ENERGY AND LIFE CYCLE ASSESSMENT OF THIN FILM CdTe PHOTOVOLTAIC MODULES

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ABSTRACT: The topic of this paper is the Life Cycle Assessment (LCA) of modern CdTe PV modules. The analysis was performed within the framework of the European research project PVACCEPT, and is based on actual production data provided by the former project partner ANTEC Solar GmbH. This latter point makes the present LCA especially worthy of attention as a preliminary indication of the future environmental impact that the upscaling of CdTe module production may entail.
The analysis is performed according to the recommendations of ISO norms 14040 and updates, and makes use of an original multi-criteria approach named SUMMA.
The performance of the analysed CdTe system is also compared to other examples of advanced PV systems based on different technologies (CIS and mc-Si), which were also part of the PVACCEPT project.
Results clearly show an overall very promising picture for CdTe technology, which is found to be characterised by favourable environmental impact indicators (e.g. 60g(abiotic matter)/kWh, 32 g(CO_2-eq)/kWh) and energy payback time (0.9 yrs), despite the comparatively low energy conversion efficiency (8%).
Keywords: CdTe, Thin Film, LCA

1 INTRODUCTION

The present study was performed as an integral part of the European research project PVACCEPT [1], which was concerned with investigating and improving the public acceptability of photovoltaic systems, especially when installed in historically relevant sites.

Besides market prices and aesthetics, two most important and interrelated aspects playing a key role in the possible future expansion of PV systems are their thermodynamic performance and environmental impact. It is especially important that the latter be assessed from a life cycle perspective, i.e.: including the upstream inefficiencies and impacts associated to the production and delivery of the primary materials that are necessary for the production of the PV modules; considering the total amount of electricity that is produced over the whole life cycle of the modules in real-life conditions; and including, wherever possible, the decommissioning phase.

Thin film PV systems, and CdTe systems in particular, still represent a negligible share of the total worldwide PV installed power, but, with the initial technical problems being overcome, and low-cost scrap-derived Si wafer production nearing its maximum capacity, an upscaling of thin film module production is foreseeable for the near future.

So far, only few scientific studies have been published on the energy and environmental performance of CdTe systems (among which [2] and [3]), and the scientific community would certainly benefit from more, since these can provide useful projections about the possible environmental consequences that the future market expansion of such systems could lead to. In particular, studies such as this, which are based on actual production data, rather than laboratory-scale prototypes, are especially informative in this regard.

2 THE ANALYSED SYSTEMS

2.1 Inventory

The analysed CdTe module was Antec Solar's 'ATF 50', for which the main material input requirements are listed in Table I (photoactive material quantities are presented in aggregated form for confidentiality reasons, but were individually available to the authors).

Item	g/m^2
Glass	24,960
Water	1,250
EVA	630
{CdTe + CdS + $CdCl_2$ + Sn + Ni/V + ITO + Sb_2Te_3}	230

Table I: Input inventory for CdTe modules

A direct process electricity consumption of 24 kWh/m^2 complements the table from the energy point of view.

Similar inventories were also made for the modules based on the two analysed alternative technologies (poly-Si and CIS), to which the calculated indicators for CdTe were compared.

When the analysis is extended to a typical grid-connected rooftop installation, additional Balance-Of-System inputs are included in all cases, namely: aluminium for the module frames, steel for the support structure, copper and plastics for the cables and contact boxes, as well as some fuel required for the installation.

2.2 Assumptions

The following set of general assumptions were made for the purposes of the present analysis:

- The expected life time of the modules was assumed to be 20 years. This is in line with what has been proven to be attainable for Si modules, and with what is declared by the manufacturers for CdTe and CIS.
- The average insulation was assumed to be the European average value of 1700 kWh/(m^2*a).
- A 20% efficiency loss was assumed with respect to nominal values for all modules, in order to cumulatively account for the losses caused by

the cables and the inverter, as well as by atmospheric dust deposition.

- All waste materials generated in the production phase are assumed to be recycled and/or safely disposed of.
- Module decommissioning at the end of their life cycle was not included in the analysis, because of the current lack of a widespread decommissioning/recycling strategy for thin film modules.

The nominal energy conversion efficiencies of the analysed thin film PV modules were assumed to be those declared by the manufacturers, i.e. 8% for CdTe and 10% for CIS. For poly-Si, the nominal efficiency was assumed to be 14%, which is a typical value for the current state of the art in actual production systems.

Finally, as far as Si wafer production is concerned, the choice was made to employ widely accepted literature data [4], which essentially reflect the exclusive use of off-grade Si from the semiconductor industry according to a purely material allocation.

3 THE METHOD

The analysis is consistent with ISO norms 14040 and updates on Life Cycle Assessment, and makes use of an in-house developed multi-criteria impact assessment approach named SUMMA [5].

In this approach, the Life Cycle Inventory (LCI) is followed by the parallel application of the following environmental impact and thermodynamic performance evaluation methods:

- Material Flow Accounting [6, 7, 8]. This method looks at material resource depletion. The chosen indicator is the Material Input Per Service (abiotic), which is a proxy for the total amount of abiotic matter (minerals, fuels, etc.) that was directly or indirectly required to provide the necessary inputs to the manufacturing process, expressed per unit of delivered service [kWh].
- Embodied Energy Analysis [9, 10]. This method accounts for the total amount of fossil fuel energy that is exploited by the process. The chosen indicator in this case is the Energy Pay-Back Time, calculated as: GER[kWh_{el}/m^2]/(Insulation[$kWh/(m^2*yr)$]*η.
- Emergy Analysis [11, 12, 13]. This method attempts to account for the total direct and indirect environmental support provided by the biosphere to the system under study, expressed in terms of solar energy. The chosen indicator here is the Solar Transformity, with units of solar equivalent Joules per Joule of electricity produced [seJ/J].
- CML 2 baseline 2000 [14]. This is a commonly employed, versatile method that includes several informative environmental impact indicators. The ones adopted here are: Global Warming Potential, Acidification Potential and Eco-toxicity Potential.

It is important to underline that the inventory analysis (LCI) forms the common basis for all the subsequent impact assessments, thus ensuring the maximum consistency of the input data and inherent assumptions.

The calculated impact indicators are then interpreted within a comparative framework, in which the results of each method are set up against each other and contribute to providing a comprehensive picture on which conclusions can be drawn.

4 RESULTS

The calculated indicators for the three PV technologies are presented in Figures 1 to 6. The bar graphs are built so as to show the contribution of the BOS components as stacked on top of that of the frameless modules, thus enabling both scenarios to be compared at the same time.

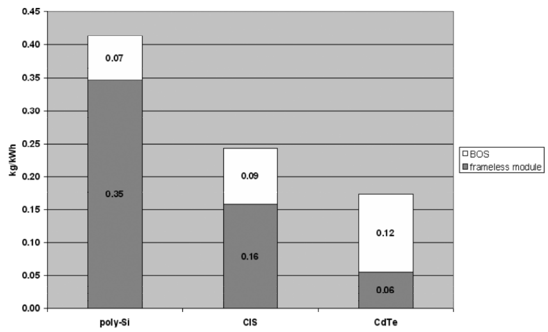

Figure 1: Material Input Per Service (abiotic)

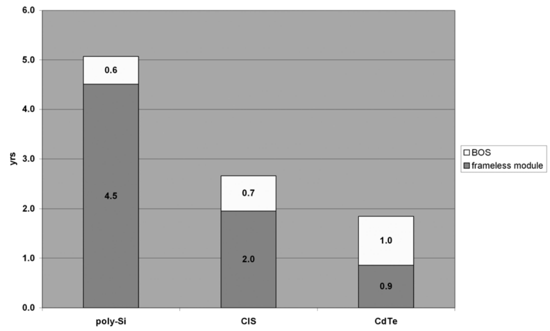

Figure 2: Energy Pay-Back Time

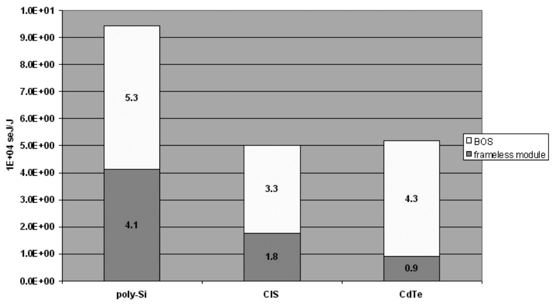

Figure 3: Solar Transformity

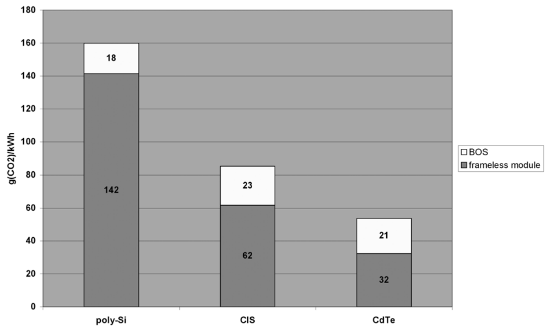

Figure 4: Global Warming Potential

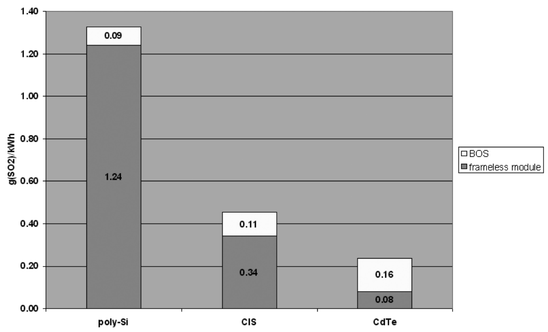

Figure 5: Acidification Potential

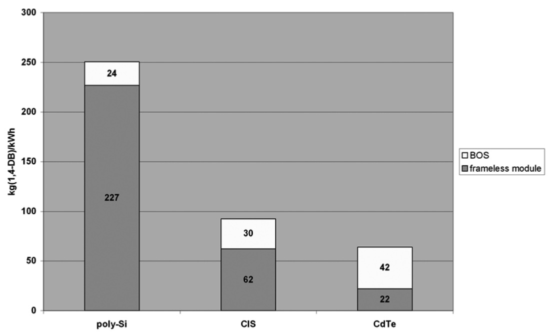

Figure 5: Eco-toxicity Potential

As can be seen from the figures, the environmental and thermodynamic performance of thin film PV modules can be considered to be already favourably competitive with respect to that offered by the more mature poly-Si technology. CdTe modules, in particular, invariably offer the best overall thermodynamic and environmental performance, in spite of their lowest nominal efficiency.

One further interesting finding is that BOS components currently have a significant effect on the performance of the complete installation relative to the modules themselves, the more so the lower the module efficiency is. This could be improved by reducing the amounts of Al and steel employed for the support structure whenever possible, and/or increasing module efficiency.

As a final important remark, it cannot be denied that the contribution of the technology-specific chemicals employed in CdTe modules to the calculated overall environmental impact indicators is still hard to quantify precisely. However, the pivotal reason for the comparatively low impact of these modules was found to lie in the fact that only very small quantities of such chemicals are employed. This is not the case with Si modules (for which Si wafer manufacture is the most impacting step), and is thus an inherent advantage of thin film PV technologies.

This technology-specific difference becomes clear when considering the relative contributions of the various inputs to each overall impact indicator. For illustrative purposes, 'pie-chart' break-downs of the calculated MIPS (abiotic) are shown in Figures 7 and 8 for frameless CdTe and poly-Si modules, respectively (in the case of CdTe, 'techn. inputs' stands for CdTe + CdS + $CdCl_2$ + Sn + Ni/V + ITO + Sb_2Te_3).

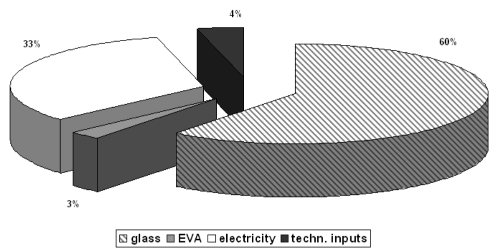

Figure 7: MIPS (abiotic) break-down for frameless CdTe modules

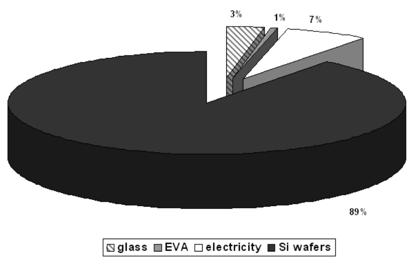

Figure 8: MIPS (abiotic) break-down for frameless poly-Si modules

5 CONCLUSIONS

CdTe has been shown to be the least impacting photovoltaic technology currently available from several important points of view.

Further research is needed to refine these results, yet the limited amounts of the employed chemicals in the photoactive thin film is recognised as an inherent advantage of this type of technology (this point also applies to CIS).

The need for further development of specific recycling strategies for module decommissioning is recognised.

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