Life Cycle Assessment of Flexcell Amorphous Silicon Modules

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Abbreviations and Glossary

a	annum (year)
a-Si	amorphous silicon
CdTe	cadmium telluride
CED	cumulative energy demand
CIS	copper indium selenide
CH	Switzerland
ES	Spain
ETFE	ethylene tetrafluoroethylene
EVA	ethylene-vinyl acetate
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
NMVOC	non-methane volatile organic compounds
ODP	ozone depletion potential
RER	Europe
TPO	thermoplastic polyolefin

Contents

1 Introduction

1.1 Background

The Swiss company VHF-Technologies SA, better known under the brand name Flexcell, was founded in 2000 at the Ecole d'Ingénieurs du Canton de Neuchâtel (EICN) in Le Locle. The aim was to create an industrial process for a technique for applying amorphous silicon by very high frequency (VHF) plasma deposition, developed at the Institute of Microtechnology (IMT) of the University of Neuchâtel.

Flexcell's technology makes it possible to use a thin, flexible plastic substrate instead of glass. In comparison with the production of traditional crystalline modules, the technology requires 300 times less semiconductor raw materials, resulting in high production volumes and low energy consumption. Owing to its highly flexible PV foil, Flexcell is to provide integration solutions for the building industry (Building Integrated Photovoltaics).[1]

Life cycle assessment (LCA) is an environmental management tool for analysing, comparing and improving the environmental performance of products or technologies. Within this project a life cycle assessment of the electricity generated with photovoltaic power plants using amorphous silicon modules produced by Flexcell is conducted and compared to other 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.

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 life cycle inventory data from the module production from March to October 2010. The data are collected and provided by Flexcell.

The goal of the life cycle assessment is to evaluate the environmental impacts caused by the production and operation of amorphous silicon modules produced by Flexcell. A special focus is laid on the carbon footprint of the modules as well as of the electricity from photovoltaic power plants composed of Flexcell modules. 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 Flexcell modules are evaluated per square meter. 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 (ecoinvent Centre 2010; Jungbluth et al. 2012; LC-inventories 2012).

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[1] Retrieved from http://www.flexcell.com/index.php?option=com_content&task=view&id=12&Itemid=51(access on 17.01.2011)

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. CML 2001
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. plastic 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 CML 2001.

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 Impacts According to CML 2001

The Dutch Institute of Environmental Sciences (CML) at Leiden University developed the CML method. This method uses a problem-oriented (mid-point) approach to assess the environmental impacts within LCA. The effect of a substance is determined relative to a reference substance. To determine these relations, often complex modelling is used. When it comes to modelling human or ecotoxicity, these models still contain large uncertainties. CML is a method assessing explicitly the effects on the environment and on living species (toxicity).

The current edition - including the latest updates from February 2008 – is used in its baseline specification (Guinée et al. 2001a; b). However, the following two indicators are not used due to known flaws:

- marine aquatic toxicity[2]
- terrestrial ecotoxicity[3]

The following eight CML indicators are calculated (the reference substance is indicated in brackets)*:*

- abiotic depletion (kg Sb eq.) – based on ultimate reserves and extraction
- ozone layer depletion (ODP) (kg CFC-11 eq.) – ODP with infinite time integration
- human toxicity (kg 1,4-DB eq.) – toxicity potential with 500a time integration
- fresh water aquatic ecotoxicity (kg 1,4-DB eq.) – toxicity potential with 500a time integration
- photochemical oxidation (kg ethene eq.) – high NO_x POCP
- acidification (kg SO_2 eq.) – average European acidification potential
- eutrophication (kg PO_4^{3-} eq.) – generic eutrophication potential

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. 2004).

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 substances. 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, noise).

1.3.5 Selection of the Principal Impact Assessment Indicators

The environmental impacts of photovoltaic electricity from Flexcell modules are expressed by 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:

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2 There are known flaws in the impact assessment method (see Frischknecht et al. 2007b)

3 There are contradicting literature sources concerning Cr (VI) emissions from wooden poles of the electricity transmission network, which leads to Cr (VI) soil emissions dominating this indicator and, hence, leading to results without informative value.

- CED, non-renewable (MJ-eq.)
- Global warming (kg CO_2 eq.)
- Ozone layer depletion (ODP) (kg CFC-11 eq.)
- Human toxicity (kg 1,4-DB eq.)
- Acidification (kg SO_2 eq.)
- Eutrophication (kg PO_4- eq.)
- Photochemical oxidation (kg ethene eq)
- Ecological Scarcity 2006, aggregated single score

The remaining indicators (renewable CED, abiotic depletion, and freshwater aquatic toxicity) 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

Foreground inventory data are mainly based on production data provided by Flexcell (VHF-Technologies SA). The primary source of background inventory data used in this study is the ecoinvent data v2.2 (ecoinvent Centre 2010) with corrections (LC-inventories 2012), which contains inventory data of many basic materials and services. The modelling and all calculations are performed with the LCA software SimaPro (PRé Consultants 2012).

Flexcell modules are designed as a roof membrane for flat roofs with an inclination of between 3° and 15°. The photovoltaic plant size is 50 kW_p on average and at least 20 kW_p.[4] However, in this project life cycle inventories of photovoltaic 3kWp flat roof installations with Flexcell modules and of 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 correlated equally with the photovoltaic plant size, the environmental impacts per kWh photovoltaic electricity are relatively independent from the plant size.

The unit process raw data as well as the EcoSpold MetaInformation are shown in Section 7.2 in the Appendix.

2.1 Photovoltaic Modules Production

2.1.1 Introduction

Flexcell produces photovoltaic thin film modules with a single junction technology that applies amorphous silicon onto a plastic substrate. The life cycle inventory is based on the product “Roofing membrane FLX-TO150”. The modules have a width of 1’320 mm, a length of 3’700 mm, and a thickness of 2.4 mm.

2.1.2 Production Volumes

Between January and October 2010, Flexcell produced modules with a total capacity of 2'008 kW_p, which equals a monthly output of 201 kW_p. However, the maximum capacity of the production facility is 830 kW_p per month or 10 MW_p per year. With few additional investments, the annual production capacity could be further increased to 20 MW_p.[5] In our analysis we consider the actual production volume in 2010 as well the module volume when producing with full capacity utilisation (10 MW_p) in a scenario.

2.1.3 Components and Materials

The type and amount of materials required for the production of the module components is presented in Tab. 2.1.

For the high purity aluminium, “aluminium, production mix, wrought alloy, at plant” is considered. The silver paste with a silver share of 70 % is considered as a low temperature lead-free photovoltaic conductive paste with a silver content of 80 % silver. For the lift-off ink 20 % carbon black and 80 % organic solvent is considered.

The thermoplastic olefins and the glass scrim are allocated to the roof of the buildings and are therefore not included in the inventory of the Flexcell modules.

[4] Personal communication with Diego Fischer, Chief Technology Officer Flexcell, on 17.02.2011

[5] Personal communication with Diego Fischer, Chief Technology Officer Flexcell, on 11.01.2011

For the tin plating of the copper components, the surface area of the copper components is calculated by adding up the total upper and lower surface of each copper component.

The polyurethane two component casting resin is taken into account with an ecoinvent dataset of polyurethane flexible foam.

Due to lack of specific data of polyphenylenoxide (PPO), the amount of the base plate for the junction box is considered with a generic dataset of organic chemicals.

The amounts of polyethylene naphthalate film, thermoplastic polyolefins, and polyethylene terephthalate film are considered to be shaped in a plastic extrusion process.

Currently, Flexcell modules have an ETFE layer of 0.1 mm thickness. Modules with 0.05 mm and 0.025 mm ETFE thickness are under development and are therefore evaluated in a scenario analysis.

Flexcell uses an ETFE foil with the product name Texlon®-System. For this product an environmental product declaration is available (BAFU 2009). Based on the declaration it is concluded that the production steps from chlorodifluoromethane to tetrafluoroethylene and finally to ETFE do not release any chlorinated or fluorinated carbons that have an effect on climate change or ozone layer depletion.

Tab. 2.1 Components and materials for the production of a Flexcell photovoltaic module of 4.88 m^2. Including production losses.

Component	Type	Weight used (g)
PEN film, extruded	Q83	319.99
Al target	high purity Al	1.97
Silane gas	60 bar	16.00
Hydrogen gas	200 bar	10.00
Diborane gas	200 bar	0.0030
Phosphine gas	200 bar	0.0010
Argon gas	200 bar	10.00
Liquid N2	liquid in tank	1500.00
ITO target	90% Indium/10% Tin	3.12
Ag paste	70% Ag content	17.78
Lift-off ink	Carbon black (20%)+ hydroxy carbitol (40%)+ solvant (40%)	11.11
ETFE	Norton C1S	663.10
EVA	Vistasolar 486.10	1872.27
EVA	Vistasolar 486.10	1123.36
TPO	Alkortop 35086-402	7503.77
TPO	00380001	1137.55
Glass scrim	Unknown	729.20
Copper - tinned - adhesive	PSA (9703)	91.05
Copper - tinned - non- adhesive	117582	4.48
Copper - tinned - non- adhesive	117582	4.48
Tape patch 2	Tape 3M 850;12mm	0.29
Junction Box	PV-JB/LC-2.5SOL/F1200D/KF	n.a.
PUR 2Comp. Casting resin A	RAKU 21-H64/16-4-15min potting life	13.09
PUR 2Comp. Casting resin B	RAKU 21-H64/43 B	2.61
Base plate for JB	PPO	6.32
Flexcell Marking / Label	PET Technifilm	0.45
Etiquette	article no.;date + TO	0.01
ETFE Protection diélectrique 1	Norton C2S;50µm	0.25
EVA Protection diélectrique 2	Vistasolar 486.10;300µm	0.84
ETFE Protection diélectrique 3	Norton C2S;50µm	0.77
EVA Protection diélectrique 4	Vistasolar 486.10;300µm	2.60
Packaging	Palette en bois	n.a.
Bande intercalaires	Plaques alvéolaire en carton	n.a.

2.1.4 Infrastructure

The infrastructure is considered with generic data of a photovoltaic module plant with a life time of 25 years and a generic annual production capacity of 10’000 modules.

2.1.5 Energy and Auxiliary Materials

The inventory covers the electricity consumption, the consumption of natural gas for heating and production energy, as well as water use. The electricity consumption is covered with 100 % hydro power from the European Union, which Flexcell purchases from the Service Industriel d'Yverdon.[6] We therefore consider the consumed electricity with an ecoinvent dataset of hydropower (from Norway).

Natural gas is considered to be burned in an industrial furnace (ecoinvent dataset of a boiler larger than 100kW). Since the data of natural gas consumption cover only the months from January to October 2010, the average natural gas consumption for heating is calculated by assuming that the consumed amount of natural gas in November and December is equal to the one in January and February. The amount of water used is considered to be discharged as sewage to a wastewater treatment plant class 3.

In a scenario, the consumption of electricity, natural gas, and tap water is considered when producing with full capacity utilisation. Since part of the consumption such as for example for heating is independent of the amount of modules produced, the total consumption per module is lower when producing with higher capacity utilisation.

Applying a regression on the monthly production and consumption data of the year 2010 results in the following equations:

$$(1) \quad E = 0.2906x + 209375$$

$$(2) \quad N_p = 0.0027x + 986.26$$

$$E = monthly\ electricity\ consumption\ (kWh)$$

$$x = monthly\ production\ volume\ (W_p)$$

$$N_p = monthly\ natural\ gas\ consumption\ for\ production\ processes\ (m^3)$$

The facility's total consumption of natural gas for heating and of water as well as the discharge of waste water is independent of the production volume. Since no reliable data of the natural gas consumption for the heating in 2010 are available, 2011 data are used and adjusted to an average climatic year based on local information about average heating degree days. In 2011, 66'051 m^3 or 2'708'000 MJ of natural gas was used. The year 2011 was significantly warmer in the Lake Neuchâtel area than an average year with 2'824 heating degree days compared to 3'157 heating degree days on average in Neuchâtel and Payerne. Hence the 2011 natural gas data were adjusted to an average year, resulting in an average consumption of 73'829 m^3 natural gas for heating per year.

The average module capacity in 2010 was 145 W_p.

Tab. 2.2 Consumption of electricity, natural gas, and water for the production of Flexcell modules.

	Unit	**Production in 2010**	**Full capacity utilisation**
Electricity	kWh/kW_p	1'433.1	541.9
Natural gas (heating)	MJ/kW_p	1'218.6	268.0
Natural gas (production processes)*	MJ/kW_p	293.4	141.0
Water consumption	m^3/kW_p	9.2	2.0

*2011 data used and adjusted to an average year

[6] Personal communication with Diego Fischer, Chief Technology Officer Flexcell, on 17.01.2011

For the Flexcell module production in 2010, 500 litres of solvents such as acetone, isopropanol, and ethylene glycol, were used.[7] We apply the average density (0.89 kg/litre) of these three substances (acetone 0.79 kg/litre, isopropanol 0.78 kg/litre, and ethylene glycol 1.11 kg/litre) which results in a solvent consumption of 5.5 g/m^2 module. This amount of solvent is added to the solvent consumption for the lift-off ink and it is considered with a generic ecoinvent dataset of organic solvents. We assume that 100 % of these solvents are emitted as non-methane volatile organic compounds (NMVOC) into air.

Atmospheric gas burners / scrubbers with an efficiency of more than 99 % are used to destroy the gaseous exhausts of the silicon deposition systems (SiH_4, H_2, B_2H_6 and PH_4). The mineral ashes (SiO_X) produced in the scrubbers are introduced in the city wastewater of the city of Yverdon. A major part is carried away (small particles), while larger particles are retained by sedimentation in a retention basin.

2.1.6 Transportation of Feedstock

Tab. 2.3 shows where the main feedstock components are produced and over which distance and with which transport mode they are delivered to the production facility in Yverdon-les-Bains in Switzerland.

The remaining components are considered with standard distance of 100 km by lorry and 600 km by rail as recommended by Frischknecht et al. (2007a) and also implemented by Jungbluth et al. (2010) for other photovoltaic technologies.

Tab. 2.3 Transport distances and transport modes of module feedstock.

Material	Route	Distance (km)	Transport mode
EVA	Dietenheim (DE) – Yverdon-les-Bains	450	Lorry
PEN	Japan – Rotterdam	20705	Freight ship
ETFE	USA – Rotterdam	6065	Freight ship
PEN, ETFE	Rotterdam - Yverdon-les-Bains	900	Lorry
Others	Standard distance	100	Lorry
Others	Standard distance	600	Rail

2.1.7 Recycling and Disposal of Modules

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

2.2 Photovoltaic Power Plants

In compliance with the ecoinvent quality guidelines, life cycle inventories of 3kW$_p$ photovoltaic power plants on flat roofs with Flexcell modules are set up.

Flexcell modules have a gross size of 4.88 m^2. Hence, for setting up a 3kWp photovoltaic power plant, 97.7 m^2 of 150 W modules are required. Furthermore, additional 3 % of modules are included due to reparations and rejects.

In 2011, Flexcell has launched also 160 W and 170 W modules with the same resource consumption as the 150 W modules.[8] Therefore, 3kWp installations operated with these modules are also included

[7] Personal communication with Diego Fischer, Chief Technology Officer Flexcell, on 17.01.2011

[8] Personal communication with Diego Fischer, Chief Technology Officer Flexcell, on 11.01.2011

in the analysis, considering that 91.6 m^2 of 160 W modules and 86.2 m^2 of 170 W modules are required.

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 are required during the life time of 30 years. Cabling and electric installations are included in compliance with the dataset established by Jungbluth et al. (2010).

The delivery of the different plant parts to the final construction place is modelled with 100 km by a delivery van. This includes the transport of the construction workers. The modules are considered to be transported by lorry over a distance of 100 km from the production facility to the point of sale in Switzerland.

In contrast to other photovoltaic technologies, Flexcell modules are not imported from abroad. However the feedstock materials are. The installation of Flexcell modules in photovoltaic power plants on buildings does not require any additional mounting system.

2.3 Electricity Generation

According to Flexcell, their modules produce more electricity per kWp than crystalline modules with the same orientation, whether they are inclined at 30°, on a flat roof or on a building facade. Their measurements at photovoltaic installations in north Switzerland with an inclination of 30° show a 7 % higher yield of modules from Flexcell compared to crystalline modules.[9]

The operation of the flat roof photovoltaic installation with Flexcell modules is considered to take place in a location in Switzerland with good conditions and an annual output of 1’050 $kWh/kW_{p.}$[10]

In a scenario, we consider the operation of the photovoltaic installation to take place in Spain. According to Jungbluth et al. (2010), the annual electricity yield of photovoltaic plants with crystalline silicon modules and optimum conditions is 922 kWh/kW_p in Switzerland and 1’394 kWh/kWp in Spain. With these data, the scaling of the electricity output of Flexcell modules in Switzerland to the situation in Spain results in an electricity yield of 1’588 kWh/kW_p.

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 (Jungbluth et al. 2010), the life time of the photovoltaic power plants is considered with 30 years.

The 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.

2.4 Other photovoltaic technologies

In order to compare Flexcell modules with other photovoltaic technologies, life cycle inventories of single-Si, multi-Si, a-si, CIS and CdTe modules are retrieved from Jungbluth et al. (2012).

9 Retrieved from http://flexcell.com/index.php?option=com_content&task=view&id=46&Itemid=42 (access on 17.01.2011)

10 Personal communication with Diego Fischer, Chief Technology Officer Flexcell, on 09.02.2011

3 Life Cycle Impact Assessment (LCIA)

In this Chapter the environmental impacts of Flexcell modules and of photovoltaic electricity from power plants operated with Flexcell 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.

3.1 Flexcell Module Production and Disposal

In Fig. 3.1 it is shown where the environmental impacts of the production and disposal of Flexcell modules stem from.

The non-renewable cumulative energy demand of the production and disposal of 1 m^2 Flexcell modules amounts to 186.1 MJ with important contributions from the production of EVA, ETFE and the consumption of natural gas. The result of photochemical oxidation is 2.4 g C_2H_4-eq./m^2 mainly caused by emissions of sulfur dioxide (52 %), carbon monoxide (13 %), and ethene (7 %) that occur in the production of the EVA, ETFE, infrastructure, and natural gas feedstock. Human toxicity impacts caused by the module production and disposal amount to 7.9 kg 1,4-DB eq./m^2. Emissions that contribute to this result are mainly arsenic and heavy metal emissions into air and water as well as emissions of polycyclic aromatic hydrocarbons in the feedstock of the various materials (29 % from the silver paste, 29 % from copper production).

The carbon footprint of Flexcell modules is 19.0 kg CO_2-eq. per square meter. Major contributions stem from the emissions of chlorofluorocarbons in the ETFE feedstock (52 %), the carbon dioxide emissions from the combustion of natural gas (23 %), and the disposal of the module in a municipal waste incineration (10 %). Eutrophication and acidification amount to 12.3 g PO_4^{3-}-eq./m^2 and 44.2 g SO_2-eq./m^2. The former indicator is dominated by the phosphate emissions into water and nitrogen oxide emissions into air, the latter is driven by sulfur dioxide, nitrogen oxide, and ammonia emissions into air. These emissions occur in many different steps of the life cycle of Flexcell modules and their feedstock materials. Depending on the indicator, the infrastructure has a share between 0 and 17 %. It contributes most (17 %) to the acidification as well as to the human toxicity and the photochemical oxidation (14 % and 15 % respectively). The disposal of modules and production wastes has a share of less than 11 % regarding all indicators.

The indicator of ozone layer depletion denotes an exception to the other indicators that are influenced by a range of components. The result of 0.4 g CFC-11 eq/m^2 module is completely driven by chlorofluorocarbon emissions in the ETFE production chain. ETFE also plays an important role for the other indicators with a share of between 6 % (eutrophication) and 52 % (climate change). Generally, the combustion of natural gas is important too with shares between 2 % (Eutrophication) and 29 % (CED, non-renewable). The contribution of the consumed electricity to all indicators is negligible, since the environmental impacts of hydropower are rather low.

The environmental impacts assessed with the Ecological Scarcity 2006 Method amount to 22'349 Ecopoints per square meter and have major contributions from the ETFE supply chain (36 %), the silver paste supply chain (19 %), the infrastructure (8 %), and the combustion of natural gas (6 %).

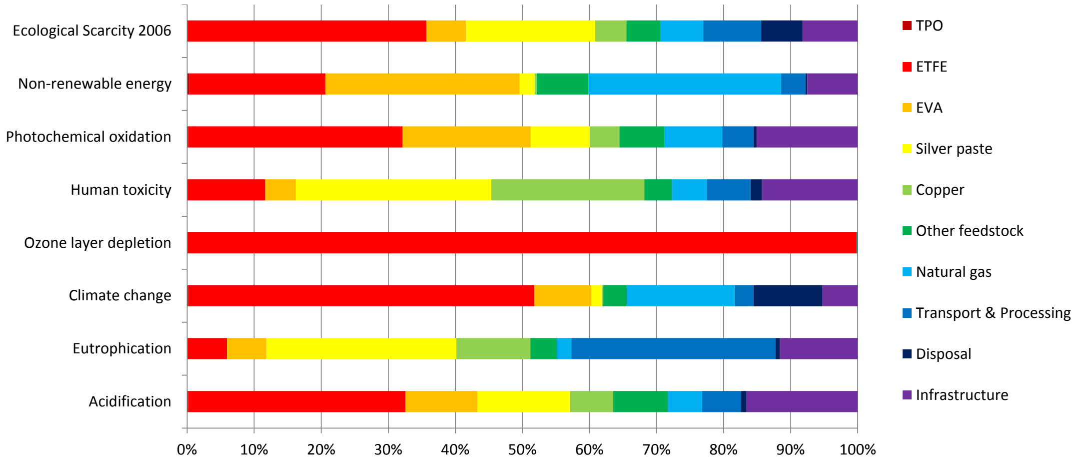

Fig. 3.1 Dominance analysis of the environmental impacts of 1 m^2 Flexcell modules. The results are scaled to 100 %.

3.2 Electricity from Photovoltaic Power Plants

The overall environmental impacts of electricity from photovoltaic flat roof installations using Flexcell modules and slanted roof installations using other technologies in Switzerland assessed with the Ecological Scarcity Method (Frischknecht et al. 2009) is presented in Fig. 3.2. Flexcell modules are the technology with the lowest overall environmental impacts due to the low module weight and therewith consumed amount of material, the use of hydropower in the production, and the fact that Flexcell modules do not require any additional mounting structure.

Around 15.9 % of the overall environmental impacts of electricity from a photovoltaic flat roof installation with Flexcell 150 W modules stem from the production of the ETFE feedstock. 32.9 % stem from the production of copper used in the inverter, in electric installations, and in the Flexcell modules.

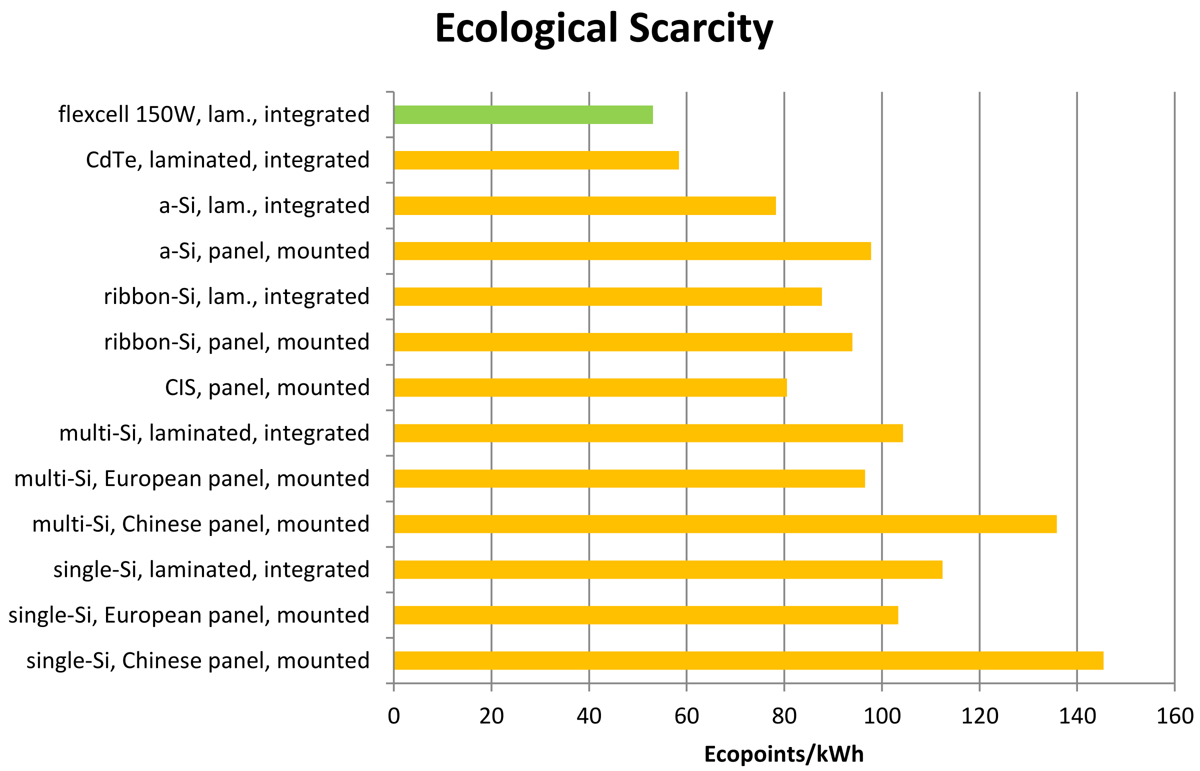

Fig. 3.2 Environmental impacts of electricity from photovoltaic flat roof installations using Flexcell modules and slanted roof installations with various different technologies in Switzerland, assessed with Ecological Scarcity (2006). Flexcell modules are in green; other module technologies in yellow. 1'050 kWh/kW_p is the yield of Flexcell PV plants; 922 kWh/kW_p yield of plants with other module technology.

In Fig. 3.3, the carbon footprint of electricity from photovoltaic roof installations in Switzerland is shown. It is 26.6 g CO_2/kWh for electricity produced with 150W Flexcell modules. The other PV technologies range between 35 g CO_2/kWh (CdTe laminates) and 111 g CO_2/kWh (Chinese single-Si panels).

In comparison with other technologies, photovoltaic installations using Flexcell modules produced in 2010 have a lower impact on climate change.

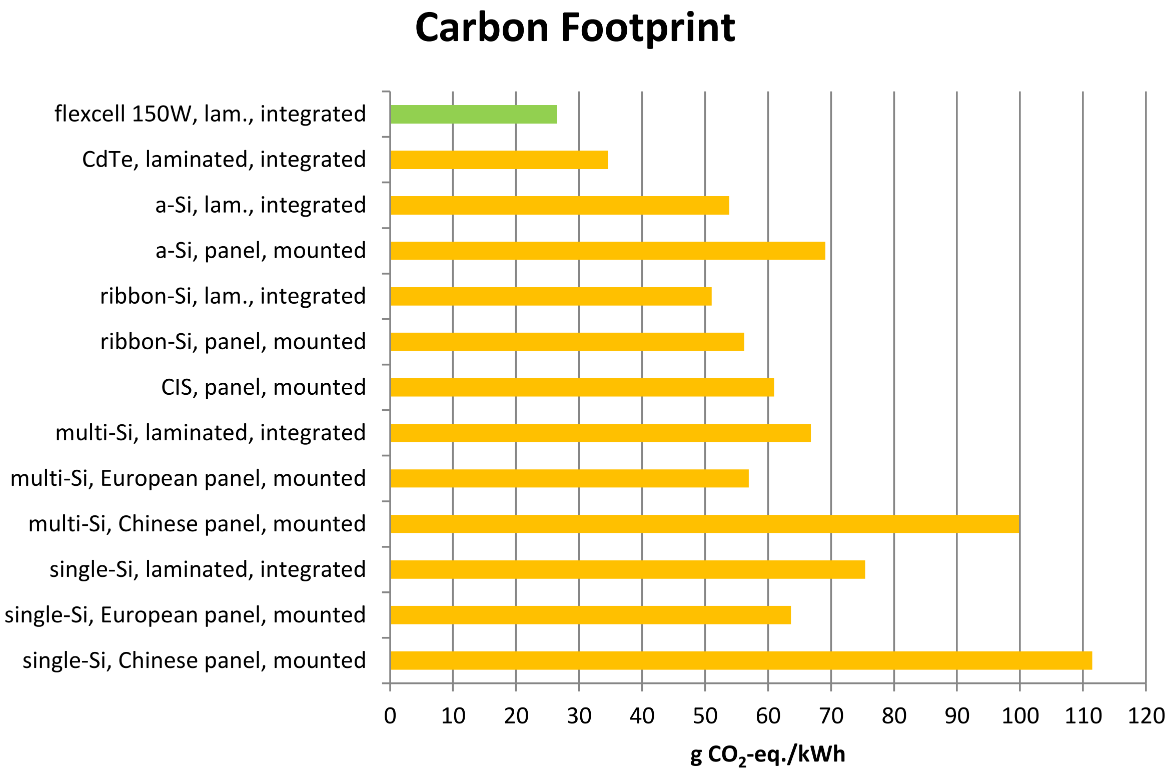

Fig. 3.3 Carbon Footprint of electricity from photovoltaic flat roof installations using Flexcell modules and slanted roof installations with various other technologies in Switzerland. Flexcell modules are in green; other module technologies in yellow. 1'050 kWh/kW$_p$ yield of Flexcell PV plants; 922 kWh/kW$_p$ yield of plants with other module technology.

The results of the Flexcell modules shown in Fig. 3.2 and Fig. 3.3 represent the Flexcell module production in 2010. In 2011, Flexcell launched 160 W and 170 W modules with the same resource consumption per square meter. This leads to lower environmental impacts per kWh electricity produced (see blue bars in Fig. 3.4).

Furthermore, the Flexcell facility was not producing at full capacity in 2010. Since a base consumption of electricity, water, and natural gas (e.g. for heating) is not dependent on the production volume, a higher capacity utilisation would lead to lower environmental impacts per module produced and per kWh electricity produced (see hatched bars in Fig. 3.4).

Electricity from photovoltaic installations with 170 W Flexcell modules produced under full capacity utilisation has environmental impacts assessed with the Method of Ecological Scarcity 2006 that are 9.4 % lower than those of electricity from photovoltaic installations with 150 W Flexcell modules produced under low capacity use in 2010. The carbon footprint of electricity from this scenario is 18.1 % lower.

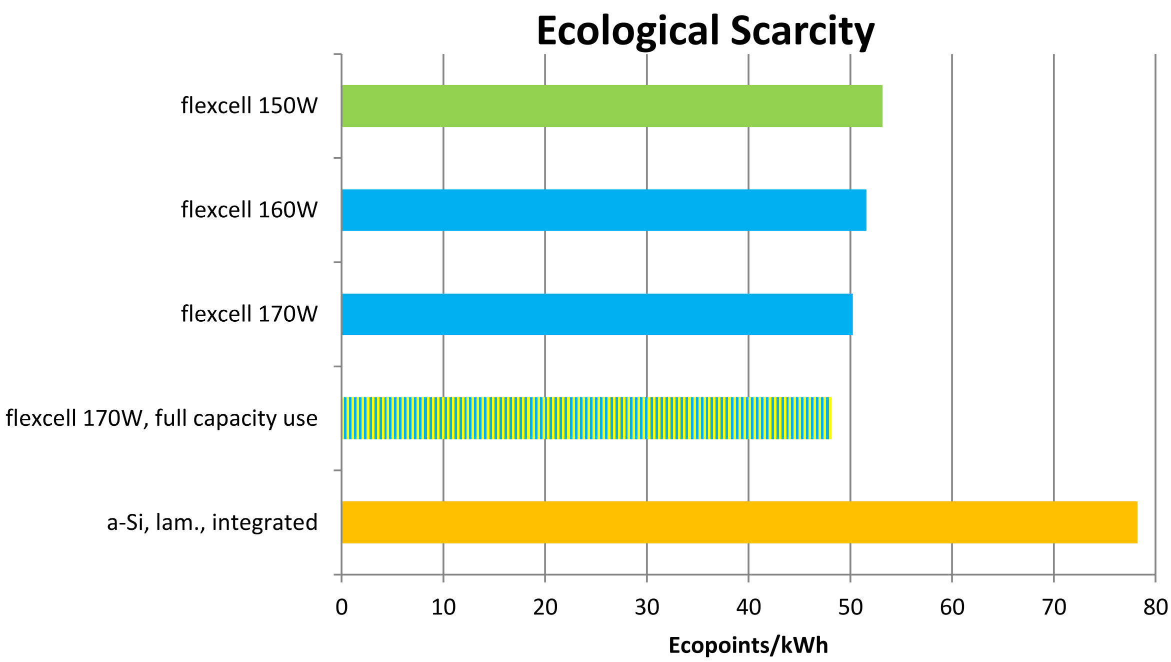

Fig. 3.4 Environmental impacts of electricity from photovoltaic roof installations with Flexcell modules in Switzerland assessed with Ecological Scarcity (2006). Green: Electricity from modules produced in 2010; blue: electricity from modules planned to be produced in 2011; yellow : electricity from a-Si laminates that are presented by Jungbluth et al. (2010) for comparison. The results of the manufacturing of the modules under full capacity are hatched. 1'050 kWh/kW_p is the yield of Flexcell PV plants; 922 kWh/kW_p yield of plants with the other module technology.

The environmental impacts of photovoltaic electricity depend on the solar irradiation that falls on the modules. In consequence, the environmental impacts of photovoltaic electricity in areas with higher irradiation, such as southern Europe, are lower, because less m^2 of modules are required to produce a certain amount of electricity.

Fig. 3.5 shows the comparison of the environmental impacts of electricity from photovoltaic flat roof installations with Flexcell modules installed in Switzerland and Spain in combination with the different production scenarios. The photovoltaic electricity produced in Spain causes about 31 % lower environmental impacts than photovoltaic electricity produced in Switzerland.

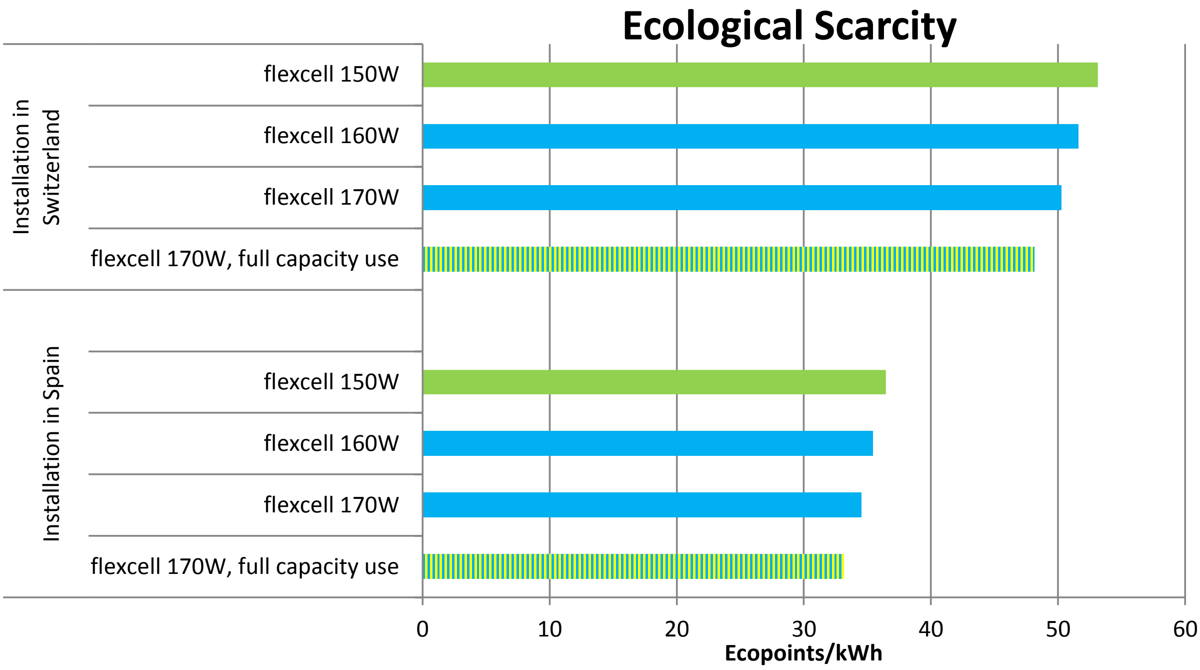

Fig. 3.5 Environmental impacts of electricity from photovoltaic flat roof installations of Flexcell modules in Switzerland and Spain assessed with Ecological Scarcity (2006). Green: Electricity from modules produced in 2010 ; blue: electricity from modules planned to be produced in 2011. The results when manufacturing the modules under full capacity use are hatched. 1'050 kWh/kW_p yield in Switzerland and 1'588 kWh/kW_p yield in Spain.

The supply chain of ETFE is a major contributor to the environmental impact of Flexcell modules. As a sensitivity analysis, the effect of a thinner ETFE coating on the environmental performance of the modules is analysed. The reduced coatings of 0.05 mm ETFE and of 0.025 mm ETFE respectively, are compared to the standard thickness of 0.1 mm ETFE. With half the thickness, the environmental impacts of a module are reduced by 18 %. A reduction by 28 % is attained with 0.025 mm of ETFE. The carbon footprint of electricity from 150W modules with 0.1 mm ETFE of 26.6 g CO_2/m^2 is reduced to 21.3 g CO_2/m^2 with the thickness of 0.05 mm and to 18.7 g CO_2/m^2 with 0.025 mm ETFE. This is a reduction of 29 %.

The effect of the improved environmental performance of the modules on the electricity produced is shown in Fig. 3.6. The impacts are reduced by 12 % and 8 % respectively. The carbon footprint of electricity produced by a 170W module with a layer of 0.05 mm is 19.5 g CO_2/kWh. A further reduction of the coating leads to a carbon footprint of 17.2 g CO_2/kWh (see Fig. 3.7).

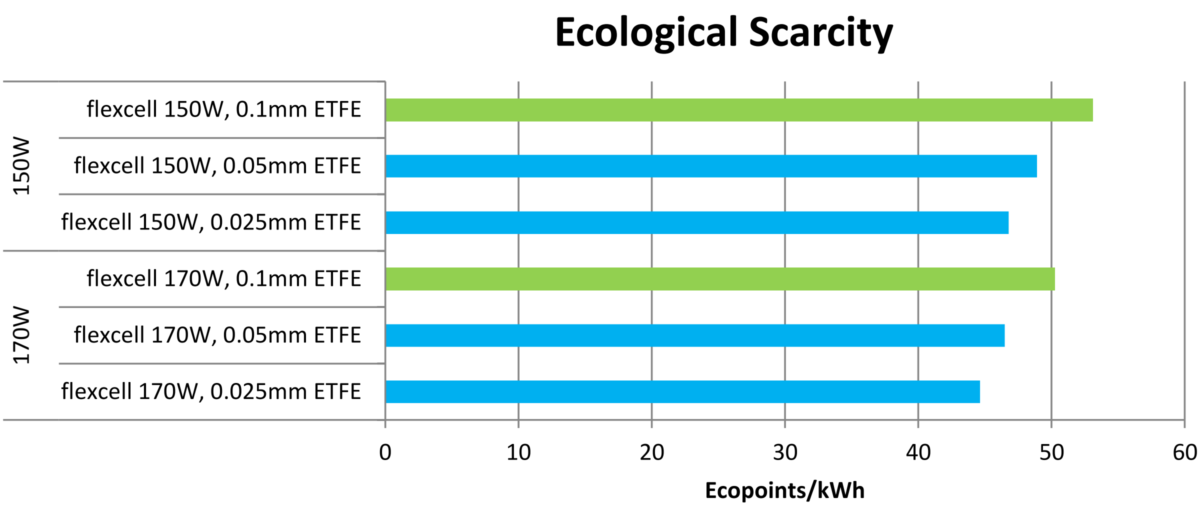

Fig. 3.6 Environmental impacts of electricity from photovoltaic flat roof installations with Flexcell modules in Switzerland assessed with Ecological Scarcity (2006). Green: electricity from modules with the standard ETFE coating of 0.1mm; blue: electricity from modules with a thinner coating. The yield of the Flexcell PV plant is 1'050 kWh/kWp.

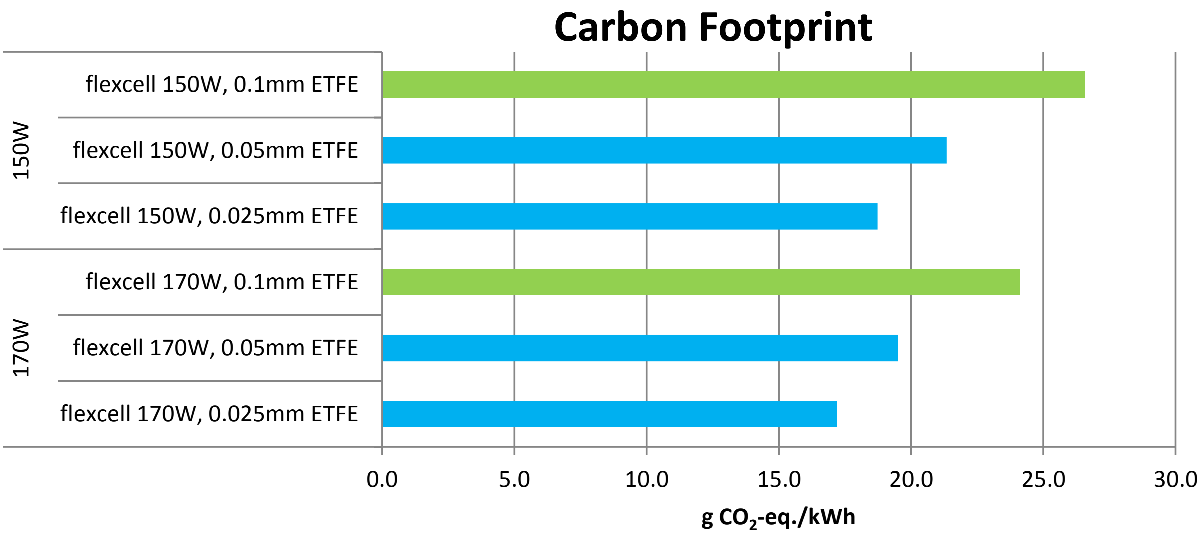

Fig. 3.7 Carbon footprint of electricity from photovoltaic flat roof installations with Flexcell modules in Switzerland assessed with IPCC (Solomon et al. 2007). Green: electricity from modules with the standard ETFE coating of 0.1mm; blue: electricity from modules with a thinner coating. The yield of the Flexcell PV plant is 1'050 kWh/kWp.

Tab. 3.1. shows the environmental impacts (Ecological Scarcity 2006) and the carbon footprint of electricity from different Flexcell modules installed in Switzerland and Spain. The carbon footprint of electricity produced in Spain with a flat roof installation using Flexcell 170 W modules that are manufactured under full capacity utilisation is about 14 g CO_2-eq./kWh.

Tab. 3.1 Environmental impacts of electricity from photovoltaic flat roof installations with Flexcell modules in Switzerland and Spain modules assessed with Ecological Scarcity 2006 and Carbon Footprint (Solomon et al. 2007). 1'050 kWh/kWp yield in Switzerland and 1'588 kWh/kWp yield in Spain.

	Environmental impacts (Ecopoints 2006/kWh)		**Carbon Footprint (g CO_2-eq./kWh)**	
	Installation in Switzerland	Installation in Spain	Installation in Switzerland	Installation in Spain
Flexcell 150W	53	36	27	18
Flexcell 160W	52	35	25	17
Flexcell 170W	50	35	24	16
Flexcell 170W, full capacity use	48	33	22	14
Flexcell 170W, 0.05 mm ETFE	47	32	20	13
Flexcell 170W, 0.025 mm ETFE	45	31	17	11

4 Data Quality Considerations

There are some uncertainties that may have a relevant impact in the evaluation.

The chlorofluorocarbon emissions from the production of the ETFE feedstock (R22) have a strong influence on the result of different indicators. It needs to be considered that the data quality of the ETFE production is medium since due to lack of production data, the material consumption and some emissions are modelled theoretically. The chlorofluorocarbon emissions important for the carbon footprint are modelled based on data reported by a chlorodifluoromethane (R22) production facility in the Netherlands covering the production in 2010.[11]

The production data from Flexcell 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.

The fact that modules with the same size can have a different capacity is taken into account in this study by analysing scenarios with 150 W, 160 W, 170 W modules.

The influence of the capacity utilisation in module manufacturing on the results is taken into account by evaluating scenarios with full capacity utilisation.

[11] Retrieved from: http://prtr.ec.europa.eu/(access on 10.05.2012)

5 Conclusions

From an environmental point of view, Flexcell modules are among the most favourable photovoltaic technologies. This is due to their low weight that leads to a relatively small amount of materials required, the production with hydropower (having relatively low environmental impacts), and the avoidance of additional mounting structure.

The supply chain of the ETFE feedstock causes significant contributions to the climate change impacts. According to our knowledge, the production of the feedstock material R22 causes significant amounts of greenhouse gas and ozone depleting substances. We recommend to identify the supplier of this feedstock material and to verify its environmental impacts of the production of R22.

The following key measures may help to further improve the environmental performance of electricity produced with Flexcell modules:

- Production of modules with higher efficiency (target in 2012: 188 W_p/laminate).
- Increase in capacity utilisation (depends on commercial success of Flexcell).
- Purchase of R22 with reduced environmental impacts by your ETFE supplier.
- Reduction in the amount of ETFE used (50 um in qualification, 25 um is possible (already used by FujiElectric).
- Reduction in the amount of natural gas consumed.
- Further reduction in the module weight or in particular in the use of silver paste.
- Make the modules recyclable and recycle production wastes.

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7 Appendix

7.1 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. 7.1):

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

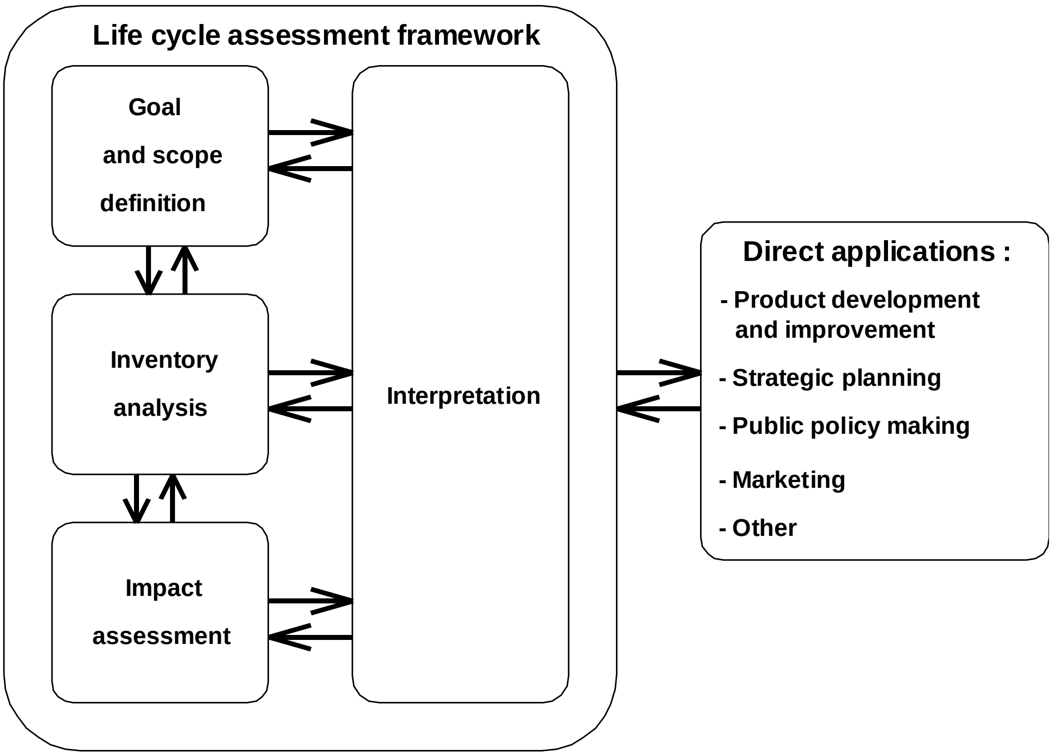

Fig. 7.1 Components of a life cycle assessment (LCA) according to the International Organization for Standardization

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-

[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.

7.2 Unit Process Raw Data

How to read the tables:

The **light green 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 **yellow and 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
NO Norway

[13] Resource extraction and emission of pollutants

Tab. 7.1 Unit process raw data of Flexcell module production with normal capacity utilisation in 2010 and with full capacity utilisation

	Name	Location	InfrastructureProcess	Unit	photovoltaic laminate, Flexcell, 0.1 mm ETFE, at plant	photovoltaic laminate, Flexcell, 0.1 mm ETFE, full capacity, at plant	photovoltaic laminate, Flexcell, 0.05 mm ETFE, at plant	photovoltaic laminate, Flexcell, 0.025 mm ETFE, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	CH	CH	CH			
	InfrastructureProcess				1	1	1	1			
	Unit				m2	m2	m2	m2			
product	photovoltaic laminate, Flexcell, 0.1 mm ETFE, at plant	CH	1	m2	1	0	0	0			
	photovoltaic laminate, Flexcell, 0.1 mm ETFE, full capacity, at plant	CH	1	m2	0	1	0	0			
	photovoltaic laminate, Flexcell, 0.05 mm ETFE, at plant	CH	1	m2	0	0	1	0			
	photovoltaic laminate, Flexcell, 0.025 mm ETFE, at plant	CH	1	m2	0	0	0	1			
infrastructure	photovoltaic panel factory	GLO	1	unit	4.00E-6	4.00E-6	4.00E-6	4.00E-6	1	3.02	(1,4,1,3,1,3,BU:3); assumption
materials	polyethylene naphthalate, at plant	RER	0	kg	6.55E-2	6.55E-2	6.55E-2	6.55E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); PEN film, extruded
	aluminium, production mix, wrought alloy, at plant	RER	0	kg	4.04E-4	4.04E-4	4.04E-4	4.04E-4	1	1.11	(3,1,1,1,1,1,BU:1.05); high purity Al
	silane, at plant	RER	0	kg	3.28E-3	3.28E-3	3.28E-3	3.28E-3	1	1.11	(3,1,1,1,1,1,BU:1.05); Silane gas
	hydrogen, liquid, at plant	RER	0	kg	2.05E-3	2.05E-3	2.05E-3	2.05E-3	1	1.11	(3,1,1,1,1,1,BU:1.05); Hydrogen gas
	diborane, at plant	GLO	0	kg	6.14E-7	6.14E-7	6.14E-7	6.14E-7	1	1.11	(3,1,1,1,1,1,BU:1.05); Diborane gas
	phosphane, at plant	GLO	0	kg	2.05E-7	2.05E-7	2.05E-7	2.05E-7	2	1.11	(3,1,1,1,1,1,BU:1.05); Phosphine gas
	argon, liquid, at plant	RER	0	kg	2.05E-3	2.05E-3	2.05E-3	2.05E-3	1	1.11	(3,1,1,1,1,1,BU:1.05); Argon gas
	nitrogen, liquid, at plant	RER	0	kg	3.07E-1	3.07E-1	3.07E-1	3.07E-1	1	1.11	(3,1,1,1,1,1,BU:1.05); Liquid N2
	indium, at regional storage	RER	0	kg	5.74E-4	5.74E-4	5.74E-4	5.74E-4	1	1.11	(3,1,1,1,1,1,BU:1.05); ITO target, 90% Indium/10% Tin
	tin, at regional storage	RER	0	kg	6.38E-5	6.38E-5	6.38E-5	6.38E-5	1	1.11	(3,1,1,1,1,1,BU:1.05); ITO target, 90% Indium/10% Tin
	conductive paste, lead free, at plant	RER	0	kg	3.64E-3	3.64E-3	3.64E-3	3.64E-3	1	1.11	(3,1,1,1,1,1,BU:1.05); silver paste (70% Ag)
	carbon black, at plant	GLO	0	kg	4.55E-4	4.55E-4	4.55E-4	4.55E-4	1	1.11	(3,1,1,1,1,1,BU:1.05); Lift-off ink, Carbon black (20%)+ hydroxy carbitol (40%)+ solvant (40%)
	solvents, organic, unspecified, at plant	GLO	0	kg	7.85E-3	7.85E-3	7.85E-3	7.85E-3	1	1.24	(3,1,1,1,3,1,BU:1.05); solvents + hydroxy carbitol in ink + other solvents
	ethylene-tetrafluoroethylene copolymers, Dyneon, at plant, update	RER	0	kg	1.36E-1	1.36E-1	6.80E-2	3.40E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); ETFE
	ethylvinylacetate, foil, at plant	RER	0	kg	6.14E-1	6.14E-1	6.14E-1	6.14E-1	1	1.11	(3,1,1,1,1,1,BU:1.05); EVA
	copper, at regional storage	RER	0	kg	2.05E-2	2.05E-2	2.05E-2	2.05E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); Copper - tinned - adhesive & non-adhesive
	electronics for control units	RER	0	kg	-	-	-	-	1	1.52	(3,1,1,1,4,1,BU:1.05); assumed for junction box
	polyurethane, flexible foam, at plant	RER	0	kg	3.21E-3	3.21E-3	3.21E-3	3.21E-3	1	1.52	(3,1,1,1,4,1,BU:1.05); assumed for PUR 2 Comp. Casting resin
	chemicals organic, at plant	GLO	0	kg	1.29E-3	1.29E-3	1.29E-3	1.29E-3	1	1.52	(3,1,1,1,4,1,BU:1.05); Base plate for junction box
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	9.16E-5	9.16E-5	9.16E-5	9.16E-5	1	1.11	(3,1,1,1,1,1,BU:1.05); Flexcell Marking / Label
	EUR-flat pallet	RER	0	unit	-	-	-	-	1	1.11	(3,1,1,1,1,1,BU:1.05);
	corrugated board, mixed fibre, single wall, at plant	CH	0	kg	-	-	-	-	1	1.11	(3,1,1,1,1,1,BU:1.05);
energy	electricity, hydropower, at power plant	NO	0	kWh	4.25E+1	1.61E+1	4.25E+1	4.25E+1	1	1.24	(3,2,1,1,3,1,BU:1.05); 100% hydropower from EU
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	4.49E+1	1.21E+1	4.49E+1	4.49E+1	1	1.24	(3,2,1,1,3,1,BU:1.05); for production and heating
water	tap water, at user	CH	0	kg	2.75E+2	6.06E+1	2.75E+2	2.75E+2	1	1.12	(3,2,1,1,1,1,BU:1.05); independent from production volume
	extrusion, plastic film	RER	0	kg	6.56E-2	6.56E-2	6.56E-2	6.56E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); Extrusion of polyolefins, PEN films, and PET label
	tin plating, pieces	RER	0	m2	3.73E-2	3.73E-2	3.73E-2	3.73E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); copper tinning
transport	transport, lorry >16t, fleet average	RER	0	tkm	4.93E-1	4.93E-1	4.32E-1	4.01E-1	1	2.05	(4,1,1,1,1,1,BU:2); specific and standard (100km) distances
	transport, freight, rail	RER	0	tkm	2.12E-1	2.12E-1	2.12E-1	2.12E-1	1	2.09	(4,5,na,na,na,na,BU:2); standard distance 600 km
	transport, transoceanic freight ship	OCE	0	tkm	2.18E+0	2.18E+0	1.77E+0	1.56E+0	1	2.05	(4,1,1,1,1,1,BU:2); import from PEN and ETFE from overseas
disposal	disposal, polyethylene naphtalate, to municipal incineration	CH	0	kg	6.55E-2	6.55E-2	6.55E-2	6.55E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); Aussumption
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	7.58E-1	7.58E-1	6.90E-1	6.56E-1	1	1.24	(3,1,1,1,3,1,BU:1.05); Aussumption
	disposal, copper, 0% water, to municipal incineration	CH	0	kg	2.05E-2	2.05E-2	2.05E-2	2.05E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); Aussumption
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	2.75E-1	6.06E-2	2.75E-1	2.75E-1	1	1.24	(3,1,1,1,3,1,BU:1.05); Aussumption
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	3.28E-3	3.28E-3	3.28E-3	3.28E-3	1	1.11	(3,1,1,1,1,1,BU:1.05);
emission air, high population density	Heat, waste	-	-	MJ	1.98E+2	1.98E+2	1.98E+2	1.98E+2	1	1.21	(4,1,1,1,1,1,BU:1.05); Calculated from energy consumption
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	7.85E-3	7.85E-3	7.85E-3	7.85E-3	1	1.56	(4,1,1,1,1,1,BU:1.5); 1% of solvents
	Carbon dioxide, fossil	-	-	kg	1.53E-2	1.53E-2	1.53E-2	1.53E-2	1	1.21	(4,1,1,1,1,1,BU:1.05); from burning solvent in scrubber
	Phosphine	-	-	kg	2.05E-9	2.05E-9	2.05E-9	2.05E-9	1	1.52	(3,1,1,1,1,1,BU:1.5); Phosphine gas, emissions
	Boric acid	-	-	kg	6.14E-9	6.14E-9	6.14E-9	6.14E-9	1	1.52	(3,1,1,1,1,1,BU:1.5); Diborane gas, emissions
	Hydrogen	-	-	kg	2.05E-3	2.05E-3	2.05E-3	2.05E-3	1	1.52	(3,1,1,1,1,1,BU:1.5); Hydrogen gas, emissions
emission water, river	Phosphate	-	-	kg	2.03E-7	2.03E-7	2.03E-7	2.03E-7	1	1.52	(3,1,1,1,1,1,BU:1.5); Phosphine, after abatement
	Boron	-	-	kg	6.08E-7	6.08E-7	6.08E-7	6.08E-7	1	5.01	(3,1,1,1,1,1,BU:5); Diborane, after abatement

Tab. 7.2 EcoSpold MetaInformation of Flexcell module production

ReferenceFunction	Name	photovoltaic laminate, Flexcell, 0.1 mm ETFE, at plant	photovoltaic laminate, Flexcell, 0.1 mm ETFE, full capacity, at plant	photovoltaic laminate, Flexcell, 0.05 mm ETFE, at plant	photovoltaic laminate, Flexcell, 0.025 mm ETFE, at plant
Geography	Location	CH	CH	CH	CH
ReferenceFunction	InfrastructureProcess	1	1	1	1
ReferenceFunction	Unit	m2	m2	m2	m2
	IncludedProcesses	Electricity and heat use, materials, transport of materials, disposal of wastes and the product. Data for direct air and water emissions were not available.	Electricity and heat use, materials, transport of materials, disposal of wastes and the product. Data for direct air and water emissions were not available.	Szenario with 0.05 mm ETFE. Electricity and heat use, materials, transport of materials, disposal of wastes and the product. Data for direct air and water emissions were not	Szenario with 0.025 mm ETFE. Electricity and heat use, materials, transport of materials, disposal of wastes and the product. Data for direct air and water emissions were not
	LocalName	Solarlaminat, Flexcell, 0.1 mm ETFE, ab Werk	Solarlaminat, Flexcell, 0.1 mm ETFE, volle Auslastung, ab Werk	Solarlaminat, Flexcell, 0.05 mm ETFE, ab Werk	Solarlaminat, Flexcell, 0.025 mm ETFE, ab Werk
	Synonyms	Solarmodul//PV-module//a-Si//thin film	Solarmodul//PV-module//a-Si//thin film	Solarmodul//PV-module//a-Si//thin film	Solarmodul//PV-module//a-Si//thin film
	GeneralComment	Production of photovoltaic thin film laminates. The laminates FLX-TO135 produced at Flexcell have a size of 4.9 m2. The weight is 2.9 kg per m2. The rated nominal power is about 145Wp per laminate. The efficiency is estimated with 4%-8% at the beginning of the life time. Degradation has to be taken into account with achieved yields.	Production of photovoltaic thin film laminates. The laminates FLX-TO135 produced at Flexcell have a size of 4.9 m2. The weight is 2.9 kg per m2. The rated nominal power is about 145Wp per laminate. The efficiency is estimated with 4%-8% at the beginning of the life time. Degradation has to be taken into account with achieved yields.	Production of photovoltaic thin film laminates. The laminates FLX-TO135 produced at Flexcell have a size of 4.9 m2. The weight is 2.8 kg per m2. The rated nominal power is about 145Wp per laminate. The efficiency is estimated with 4%-8% at the beginning of the life time. Degradation has to be taken into account with achieved yields.	Production of photovoltaic thin film laminates. The laminates FLX-TO135 produced at Flexcell have a size of 4.9 m2. The weight is 2.8 kg per m2. The rated nominal power is about 145Wp per laminate. The efficiency is estimated with 4%-8% at the beginning of the life time. Degradation has to be taken into account with achieved yields.
	InfrastructureIncluded	1	1	1	1
	Category	photovoltaic	photovoltaic	photovoltaic	photovoltaic
	SubCategory	production of components	production of components	production of components	production of components
TimePeriod	StartDate	2010	2010	2010	2010
	EndDate	2010	2010	2010	2010
Geography	Text	Data for Flexcell in Switzerland	Data for Flexcell in Switzerland	Data for Flexcell in Switzerland	Data for Flexcell in Switzerland
Technology	Text	Modern plant with low capacity utilisation.	Modern plant with full capacity utilisation.	Modern plant with low capacity utilisation.	Modern plant with low capacity utilisation.
Representativeness	Percent	100%	100%	100%	100%
	ProductionVolume	2.01 MWp	2.01 MWp	2.01 MWp	2.01 MWp

Tab. 7.3 Unit process raw data of 3kWp flat roof photovoltaic installations with different Flexcell modules

	Name	Location	InfrastructureProcess	Unit	3kWp flat-roof installation, flexcell 150W, laminate, integrated	3kWp flat-roof installation, flexcell 160W, laminate, integrated	3kWp flat-roof installation, flexcell 170W, laminate integrated	3kWp flat-roof installation, flexcell 170W, full capacity, integrated	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	CH	CH	CH			
	InfrastructureProcess				1	1	1	1			
	Unit				unit	unit	unit	unit			
technosphere	electricity, low voltage, at grid	CH	0	kWh	4.00E-2	4.00E-2	4.00E-2	4.00E-2	1	1.20	(3,4,3,1,1,5); Energy use for erection of 3kWp plant
	inverter, 2500W, at plant	RER	1	unit	2.40E+0	2.40E+0	2.40E+0	2.40E+0	1	1.00	(2,4,1,1,1,na); Literature, 1 repair in the life time
	electric installation, photovoltaic plant, at plant	CH	1	unit	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.20	(3,4,3,1,1,5); Literature
	photovoltaic laminate, Flexcell, 0.1 mm ETFE, at plant	CH	1	m2	100.61	94.32	88.77	-	1	1.20	(3,4,3,1,1,5); Calculation, 2% of modules repaired in the life time, 1% rejects
	photovoltaic laminate, Flexcell, 0.1 mm ETFE, full capacity, at plant	CH	1	m2	-	-	-	8.88E+1	1	1.20	(3,4,3,1,1,5); Calculation, 2% of modules repaired in the life time, 1% rejects
	transport, van <3.5t	CH	0	tkm	3.72E+1	3.54E+1	3.38E+1	3.38E+1	1	1.20	(3,4,3,1,1,5); electric parts and panel 100km to construction place
	transport, lorry 3.5-20t, fleet average	CH	0	tkm	2.92E+1	2.74E+1	2.57E+1	2.57E+1	1	1.20	(3,4,3,1,1,5); standard distance 100 km
emission air	Heat, waste	-	-	MJ	1.44E-1	1.44E-1	1.44E-1	1.44E-1	1	1.20	(3,4,3,1,1,5); calculated with electricity use
	3kWp flat-roof installation, flexcell 150W, laminate, integrated	CH	1	unit	1.00E+0	0	0	0			
	3kWp flat-roof installation, flexcell 160W, laminate, integrated	CH	1	unit	0	1.00E+0	0	0			
	3kWp flat-roof installation, flexcell 170W, laminate integrated	CH	1	unit	0	0	1.00E+0	0			
	3kWp flat-roof installation, flexcell 170W, full capacity, integrated	CH	1	unit	0	0	0	1.00E+0			

Tab. 7.4 EcoSpold MetaInformation of 3kWp flat roof photovoltaic installations with different Flexcell modules

ReferenceFunction	Name	3kWp flat-roof installation, flexcell 150W, laminate, integrated	3kWp flat-roof installation, flexcell 160W, laminate, integrated	3kWp flat-roof installation, flexcell 170W, laminate integrated	3kWp flat-roof installation, flexcell 170W, full capacity, integrated
Geography	Location	CH	CH	CH	CH
ReferenceFunction	InfrastructureProcess	1	1	1	1
ReferenceFunction	Unit	unit	unit	unit	unit
	IncludedProcesses	All components for the installation of a 3kWp photovoltaic plant, energy use for the mounting, transport of materials and persons to the construction place.	All components for the installation of a 3kWp photovoltaic plant, energy use for the mounting, transport of materials and persons to the construction place.	All components for the installation of a 3kWp photovoltaic plant, energy use for the mounting, transport of materials and persons to the construction place.	All components for the installation of a 3kWp photovoltaic plant, energy use for the mounting, transport of materials and persons to the construction place.
	LocalName	3kWp Flachdachanlage, Flexcell 150W, laminiert, integriert,	3kWp Flachdachanlage, Flexcell 160W, laminiert, integriert,	3kWp Flachdachanlage, Flexcell 170W, laminiert, integriert,	3kWp Flachdachanlage, Flexcell 150W, volle Kapazität, integriert
	Synonyms	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon
	GeneralComment	Photovoltaic installation with a capacity of 3kWp and a life time of 30 years installed in CH.	Photovoltaic installation with a capacity of 3kWp and a life time of 30 years installed in CH.	Photovoltaic installation with a capacity of 3kWp and a life time of 30 years installed in CH.	Photovoltaic installation with a capacity of 3kWp and a life time of 30 years installed in CH.
	InfrastructureIncluded	1	1	1	1
	Category	photovoltaic	photovoltaic	photovoltaic	photovoltaic
	SubCategory	production of	production of	production of	production of
TimePeriod	StartDate	2005	2005	2005	2005
	EndDate	2010	2010	2010	2010
Geography	Text	Data from a Swiss company.	Data from a Swiss company.	Data from a Swiss company.	Data from a Swiss company.
Technology	Text	Calculation of amount of modules used based on 150 Wp power output per module.	Calculation of amount of modules used based on 160 Wp power output per module.	Calculation of amount of modules used based on 170 Wp power output per module.	Calculation of amount of modules used based on 170 Wp power output per module.

Tab. 7.5 Unit process raw data of electricity from 3kWp flat roof photovoltaic installations with different Flexcell modules installed in Switzerland and Spain

	Name	Location	Unit	electricity, PV, at 3kWp flat-roof, flexcell 150W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 150W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 160W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 170W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 160W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 170W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 170W, full capacity, integrated	electricity, PV, at 3kWp flat-roof, flexcell 170W, full capacity, integrated
	Location			CH	ES	CH	CH	ES	ES	CH	ES
	InfrastructureProcess			0	0	0	0	0	0	0	0
	Unit			kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
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	3.85E+0	3.85E+0
technosphere	tap water, at user	CH	kg	2.07E-2	1.37E-2	1.94E-2	1.82E-2	1.28E-2	1.21E-2	1.82E-2	1.21E-2
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	m3	2.07E-5	1.37E-5	1.94E-5	1.82E-5	1.28E-5	1.21E-5	1.82E-5	1.21E-5
	3kWp flat-roof installation, flexcell 150W, laminate, integrated	CH	unit	1.06E-5	7.00E-6		-	-	-	-	-
	3kWp flat-roof installation, flexcell 160W, laminate, integrated	CH	unit	-	-	1.06E-5	-	7.00E-6	-	-	-
	3kWp flat-roof installation, flexcell 170W, laminate integrated	CH	unit	-		-	1.06E-5	-	7.00E-6	-	-
	3kWp flat-roof installation, flexcell 170W, full capacity, integrated	CH	unit	-	-	-	-	-	-	1.06E-5	7.00E-6
emission air	Heat, waste	-	MJ	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1

Tab. 7.6 EcoSpold MetaInformation of electricity from 3kWp flat roof photovoltaic installations with different Flexcell modules installed in Switzerland and Spain

ReferenceFunction	Name	electricity, PV, at 3kWp flat-roof, flexcell 150W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 150W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 160W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 170W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 160W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 170W, lam., integrated	electricity, PV, at 3kWp flat-roof, flexcell 170W, full capacity, integrated	electricity, PV, at 3kWp flat-roof, flexcell 170W, full capacity, integrated
Geography	Location	CH	ES	CH	CH	ES	ES	CH	ES
ReferenceFunction	InfrastructureProcess	0	0	0	0	0	0	0	0
ReferenceFunction	Unit	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
	IncludedProcesses	Infrastructure for 3kWp PV-plant. Water use for cleaning. Amount of solar energy transformed to electricity. Waste heat emission due to losses of electricity in the system.	Infrastructure for 3kWp PV-plant. Water use for cleaning. Amount of solar energy transformed to electricity. Waste heat emission due to losses of electricity in the system.	Infrastructure for 3kWp PV-plant. Water use for cleaning. Amount of solar energy transformed to electricity. Waste heat emission due to losses of electricity in the system.	Infrastructure for 3kWp PV-plant. Water use for cleaning. Amount of solar energy transformed to electricity. Waste heat emission due to losses of electricity in the system.	Infrastructure for 3kWp PV-plant. Water use for cleaning. Amount of solar energy transformed to electricity. Waste heat emission due to losses of electricity in the system.	Infrastructure for 3kWp PV-plant. Water use for cleaning. Amount of solar energy transformed to electricity. Waste heat emission due to losses of electricity in the system.	Infrastructure for 3kWp PV-plant. Water use for cleaning. Amount of solar energy transformed to electricity. Waste heat emission due to losses of electricity in the system.	Infrastructure for 3kWp PV-plant. Water use for cleaning. Amount of solar energy transformed to electricity. Waste heat emission due to losses of electricity in the system.
	LocalName	Strom, Photovoltaik, ab 3kWp, Flachdach, Flexcell 150W, laminiert, integriert	Strom, Photovoltaik, ab 3kWp, Flachdach, Flexcell 150W, laminiert, integriert	Strom, Photovoltaik, ab 3kWp, Flachdach, Flexcell 160W, laminiert, integriert	Strom, Photovoltaik, ab 3kWp, Flachdach, Flexcell 170W, laminiert, integriert	Strom, Photovoltaik, ab 3kWp, Flachdach, Flexcell 160W, laminiert, integriert	Strom, Photovoltaik, ab 3kWp, Flachdach, Flexcell 170W, laminiert, integriert	Strom, Photovoltaik, ab 3kWp, Flachdach, Flexcell 170W, volle Kapazität, integriert	Strom, Photovoltaik, ab 3kWp, Flachdach, Flexcell 170W, volle Kapazität, integriert
	Synonyms	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon	Solarmodul//PV-module//amorphous silicon
	GeneralComment	Assumption for electricity production of photovoltaic plants with good performance. Average performance is lower while optimum performance would be higher. Dataset can be used for comparison of energy technologies in Switzerland, but not for assessment of average production patterns. Yield data must be corrected for the installations used in other countries.	Assumption for electricity production of photovoltaic plants with good performance. Average performance is lower while optimum performance would be higher. Dataset can be used for comparison of energy technologies in Switzerland, but not for assessment of average production patterns. Yield data must be corrected for the installations used in other countries.	Assumption for electricity production of photovoltaic plants with good performance. Average performance is lower while optimum performance would be higher. Dataset can be used for comparison of energy technologies in Switzerland, but not for assessment of average production patterns. Yield data must be corrected for the installations used in other countries.	Assumption for electricity production of photovoltaic plants with good performance. Average performance is lower while optimum performance would be higher. Dataset can be used for comparison of energy technologies in Switzerland, but not for assessment of average production patterns. Yield data must be corrected for the installations used in other countries.	Assumption for electricity production of photovoltaic plants with good performance. Average performance is lower while optimum performance would be higher. Dataset can be used for comparison of energy technologies in Switzerland, but not for assessment of average production patterns. Yield data must be corrected for the installations used in other countries.	Assumption for electricity production of photovoltaic plants with good performance. Average performance is lower while optimum performance would be higher. Dataset can be used for comparison of energy technologies in Switzerland, but not for assessment of average production patterns. Yield data must be corrected for the installations used in other countries.	Assumption for electricity production of photovoltaic plants with good performance. Average performance is lower while optimum performance would be higher. Dataset can be used for comparison of energy technologies in Switzerland, but not for assessment of average production patterns. Yield data must be corrected for the installations used in other countries.	Assumption for electricity production of photovoltaic plants with good performance. Average performance is lower while optimum performance would be higher. Dataset can be used for comparison of energy technologies in Switzerland, but not for assessment of average production patterns. Yield data must be corrected for the installations used in other countries.
	InfrastructureIncluded	1	1	1	1	1	1	1	1
	Category	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic	photovoltaic
	SubCategory	power plants	power plants	power plants	power plants	power plants	power plants	power plants	power plants
TimePeriod	StartDate	2000	2000	2000	2000	2000	2000	2000	2000
	EndDate	2010	2010	2010	2010	2010	2010	2010	2010
Geography	Text	Installation in Switzerland	Installation in Spain	Installation in Switzerland	Installation in Switzerland	Installation in Spain	Installation in Spain	Installation in Switzerland	Installation in Spain
Technology	Text	Electricity production with grid-connected photovoltaic power plants integrated in buildings slanted roof. 1'050 kWh/kWp annual electricity output, 1'117 kWh/m2 irradiation.	Electricity production with grid-connected photovoltaic power plants integrated in buildings slanted roof. 1'588 kWh/kWp annual electricity output, 1'660 kWh/m2 irradiation.	Electricity production with grid-connected photovoltaic power plants integrated in buildings slanted roof. 1'050 kWh/kWp annual electricity output, 1'117 kWh/m2 irradiation.	Electricity production with grid-connected photovoltaic power plants integrated in buildings slanted roof. 1'050 kWh/kWp annual electricity output, 1'117 kWh/m2 irradiation.	Electricity production with grid-connected photovoltaic power plants integrated in buildings slanted roof. 1'588 kWh/kWp annual electricity output, 1'660 kWh/m2 irradiation.	Electricity production with grid-connected photovoltaic power plants integrated in buildings slanted roof. 1'588 kWh/kWp annual electricity output, 1'660 kWh/m2 irradiation.	Electricity production with grid-connected photovoltaic power plants integrated in buildings slanted roof. 1'050 kWh/kWp annual electricity output, 1'117 kWh/m2 irradiation.	Electricity production with grid-connected photovoltaic power plants integrated in buildings slanted roof. 1'588 kWh/kWp annual electricity output, 1'660 kWh/m2 irradiation.