LCA screening of a recycling process for silicon based PV modules


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Content

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- Life Cycle Assessment (LCA)
- End of Life of Si-PV Modules
- Main Approach and assumptions for LCA consideration
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- Contribution of End of life phase to the whole life cycle
- Scenarios: Secondary material shares, transport distances, Process throughput
- Summary and Conclusion
Fraunhofer IBP, dept. Life Cycle Engineering (GaBi)

- Founded 1989 – Prof. Dr.-Ing. Peter Eyerer (IKP), since 2006 chair for building physics (LBP), since 2008 part of Fraunhofer IBP
- Interdisciplinary team of 24 full time academic staff (chemical, mechanical, environmental and process engineers; economists, geoecologist, ...)

Industry and research projects on ecological-economic-technical analysis and decision-support of products, processes and services

Methodology development (Life Cycle Engineering and Sustainability, substance flow analysis, Indicators)

Software and database development and maintenance (GaBi software, DfE-tools)
Life Cycle Assessment: Product life cycle

- Raw material extraction
- Manufacturing
- Utilization
- Recycling
  - energetic and material recovery
- Disposal

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Life Cycle Assessment according to ISO14040,44

Environmental profile

Life Cycle Impact Assessment (LCIA)

Life Cycle Inventory (LCI)

Product Life Cycle

Primary Energy Demand, Resource depletion, Global Warming, Summer Smog, Acidification, Eutrophication, Toxicity...

CO₂ → CO 
CF₄ → CH₄ 
N₂O → HCl 
NOₓ → SO₂ 
NH₃ → Phosphate 
NH₄ → NOₓ...

Output
Input
Output
Input
Output
Input
Output
Input
Output
Input

Raw material extraction 
Production intermediates 
Manufacturing 
Utilisation 
Recycling, Recovery, Disposal
End of Life options of products and materials

- Reuse of products or components in further applications
- Refurbishment of components for reuse in similar applications
- Recycling of materials for further utilization
- Incineration of materials
- Disposal of material as wastes (e.g. land filling of solid and liquid fractions)
Accounting for environmental benefits from material recycling and energy recovery in LCA

- Material recycling
  - Substitution of primary materials
  - Requirement: No changes of inherent material properties
  - Downcycling requires an expansion of system boundaries

- Energy recovery
  - Substitution of power, heat or steam generation
Considered recycling benefits in this study

Glass recycling
- Credits are given for
  - the substitution of raw materials (batch material mix)
  - avoiding CO\textsubscript{2} emissions due to carbon reduction of raw materials (e.g. limestone)
  - energy reduction in the melting process (around $\sim$ 3\% per 10\% cullet share)

Copper / Aluminum Recycling
- Substitution of primary materials (environmental impacts due to processing (e.g. melting and refining are accounted)

Plastic Wastes
- Incineration and energy recovery (substitution of energy generation)
PV module recycling at Maltha

Disassembly of spent PV modules (frames and boxes)

Wheel loader

Shredder

Material flows to further treatment

Flat glass recycling line
Module recycling: Simplified process flow-chart

**Input flows**
- PV module Waste (Transport to site)
- Electricity mix (Belgium power grid / on-site PV plant (50%/50%))

**Processing**
- Module preparation (manual)
- Shredder
- Recycling line
  - Manual pre-sorting
  - Crushing
  - Fe separation
  - Extraction
  - Non Fe separation
  - Separation of stone, porcelain, ceramics
  - Process control
  - Glass separation
- Wheel loader

**Output flows**
- Frames
- Junction box
- Glass cullet
- PV Cell/ Polymer foil compound
- Ferro waste
- Other wastes
- Metal recycling
- Storage
- Disposal (landfill)
- Glass recycling

**EOL Treatment**
- Al recycling
- Cu recycling
- Plastic waste incineration

**Ganzheitliche Bilanzierung**

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Life cycle assessment – Boundary conditions

Reference Case

- Secondary material content of frames and cables according to EU average
- Transport to site 200km

Scenarios

- Secondary material content
  1. Industry average (EU-Mix): Copper wire 45.7%; aluminum frame 50%
  2. 90% Secondary material content
  3. 100% primary materials
- Transport distances
- Process throughput
Inventory data and main assumptions

LCA of the running PV module recycling process at Maltha recycling, BE using a flat glass recycling line.

- **Material mix PV module waste:**
  (~65% glass; ~15% PV / laminate compound; ~2% plastics and metals; ~5% other wastes; ~11% frames, ~1.5% junction boxes)

- **Transport distances:** PV modules to site 200km, materials to recycling 30-50km

- **Recycling Processes:** On-site data collection at Maltha, Lommel

- **Energy mix:** 50% Belgium power mix, 50% on-site PV power plant

- **Glass recycling:** According to slide 8

- **Material recycling and disposal:** GaBi (5) standard datasets

- **Wheel loader:** GaBi (5) standard dataset
Results: cSi PV Module Recycling
(Secondary material share (EU average): Al 50%; Cu 45.7%)

-100%  -80%  -60%  -40%  -20%  0%  20%

Acidification Potential (AP)  Eutrophication Potential (EP)  Global Warming Potential (GWP)  Photochem. Ozone Creation Potential (POCP)  Primary energy from resources [PED]

Glass Cullet to Recycling  Aluminum frame recycling (50% sec. mat.)  Credit for recycling of steel scrap  Recycling of Junction boxes and Cables (45.7% sec. mat.)  Waste incineration of untreated wood  Waste incineration of light fractions  Disposal of solid Wastes (landfill for glass and inert wastes)  Electricity Mix (Recycling Site)  Wheel loader  Transportation to Recycling Plant (Truck) (200km)
Global Warming Potential - cSi PV Module Recycling
(Comparison sec. mat. shares in Al-frame and Cu-cable)

CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years)
[kg CO2-Equiv./ton of spent modules]

<table>
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<th>Primary materials</th>
<th>Industry average (~50% sec. mat.)</th>
<th>High sec. mat. content (90%)</th>
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<td>Electricity Mix (Recycling Site)</td>
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<td>Wheel loader</td>
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<td>Transportation to Recycling Plant (Truck) (200km)</td>
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Relative contribution of the PV module recycling to the whole module life cycle

- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Global Warming Potential (GWP)
- Photochem. Ozone Creation Potential (POCP)
- Primary energy from resources (net cal. value) (PED)

-10% -11% -8% -10% -6% -8% -4% -4% -5% -6%

PV-Module Recycling (xSi)  Production Mono-cSi PV Module  Production Multi-cSi PV Module
Dependency of transport distances

-0.30  -0.25  -0.20  -0.15  -0.10  -0.05  0.00  0.05  0.10
Transport scenario 50km  Transport scenario 100km  Transport scenario 200km  Transport scenario 300km  Transport scenario 500km

kg phosphate-equiv./ton spent PV modules

-0.30 -0.25 -0.20 -0.15 -0.10 -0.05 0.00 0.05 0.10

Transport to site  PV module recycling

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Scenario: Increasing throughput of glass recycling line

CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]

Primary energy from resources (net cal. value) [MJ]

- Glass Cullet to Recycling
- Aluminum frame recycling (50% sec. mat.)
- Credit for recycling of steel scrap
- Recycling of Junction boxes and Cables (45.7% sec. mat.)
- Waste incineration of untreated wood
- Waste incineration of light fractions
- Disposal of solid Wastes (landfill for glass and inert wastes)
- Electricity Mix (Recycling Site)
- Wheel loader
- Transportation to Recycling Plant (Truck) (200km)
Summary and Outlook

- Recycling can lead to a reduction of the environmental profile of the PV module life cycle (around 4% -11% depending on the module technology and considered impact category.)
- The main impacts of the recycling processes are related to the transports and electricity use.
- The high share of PV power (50%) leads to significant reduction of the environmental profile of used electricity.
- Main benefits from aluminium and glass recycling. Secondary material content of aluminium frames plays a decisive role.
- Higher transport distances mainly result in higher contributions to eutrophication and photochem. ozone creation potential.

Further aspects need to be addressed:
- Investigation of the environmental profile of the further treatment of the silicon-cell /polymer-foil laminate.
Thank you for your attention!