treeze Ltd., Kanzleistrasse 4, CH-8610 Uster, www.treeze.ch

Life Cycle Assessment of Oerlikon Solar μC-Si solar modules

Authors
Karin Flury, Rolf Frischknecht, René Itten

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Authors	Karin Flury2), Rolf Frischknecht1), René Itten1) 1) treeze Ltd., fair life cycle thinking Kanzleistr. 4, CH-8610 Uster www.treeze.ch Phone+41 44 940 61 91, Fax +41 44 940 61 94 frischknecht@treeze.ch 2) ESU-services Ltd, fair consulting in sustainability Margrit Rainer-Strasse 11c, CH-8050 Zürich www.esu-services.ch
Commissioner	Oerlikon Solar
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Summary

Oerlikon Solar provides equipment and turnkey manufacturing lines for the production of thin film solar modules of both, the amorphous (a-Si) and the micromorph (µC-Si) tandem technology. Within this project a life cycle assessment (LCA) of the electricity generated with photovoltaic power plants using µC-Si solar modules produced in Oerlikon Solar's "ThinFab" is conducted. The study is financed by the Swiss Federal Office of Energy (SFOE) in the framework of the Task 12 of the Photovoltaic Powers System Programme (PVPS) of the International Energy Agency (IEA).

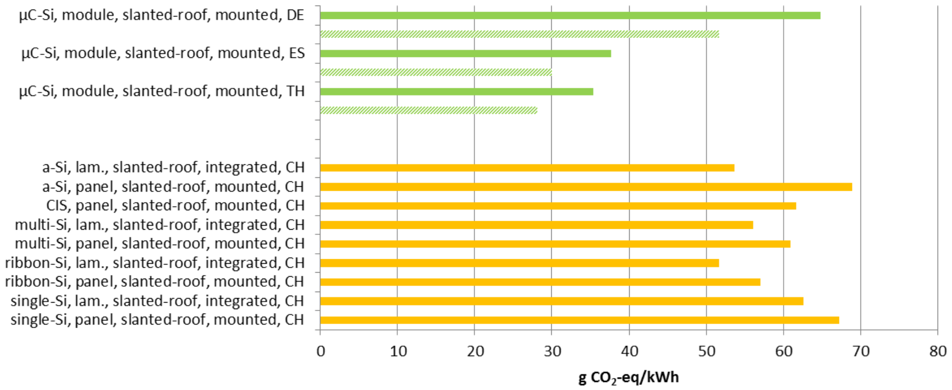
The life cycle inventory is based on the planning data of a "ThinFab" with an annual capacity of 120 MW. The production location is assumed to be in China as the majority of Oerlikon Solar's customers are and will be Chinese. The modules produced are µC-Si solar modules on glass substrates. The modules have a width of 1'100 mm and a length of 1'300 mm which results in the surface area of 1.4 m^2. The thickness of the front glass is 3.2 mm and the one of the back glass is 2.0 mm, respectively. The module efficiency is 10 % and each module has a capacity of 143 W_p.

It is found that the main environmental impacts are caused by the electricity consumption in the manufacturing of the modules, by the front and back glass as well as by the cupper in the different wires installed. The process gases are relevant for the cumulative energy demand, the human toxicity impacts and the greenhouse gas emissions.

The overall greenhouse gas emissions of electricity from photovoltaic installations using µC-Si solar modules installed on a slanted roof in Germany, Spain and Thailand are compared to slanted roof installations using other photovoltaic technologies manufactured in Europe and operated in Switzerland The results are presented below. The carbon footprint is 33.1 g CO_2-eq/kWh for electricity produced with µC-Si solar modules in Spain. Other PV technologies operated in Switzerland range between 51 g CO_2-eq/kWh (ribbon-Si laminate) and 69 g CO_2-eq/kWh (a-Si panels).

The non-renewable energy payback time (NREPBT) is 1.0, 1.3 and 1.5 years for power plants installed on a slanted roof in Bangkok, Madrid, and Munich, respectively. The non-renewable energy payback time is 0.2 to 0.3 years longer for open ground installations compared to roof-top installations.

In a sensitivity analysis, the influence of the production site and thus of the electricity mix used in the module production is examined. As shown below, the change from the Chinese (green bars) to the European electricity mix (light green bars) has a significant impact on the carbon footprint of the photovoltaic electricity. The use of the European electricity mix reduces greenhouse gas emissions by 14 %.



Carbon Footprint of electricity from photovoltaic slanted-roof installations using modules produced in the "ThinFab" in China and from photovoltaic slanted roof installations using various different technologies in Switzerland, assessed with Ecological Scarcity (2006). Green: thin-film modules produced in China; Light green: thin-film modules produced in Europe.

Abbreviations and Glossary

a	annum (year)
CdTe	cadmium telluride
CDA	compressed dried air
CED	cumulative energy demand
CIS	copper indium selenide
CH	Switzerland
CN	China
DE	Germany
ES	Spain
EPBT	energy payback time
NREPBT	non-renewable energy payback time
EVA	ethylene-vinyl acetate
GLO	Global average
GWP	Global warming potential
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
NMVOC	non-methane volatile organic compounds
RER	Europe
TH	Thailand
VOC	volatile organic compounds
μC-Si	micromorph

Contents

1 Introduction

1.1 Background

Oerlikon Solar is a Swiss company with headquarter in Trubbach. The company provides equipment and turnkey manufacturing lines for the production of thin film solar modules of both, the amorphous (a-Si) and the micromorph (μC-Si) tandem technology[1].

By the end of 2010, Oerlikon Solar had 14 customers in seven different countries. These customers produced 3.5 million modules with a total capacity of 450 MW[1].

Oerlikon Solar has launched a new production line “ThinFab” for the manufacturing of μC-Si solar modules. The “ThinFab” reduces not only the production costs but also the energy demand during the manufacturing of the modules[1].

Life cycle assessment (LCA) is an environmental management tool for analysing, comparing and improving the environmental performance of products or technologies. Stucki & Frischknecht (2010) present up to date results of the life cycle assessment of photovoltaic electricity generated in Switzerland and show that the generation of photovoltaic electricity can support the reduction of the environmental impacts of the Swiss electricity mix, in particular regarding greenhouse gas emissions and nuclear wastes.

Within this project a life cycle assessment of the electricity generated with photovoltaic power plants using μC-Si solar modules produced in Oerlikon Solar’s “ThinFab” is conducted. The study is financed by the Swiss Federal Office of Energy (SFOE) in the framework of the Task 12 of the Photovoltaic Powers System Programme (PVPS) of the International Energy Agency (IEA). The activities are covered by the subtask 2 on LCA of the IEA PVPS task 12 on “PV environmental health and safety activities”.

1.2 Goal and Scope

The life cycle assessment is modelled based on the general properties of a “ThinFab” with an annual production capacity of 120 MW. The data are collected and provided by Oerlikon Solar.

The goal of the life cycle assessment is to evaluate the environmental impacts that are caused by the production and operation of μC-Si solar modules produced in a “ThinFab”. A special focus is laid on the carbon footprint of electricity from photovoltaic power plants based on the μC-Si solar modules under study as well as of the modules themselves. Furthermore, it is identified where the major contributions to the overall environmental impacts come from in order to enable the determination of key factors for improvement measures.

The modules are evaluated per module with a surface area of 1.4 m^2. Photovoltaic electricity is analysed per kWh at busbar.

The results of the life cycle assessment are compared to the environmental impacts from other photovoltaic technologies.

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[1] http://www.oerlikon.com/solar/, October 2011

1.3 Impact Assessment Methods

The following sets of indicators are used in this study:

1. Cumulative energy demand (renewable and non-renewable)
2. Global Warming Potential 2007
3. ReCiPe 2008
4. Ecological Scarcity 2006

1.3.1 Cumulative Energy Demand (CED)

The CED (implementation according to Frischknecht et al. 2007b) describes the consumption of fossil, nuclear and renewable energy sources throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g. plastics as construction or raw materials. This method has been developed in the early seventies after the first oil price crisis and has a long tradition (Boustead & Hancock 1979; Pimentel 1973). A CED assessment can be a good starting point in an environmental assessment due to its simplicity in concept and its easy comparability with CED results in other studies. However, it does not valuate environmental impacts and, as a consequence, cannot replace an assessment with the help of a comprehensive impact assessment method such as ReCiPe 2008.

The following two CED indicators are calculated:

- CED, non-renewable (MJ oil-eq.) – fossil and nuclear
- CED, renewable (MJ oil-eq.) – hydro, solar, wind, geothermal, biomass

1.3.2 Global Warming Potential 2007 (GWP)

All substances that contribute to climate change are included in the global warming potential (GWP) indicator according to IPCC (Solomon et al. 2007). The residence time of the substances in the atmosphere and the expected immission design are considered to determine the global warming potentials. The potential impact of the emission of one kilogramme of a greenhouse gas is compared to the emission of one kilogramme CO_2 resulting in kg CO_2-equivalents. These so called global warming potentials are determined applying different time horizons (20, 100 and 500 years). The short integration period of 20 years is relevant because a limitation of the gradient of change in temperature is required to secure the adaptation ability of terrestrial ecosystems. The long integration time of 500 years is about equivalent with the integration until infinity. This allows monitoring the overall change in temperature and thus the overall sea level rise, etc..

In this study a time horizon of 100 years is chosen for the evaluation.

1.3.3 Environmental impact indicators according to ReCiPe 2008

The ReCiPe 2008 method (Goedkoop et al. 2009) was developed by the Dutch National Institute for Public Health and the Environment (RIVM), the Radboud University, the Dutch Institute of Environmental Sciences (CML) at Leiden University and PRé Consultants.

The method determines environmental indicators at midpoint and endpoint level. Analyses on both levels are possible. The following eighteen ReCiPe midpoint indicators are calculated (the reference substance is indicated in brackets)*:*

- Climate change (kg CO2 eq.)
- Ozone depletion (ODP) (kg CFC-11 eq.)
- Terrestrial acidification (kg SO_2 eq.)
- Freshwater eutrophication (kg P eq.)
- Marine eutrophication (kg P eq.) *
- Human toxicity (kg 1,4-DB eq.)
- Photochemical oxidation (kg NMVOC eq.)
- Particulate matter formation (kg PM_{10} eq.)
- Terrestrial ecotoxicity (kg 1,4-DB eq.)
- Freshwater ecotoxicity (kg 1,4-DB eq.)
- Marine ecotoxicity (kg 1,4-DB eq.)
- Ionising radiation (kg U^{235} eq.)
- Agricultural land occupation (m^2*yr eq.)
- Urban land occupation (m^2*yr eq.)
- Natural land transformation (m^2 eq.)
- Water depletion (m^3 eq.) *
- Mineral resource depletion (kg Fe eq.)
- Fossil resource depletion (kg oil eq.)

*: not part of the endpoint indicator results.

The midpoint indicators are aggregated to three endpoint indicators:

- Damage to Human health (Disability-adjusted loss of life years)
- Damage to ecosystems (Loss of species during a year)
- Damage to resource availability (Increased cost)

The damages to these three safeguard subjects are weighted and aggregated to one single score. Three different perspectives were developed to represent different perceptions of the world with regard to time preference, uncertainty or local preference (hierarchist, individualist and egalitarian). The hierarchist perspective is the most balanced type (balance between future and present impacts, between risks and benefits and between his or her neighbourhood and the world). It is chosen for the ReCiPe assessment in this study. The latest version of ReCiPe 2008 (version 1.01) is applied.

1.3.4 Ecological Scarcity 2006

The ecological scarcity method (Frischknecht et al. 2008) evaluates the inventory results on a distance to target principle. The calculation of the eco-factors is based on one hand on the actual emissions (actual flow) and on the other hand on Swiss environmental policy and legislation (critical flow). These goals are:

- Ideally mandatory or at least defined as goals by the competent authorities,
- formulated by a democratic or legitimised authority, and
- preferably aligned with sustainability.

The weighting is based on the goals of the Swiss environmental policy; global and local impact categories are translated to Swiss conditions, i.e. normalised. The method is applicable to other regions as well. Eco-factors were also developed for the Netherlands, Norway, Sweden (Nordic Council of Ministers 1995, Tab. A22 / A23), Belgium (SGP 1994) and Japan (Miyazaki et al. 2004Büsser et al. 2012).

The ecological scarcity method allows for an *optimisation within the framework of a country's environmental goals*.

The environmental and political relevance is essential for the choice of substances. The environmental policy does by far not define goals for all potential pollutants and resources. Thus the list of eco-factors is limited. This particularly applies to substances with low or unknown environmental relevance in Switzerland and Europe (e.g. sulphate emissions in water bodies).

1.3.5 Selection of the Principal Impact Assessment Indicators

The environmental impacts of photovoltaic electricity and the photovoltaic modules are expressed with the environmental indicators described in the previous Subsections. The main impact assessment and discussion, however, is based on a selection of eight indicators, which are relevant in the context of this study. These are:

- CED, non-renewable (MJ-eq.)
- Climate change (kg CO_2 eq.)
- Ozone depletion (ODP) (kg CFC-11 eq.)
- Human toxicity (kg 1,4-DB eq.)
- Terrestrial acidification (kg SO_2 eq.)
- Freshwater eutrophication (kg P eq.)
- Photochemical oxidation (kg NMVOC eq.)
- Ecological Scarcity 2006, aggregated single score

The remaining indicators were evaluated as well but not discussed separately as they often do not provide additional insights. They are mentioned and discussed in those cases where they are relevant.

2 Life Cycle Inventories

The first part of the life cycle inventory consists of the production of the modules. The consumption of energy and materials as well as the relevant emissions are described. The annual production of the "ThinFab" is used as reference flow. The unit process raw data as well as the EcoSpold MetaInformation are shown per module (Section 6.3 in the Appendix).

The second and the third part describe the installation and operation of the modules.

In this project life cycle inventories of photovoltaic 3kWp installations with µC-Si solar modules and of the electricity generation therewith are established in order to be comparable with photovoltaic 3kWp installations reported in ecoinvent. Since usually most of the environmental impacts and the amount of generated electricity correlate with the photovoltaic plant size, the environmental impacts per kWh photovoltaic electricity are relatively independent of the plant size.

2.1 Photovoltaic Modules Production

2.1.1 Introduction

The life cycle inventory is based on the planning data of a "ThinFab" with an annual capacity of 120 MW. The described facility is expected to start the production in summer 2012 and reach full capacity production in January 2013. The production location is assumed to be in China as the majority of Oerlikon Solar's customers are and will be Chinese[2].

The modules produced in the "ThinFab" are µC-Si solar modules on glass substrates. The modules have a width of 1'100 mm and a length of 1'300 mm which results in the size of 1.4 m^2. The thickness of the front glass is 3.2 mm and the one of the back glass is 2.0 mm, respectively. The module efficiency is 10 % and each module has a capacity of 143 W_p.

2.1.2 Production Volumes

The annual production capacity of the "ThinFab" is 120 MW. This is a total output of 841'223 modules per year with a capacity of 143 W_p each. The losses (rejects) along the production line are 3 %. They are considered in the inventory of the material and energy flows.

2.1.3 Components and Materials

The type and amount of materials and gases annually consumed is presented in Tab. 2.1. The material consumption per module is shown as raw data in Section 6.3 in the Appendix.

The annual gas consumption is directly derived from the specifications of Oerlikon Solar. For mixed process gases (Phosphine 2 % in Hydrogen and Trimethylboron 2 % in Hydrogen), the components (active gas and hydrogen) are considered separately. The consumption of methane and natural gas is combined as natural gas. Due to lack of specific data of diethylzinc (DEZ) its supply chain is considered with a generic dataset of "organic chemicals".

The consumption of materials and consumables also includes the scraps and rejected modules. The amounts listed in Tab. 2.1 include a production efficiency of 97 %.

Due to lack of specific data and their relatively low amount, the electrical isolation tape, the edge sealant and the hotmelt are not considered in the inventory.

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[2] Personal communication with Irene Steimen (Oerlikon Solar), Oktober 2011

Tab. 2.1 Components and materials for the annual production µC-Si solar modules (including production losses).

	Component	Ecoinvent process	Specifications	Unit	Per year
Gas consumption	Nitrogen	nitrogen, liquid, at plant/RER/	1.185 kg/m^3 (1.013bar, 15°C)[3]	kg	6.14E+06
	Silan	silane, at plant/RER	1.35 kg/m^3 (1.013bar, 15°C)[3]	kg	2.55E+04
	Hydrogen	hydrogen, liquid, at plant/RER	0.085 kg/m^3 (1.013bar, 15°C)[3]	kg	4.08E+04
	Phosphine	phosphane, at plant/GLO	1.45 kg/m^3 (1.013bar, 15°C)[3]	kg	2.83E+01
	TMB	trimethyl borate, at plant/GLO	2.3 kg/m^3 (1.013bar, 15°C)[3]	kg	9.98E+00
	Carbon dioxide	carbon dioxide liquid, at plant/RER	1.87 kg/m^3 (1.013bar, 15°C)[3]	kg	2.30E+03
	Nitrogen trifluoride	nitrogen trifluoride, at plant/RER	3.003 kg/m^3 (1.013bar, 15°C)[3]	kg	7.12E+04
	Argon	argon, liquid, at plant/RER	1.67 kg/m^3 (1.013bar, 15°C)[3]	kg	2.66E+04
	Diborane	diborane, at plant/GLO	1.18 kg/m^3 (1.013bar, 15°C)[3]	kg	2.05E+01
	Oxygen	oxygen, liquid, at plant/RER	1.365 kg/m^3 (1.013bar, 15°C)[3]	kg	3.32E+05
	Natural gas & Methan	natural gas, high pressure, at consumer/CH	0.8 kg/m^3, 45 MJ/kg[4]	MJ	4.90E+06
	Diethylzinc (DEZ)	chemicals organic, at plant/GLO	/	kg	4.77E+04
Materials	Glass	solar glass, low-iron, at regional storage/RER	1300*1100mm	kg	1.61E+07
	Silver	silver, at regional storage/RER	Containing glue	kg	1.98E+02
	Bisphenol F	bisphenol A, powder, at plant/RER	Containing glue	kg	1.32E+02
	Copper cable	copper, at regional storage/RER, wire drawing, copper/RER	Solder Strings, copper core 0.08*2mm	kg	1.09E+04
	Adhesive	adhesive for metals, at plant/DE	Fixation pad & glue pad	kg	4.34E+03
	EVA foil	ethylvinylacetate, foil, at plant/RER	Density 0.96 g/cm^3 [5]	kg	5.43E+05
	Plastic	polyethylene, HDPE, granulate, at plant/RER, injection moulding/RER	Junction Box, assumptions	kg	1.29E+04
	Cable	cable, three-conductor cable, at plant/GLO	Junction Box, assumptions	m	2.44E+05
	Silicon pottant	silicone product, at plant/RER	Glue sealant, 2.329 g/cm^3 [6]	kg	2.02E+04
	Detergent	zeolite, slurry, 50% in H2O, at plant/RER	/	kg	3.90E+04

2.1.4 Infrastructure

The infrastructure of the building is modelled based on the ecoinvent process “solar collector factory” (Tab. 2.2). The size is linearly scaled according to the land use of the buildings. The “ThinFab” has a built up area of 12’800 m^2. This corresponds to 1.69 times the building area of one solar collector factory. Consequently, the “ThinFab” is modelled as 1.69 solar collector factories, including the infrastructure of the building as well as the land use of planted areas and parking areas. The lifespan of the factory is 50 years.

The machines of the production line are inventoried based on their weight as it is specified by Oerlikon Solar. The lifetime of the machines is 50 years, in accordance with the one of the factory.

Tab. 2.2 Infrastructure of the “ThinFab”.

	Component	Ecoinvent process	Specifications	Unit	Per year
Infra-struc-ture	Solar fab	solar collector factory/RER	Scaled based on built up area	unit	3.37E-02
	Machines	metal working machine, unspecified, at plant/RER	/	kg	2.61E+04

2.1.5 Production Process

The inventory of the production process covers the electricity consumption, the production and use of compressed dried air (CDA) as well as water consumption. The annual input is shown in Tab. 2.3.

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[3] http://encyclopedia.airliquide.com, October 2011

[4] Frischknecht et al. 2007a

[5] http://www.novopolymers.com/en/node/2, October 2011

[6] http://www.wiley.com/WileyCDA/Section/id-407379.html, October 2011

The factory is supplied with high voltage electricity from the Chinese grid. The uptime of the equipment is already included in the specifications of Oerlikon Solar. The electricity consumption of the facility (light, air conditioning, CDA generation, ventilation etc.) is declared to be an additional 50 % to the total electricity consumption of the equipment. As the generation of CDA is inventoried separately, its electricity consumption ($2.47*10^5$ kWh/a) is subtracted from the total electricity consumption of the facility.

The amount of waste heat produced in the factory is specified by Oerlikon Solar.

The consumption of CDA is based on the specifications of Oerlikon Solar. The modelling of CDA production is based on assumptions. A factor 7 is used to convert the figures from the reference conditions of 1 atm to the conditions of the ecoinvent process used (7 bar). The uptime of the equipment is considered in the annual CDA consumption.

The cooling water is inventoried according to the specifications of Oerlikon Solar. The uptime of the cooling water supply is estimated to be 100 %. It is assumed that 5 % of the cooling water is evaporated. The rest is returned to the watershed.

The annual demineralized and deionized water consumption considers the uptime of the equipment. It is based on the specifications of Oerlikon Solar.

Tab. 2.3 Components and materials for the annual production µC-Si solar modules (including production losses).

	Component	Ecoinvent process	Specifications	Unit	Per year
Electricity, CDA, water	Electricity	electricity, high voltage, at grid/CN	/	kWh	5.16E+07
	Heat emission	Heat, waste, air, high population density	/	MJ	4.92E+07
	Compressed dried air (CDA)	compressed air, average generation, >30kW, 7 bar gauge, at compressor/RER	/	m^3	1.48E+06
	Cooling water	Water, unspecified natural origin, CN	Chilled & tempered	m^3	3.22E+06
	Demineralized water	water, decarbonised, at plant/RER	Density: 1000 kg/m^3	kg	5.26E+07
	Deionized water	water, deionised, at plant/CH	Density: 1000 kg/m^3	kg	9.92E+07

2.1.6 Transportation

It is assumed that the materials and consumables are purchased from Chinese suppliers. European standard distances are applied as a rough approximation. In contrast to European transport models, all transports are assumed to be carried out by lorries though (see Tab. 2.4).

The equipment is mostly manufactured in Europe and, as a consequence, it needs to be shipped to China first (Rotterdam-Shanghai 20’000 km). The distance covered by lorry equals twice the distance Zurich-Rotterdam (800 km). This includes the transport within Europe as well as from Shanghai to the production site.

Tab. 2.4 Transport distances and services for the material necessary to run the "ThinFab" for one year.

	Material	Weight (t/a)	Standard distances (km)	tkm/a
Lorry	Glass	1.98E+04	700	6.07E+07
	Plastics	5.76E+02	300	
	Gases	6.65E+03	150	
	Materials and consumables	1.52E+05	300	
	To recycling	1.29E+02	50	
	To incineration		10	
	Returned to producer	4.35E+02	700 (glass), 300 (foil)	
	Machines	1.31E+03	1'600	
Ship			20'000	2.61E+07

2.1.7 Waste Water and Emissions

The waste water produced in the "ThinFab" is treated on-site before it is discharged to the communal waste water system. The emissions shown in Tab. 2.5 refer to the concentrations after the treatment.

Hazardous exhaust air is treated in abatement units before the release to the environment. The final outlet complies with the Swiss environmental legislation. Exhaust air from harmless sources is released directly.

Certain emissions to the water (deionised water (2.5% $FeCl_3$, 2.5% citric acid, total Zn app 500 mg/l, dissolved Zn app. 95%, dissolved Zn and liquid DEZ) as well as the sludge from the waste water treatment are not considered due to the lack of data.

Tab. 2.5 Waste water emissions and emissions to nature caused by the annual production of modules in the "ThinFab".

	Component	Ecoinvent process / elementary flow	Unit	Per year
Waste water	Waste water	treatment, sewage, unpolluted, from residence, to wastewater treatment, class 2	m^3	1.52E+05
	Suspended solids	Suspended solids, unspecified	kg	2.73E+04
	Fluoride (F^-)	Fluoride, water, unspecified	kg	2.28E+03
	COD	COD, Chemical Oxygen Demand, water, unspecified	kg	7.18E+03
	Phosphor (total-P)	Phosphorus, water, unspecified	kg	6.07E+01
	Nitrogen (total N)	Nitrogen, water, unspecified	kg	2.43E+02
	Boron (B)	Boron, water, unspecified	kg	3.03E+01
	Zinc (Zn)	Zinc, ion, water, unspecified	kg	1.52E+01
	Chloride (Cl^-)	Chloride, water, unspecified	kg	2.09E+05
	Calcium	Calcium, ion, water, unspecified	kg	1.06E+02
Emissions to air	Fluoride	Hydrogen fluoride, air, high population density	kg	1.49E-01
	Dust	Particulates, > 10 um, air, high population density	kg	3.56E+00
	VOC	NMVOC, non-methane volatile organic compounds, , air, high population density	kg	4.57E+02
	NO_x	Nitrogen oxides, air, high population density	kg	7.70E+02
	CO	Carbon monoxide, fossil, air, high population density	kg	1.30E+02
	NF_3	Nitrogen fluoride, air, high population density	kg	1.30E+00
	CO_2	Carbon dioxide, fossil, air, high population density	kg	2.56E+07

2.1.8 Recycling and Disposal of the Production Waste and the Modules

The wastes incurring during the operation of the "ThinFab" are treated differently. According to the specifications of Oerlikon Solar 4 % of the glass waste is returned to the supplier for reuse, 27 % is recycled and the rest goes to the municipal incineration. One part of this glass waste are half-finished modules that are rejected.

The remains of the EVA foil are returned to the supplier for reuse. The transport distances are already described in Section 2.1.6.

It is assumed that the modules are disposed of in a municipal incineration after they reach their end of life.

Tab. 2.6 Waste flows of the annual production of modules in the "ThinFab".

	Component	Ecoinvent process	Specifications	Unit	Per year
Waste	Glass	disposal, glass, 0% water, to municipal incineration		kg	1.60E+07
	Rubber	disposal, rubber, unspecified, 0% water, to municipal incineration		kg	5.00E+02
	Solvent mixture	disposal, solvents mixture, 16.5% water, to hazardous waste incineration	Solvent mixture from EVA foil	kg	7.28E+01

2.2 Photovoltaic Power Plants

In compliance with the ecoinvent quality guidelines, life cycle inventories of $3kW_p$ photovoltaic power plants on flat roofs, slanted roof tops as well as open ground areas with thin-film modules are set up. The power plants are assumed to be located in Germany, Spain and Thailand.

The modules have a size of 1.4 m^2. Hence, for setting up a 3kWp photovoltaic power plant, 29.4 m^2 of 143 W_p modules are required. Furthermore, additional 3 % of modules are included due to reparations and rejects.

The recommended frame for the installation of the modules by Oerlikon Solar consists of aluminium. For the installation on open ground and on flat roof tops, the same frame is recommended which results in only one dataset for installations on flat areas. The modules are attached to the frame by aluminium clips.

Based on information from Jungbluth et al. (2010) 0.04 kWh electricity is considered for the erection of the power plant and one unit of electric installations as well as 2.4 units of inverters with a capacity of 2500 W (lifetime 15 years) are required during the life time of 30 years. Cabling and electric installations are included in compliance with the datasets established by Jungbluth et al. (2010).

It is assumed that the construction materials as well as the electrical parts are supplied by local manufacturers. Supplier logistics are approximated with European standard distances. The modules are shipped from China to Thailand and Europe, respectively.

2.3 Electricity generation

According to Oerlikon Solar, the modules are installed on slanted roof tops, on flat roof tops and on open ground areas.

The operation of the photovoltaic power plant takes place in a location in Germany, Spain and Thailand with good conditions. The regional solar irradiation and the annual outputs are listed in Tab. 2.7. The annual outputs are given as country average slanted roof, country average optimal angle and average for specific locations.

Tab. 2.7 Solar irradiation and annual output of the locations.

Country	Solar irradiation (kWh/m^2a)	Annual output slanted roof (kWh/kW_p)	Annual output optimal angle (kWh/kW_p)	Annual output specific location (kWh/kW_p)
Germany	972[7]	809[8]	937[7]	1076[9]
Spain	1660[7]	1394[8]	1444[7]	1510[9]
Thailand	1764[10]	1481[11]	1535[11]	1470[9]

In compliance with methodology guidelines on life cycle assessment of photovoltaic electricity published by the International Energy Agency (Alsema et al. 2009) and with the ecoinvent datasets on PV, the life time of the photovoltaic power plants is considered with 30 years.

Water use for cleaning of the modules is considered with 20 litre water per year and square meter. Its treatment in a wastewater treatment plant is accounted for (Jungbluth et al. 2010).

According to Jungbluth et al. (2010), 3.85 MJ of solar energy is required in order to generate 1 kWh of electricity and 0.25 MJ of waste heat. The waste heat corresponds to the losses in cabling and inverter.

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[7] http://re.jrc.ec.europa.eu/pvgis/apps/pvreg.php?lang=e, October 2011

[8] Jungbluth et al. 2010

[9] Munich, Madrid and Bangkok in case of Germany, Spain and Thailand, respectively

[10] Janjai et al. 2011

[11] Own assumption

3 Life Cycle Impact Assessment (LCIA)

In this Chapter the environmental impacts of the µC-Si solar modules and of photovoltaic electricity from power plants operating with the modules along the life cycle are evaluated. The life cycle includes all stages from the production of feedstock to the disposal of modules in a municipal incineration plant.

3.1 Module Production and Disposal

In Fig. 3.1 it is shown where the environmental impacts of the production and disposal of thin-film modules stem from. More detailed information is listed in Tab. 6.1 in the Appendix.

The non-renewable cumulative energy demand of the production and disposal of one module amounts to 1.36 GJ. Important contributions are the electricity consumption, the glass, transports and process gas consumption. The photochemical oxidation potential is 0.54 kg NMVOC per module mainly caused by the electricity and glass consumption as well as transports. Human toxicity impacts are caused by the module production and disposal and amount to 39.6 kg 1,4-DB eq. per module. Emissions that contribute to this result are mainly caused by the materials (i.e. the cables of the junction box) and by the electricity and process gas consumption (i.e. nitrogen trifluoride and nitrogen).

The carbon footprint is 133 kg CO_2-eq. per module. Major contributions stem from the electricity consumption (53 %), the carbon dioxide emissions from the process gas supply (18.7 %; 16 % nitrogen trifluoride, 2 % nitrogen), and the glass manufacturing (16.0 %). Eutrophication and acidification amount to 28.0 g P-eq. and 93.7 g SO_2-eq. per module. The former indicator is dominated by emissions due to the cables of the junction box (copper) and the electricity supply, the latter mainly by the electricity supply.

The share of the infrastructure is small. It has a maximum contribution of 1.65 % regarding human health. The disposal of modules and production wastes has a maximum share of about 7.08 % in the Ecological Scarcity 2006 score.

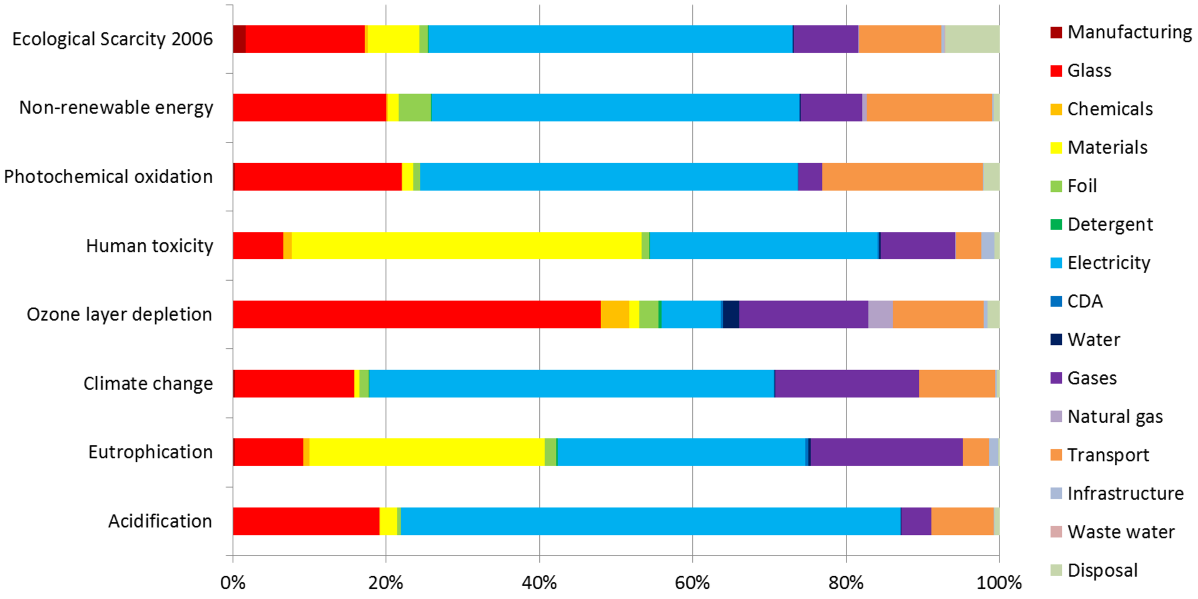

Fig. 3.1 Dominance analysis of the environmental impacts of 1 module produced in the "ThinFab". The results are scaled to 100 %.

The environmental impacts assessed with the Ecological Scarcity 2006 Method amount to 128'443 Ecopoints per module and have major contributions from the electricity production (47.5 %), glass consumption (15.6 %) and transports (10.8 %).

3.2 Electricity from Photovoltaic Power Plants

The overall environmental impacts of electricity from photovoltaic installations using µC-Si solar modules produced in the "ThinFab" installed on a slanted roof in Germany, Spain and Thailand are compared to slanted roof installations using other photovoltaic technologies manufactured in Europe and operated in Switzerland based on the assessment with the Ecological Scarcity Method (Frischknecht et al. 2009). The results are presented in Fig. 3.2. The µC-Si solar modules installed in Germany cause roughly similar overall environmental impacts like the other technologies. The installation and operation in regions with higher solar irradiation cause significantly lower environmental impacts.

In a sensitivity analysis, the influence of the electricity mix used in the module production is examined. As shown in Fig. 3.2, the change from the Chinese (green bars) to the European electricity mix (light green bars) reduces the environmental impacts by about 4 %. The environmental impacts from a photovoltaic installation in Germany decrease from 85.8 ecopoints/kWh to 82.4 ecopoints/kWh. All other parameters are unchanged.

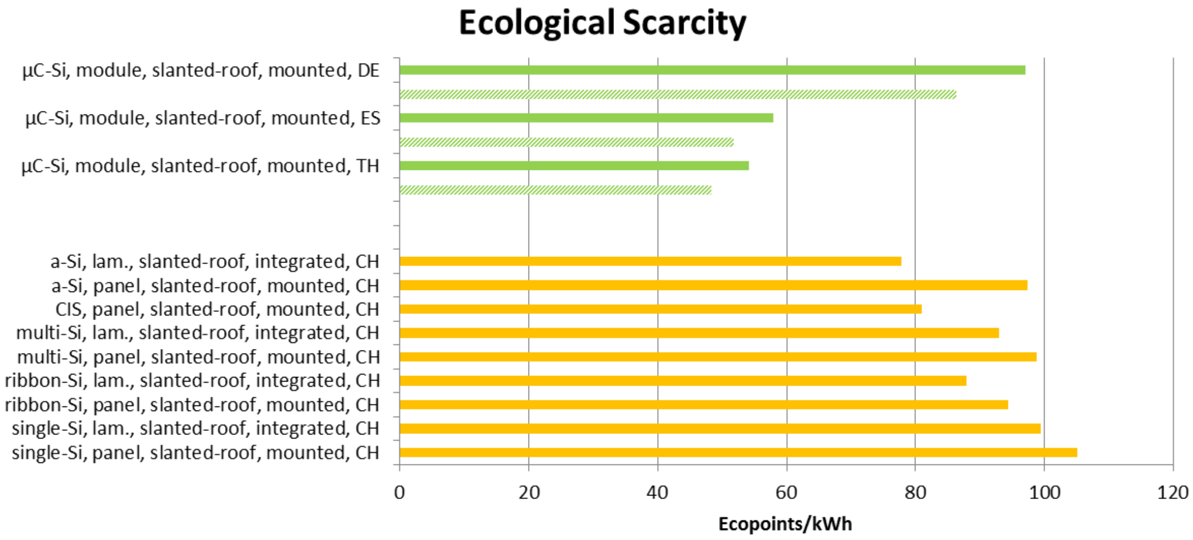

Fig. 3.2 **Environmental impacts of electricity from photovoltaic slanted-roof installations using modules produced in the "ThinFab" in China and from photovoltaic slanted roof installations using various different technologies in Switzerland, assessed with Ecological Scarcity (2006).**
Green: thin-film modules manufactured in China; Light green: thin film modules manufactured in Europe; Yellow: other module technologies manufactured in Europe
Electricity output: Germany: 809 kWh/kWp; Spain: 1394 kWh/kWp Thailand; 1481 kWh/kW$_p$; plants with other module technologies: 922 kWh/kW$_p$.

In Tab. 3.1 the total environmental impacts of the installation on slanted-roof tops are compared to the impacts of the installation on open ground.

Tab. 3.1 Environmental impacts of electricity from photovoltaic slanted-roof and open ground installation using µC-Si solar modules produced in the "ThinFab" (Ecological Scarcity, UBP/kWh).

	Slanted-roof installation			Open ground installation		
Country	**Germany**	**Spain**	**Thailand**	**Germany**	**Spain**	**Thailand**
µC-Si solar module	85.8	51.4	48.3	86.0	57.1	53.8
Sensitivity analysis: Production with European electricity mix	82.4	49.4	46.4	/	/	/

In Fig. 3.3, the carbon footprint of electricity from different photovoltaic slanted-roof installations is shown. The carbon footprint is 57.0 g CO_2-eq/kWh, 33.1 g CO_2-eq/kWh and 31.1 g CO_2-eq/kWh for electricity produced with µC-Si solar modules in Germany, Spain and Thailand, respectively. Other PV technologies operated in Switzerland range between 51 g CO_2-eq/kWh (ribbon-Si laminate) and 69 g CO_2-eq/kWh (a-Si panels).

In comparison with other technologies, photovoltaic installations using µC-Si solar modules have similar impacts on climate change as other technologies.

The change in the electricity mix during the production of the modules has a significant impact on the carbon footprint of the photovoltaic electricity. The use of the European electricity mix reduces greenhouse gas emissions by about 14 %. In Fig. 3.3 it can be observed that the change in the electricity mix decreases the carbon footprint of the electricity from the German µC-Si photovoltaic plant to a level below the carbon footprint of other technologies.

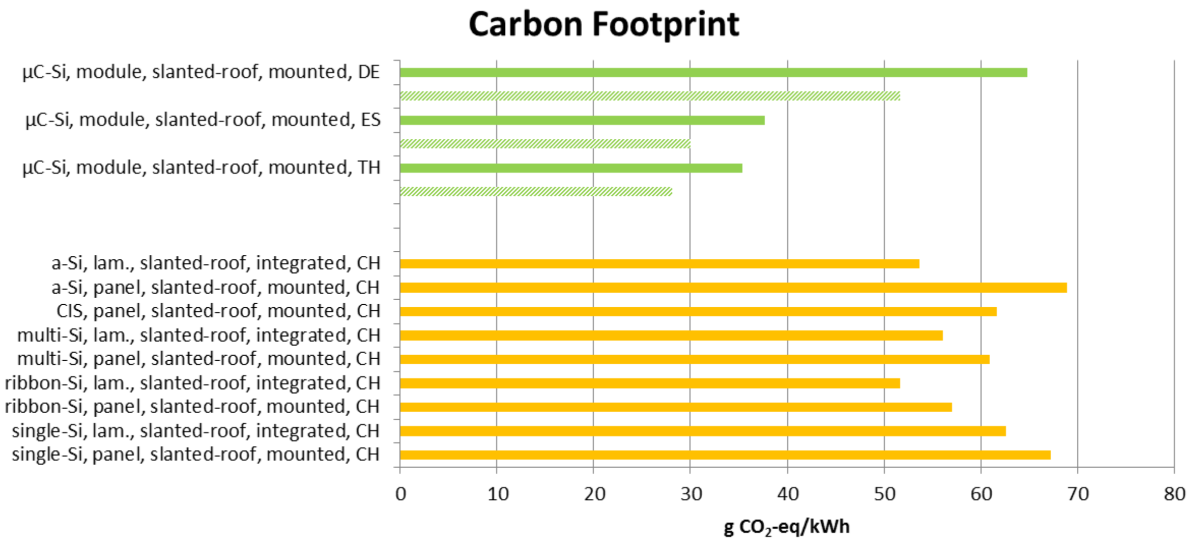

Fig. 3.3 Carbon Footprint of electricity from photovoltaic slanted-roof installations using modules produced in the "ThinFab" in China and from photovoltaic slanted roof installations using various different technologies in Switzerland, assessed with Ecological Scarcity (2006). Green: thin-film modules produced in China; Light green: thin-film modules produced in Europe; Yellow: other module technologies manufactured in Europe; Electricity output: Germany: 809 kWh/kWp; Spain: 1394 kWh/kWp; Thailand: 1481 kWh/kW$_p$; plants with other module technologies: 922 kWh/kW$_p$.

Tab. 3.2 compares the greenhouse gas emissions of installations on slanted-roof tops to the installations on open ground.

Tab. 3.2 Greenhouse gas emissions of electricity from photovoltaic slanted-roof and open ground installation using µC-Si solar modules produced in the "ThinFab". Greenhouse gas emissions (g CO_2-eq/kWh).

	Slanted-roof installation			Open ground installation		
Country	**Germany**	**Spain**	**Thailand**	**Germany**	**Spain**	**Thailand**
µC-Si solar module	57.0	33.1	31.1	60.1	39.0	36.8
Sensitivity analysis: Production with European electricity mix	48.7	28.3	26.6	/	/	/

3.3 Energy payback time

The energy payback time is defined as the period required for a renewable energy system to generate the same amount of energy (in terms of primary energy equivalent) that was used to produce the system itself. The calculation of the energy payback time is described by the following formula:

$$Energy\ Payback\ Time = \frac{E_{mat} + E_{manuf} + E_{trans} + E_{inst} + E_{EOL}}{\frac{E_{agen}}{\eta_G} + E_{O\&M}}$$

E_{mat}:	Primary energy demand to produce materials comprising PV system
E_{manuf}:	Primary energy demand to manufacture PV system
E_{trans}:	Primary energy demand to transport materials used during the life cycle
E_{inst}:	Primary energy demand to install the system
E_{EOL}:	Primary energy demand for end-of-life management
E_{agen}:	Annual electricity generation
$E_{O\&M}$:	Annual energy demand for operation and maintenance
η_G:	Grid efficiency, average primary energy to electricity conversion efficiency at the demand side

Mainly two conceptual approaches are used in current LCA studies on photovoltaics. The calculations of the first approach are based on the total (renewable and non-renewable, excluding solar irradiation during operation) primary energy demand referred to as energy payback time (EPBT) and the second approach is based on the non-renewable primary energy demand referred to as non-renewable energy payback time (NREPBT).

Tab. 3.3 the NREPBT of the µC-Si solar modules produced in the "ThinFab" are shown for different countries, installation types and production sites. The calculations are based on the national electricity mixes of the countries, in which the PV systems are installed, are considered. The NREBPT for PV systems is lower in Thailand than in Spain despite the higher energy yield in Spain compared to Thailand. The main reason for this is the higher non-renewable primary energy demand of electricity in Thailand is higher than in Spain.

Therefore, the lower non-renewable primary energy demand of the electricity replaced in Spain extends the NREPBT of the PV system installed in Spain compared to the PV system installed in Thailand. The same situation occurs for PV systems installed in Germany. The non-renewable primary energy demand of the German electricity mix is higher than the non-renewable primary energy demand of the Spanish one. That is why the NREPBT of the PV system installed in Spain is 15 % lower compared to the NREPBT of the PV system installed in Germany although the yield in Spain is 45 % higher compared to the yield in Germany.

The NREPBT of open ground and flat roof PV installations is higher because of the frame, which is needed to mount the panels. These frames are made of aluminium and have a high primary energy demand. Therefore, the NREPBT of open ground and flat roof PV installations is 0.2 to 0.3 years longer than the one of slanted roof PV installations.

The transport distances only have a minor impact on the non-renewable primary energy demand. The difference between the panels produced in Europe and China and installed in Germany, Spain and Thailand are within a range of a few per cent. The energy yield shows a variation up to 30 % and the non-renewable energy demand of the German, Spanish and Thai electricity mixes show a variation up to 15 %. The deciding factors are the yield of PV installations and the electricity mixes of the countries, in which the PV systems are installed.

Tab. 3.3 Non-renewable energy payback time in years of slanted-roof and open ground photovoltaic installations using μC-Si solar modules produced in the "ThinFab" in Europe and China, installed in Germany (Munich), Spain (Madrid) and Thailand (Bangkok)
Munich: 1076 kWh/kWp; Madrid: 1510 kWh/kWp; Bangkok: 1470 kWh/kWp

	Slanted-roof installation			Open ground installation		
Country	Germany (Munich)	Spain (Madrid)	Thailand (Bangkok)	Germany (Munich)	Spain (Madrid)	Thailand (Bangkok)
Production Europe	1.5	1.3	1.1	1.8	1.5	1.3
Production China	1.5	1.3	1.0	1.8	1.5	1.3

4 Data Quality Considerations

The production data from Oerlikon Solar covering the consumption of feedstock materials, energy and water are reliable. The modelling of the construction and operation of $3kW_p$ photovoltaic power plants is consistent with the ecoinvent datasets described by Jungbluth et al. (2010) and allows for a comparison with other technologies.

5 Conclusions

The most important factors influencing the carbon footprint and the environmental impacts in general of the µC-Si solar modules are the electricity consumption during the production, the glass input, the transport services as well as the gas consumption.

The sensitivity analysis on the electricity mix during the production shows clearly, that the electricity mix (quality) and the amount of electricity consumed (quantity) have an impact on the environmental performance of the modules.

A significant improvement potential lies also in the amount of glass used per module.

Installations under optimal conditions and in regions with comparatively higher solar irradiation lead to higher electricity yields and consequently to the reduction of the environmental impacts per kWh electricity produced.

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6 Appendix

6.1 Life Cycle Assessment (LCA) Methodology

The life cycle assessment (LCA) – sometimes also called ecobalance – is a method to assess the environmental impacts of a product[12]. The LCA is based on a perspective encompassing the whole life cycle. Hence, the environmental impacts of a product are evaluated from cradle to grave, which means from the resource extraction up to the disposal of the product and also the production wastes.

The International Organization for Standardization (ISO) has standardised the general procedure of conducting an LCA in ISO 14040 (International Organization for Standardization (ISO) 2006a) and ISO 14044 (International Organization for Standardization (ISO) 2006b).

A LCA consists of four phases (Fig. 6.1):

- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment
- Interpretation

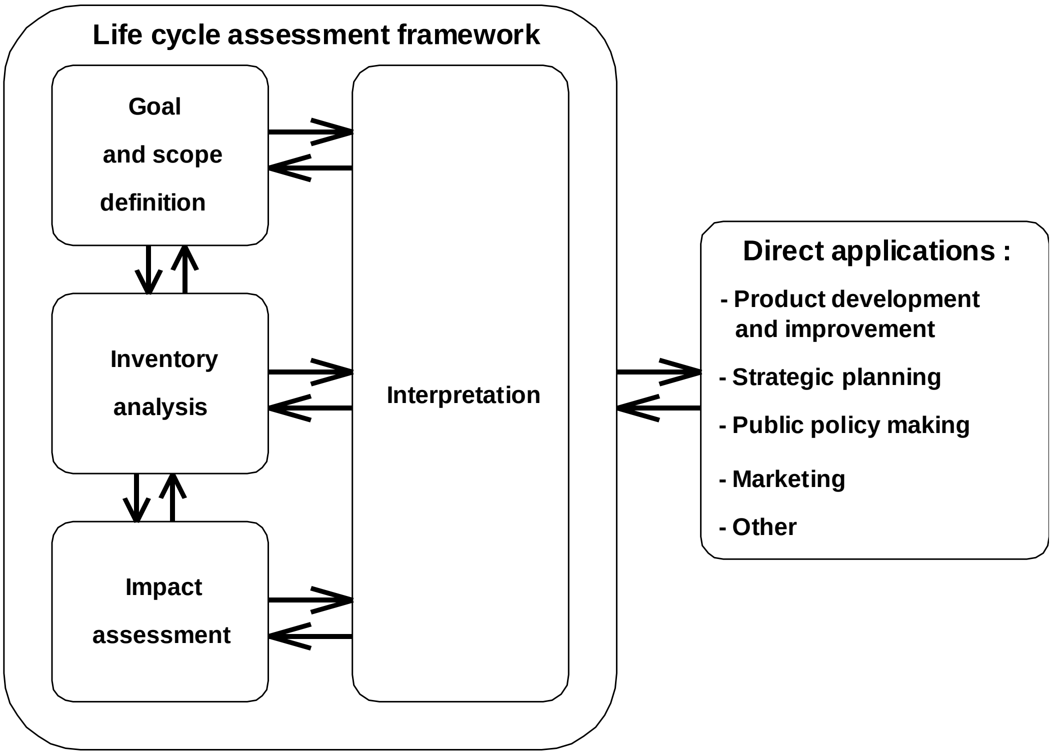

Fig. 6.1 Components of a life cycle assessment (LCA) according to the International Organization for Standardization

The *Goal Definition* (phase 1) covers the description of the object of investigation. The environmental aspects to be considered in the interpretation are also defined here. The *Scope Definition* includes the way of modelling the object of investigation, the identification as well as the description of the pro-

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[12] The term product also encompasses services

cesses of importance towards the object of investigation. The functional unit, which determines the base for the comparison, is defined here.

The direct environmental impacts[13], the amount of semi-finished products, auxiliary materials and energy of the processes involved in the life cycle are determined and inventoried in the *Inventory Analysis* (phase 2). This data is set in relation to the object of investigation, i.e. the functional unit. The final outcome consists of the cumulative resource demands and emissions of pollutants.

The Inventory Analysis provides the basis for the *Impact Assessment* (phase 3). The application of current valuation methods, e.g. eco-indicator, ecological scarcity or CML, to the inventory results in indicator values that are used and referred to in the interpretation.

The results of the inventory analysis and the impact assessment are analysed and commented in the *Interpretation* (phase 4) according to the initially defined goal and scope of the LCA. Final conclusions are drawn and recommendations stated.

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[13] Resource extraction and emission of pollutants

6.2 Detailed Results

Tab. 6.1 Contribution of the material and energy flows to the total environmental impacts of a µC-Si solar module

Category	Material-/Energy flow	Climate change	Freshwater eutrophication	Human toxicity	Ozone depletion	Photochemical oxidant formation	Terrestrial acidification	Ecological Scarcity	CED (non-renewable fossil)
CDA	CDA	0.103%	0.426%	0.230%	0.277%	0.050%	0.052%	0.109%	0.208%
Chemicals	Silver	0.018%	0.746%	1040%	0.028%	0.050%	0.049%	0.268%	0.025%
	Bisphenol	0.001%	0.000%	0.000%	0.001%	0.000%	0.000%	0.001%	0.001%
	Adhesive	0.017%	0.004%	0.008%	0.013%	0.026%	0.014%	0.022%	0.032%
	Silicone	0.048%	0.045%	0.033%	3.638%	0.035%	0.023%	0.050%	0.103%
Detergent	Detergent	0.066%	0.190%	0.154%	0.406%	0.049%	0.038%	0.090%	0.112%
Disposal	Disposal, solvents	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	Disposal, glass	0.345%	0.153%	0.643%	1519%	2.007%	0.620%	7.075%	0.653%
	Disposal, rubber	0.001%	0.000%	0.000%	0.000%	0.000%	0.000%	0.001%	0.000%
Electricity	Electricity	52.738%	32.273%	29.585%	7.797%	49.220%	65.107%	47.470%	46.558%
Foil	Ethylvinylacetat	1274%	1572%	0.960%	2.439%	0.934%	0.489%	1080%	4.060%
Gases	Nitrogen	2.164%	8.491%	4.009%	5.867%	1035%	1053%	2.158%	4.408%
	Phosphane	0.000%	0.012%	0.001%	0.001%	0.000%	0.000%	0.003%	0.001%
	Hydrogen	0.060%	0.009%	0.007%	0.006%	0.041%	0.017%	0.039%	0.234%
	Silane	0.743%	1464%	0.707%	3.583%	0.349%	0.276%	0.578%	1450%
	Trimethyl borate	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
	Carbon dioxide	0.002%	0.002%	0.002%	0.005%	0.001%	0.000%	0.002%	0.002%
	Nitrogen trifluoride	15.576%	9.393%	4.822%	6.735%	1512%	2.473%	5.425%	4.969%
	Argon	0.007%	0.026%	0.012%	0.018%	0.003%	0.003%	0.007%	0.014%
	Oxygen	0.110%	0.433%	0.204%	0.299%	0.053%	0.054%	0.110%	0.225%
	DEZ	0.080%	0.055%	0.039%	0.329%	0.062%	0.033%	0.092%	0.252%
	Diborane	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
Glas	Glas	15.554%	8.949%	6.597%	48.017%	21785%	19.062%	15.561%	19.074%
Infrastructure	Factory	0.049%	0.433%	0.617%	0.120%	0.055%	0.058%	0.147%	0.078%
	Equipment	0.099%	0.773%	1033%	0.332%	0.084%	0.085%	0.267%	0.155%
Manufacturing	Modul	0.283%	0.258%	0.002%	0.000%	0.269%	0.055%	1726%	0.000%
Materials	Cable	0.520%	28.079%	41861%	0.710%	1235%	2.074%	6.162%	1354%
	Copper	0.018%	2.441%	3.660%	0.042%	0.080%	0.169%	0.514%	0.030%
	Wire drawing	0.004%	0.106%	0.150%	0.013%	0.007%	0.008%	0.028%	0.008%
	Injection moulding	0.015%	0.034%	0.017%	0.602%	0.008%	0.006%	0.014%	0.029%
	Polyethlyene	0.022%	0.001%	0.001%	0.000%	0.024%	0.010%	0.016%	0.082%
Natural gas	Natural gas	0.055%	0.006%	0.006%	3.240%	0.059%	0.028%	0.059%	0.515%
Transport	Transport, lorry, small	9.313%	3.098%	3.146%	10.741%	19.056%	7.085%	9.927%	14.255%
	Transport, lorry, big	0.359%	0.118%	0.123%	0.905%	0.895%	0.294%	0.411%	0.557%
	Transport, ship	0.245%	0.154%	0.093%	0.209%	0.944%	0.716%	0.429%	0.356%
Waste water	Waste water	0.044%	0.036%	0.060%	0.049%	0.032%	0.015%	0.054%	0.049%
Water	Demineralized water	0.000%	0.000%	0.001%	0.001%	0.000%	0.000%	0.005%	0.000%
	Deionised water	0.065%	0.217%	0.179%	2.058%	0.042%	0.034%	0.099%	0.150%
	Total	133.31	0.0280	39.60	0.000	0.54	0.937	128'443	1'446
	Unit/module	kg CO2 eq	kg P eq	kg 1,4-DB eq	mg CFC-11eq	kg NMVOC	kg SO2 eq	ecopoints	MJ-eq

6.3 Unit Process Raw Data

How to read the tables:

The **light yellow fields** describe the name of the product/process, its region (e.g. RER stands for Europe) and the unit data it refers to. It is the output product (the reference output) of the process and always equal to '1'. The **blue fields** show the inputs and outputs of the respective processes. The **grey fields** specify whether it is an input from or an output to nature or technosphere and the compartment to which a pollutant is emitted. For each product, additional descriptive information is given in separate tables.

The location codes (an extended ISO alpha-2 code-set) have the following meaning:

GLO	Global
RER	Europe
ES	Spain
CH	Switzerland

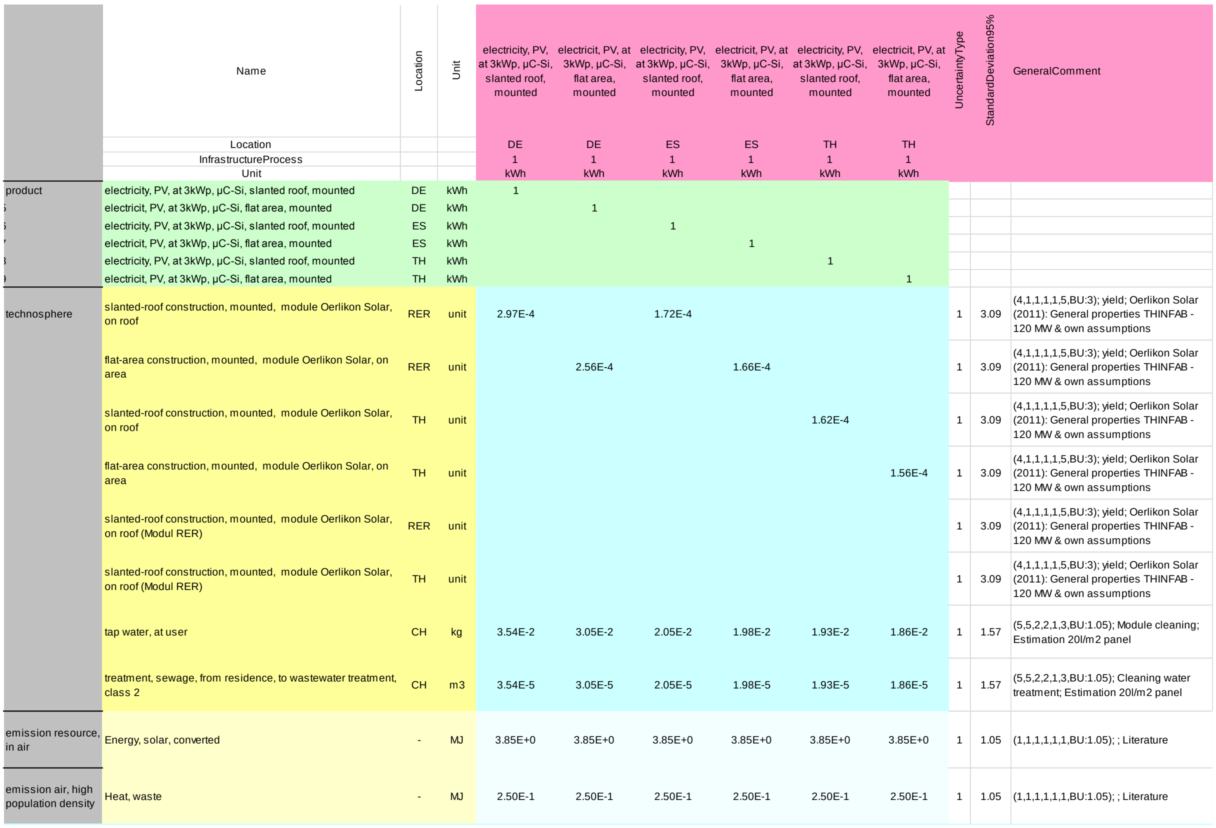
Tab. 6.2 Unit process raw data of the production of 1 µC-Si solar module (143 W_p, 1.4 m^2).

	Name	Location	Unit	photovoltaic module, µC-Si, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CN			
	InfrastructureProcess			1			
	Unit			unit			
	photovoltaic module, µC-Si, at plant	CN	unit	1			
	photovoltaic module, µC-Si, at plant	RER	unit				
technosphere	solar glass, low-iron, at regional storage	RER	kg	1.92E+1	1	1.30	(4,1,1,1,1,5,BU:1.05); Front- and Back-Glass, incl. wastes; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	silver, at regional storage	RER	kg	2.35E-4	1	1.30	(4,1,1,1,1,5,BU:1.05); Contacting Glue; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	bisphenol A, powder, at plant	RER	kg	1.57E-4	1	1.30	(4,1,1,1,1,5,BU:1.05); Contacting Glue; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	cable, three-conductor cable, at plant	GLO	m	2.90E-1	1	1.30	(4,1,1,1,1,5,BU:1.05); Junction Box; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	copper, at regional storage	RER	kg	1.30E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Solder Strings Long & Cross contacting ribbon & Junction Box; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	wire drawing, copper	RER	kg	1.30E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Solder Strings Long & Cross contacting ribbon & Junction Box; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	adhesive for metals, at plant	DE	kg	5.15E-3	1	1.30	(4,1,1,1,1,5,BU:1.05); Fixation pad for solder strings long & Glue pad; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	ethylvinylacetate, foil, at plant	RER	kg	6.46E-1	1	1.30	(4,1,1,1,1,5,BU:1.05); Encapsulation; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	polyethylene, HDPE, granulate, at plant	RER	kg	1.54E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Junction Box; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	injection moulding	RER	kg	1.54E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Junction Box; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	silicone product, at plant	RER	kg	2.40E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Silicon pottant & sealant; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	zeolite, slurry, 50% in H2O, at plant	RER	kg	4.64E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Detergent; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	electricity, high voltage, at grid	CN	kWh	6.13E+1	1	1.30	(4,1,1,1,1,5,BU:1.05); Electricity (equipment & operation of the facility); Oerlikon Solar (2011): General properties THINFAB - 120 MW
	compressed air, average generation, >30kW, 7 bar gauge, at compressor	RER	m3	1.76E+0	1	1.30	(4,1,1,1,1,5,BU:1.05); compressed dried air (CDA); Oerlikon Solar (2011): General properties THINFAB - 120 MW
	water, decarbonised, at plant	RER	kg	6.25E+1	1	1.30	(4,1,1,1,1,5,BU:1.05); Water demineralised; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	water, deionised, at plant	CH	kg	1.18E+2	1	1.30	(4,1,1,1,1,5,BU:1.05); Water deionised; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	nitrogen, liquid, at plant	RER	kg	7.30E+0	1	1.30	(4,1,1,1,1,5,BU:1.05); Nitrogen, technical & process; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	silane, at plant	RER	kg	3.03E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Silane; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	hydrogen, liquid, at plant	RER	kg	4.85E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Hydrogen; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	phosphane, at plant	GLO	kg	3.36E-5	1	1.30	(4,1,1,1,1,5,BU:1.05); Phosphine; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	trimethyl borate, at plant	GLO	kg	1.19E-5	1	1.30	(4,1,1,1,1,5,BU:1.05); Trimethylboron 2% in Hydrogen; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	carbon dioxide liquid, at plant	RER	kg	2.73E-3	1	1.30	(4,1,1,1,1,5,BU:1.05); Carbon dioxide; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	nitrogen trifluoride, at plant	RER	kg	8.46E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Hydrogen trifluoride; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	argon, liquid, at plant	RER	kg	3.16E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Argon; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	diborane, at plant	GLO	kg	2.44E-5	1	1.30	(4,1,1,1,1,5,BU:1.05); Diborane - 2% in Hydrogen; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	oxygen, liquid, at plant	RER	kg	3.94E-1	1	1.30	(4,1,1,1,1,5,BU:1.05); Oxygen Technical; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	natural gas, high pressure, at consumer	CH	MJ	6.27E+0	1	1.30	(4,1,1,1,1,5,BU:1.05); Natural gas; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	chemicals organic, at plant	GLO	kg	5.67E-2	1	1.30	(4,1,1,1,1,5,BU:1.05); Diethylzinc (DEZ); Oerlikon Solar (2011): General properties THINFAB - 120 MW
	treatment, sewage, unpolluted, from residence, to wastewater treatment, class 2	CH	m3	1.80E-1	1	1.30	(4,1,1,1,1,5,BU:1.05); Waste water flow (substances specified separately); Oerlikon Solar (2011): General properties THINFAB - 120 MW
	disposal, solvents mixture, 16.5% water, to hazardous waste incineration	CH	kg	8.66E-5	1	1.30	(4,1,1,1,1,5,BU:1.05); Solvent mixture from EVA foil; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	disposal, glass, 0% water, to municipal incineration	CH	kg	1.90E+1	1	1.30	(4,1,1,1,1,5,BU:1.05); Waste glasses, laminated (disposal / incineration / reuse as fibre glass / recycling) & disposal of the module at the end of its lifetime; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	disposal, rubber, unspecified, 0% water, to municipal incineration	CH	kg	5.94E-4	1	1.30	(4,1,1,1,1,5,BU:1.05); Hotmelt (synthetic rubber, no hazardous component); Oerlikon Solar (2011): General properties THINFAB - 120 MW
	transport, lorry 16-32t, EURO3	RER	tkm	6.91E+1	1	2.09	(4,5,na,na,na,na,BU:2); Waste glass and waste foil, returned to supplier & waste glass to recycling; own assumption
	transport, lorry 20-28t, fleet average	CH	tkm	2.49E+0	1	2.09	(4,5,na,na,na,na,BU:2); Transport of the materials and consumables; own assumption
	transport, transoceanic freight ship	OCE	tkm	3.11E+1	1	2.09	(4,5,na,na,na,na,BU:2); Shipping of the equipment from Europe to China; own assumption
	solar collector factory	RER	unit	4.01E-8	1	3.14	(4,1,1,1,3,5,BU:3); Infrastructure building, incl. land use; Oerlikon Solar (2011): General properties THINFAB - 120 MW; extrapolated based on assumptions
	metal working machine, unspecified, at plant	RER	kg	3.11E-2	1	3.14	(4,1,1,1,3,5,BU:3); Infrastructure machines; Oerlikon Solar (2011): General properties THINFAB - 120 MW
resource, in water	Water, unspecified natural origin, CN	-	m3	3.83E+0	1	1.30	(4,1,1,1,1,5,BU:1.05); Cooling water (chilled and tempered); Oerlikon Solar (2011): General properties THINFAB - 120 MW
emission air, high population density	Hydrogen fluoride	-	kg	1.78E-7	1	1.62	(4,1,1,1,1,5,BU:1.5); HF / F-; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Particulates, > 10 um	-	kg	4.24E-6	1	1.62	(4,1,1,1,1,5,BU:1.5); Dust (SiO2, ZnO); Oerlikon Solar (2011): General properties THINFAB - 120 MW
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	kg	5.43E-4	1	1.62	(4,1,1,1,1,5,BU:1.5); Volatile organic compounds (VOC); Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Nitrogen oxides	-	kg	9.16E-4	1	1.62	(4,1,1,1,1,5,BU:1.5); NOx; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Carbon monoxide, fossil	-	kg	1.55E-4	1	5.10	(4,1,1,1,1,5,BU:5); CO; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Carbon dioxide, fossil	-	kg	3.50E-1	1	1.62	(4,1,1,1,4,5,BU:1.05); CO2; assumption
	Nitrogen fluoride	-	kg	1.55E-6	1	1.62	(4,1,1,1,1,5,BU:1.5); NF3; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Heat, waste	-	MJ	5.85E+1	1	1.30	(4,1,1,1,1,5,BU:1.05); Waste heat; Oerlikon Solar (2011): General properties THINFAB - 120 MW
emission air, unspecified	Water, CN	-	kg	1.91E+2	1	1.62	(4,1,1,1,1,5,BU:1.5); Evaporated water; assumption
emission water, unspecified	Suspended solids, unspecified	-	kg	3.25E-2	1	1.62	(4,1,1,1,1,5,BU:1.5); Total suspended solids (TSS); Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Water	-	kg	3.64E+3	1	1.62	(4,1,1,1,1,5,BU:1.5); Cooling water Released ; Assumption
	Fluoride	-	kg	2.71E-3	1	1.62	(4,1,1,1,1,5,BU:1.5); Fluoride, after on-site waste water treatment; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	COD, Chemical Oxygen Demand	-	kg	8.53E-3	1	1.62	(4,1,1,1,1,5,BU:1.5); COD, after on-site waste water treatment; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Phosphorus	-	kg	7.22E-5	1	1.62	(4,1,1,1,1,5,BU:1.5); Phosphorus, after on-site waste water treatment; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Nitrogen	-	kg	2.89E-4	1	1.62	(4,1,1,1,1,5,BU:1.5); Nitrogen, after on-site waste water treatment; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Boron	-	kg	3.61E-5	1	5.10	(4,1,1,1,1,5,BU:5); Boron, after on-site waste water treatment; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Zinc, ion	-	kg	1.80E-5	1	5.10	(4,1,1,1,1,5,BU:5); Zinc, after on-site waste water treatment; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Chloride	-	kg	2.48E-1	1	3.09	(4,1,1,1,1,5,BU:3); Chloride, after on-site waste water treatment; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	Calcium, ion	-	kg	1.26E-4	1	3.09	(4,1,1,1,1,5,BU:3); Calcium, after on-site waste water treatment; Oerlikon Solar (2011): General properties THINFAB - 120 MW

Tab. 6.3 Unit process raw data of the installation of 1 µC-Si solar module (143 W_p, 1.4 m^2).

	Name	Location	InfrastructureProcess	Unit	slanted-roof construction, mounted, module Oerlikon Solar, on roof	flat-area construction, mounted, module Oerlikon Solar, on area	slanted-roof construction, mounted, module Oerlikon Solar, on roof	flat-area construction, mounted, module Oerlikon Solar, on area	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	TH	TH			
	InfrastructureProcess				1	1	1	1			
	Unit				unit	unit	unit	unit			
product	slanted-roof construction, mounted, module Oerlikon Solar, on roof	RER	1	unit	1						
	flat-area construction, mounted, module Oerlikon Solar, on area	RER	1	unit		1					
	slanted-roof construction, mounted, module Oerlikon Solar, on roof	TH	1	unit			1				
	flat-area construction, mounted, module Oerlikon Solar, on area	TH	1	unit				1			
technosphere	photovoltaic module, µC-Si, at plant	CN	1	unit	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	3.02	(2,1,1,1,1,4,BU:3); Module; Oerlikon Solar (2011): General properties THINFAB - 120 MW
	electric installation, photovoltaic plant, at plant	CH	1	unit	4.77E-2	4.77E-2	4.77E-2	4.77E-2	1	3.08	(3,4,3,1,1,5,BU:3); cabling, lightning protection and fuse box; Literature
	aluminium, production mix, at plant	RER	0	kg	3.81E+0	9.32E+0	3.81E+0	9.32E+0	1	1.12	(2,1,1,1,1,4,BU:1.05); Frame and clips; Oerlikon Solar (2011): Recommendation to customer
	adhesive for metals, at plant	DE	0	kg	2.65E-4	2.65E-4	2.65E-4	2.65E-4	1	1.12	(2,1,1,1,1,4,BU:1.05); Adhesive for clips on frame; Oerlikon Solar (2011): Recommendation to customer
	inverter, 2500W, at plant	RER	1	unit	1.14E-1	1.14E-1	1.14E-1	1.14E-1	1	3.02	(2,4,1,1,1,na,BU:3); Inverter; Literature, 1 repair in the life time
	electricity, low voltage, production RER, at grid	RER	0	kWh	5.72E-2	5.72E-2			1	1.28	(3,4,3,1,1,5,BU:1.05); Energy for mounting; Energy use for erection of 3kWp plant
	electricity, low voltage, at grid	CN	0	kWh			5.72E-2	5.72E-2	1	1.28	(3,4,3,1,1,5,BU:1.05); Energy for mounting; Energy use for erection of 3kWp plant
	transport, lorry 20-28t, fleet average	CH	0	tkm	6.00E+0	7.10E+0	1.80E+1	2.13E+1	1	2.09	(4,5,na,na,na,na,BU:2); Transport of module and material; Assumption
	transport, freight, rail	CH	0	tkm	1.20E+1	1.42E+1	0	0	1	2.09	(4,5,na,na,na,na,BU:2); Transport of module and material; Assumption
	transport, transoceanic freight ship	OCE	0	tkm	2.41E+2	2.41E+2	3.01E+1	3.01E+1	1	2.09	(4,5,na,na,na,na,BU:2); Transport of module; Assumption

Tab. 6.4 Unit process raw data of 1 kWh electricity produced with a µC-Si solar power plant, 3kW$_p$.



	Name	Location	Unit	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	electricit, PV, at 3kWp, µC-Si, flat area, mounted	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	electricit, PV, at 3kWp, µC-Si, flat area, mounted	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	electricit, PV, at 3kWp, µC-Si, flat area, mounted	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			DE	DE	ES	ES	TH	TH			
	InfrastructureProcess			1	1	1	1	1	1			
	Unit			kWh	kWh	kWh	kWh	kWh	kWh			
product	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	DE	kWh	1								
	electricit, PV, at 3kWp, µC-Si, flat area, mounted	DE	kWh		1							
	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	ES	kWh			1						
	electricit, PV, at 3kWp, µC-Si, flat area, mounted	ES	kWh				1					
	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	TH	kWh					1				
	electricit, PV, at 3kWp, µC-Si, flat area, mounted	TH	kWh						1			
technosphere	slanted-roof construction, mounted, module Oerlikon Solar, on roof	RER	unit	2.97E-4		1.72E-4				1	3.09	(4,1,1,1,1,5,BU:3); yield; Oerlikon Solar (2011): General properties THINFAB - 120 MW & own assumptions
	flat-area construction, mounted, module Oerlikon Solar, on area	RER	unit		2.56E-4		1.66E-4			1	3.09	(4,1,1,1,1,5,BU:3); yield; Oerlikon Solar (2011): General properties THINFAB - 120 MW & own assumptions
	slanted-roof construction, mounted, module Oerlikon Solar, on roof	TH	unit					1.62E-4		1	3.09	(4,1,1,1,1,5,BU:3); yield; Oerlikon Solar (2011): General properties THINFAB - 120 MW & own assumptions
	flat-area construction, mounted, module Oerlikon Solar, on area	TH	unit						1.56E-4	1	3.09	(4,1,1,1,1,5,BU:3); yield; Oerlikon Solar (2011): General properties THINFAB - 120 MW & own assumptions
	slanted-roof construction, mounted, module Oerlikon Solar, on roof (Modul RER)	RER	unit							1	3.09	(4,1,1,1,1,5,BU:3); yield; Oerlikon Solar (2011): General properties THINFAB - 120 MW & own assumptions
	slanted-roof construction, mounted, module Oerlikon Solar, on roof (Modul RER)	TH	unit							1	3.09	(4,1,1,1,1,5,BU:3); yield; Oerlikon Solar (2011): General properties THINFAB - 120 MW & own assumptions
	tap water, at user	CH	kg	3.54E-2	3.05E-2	2.05E-2	1.98E-2	1.93E-2	1.86E-2	1	1.57	(5,5,2,2,1,3,BU:1.05); Module cleaning; Estimation 20l/m2 panel
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	m3	3.54E-5	3.05E-5	2.05E-5	1.98E-5	1.93E-5	1.86E-5	1	1.57	(5,5,2,2,1,3,BU:1.05); Cleaning water treatment; Estimation 20l/m2 panel
emission resource, in air	Energy, solar, converted	-	MJ	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); ; Literature
emission air, high population density	Heat, waste	-	MJ	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ; Literature

Tab. 6.5 EcoSpold MetaInformation

photovoltaic module, µC-Si, at plant	slanted-roof construction, mounted, module Oerlikon Solar, on roof	flat-area construction, mounted, module Oerlikon Solar, on area	slanted-roof construction, mounted, module Oerlikon Solar, on roof	flat-area construction, mounted, module Oerlikon Solar, on area	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	electricit, PV, at 3kWp, µC-Si, flat area, mounted	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	electricit, PV, at 3kWp, µC-Si, flat area, mounted	electricity, PV, at 3kWp, µC-Si, slanted roof, mounted	electricit, PV, at 3kWp, µC-Si, flat area, mounted
CN	RER	RER	TH	TH	DE	DE	ES	ES	TH	TH
1	1	1	1	1	1	1	1	1	1	1
unit	unit	unit	unit	unit	kWh	kWh	kWh	kWh	kWh	kWh
This dataset includes the most important materials, energy flows and emissions of the manufacturing of one thin-film module in Oerlikon Solar's "ThinFab". Furthermore it includes the infrastructure of the facility and the transport of the materials.	This dataset includes the most important material consumption as well as the energy needed for the installation of a module. Furthermore it includes the transport of the material as well as of the module to the construction site.	This dataset includes the most important material consumption as well as the energy needed for the installation of a module. Furthermore it includes the transport of the material as well as of the module to the construction site.	This dataset includes the most important material consumption as well as the energy needed for the installation of a module. Furthermore it includes the transport of the material as well as of the module to the construction site.	This dataset includes the most important material consumption as well as the energy needed for the installation of a module. Furthermore it includes the transport of the material as well as of the module to the construction site.	The dataset includes the electricity production by an a-Si thin-film PV power plant mounted on a slanted roof in Germany.	The dataset includes the electricity production by an a-Si thin-film PV power plant mounted on a flat area in Germany.	The dataset includes the electricity production by an a-Si thin-film PV power plant mounted on a slanted roof in Spain.	The dataset includes the electricity production by an a-Si thin-film PV power plant mounted on a flat area in Spain.	The dataset includes the electricity production by an a-Si thin-film PV power plant mounted on a slanted roof in Thailand.	The dataset includes the electricity production by an a-Si thin-film PV power plant mounted on a flat area in Thailand.
Solarmodule, PV, µC-Si	Schrägdachkonstruktion, aufgesetzt, Modul Oerlikon Solar, auf Dach	Konstruktion auf Fläche, aufgesetzt, Modul Oerlikon Solar, auf Fläche	Schrägdachkonstruktion, aufgesetzt, Modul Oerlikon Solar, auf Dach	Konstruktion auf Fläche, aufgesetzt, Modul Oerlikon Solar, auf Fläche	Strom, Photovoltaik, ab 3kWp, µC-Si, Schrägdach, aufgesetzt	Strom, Photovoltaik, ab 3kWp, µC-Si, Fläche, aufgesetzt	Strom, Photovoltaik, ab 3kWp, µC-Si, Schrägdach, aufgesetzt	Strom, Photovoltaik, ab 3kWp, µC-Si, Fläche, aufgesetzt	Strom, Photovoltaik, ab 3kWp, µC-Si, Schrägdach, aufgesetzt	Strom, Photovoltaik, ab 3kWp, µC-Si, Fläche, aufgesetzt
	0	0	0	0	0	0	0	0	0	0
Characteristics of the module: area: 1.4m2, expected lifespan: 30 years, capacity: 142Wp, efficiency 10%	This dataset refers to the installation of 1 module. Area of one module: 1.4m2. Expected lifespan: 30 years.	This dataset refers to the installation of 1 module. Area of one module: 1.4m2. Expected lifespan: 30 years.	This dataset refers to the installation of 1 module. Area of one module: 1.4m2. Expected lifespan: 30 years.	This dataset refers to the installation of 1 module. Area of one module: 1.4m2. Expected lifespan: 30 years.	744kWh/kWp; Capacity: 143Wp/module. Module efficiency 10%. Expected lifespan: 30 years.	862kWh/kWp; Capacity: 143Wp/module. Module efficiency 10%. Expected lifespan: 30 years.	1282kWh/kWp; Capacity: 143Wp/module. Module efficiency 10%. Expected lifespan: 30 years.	1328kWh/kWp; Capacity: 143Wp/module. Module efficiency 10%. Expected lifespan: 30 years.	1263kWh/kWp; Capacity: 143Wp/module. Module efficiency 10%. Expected lifespan: 30 years.	1385kWh/kWp; Capacity: 143Wp/module. Module efficiency 10%. Expected lifespan: 30 years.
1	1	1	1	1	1	1	1	1	1	1
photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic
production of components	production of components	production of components	production of components	production of components	power plants	power plants	power plants	power plants	power plants	power plants
Photovoltaik	Photovoltaik	Photovoltaik	Photovoltaik	Photovoltaik	Photovoltaik	Photovoltaik	Photovoltaik	Photovoltaik	Photovoltaik	Photovoltaik
Herstellung Komponenten	Herstellung Komponenten	Herstellung Komponenten	Herstellung Komponenten	Herstellung Komponenten	Kraftwerke	Kraftwerke	Kraftwerke	Kraftwerke	Kraftwerke	Kraftwerke
2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
1	1	1	1	1	1	1	1	1	1	1
China	Europe	Europe	Thailand	Thailand	Germany	Germany	Spain	Spain	Thailand	Thailand
Thin Film a-Si Solar Module	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame	Thin Film Silicon Solar Module on aluminium frame
100	100	100	100	100	100	100	100	100	100	100
120MW	120MW	120MW	120MW	120MW	744kWh/kWp	862kWh/kWp	1282kWh/kWp	1328kWh/kWp	1362kWh/kWp	1411kWh/kWp
Planning data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar	Data provided by Oerlikon Solar
none	none	none	none	none	none	none	none	none	none	none
none	none	none	none	none	none	none	none	none	none	none
31.10.2011	31.10.2011	31.10.2011	31.10.2011	31.10.2011	31.10.2011	31.10.2011	31.10.2011	31.10.2011	31.10.2011	31.10.2011
\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_Oerlikon Solar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process	\\Server\e\ESU-Docs\Projekte laufend\174 Photovoltaic, IEA Task 12\DatenErgebnisse\Oerlikon Solar\EcoSpold\[174_OerlikonSolar_EcoSpold_v0.7.xlsx]X-Process