficiency (%) | 11.7<br>[6] | BAU:17.7 REAL:19.9 OPT:22.7<br>[6] |
| Life Time (yr) | 30<br>[6] | BAU:30 REAL:35 OPT:40<br>[6] |
| Degradation (%/yr) | 0.5 [11] | |
| Performance Ratio (%) | 0.8 | |
| Electricity quantity for module manufacturing processes | 0 (reduction percentage compared to current situation) | BAU:14 REAL:19 OPT:26<br>[6] |
| Metal recovery rates (%) | Al: 35, Cu: 40, steel :90<br>[12] | Al: 79, Cu: 76, steel:90<br>[13] |

Figure 1 represents the parameterized LCA model. Blue boxes indicate input parameters. They correspond to:

- Parameters that are likely to evolve in the future (blue boxes with solid line), such as technological PV characteristics (module efficiency, life-time, semi-conductor layer-thickness …) and variables related to module manufacturing and recycling processes (electricity quantity, metals recovery rates, electricity mix)
- Parameters that are associated to spatial variability (blue boxes with dashed line), such as irradiation.

Values taken by input parameters are specified in Table I. Prospective values for 2050 are estimated under different scenarios for technological improvements and for future electricity mixes. We use the 3 technological scenarios defined by [6], corresponding to three levels of technological improvements: "BAU" (Business As Usual) with limited improvements, "REAL" with realistic improvements, and "OPT" with optimistic improvements. Scenarios for future electricity mixes are from the IEA [9]: 3 scenarios are provided based on different policy assumptions and resulting in different decline levels in carbon intensity: the "Current Policies scenario" (S1), the "New Policies scenarios" (S2), and the "450 scenario" (S3).
The number of parameters could be increased in a more refined model. For instance, transport of the system components is considered constant here, although it could be parameterized to account for the variability due to the site location.

The input parameters influence the LCI of considered systems. This LCI is made of four parts (Figure 1):

- Module manufacturing processes. Reference fluxes are based on data from first solar panel factories located in Germany, the US, and Malaysia.
- Balance of system (BOS), including fixed-mounting structure, cabling, inverters, transformers, other support structure (conduits and fittings, concrete pads and footings, and wood posts), operation and maintenance, and site construction. Reference fluxes were based on data from First Solar panel published in [14].
- Module takeback and recycling schemes. Reference fluxes are based on data from First Solar and published in [15].
- BOS recycling, including transport, metal recycling, and disposal of concrete and PVC. Reference fluxes are based on the BOS LCI and recycling assumptions derived from [12] and [13].

Background processes LCI are taken from the ecoinvent v2.2 database [16].

The electricity production over the life cycle (EP) is evaluated with this formula:

$$EP = \sum_{i=0}^{N-1} PR \times P_p \times GTI \times (1-d)^i$$

with PR being the performance ratio, Pp the nominal power, GTI being the yearly global tilted irradiation, d the degradation rate, and N the system life-time. The irradiation is an important parameter that induces a large variability of electricity generation capacity.

## 3 RESULTS AND DISCUSSIONS

GHG performances are evaluated by applying the parameterized LCA model to values of input parameters specified in Table I for the current and future situation under different prospective scenarios.

Reduction percentage between the current and future situations are summarized in Table II depending on the different scenarios for technological improvements (BAU, REAL, OPT) and for future electricity mixes (S1, S2, S3). For each scenario combination, ranges correspond to differences in module manufacturing origin.

**Table II:** summary of reduction in prospective GHG performances as compared to the current situation.

| Scenario | BAU | REAL | OPT |
|---|---|---|---|
| S1 | 48-56% | 61-67% | 70-75% |
| S2 | 52-59% | 63-69% | 72-77% |
| S3 | 61-69% | 71-76% | 77-82% |

Figure 2 shows the current and prospective GHG performances for the REAL scenario for a yearly global tilted irradiation of 1800kWh/m$^2$/yr (considering PV panels are inclined at an angle of 30° and face south), which would be a typical irradiation for South West of France. Error bars represent values obtained for the OPT and BAU scenarios. The 3 alternatives for the electricity mixes are considered (S1, S2 and S3) as well as the 3 countries of manufacturing. China has also been considered for comparison, although we had no reference fluxes for this module manufacturing origin. Non-parameterized data were taken from the Malaysian panel factory, and parameters were adapted to China (such as the electricity mix). Current GHG performances are ranging from 12 to 16 $gCO_2eq$/kWh and are foreseen to reach low values such as 4 $gCO_2eq$/kWh considering the best configuration for this specific irradiation (1800kWh/m$^2$/yr). Such low levels are explained by the technological improvement in module efficiencies as well as the low carbon content for the manufacturing electricity. We can identify that the largest differences between all prospective scenarios are due the technological enhancement of the pathway (reduction between the BAU and OPT scenarios are higher than between the S1 and S3 scenarios in Table II).

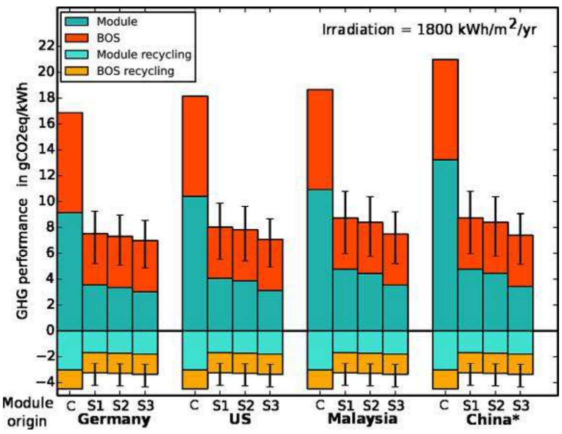


Figure 2: Current (C) and prospective GHG performances

Figure 3 shows a map of prospective GHG performance under the S2 and REAL scenarios (average scenario among the proposed scenarios), with module manufactured in Germany. As expected, the best performances are found for southern Europe with GHG values as low as 2 $gCO_2eq/kWh$. Performances for Northern Europe for large scale PV CdTe Technology are however still very low (around 6 $gCO_2eq/kWh$ for Germany).

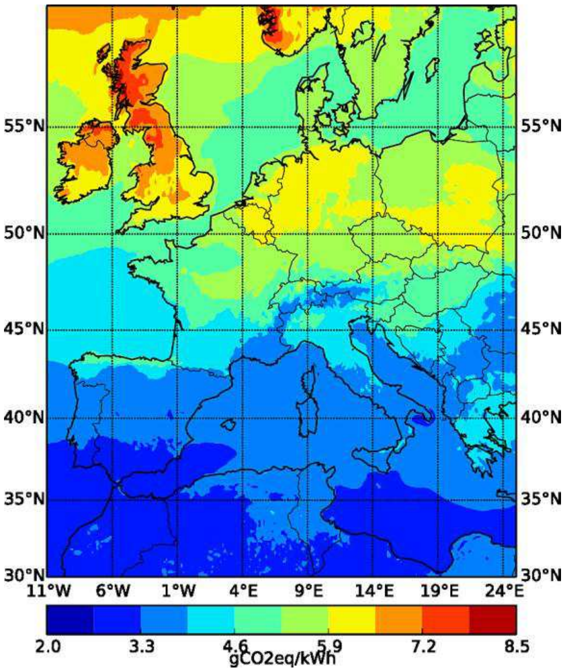


Figure 3: GHG performance for the REAL and S2 scenarios for module manufactured in Germany (considering that panels are inclined at an angle of 30° and face South).

## 4 CONCLUSION AND PERSPECTIVE

Based on prospective scenarios accounting for technological improvement, electricity mixes evolution and various CdTe module manufacturing origin, we compare the GHG performance of large scale PV ground mounted systems (5MWp) with the current situation. By coupling the LCA parameterized model to average European annual solar irradiation, we are able to provide European GHG performances maps. Based on these results we highlight the following key points:

- A significant decrease in GHG performances is to be found for the prospective scenarios compared to the current situation ranging from 50 to 80% depending on the scenarios.
- Prospective technological improvements seem to induce more uncertainties than prospective electricity mixes. Further investigations should be initiated by running a global sensitivity approach to identify the order of importance among the different parameters (technological, location and pathway scheme) to support decisions makers in the development of the PV pathway. A first attempt has been realized in [17] for residential PV systems.
- Refinement of the parameterized LCA model for large scale CdTe PV systems is to be undertaken with additional parameters (e.g. transport scheme, enhanced recycling scenarios)

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