Thin-Film Solar Cells – Sustainability Decision Support in Parallel to Recycling Process Development

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Abstract

The EU funded project 'Sustainability Evaluation of Solar Cell Systems' (SENSE) was created in the context of alternative energy supply from renewable sources. Parallel to recycling process development, an innovative factor in this project, a sustainability assessment based on Life Cycle Engineering (LCE) – the combination of environmental, technical and economic analysis – with the aim of a sustainability decision support will be applied. The thin-film solar modules types: a-Si, CIS, CdTe will be evaluated.

Keywords: Solar cell, LCE, sustainability, decision support, recycling

Purpose of the work

Solar energy constitutes one of the alternatives among the available renewable energy sources most investigated for a near future. In this context, a consortium of producers, recyclers and scientists have joined their expertise in the ongoing 5th framework EU funded project SENSE in order to assess the sustainability aspects of the thin-solar cells as well as to develop practical recycling strategies for them. Considered are the thin-film solar modules types a-Si, CIS and CdTe. This work presents the present status of the project.

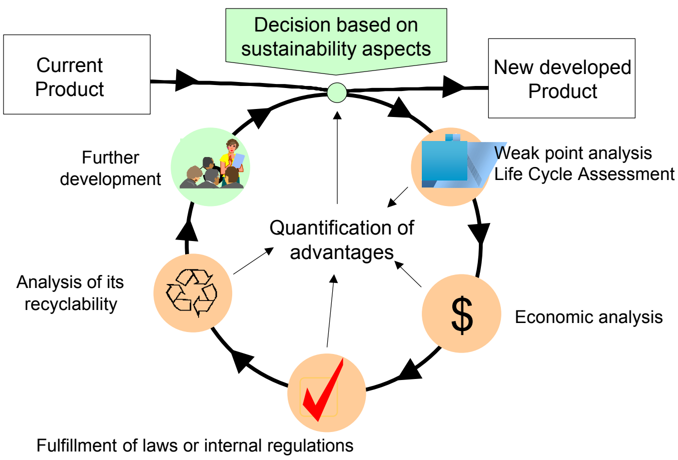

Figure 1: (Product) Improvement Circle

Approach

The approach of Life Cycle Engineering (LCE) (Eyerer, 1996) is used to analyse these thin-film solar cells, to support the development of recycling processes and to optimize solar cells. LCE is a concept based on technical and economic specifications in order to investigate the environmental, economic and social impacts of products, systems and services during their whole life cycle (Production Phase, Use Phase and End-of-life (Disposal, Recycling, Recovery)). This multi-dimension analyses assures that all essential factors are taken into consideration. The use of LCE during the design and development phase of the recycling possibilities assures that the best recycling route is chosen and avoid that environmental burdens are just 'shifted' to other life cycle phase, but treated where appropriate.

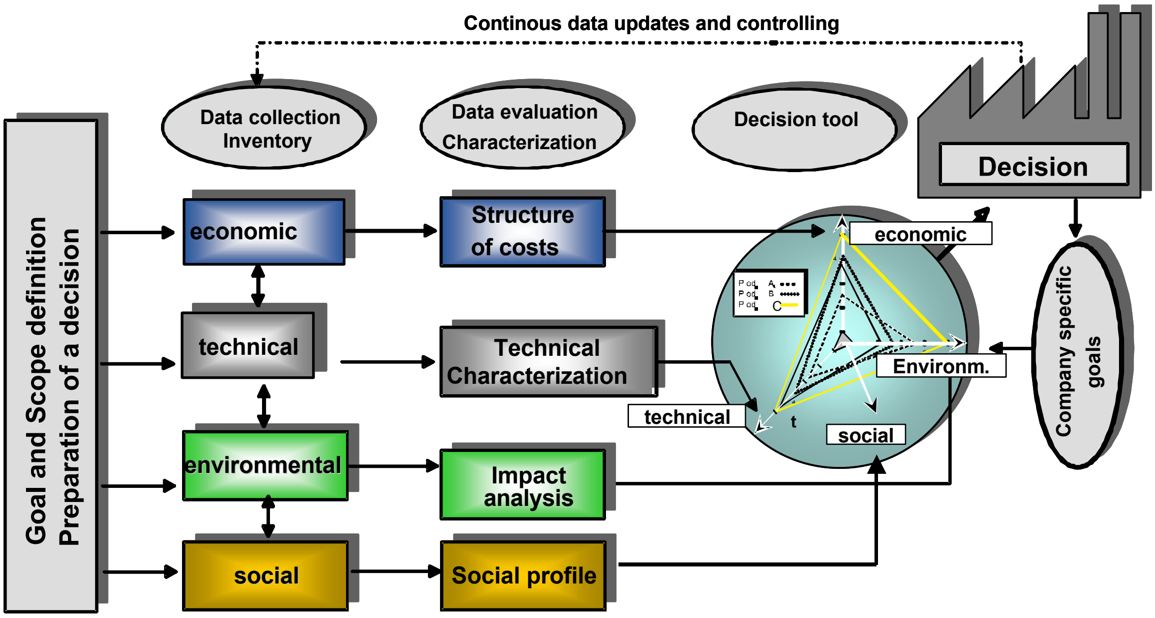

Figure 2: LCE as a decision support tool

Scientific innovation and relevance

SENSE contributes in a substantial manner to both the technological improvement of photovoltaic (PV) systems and to advance the state of the art of the Life Cycle Engineering method in the solar energy system field. In particular, it takes an innovative approach taking into consideration the whole life cycle of PV systems, with a focus on recycling phase. So far, projects have focused on the production phase only and no large efforts have been dedicated to the development of the recycling system of these technologies. SENSE tackles both environmental and economic aspects, providing cost-effective reliable PV technologies as a result.

Results

Scope
Production of solar panels – infrastructure (converters, batteries, etc.), use and end-of-life

Impact assessment
For all life cycle phases, aggregation of emissions/resource consumption to impacts using the following impact categories has been decided:

- CML 96
- CML 2001

Many impact categories are published, but only a few are generally and globally accepted. The Centre of Environmental Science – Leiden University (CML) publishes on a regular basis compilations of own and externally developed characterisation and normalisation factors (CML, 2001) which can be used to show environmental impacts of several inventory categories. The CML impact category sets are one of the most used sets in Life Cycle Assessment (LCA) in practice. They have the advantage of addressing many elementary flows, for which other methods no characterisation factors offer.
In practice, the impact categories, which will be used, are:

- Energy
- GWP (Greenhouse warming potential)
- AP (Acidification potential, “acid rain”)
- POCP (Photochemical oxidant creation potential, “summer smog”)
- EP (Eutrophication potential)
- ODP (Ozone depletion potential)

Production Phase

The functional unit to be used in this phase is: **1 m^2 solar cell**

Although practical data is still in a collecting process, a desktop study provided a first screening of the main contributors for the most relevant environmental issues. The importance of the study is the valuable information provided in terms of where to focus on during the data collection. This procedure ensures an effective and targeted data collection.

To complete these public available data, considerable part of the required data on materials is covered by the data sets contained in IKP’s databases (e.g. glass, various metals, EVA, desalinated water, energy supply, auxiliaries). Data lacks in the present databases are actually closed.

Most relevant environmental issues - as learned from the estimated results from public available data as described above - in the module productions (including pre-chains, excluding use and end of life) are:

- GWP (and energy consumption)
- POCP
- AP
- EP

The main contributors for these categories are presented at Table 2.

Use Phase

The functional unit to be used here is defined to **kWh/m^2 *year**.

In this phase, it must be defined the kind of solar module to be investigated and the appropriate mean of comparison. Depending on the application area, different comparisons can be conducted. See Table 1.

Table 1 – Application areas

No	Kind of solar module	Comparison with
1	Power modules	Power grid mix
2	Building integrated	Power grid mix
3	Mobile modules (incl. Battery)	Small power plant, diesel generator

The use phase is also very much dependent on the geographical area it is employed, since solar radiation is variable. So this factor has also be taken into account.
A summary of the main factors is presented at Table 2.

Recycling phase

The functional unit to be used here will vary **according to the production process** analysed.

As mentioned before, a novelty of this project is the focus on the recycling phase of thin-film solar cells.
On the one hand recycling processes provide usable secondary materials or products, which is a benefit for the product life cycle, but they cause additional environmental impact for the regarded life cycle. Only if the recovery of materials uses less energy and causes less emissions compared to the virgin production, this will lead to an overall reduction of environmental impacts and energy consumption and therefore, for example, reduce numbers life energy payback time. So the consideration of recycling processes leads to additional challenge, which also influences the life cycle analysis results.
Other very important aspect in the recycling process development is the influence of this end-of-life phase in the production and use phase. An improvement of solar cell construction with the goal of a better recyclability can have effect on e.g. the production phase in terms of higher (or also lower) environmental impacts and on the use phase (e.g. by a change of the efficiency factor as a consequence of the new material).
Moreover, in order to quantify the benefits of recycling, considering the gained secondary products, the use of 'credits' will be applied. They are represented by the saved environmental impact obtained by the usable secondary product in other life cycle of the product. In the case of SENSE, they will be based on: physical figures, economical figures and on estimated reuse-loop.
The application of the LCE enable the calculation of the environmental and economical 'break-even', i.e. a trade-off between overall environmental impact reduction and efforts applied.
The importance of its application during the development of recycling processes is support in the choice of the optimal options provided.

Various processes need to be investigated. Some of them can be mentioned:

- **Crushing and grinding**: separation by grinding, analysis of valuable materials in fractions, elimination/reduction of dust/safety at work issues, analysis of machine wear, evaluation of grinding equipment;

- **Thermal treatment**: heating graphics (to avoid crackling), oxidation of valuable materials;
- **Hot wire cutting**: laboratory system for small panels or panel cuts, pilot system for big panels;
- **Ablation, Sandblasting**: sandblasting in big panel surfaces (cracked, and not cracked), sandblasting glass grist, abrasion in mixing reactor, separation of sand and valuable materials;
- **Water jet cutting**: adaptation of cutting system to horizontal application, separation of EVA and valuable materials, separation of water and valuable materials;
- **Chemical treatment**: organic dilution of EVA (ethylene vinyl acetate), effluent management/environmental/safety issues, development a multi-stage material winning process, effluent management/environmental/safety issues;
- **Glass melting**: exploration of the possibility of adding to recycled glass grist.

<u>Summary</u>

A summary of the main factors of the three life cycle phases is presented at Table 2.

Table 2 – Main factors to be taken into consideration when collecting data for LCE

Production phase	Use phase	Recycling phase
• Electricity supply for the solar cell production • Glass production and material supply for the photoactive layers • Energy consumption • Use of organic solvents • Ethylene Vinyl Acetate production • Some metals such as Cd, Se, Te, In, etc.	• Application area • Geographical region	• Appropriate recycling route for a specific material • Appropriate credits to be considered in the whole life cycle

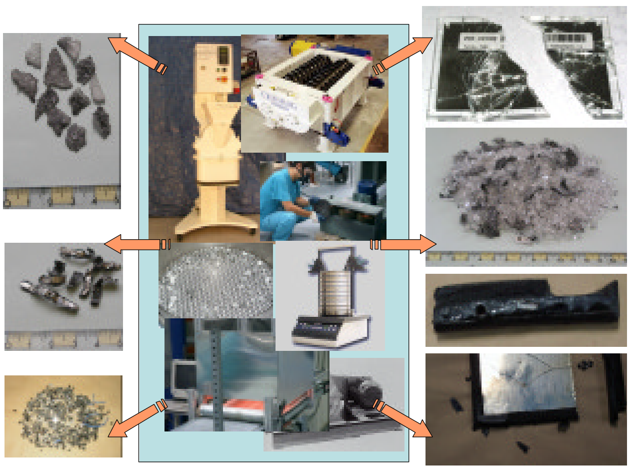

Figure 3 – Recycling of thin-film cells, screening test

Conclusions

In SENSE, a project funded by the European Union in the 5th framework programme, the whole life cycle of thin-film solar cells will be considered. In parallel sustainable recycling processes will be investigated.

The knowledge of various recycling technologies, together with the results of the production and use phase will lead to optimal environmental solutions. The application of LCE during the development stage enable a continuous decision support for these options, based on environmental, technical and economic factors applied in the whole life cycle of the product. The achievement of economic targets as well contributes to the further development of a sustainable energy supply.

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