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Life Cycle Assessment of Active Glass Façades

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Abbreviations and Acronyms

a	year (annum)
AC	alternating current
AHB	Office for Building Engineering of the City of Zurich (German: Amt für Hochbauten der Stadt Zürich)
BIPV	building integrated photovoltaics
BOS	balance of system
CdTe	cadmium-telluride
CED	cumulative energy demand
CH	Switzerland
CI(G)S	copper-indium-gallium-selenide
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
DC	direct current
ENTSO-E	European Network of Transmission System Operators for Electricity
EPDM	ethylene propylene diene monomer
EVA	Ethylvinylacetate
FOEN	Swiss Federal Office for the Environment
GHG	greenhouse gas
GLO	global average
GWP	global warming potential
IFS	Inventare Fokus Schweiz
KBOB	Coordination Group for Construction and Property Services (German: Koordinationskonferenz der Bau- und Liegenschaftsorgane des Bundes)
kWh	kilowatt hour
kWp	kilowatt peak
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
mono-Si	monocrystalline silicon
multi-Si	multicrystalline silicon
p	piece
PEF	product environmental footprint
PEFCR	product environmental footprint category rule
PERC	passivated emitter and rear cell
POE	Polyolefin Elastomers
PV	photovoltaics

PVB	Polyvinylbutyral
PVF	Polyvinylflouride
RER	Europe
SFOE	Swiss Federal Office of Energy
tkm	tonne kilometre (unit for transportation services)
UBP	eco-points (German: Umweltbelastungspunkte)
UVEK	Federal Department of the Environment, Transport, Energy and Communications (German: Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation)

Summary

In this study, the environmental impacts of the active glass façades of five buildings and of the roof-integrated PV system of one building are analysed following a life cycle assessment approach. Additionally, the primary energy demand, greenhouse gas emissions and total environmental impacts of six façade constructions with different PV modules and substructures, which are exhibited in the UmweltArena Spreitenbach, are assessed.

The life cycle assessments of the active glass façades of the selected buildings include the manufacture of the PV modules, the substructure, the electric installation, the solar inverters, the power optimisers (if applicable) as well as the joints and edge seals (if applicable). The transport of the components (substructure and PV panels) to the installation site, the construction efforts during mounting, the use phase of the PV systems as well as their dismantling and recycling are also considered. The life cycle assessments of the façade constructions account for the supply of the PV modules and the substructure at a regional storage in Switzerland and includes their treatment and disposal or recycling at the end of life. Different functional units are used in this study depending on the analysed object (active glass façade of selected buildings: 1 m^2; electricity produced with the active glass façade of selected buildings: 1 kWh AC electricity at the busbar; façade constructions: 1 m^2).

The data for the life cycle assessments of the active glass façades of the selected buildings and of the façade constructions were collected from architects, installers and manufacturers. Data on some components (e.g. PV cells and electric installation) were only available for some of the buildings analysed. Generic data reported by Frischknecht et al. (2020) were used in the remaining cases. The recycling of PV modules was modelled using the best available data (Stolz et al. 2018). The life cycle inventories created in this study were linked to the UVEK life cycle assessment data DQRv2:2018 (KBOB et al. 2018), which are based on ecoinvent data v2.2 (ecoinvent Centre 2010). The environmental impacts of the active glass façades and façade constructions analysed in this study were assessed with three different impact assessment methods (ecological scarcity method 2013 according to Frischknecht and Büsser Knöpfel (2013), expressed in eco-points (UBP); cumulative energy demand (CED), which is further separated into renewable and non-renewable CED and expressed in kWh oil-eq, according to Frischknecht et al. (2015b); greenhouse gas (GHG) emissions, expressed in kg CO_2-eq, based on the 100 year global warming potentials (GWPs) reported by IPCC (2013)).

The environmental impacts of the six building-integrated PV systems per m^2 are shown in Tab. Z. 1. The lowest environmental impacts according to CED and UBP per m^2 active glass façade/roof are caused by the roof-integrated PV system of the apartment building Rudolf. The façade-integrated PV system of the Grosspeter Tower causes the lowest greenhouse gas emissions per m^2.

Tab. Z. 1 Overview of the environmental impacts of the active glass façades of the six selected buildings per m^2 façade construction (gross: all impacts attributed to electricity production; net: impacts of front glass and substructure attributed to the building, remaining impacts attributed to electricity production).

		unit	Overall environmental impact	Cumulative energy demand total	Cumulative energy demand non-renewable	Cumulative energy demand renewable	Greenhouse gas emissions
			UBP	kWh oil-eq	kWh oil-eq	kWh oil-eq	kg CO_2-eq
Grosspeter Tower	**gross**	m^2	583'000	683	619	63.7	145
	net	m^2	526'000	461	428	33.0	99.1
Flumroc	**gross**	m^2	804'000	1'050	948	105	221
	net	m^2	741'000	802	731	71.0	170
Solaris	**gross**	m^2	445'000	1'150	1'050	107	291
	net	m^2	357'000	807	745	62.0	218
Viridén	**gross**	m^2	409'000	1'080	992	92.4	237
	net	m^2	344'000	824	766	58.0	183
Setz	**gross**	m^2	611'000	1'420	1'270	151	316
	net	m^2	526'000	1'050	956	94.0	245
Rudolf	**gross**	m^2	256'000	693	610	82.3	162
	net	m^2	212'000	551	499	52.0	132

The gross and net environmental impacts per kWh produced electricity are displayed in Tab. Z. 2 (gross: all impacts attributed to electricity production; net: impacts of front glass and substructure attributed to the building, remaining impacts attributed to electricity production). The lowest environmental impacts (according to all impact assessment indicators) per kWh produced electricity are caused by the roof-integrated PV system of the apartment building Rudolf. The highest cumulative energy demand and greenhouse gas emissions per kWh BIPV electricity is associated to the façade-integrated PV system of the apartment building Viridén. According to the ecological scarcity method, the highest impacts per kWh produced electricity are caused by the façade-integrated PV system of the Grosspeter Tower. This can be explained by the fact, that the entire façades of the Grosspeter Tower and the apartment building Viridén (including parts with low solar irradiation such as the north façade and balcony niches) are covered with active PV panels.

Tab. Z. 2 Overview of the gross environmental impacts of 1 kWh electricity caused by the active glass façades of the six buildings (gross: all impacts attributed to electricity production; net: impacts of front glass and substructure attributed to the building, remaining impacts attributed to electricity production).

		unit	Overall environmental impact	Cumulative energy demand			Greenhouse gas emissions
				total	non-renewable	renewable	
			UBP	kWh oil-eq	kWh oil-eq	kWh oil-eq	kg CO_2-eq
Grosspeter Tower	**gross**	kWh	553	1.71	0.583	1.13	0.136
	net	kWh	499	1.50	0.402	1.10	0.093
Flumroc	**gross**	kWh	304	1.46	0.354	1.11	0.082
	net	kWh	280	1.37	0.273	1.10	0.063
Solaris	**gross**	kWh	347	1.97	0.815	1.15	0.226
	net	kWh	280	1.70	0.579	1.12	0.169
Viridén	**gross**	kWh	485	2.34	1.16	1.18	0.278
	net	kWh	408	2.04	0.900	1.14	0.215
Setz	**gross**	kWh	211	1.55	0.430	1.12	0.107
	net	kWh	182	1.43	0.324	1.10	0.083
Rudolf	**gross**	kWh	65.6	1.24	0.147	1.09	0.039
	net	kWh	55.0	1.20	0.120	1.08	0.032

The environmental impacts of the analised façade construction systems are summarized in Tab. Z. 3. The lowest environmental impacts (according to all impact assessment indicators) are caused by the façade construction system by Eternit. The highest environmental impacts according to the cumulative energy demand and the greenhouse gas emissions are caused by the construction system developed by Ecolite. The system Sto Ventec ARTline inlay causes the highest overall environmental impacts according to the ecological scarcity method 2013.

Tab. Z. 3 Overview of the environmental impacts of the active glass façade construction systems (and the contributions of the substructures and PV panels thereof) exhibited at the UmweltArena in Spreitenbach per m² façade construction.

	unit	Overall environmental impact	Cumulative energy demand			Greenhouse gas emissions
			total	non-renewable	renewable	
		UBP	kWh oil-eq	kWh oil-eq	kWh oil-eq	kg CO_2-eq
Eternit	m²	180'000	554	504	50.3	144
thereof substructure	m²	3'320	16.2	12.1	4.17	2.70
thereof PV panel	m²	172'000	523	477	45.4	138
Sto Ventec ARTline inlay	m²	552'000	614	552	62.3	132
thereof substructure	m²	38'600	144	123	21.1	27.7
thereof PV panel	m²	512'000	466	425	41.0	104
Sto Ventec ARTline invisible	m²	546'000	604	544	59.5	126
thereof substructure	m²	49'700	202	170	31.8	38.3
thereof PV panel	m²	495'000	398	370	27.4	87.2
Kioto Solar/GFT	m²	231'000	760	680	79.9	184
thereof substructure	m²	53'200	220	187	33.5	42.0
thereof PV panel	m²	173'000	525	479	45.7	139
René Schmid Architekten AG / Max Vogelsang AG	m²	205'000	681	557	124	157
thereof substructure	m²	26'100	133	55.9	77.2	13.0
thereof PV panel	m²	173'000	529	483	46.1	140
Ecolite concrete substrate	m²	240'000	829	739	90.9	193
thereof substructure	m²	61'700	263	224	38.8	50.2
thereof PV panel	m²	174'000	555	503	51.6	140
Ecolite brick substrate	m²	251'000	875	778	96.8	202
thereof substructure	m²	72'500	308	263	44.7	59.4
thereof PV panel	m²	174'000	555	503	51.6	140
Ecolite average	m²	246'000	857	762	94.5	199
thereof substructure	m²	68'200	290	247	42.3	55.7
thereof PV panel	m²	174'000	555	503	51.6	140

The data quality is generally considered to be good as it was collected directly from architects, installers and manufacturers. Only limited data was available on the electric installations of the selected buildings. Furthermore, life cycle inventory data are missing for microinverters and power optimisers, which were therefore modelled with life cycle inventories of solar inverters, and scaled by mass. No information was available on the digital printing of the PV modules. The impacts were claimed to be negligible by the manufacturers in most cases. The relative efficiency loss due to the digital printing of the PV modules is a source of uncertainty.

The results showed that the environmental impacts of BIPV building elements are mainly influenced by PV technology (crystalline silicon versus thin film PV panels), the amount of glass used in the PV panels and the presence of power optimisers. Same is valid for the environmental impacts of BIPV electricity, which is additionally strongly influenced by the specific yield of the PV system.

We furthermore conclude, that the environmental benefits of the multifunctionality of BIPV elements (weather protection and electricity production) is compensated by reduced yields due to colouring and partly suboptimal orientation of the panels. In comparison to the consolidated life cycle inventories of PV panels and their supply chains (Frischknecht et al. 2020), our assessment resulted in substantially higher specific environmental impacts.

To reduce the environmental impacts of BIPV electricity, we recommend to develop and apply colour coatings with less impact on the PV panel efficiency. Furthermore, we recommend to cross-check the material efficiency of BIPV panels in particular in terms of glass thickness. Due to the high contribution of microinverters and power optimisers to the total environmental impacts in the current study, we recommend to establish life cycle inventories of these. This would open up the possibility to assess their environmental benefits (increased electricity production) in comparison to the environmental impacts caused by their supply.

Content

1 Introduction

Photovoltaics (PV) is a key technology in the Swiss energy strategy. By 2050 PV is expected to cover about one quarter of the Swiss electricity demand (EnergieSchweiz 2016). This goal is to be achieved, among other measures, by new cantonal regulations on the self-production of electricity in new buildings (EnDK & EnFK 2015). The recent developments in terms of efficiency, costs, manufacture and design of PV modules have led to many new and aesthetically appealing products that are increasingly integrated into the roof or façade of buildings (Bonomo et al. 2017; EnergieSchweiz 2016).

In the last few years, various buildings were constructed with PV systems integrated into the roof or façade (so-called building-integrated photovoltaics, BIPV). While the environmental impacts of buildings and PV systems have already been investigated in several life cycle assessment (LCA) studies (Frischknecht et al. 2015a; Tschümperlin et al. 2016a; Wyss et al. 2014), the life-cycle environmental impacts of façade-integrated PV systems, so-called active glass façades, are only poorly known. The goal of this project is to gain a deeper understanding of the primary energy demand, greenhouse gas (GHG) emissions and total environmental impacts of producing, mounting and dismantling/recycling of façade-integrated PV systems.

In this study, the environmental impacts of the active glass façades of five buildings and of the roof-integrated PV system of one building are analysed following a life cycle assessment approach. Additionally, the primary energy demand, greenhouse gas emissions and total environmental impacts of six façade constructions with different PV modules and substructures, which are exhibited in the UmweltArena Spreitenbach, are assessed. The life cycle inventories (LCIs) compiled in this project and the datasets on photovoltaic supply chaines created in previous studies are then consolidated in view of making them available via "Inventare Fokus Schweiz" (IFS) for ecoinvent v3.

The scope of this study is described in Chapter 2 and the investigated objects are characterised in Chapter 3. The life cycle inventories and the impact assessment results of the analysed objects are presented in Chapters 4 and 5, respectively. The quality of the collected data and the uncertainty of the results are discussed in Chapter 7. The consolidation of the life cycle inventories of PV systems is documented in Chapter 8.

2 Scope

2.1 Functional unit

Different functional units are used in this study depending on the analysed object:

- active glass façade of selected buildings: 1 m^2;
- electricity produced with the active glass façade of selected buildings: 1 kWh AC electricity;
- façade constructions: 1 m^2.

Furthermore, the following reference units are used to describe the environmental impacts of elements of active glass façades and façade constructions. These reference units are selected in view of facilitating the designers work. They shall not be used as a basis for comparisons.

- PV modules: 1 m^2;
- substructure: 1 m^2;
- electric installation: 1 m^2.

2.2 System boundary

The life cycle assessments of the active glass façades of the selected buildings include the manufacture of the PV modules, the substructure, the electric installation, the solar inverters, the power optimisers (if applicable) as well as the joints and edge seals (if applicable). The transport of the components (substructure and PV panels) to the installation site, the construction efforts during mounting, the use phase of the PV systems as well as their dismantling and recycling are also considered.

The life cycle assessments of façade constructions account for supply of the PV modules and the substructure at a regional storage in Switzerland. The disposal or recycling at the end of life is also included.

2.3 Data sources

The data for the life cycle assessments of the active glass façades of the selected buildings and of the façade constructions were collected from architects, installers and manufacturers using an excel-based questionnaire. The data collection focused on the following components:

- PV system: type, power output, projected or measured yield;
- PV modules: technology, manufacturer, production country, efficiency, size, composition, frame;
- passive modules (if applicable): size, composition, frame;

- crystalline-silicon PV cells (if applicable and information is available): manufacturer, production country, wafer thickness, number of cells;
- substructure: manufacturer, production country, specific weight, weight of the most important materials;
- electric installation: cable length, cable type, fuse box;
- inverters: number, power;
- power optimisers (if applicable): number, power;
- joints and edge seals (if applicable and information is available).

Data on some components (e.g. PV cells and electric installation) were only available for some of the buildings analysed. Generic data reported by Frischknecht et al. (2020) were used in the remaining cases. The recycling of PV modules was modelled using the best available data (Stolz et al. 2018).

For the life cycle assessment of façade constructions, data were collected on the PV modules and the substructure. The data collection was supported by the UmweltArena in Spreitenbach, which provided the contact information of the exhibitors. To ensure the comparability of the data, the manufacturers were asked to provide data for a generic integrated façade installation to be integrated in a new building, which is assumed to have a height of about 14 m. The thickness of the insulation material is assumed to be approximately 20 cm. The mass of the PV modules should be determined based on specific data for a typical façade construction, but 22 kg/m^2 were given as a reference value in case of missing information.

The life cycle inventories created in this study were linked to the UVEK life cycle assessment data DQRv2:2018 (KBOB et al. 2018), which are based on ecoinvent data v2.2 (ecoinvent Centre 2010). This data source contains extensive updates on energy supply and material production datasets and ensures methodological continuity with former versions of the ecoinvent database (Frischknecht et al. 2007). The analyses were performed with SimaPro v9.1.0.7 (PRé Consultants 2019).

2.4 Allocation

The manufacturing and construction efforts of 1 m^2 active glass façade and of 1 m^2 façade construction are fully attributed to the façade elements and thus to the building, in particular to its construction stage (Module A in EPD-terms).

Because active glass façades produce electricity during the use of the building and because a share or all of this electricity is sold to third parties, the environmental impacts related to the electricity produced needs to be quantified.

For that purpose all elements solely required for electricity production would need to be identified, namely the semiconductor, the PV panel backsheet (if applicable), the cabling, the inverters and the power optimisers (if applicable). The front cover (glass) is considered as the weather protection layer of the building and would thus be fully attributed to the building. The same would be true for the mounting structure, which is also required for a passive façade. In this study, we distinguish between the gross (all elements are attributed to the electricity production) and the net (impacts of front glass and substructure attributed to the building, remaining impacts attributed to electricity production) environmental impacts.

This approach is in line with the harmonised draft guidelines of Task 12 and Task 15 of the IEA Photovoltaic Power Systems (PVPS) Programme (Frischknecht & Stolz 2018).

Recycling of materials is modelled according to the recycled content approach. The recycled content approach represents the concept of strong sustainability (see also Frischknecht 2007, 2010). Materials to be recycled leave the system neither with burdens nor with attributing credits to the system left. Materials made from secondary raw materials bear the loads of scrap collection, sorting and refining.

Using the method of ecological scarcity 2013 (Frischknecht & Büsser Knöpfel 2013) the dissipative use of resources is evaluated. This means that a resource correction is applied to metal building materials. The simplified assumption is that metals can be 100% recycled at the end of the product's life and therefore fully recovered. The credit is granted for the respective primary portion of the metal used.

2.5 Impact assessment indicators

The environmental impacts of the active glass façades and façade constructions analysed in this study were assessed with three different impact assessment methods:

- Ecological scarcity method 2013 according to Frischknecht and Büsser Knöpfel (2013), expressed in eco-points (UBP);
- Cumulative energy demand (CED), which is further separated into renewable and non-renewable CED and expressed in kWh oil-eq, according to Frischknecht et al. (2015b);
- Greenhouse gas (GHG) emissions, expressed in kg CO_2-eq, based on the 100 year global warming potentials (GWPs) reported by IPCC (2013).

3 Characterisation of investigated objects

3.1 Overview

The following subchapters give an overview of the PV systems and components analysed in this study. The active glass façades are characterised in Subchapter 3.2. The façade constructions are introduced in Subchapter 3.3. The electric installations for two additional façade-integrated PV systems are described in Subchapter 3.4.

3.2 Active glass façades

Some characteristics of the investigated buildings with integrated PV systems are compiled in Tab. 3.1. Four buildings have active glass façades, one building (multi-family house Rudolf, Thun) has a roof-integrated PV system and one building (apartment building Solaris 416) has active glass façades as well as a roof-integrated PV system. The office building Grosspeter Tower in Basel as well as the apartment buildings Viridén and Solaris 416 in Zurich have integrated PV systems on all façades (South, East, West, North). The three active glass façades of the office building Flumroc in Flums face South-East, South-West and North-East; the North-West façade is plastered. The apartment building Setz in Möriken has an integrated PV system on part of the South façade. The power output of the façade-integrated PV systems of the analysed buildings ranges from 3.57 kWp (Setz, Möriken) to 440 kWp (Grosspeter Tower, Basel).

All buildings with façade-integrated PV installations also have rooftop PV systems. Apart from Solaris 416 and Rudolf, the rooftop PV systems are building-attached rather than building-integrated. The PV systems on the rooftop of the buildings Grosspeter Tower, Flumroc, Viridén and Setz are thus not taken into account in this study. The rooftop-integrated PV system of the apartment building Solaris 416 and Rudolf are very similar to the active glass façade and therefore included in the life cycle assessment.

The PV modules of the buildings considered are either based on monocrystalline-silicon (mono-Si) cells or a copper-indium-gallium-selenide (CI(G)S) thin film. The mono-Si modules of the active glass façades of the residential buildings Viridén and Solaris 416 in Zurich were digitally printed with ceramic ink. Furthermore, the edges of the PV modules for the Grosspeter Tower in Basel were screen-printed. The PV modules of the remaining buildings (Flumroc, Setz, Rudolf) are not coloured.

The analysed buildings are depicted in Fig. 3.1.

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Tab. 3.1 Characterisation of the selected buildings with integrated PV systems.

	Grosspeter Tower	**Flumroc**	**Viridén**	**Solaris 416**	**Setz**	**Rudolf**
Location	Grosspeterstrasse, Basel	Industriestrasse, Flums	Hofwiesen- / Rothstrasse, Zurich	Seestrasse, Zurich	Grabenweg, Möriken	Schubertstrasse, Thun
Building type	Commercial and office building	Office building	Residential building	Residential building	Residential building	Residential building
Construction year	2017	2014 (refurbishment)	2016 (refurbishment)	2017	2019	2013 (refurbishment)
Owner	PSP Real Estate AG	Flumroc AG	EcoRenova AG	huggenbergerfries Architekten AG	Immo Treier AG	Thomas Rudolf
Architect	Burckhardt + Partner AG	Viridén + Partner AG	Viridén + Partner AG	huggenbergerfries Architekten AG	Setz Architektur	Architektur Atelier Adrian Christen
PV system	façade-integrated (440 kWp) rooftop, mounted (100 kWp; *not considered*)	façade-integrated (57.3 kWp) rooftop, mounted (71.3 kWp; *not considered*)	façade-integrated (159 kWp) rooftop, mounted (30 kWp; *not considered*)	façade-integrated (46.5 kWp) rooftop-integrated (25.2 kWp)	façade-integrated (3.57 kWp) rooftop, mounted (*not considered*)	rooftop-integrated (34.6 kWp)
PV façade orientation	South, East, West, North	South-East, South-West, North-East	South, East, West, North	South, East, West, North	South	-
PV module manufacturer	NICE Solar Energy GmbH	Solar Frontier	Kioto Photovoltaics GmbH	LOF Solar	Kioto Photovoltaics GmbH	Meyer Burger
PV technology	CIGS	CIS	monocrystalline silicon	monocrystalline silicon	monocrystalline silicon	monocrystalline silicon PERC
PV module colour	screen printing at the edges (black)	-	satin finish and digital ceramic printing (grey)	digital ceramic printing (red-brown)	-	-
Substructure manufacturer	Sto AG / Hevron SA	gft Fassaden AG	gft Fassaden AG	gft Fassaden AG	BE Netz AG	Meyer Burger
LCIs displayed in	Tab. A. 1; Tab. B. 1	Tab. A. 2; Tab. B. 2	Tab. A. 2; Tab. B. 3	Tab. A. 2; Tab. B. 8	Tab. A. 7; Tab. B. 7	Tab. A. 6; Tab. B. 9

Fig. 3.1 Photographs of the selected buildings with integrated PV systems: 1) Grosspeter Tower, Basel[1]; 2) Flumroc, Flums (Flumroc 2015); 3) Viridén+Partner, Zurich[2]; 4) Solaris 416, Zurich[3]; 5) Setz, Möriken[4]; 6) Rudolf, Thun[5].

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[1] Source and Copyright © Solar Agentur Schweiz (https://www.solaragentur.ch/sites/default/files/gross-peter_tower_basel_1.jpg, accessed on 30.09.2019).

[2] http://www.viriden-partner.ch/plus-nullenergiehaeuser (accessed 30.09.2019).

3.3 Façade constructions

The façade constructions analysed consist of a PV module and a substructure, which can usually be combined independently of each other. However, some components require certain preconditions to be fulfilled. The systems were selected based on the exhibition on active glass façades in the UmweltArena in Spreitenbach as of 2019. Six of the eight exhibitors agreed to provide data for the life cycle assessment of their systems, which are characterised in Tab. 3.2. Another company, Helion, did not have access to primary data but declared that their façade construction shown in the UmweltArena was based on the same components as the system of Ecolite.

Many data providers emphasized the flexibility of their systems with regard to the size, shape and colour of the PV modules. Some manufacturers even offer a selection of different PV technologies (e.g. monocrystalline silicon and multicrystalline silicon cells). The size and shape of PV modules affect the demand of substructure. Smaller PV modules generally require heavier substructure per m^2. The demand of substructure also depends on the wall type and is usually higher for brick walls compared to concrete walls.[6]

Each of the PV module manufacturers offers a range of different colours and coverage ratios. The relative power loss varies depending on the colour, the coverage ratio and the colouring technique. In the life cycle assessment of façade constructions, we analysed typical configurations or focused on a configuration used for a specific building.

Five of the six façade constructions analysed rely on monocrystalline silicon PV modules. The system developed by Sto uses CIGS PV modules. The Solaxess film can generally be applied on any PV module, although the combination with monocrystalline PERC (passivated emitter and rear cell) or heterojunction (HJT) technology results in a lower power loss compared to other technologies.[7] The façade construction developed by René Schmid Architekten AG relies on relatively small PV modules (0.444 m^2) with a wide inactive edge. The PV modules can therefore be installed with different degrees of overlap, which allows a higher share of modules of the same size to be installed. All the PV modules investigated are frameless.

The substructures manufactured by Sto, gft and Ecolite are mainly made of aluminium and stainless steel. Small amounts of glass-fibre reinforced plastic are used to avoid thermal bridges. The manufacturers Eternit and René Schmid Architekten AG / Max Vogelsang AG additionally rely on wood for their substructures.

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3 https://www.hbf.ch/projekte/wohnbauten/wohnhaus-solaris-zuerich/ (accessed on 30.09.2019).

4 Source and Copyright © Setz Architektur AG

5 Source and Copyright © Luftbild Drohne Thun (www.luftbild-drohne-thun.ch)

6 Personal communication Samuel Bregenzer, Ecolite, 10.04.2019 and Dominic Müller, gft, 08.10.2019.

7 Personal communication Peter Röthlisberger, Solaxess, 11.03.2019.

Tab. 3.2 Characterisation of the analysed façade constructions. *[Solaxess has withdrawn from this LCA study after completion of the data collection]*

		Eternit	**Sto**	**Kioto Photovoltaics / gft**	**René Schmid Architekten AG / Max Vogelsang AG**	**Ecolite**	**Solaxess / gft**
	System name	Sunskin Façade	StoVentec ARTline	-	Scaled Active Building Skin	-	-
PV modules	Manufacturer	Kioto Photovoltaics GmbH	NICE Solar Energy GmbH	Kioto Photovoltaics GmbH	Kioto Photovoltaics GmbH	Standard module	3S Solar Plus
	Model	Sunskin Façade	-	PVP-GExxxM	PVP-GE040M	-	SkySlate Black
	Technology	monocrystalline silicon PERC	CIGS	monocrystalline silicon	monocrystalline silicon	monocrystalline silicon	monocrystalline silicon PERC
	Area	1.11 m^2	0.72 m^2	1.69 m^2	0.444 m^2	-	1.64 m^2
	Frame	frameless	frame only for system inlay	usually frameless	frameless	aluminium frame	frameless
	Efficiency	18.0 % (without colour)	9.5 % (without colour)	17.5 % (without colour) 12.5 % (grey colour, 100 % coverage)	9.1 % (grey colour, 55 % coverage)	-	17.1 % (without colour)
	Colour	digital ceramic printing	screen printing	digital ceramic printing	digital ceramic printing	-	Solaxess film
Substructure	Manufacturer	Eternit (Schweiz) AG	Verotec GmbH	gft Fassaden AG	Max Vogelsang AG	Ecolite AG	gft Fassaden AG
	Model	Sunskin Façade	-	GFT 66	-	KA Solar	GFT 66
	Main materials	wood, aluminium, EPDM	aluminium, stainless steel	aluminium, stainless steel	wood, stainless steel	aluminium, stainless steel, glass-fibre reinforced plastic	aluminium, stainless steel
	LCIs displayed in	Tab. A. 3; Tab. B. 6	Tab. A. 1; Tab. B. 1	Tab. A. 2; Tab. B. 4	Tab. A. 4; Tab. B. 5	Tab. A. 5	Tab. A. 2

3.4 Electric installation

Data on the electric installation of two residential buildings with active glass façades were provided by Christian Renken, CR Energie. One system is installed on a single-family house in Aven and has a maximum power output of 3.24 kWp. The other PV system is integrated in the façades of two multi-family houses in Zurich, which have a common grid connection point. The maximum power output of this system is 85.6 kWp.

Both PV systems analysed use micro-inverters, which are mounted on each PV module. Alternating current (AC) cables are then used to connect the PV modules with each other and with the fuse box. Micro-inverters are less common than central inverters combined with power optimisers. Additional information was therefore collected on the differences between the electric installation with AC cabling (micro-inverters) and with direct current (DC) cabling (central inverter).

4 Life cycle inventories

4.1 Overview

The life cycle inventory analysis is divided in the following sub-processes and discussed separately in different Subchapters: active glass façades as used in the six selected buildings (Subchapter 4.2) and façade constructions as exhibited at the UmweltArena in Spreitenbach (Subchapter 4.3).

The life cycle inventory data of the substructures are shown in Annex A. The substructures were modelled using manufacturer-specific data.

The life cycle inventory data of the PV modules are shown in Annex B. CIS and mono-Si PV modules were modelled based on the life cycle inventories described in Frischknecht et al. (2020). The PV modules used at the apartment building Viridén are based on a previous update of the above mentioned study (Frischknecht et al. 2015a). The inventories were adapted with manufacturer-specific information on frame, front glass thickness, thickness of back glass or polyvinyl flouride (PVF) foil use as back sheet, and encapsulation material (ethyl vinyl acetate (EVA), polyolefin elastomer (POE) or polyvinyl butyral (PVB)). The blind modules were modelled by using the inventories of the manufacturer-specific PV modules and removing all components necessary for power generation. PV panel recycling was modelled according to the life cycle inventory described in Stolz et al. (2018).

To model the disposal of the substructures and PV modules, it was assumed that metals and wood are recycled, and plastic parts are disposed of in municipal incinerations. A resource correction was applied for the primary share of all metals (i.e. aluminium, chromium, iron and zinc).

The BOS was modelled based on the life cycle inventories described in Frischknecht et al. (2020). The inventory data is shown in Annex C. The cable lengths and cable diameters as well as the weight of the fuse boxes were adapted according to specific information for each building. The inverters were modelled based on the life cycle inventory described in Tschümperlin et al. (2016b) and scaled according to the mass of the inverters. The power optimizers were modelled as invertors, also scaled with their mass. The lifetime of the inverters and power optimizers is assumed to be 15 years.

4.2 Active glass façades

The inventories of the building-integrated PV systems of the six selected buildings include the façade substructures, PV panels, blind modules, BOS (inverters, power optimizer, cabling, lightning protector, fuse box), joints and edge seals (if applicable) and the disposal of the substructures and PV panels. Due to the lack of information, the colour coatings of the PV modules were not included in the inventory. The active glass façades of the buildings are assumed to have a lifetime of 30 years.

The life cycle inventories were calculated firstly to represent 1 m^2 of each façade (Tab. 4.1), and secondly to model the production of 1 kWh electricity (Tab. 4.2), which takes into account the maximum power and the annual yields of the plants and allows a direct comparison.

Tab. 4.1 Life cycle inventory data of 1m^2 of the PV façade installations of the six selected buildings.

	Name	Location	Infrastructure Process	Unit	PV facade installation, CIS, integrated, 440 kWp, Grosspeter Tower, at building	PV facade installation, CIS, integrated, 57.3 kWp, Flumroc, at building	PV facade and roof installation, single-Si, integrated, 71.7 kWp, Solaris, at building	PV facade installation, single-Si, integrated, 159 kWp, Viridén, at building	PV facade installation, single-Si, integrated, 3.57 kWp, MFH Setz, at building	PV roof installation, single-Si, integrated, 34.56 kWp, MFH Rudolf, at building	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH	CH	CH	CH	CH			
	Infrastructure Process				1	1	1	1	1	1			
	Unit				m2	m2	m2	m2	m2	m2			
product	PV facade installation, CIS, integrated, 440 kWp, Grosspeter Tower, at buil	CH	1	m2	1								
	PV facade installation, CIS, integrated, 57.3 kWp, Flumroc, at building	CH	1	m2		1							
	PV facade and roof installation, single-Si, integrated, 71.7 kWp, Solaris, at I	CH	1	m2			1						
	PV facade installation, single-Si, integrated, 159 kWp, Viridén, at building	CH	1	m2				1					
	PV facade installation, single-Si, integrated, 3.57 kWp, MFH Setz, at buildin	CH	1	m2					1				
	PV roof installation, single-Si, integrated, 34.56 kWp, MFH Rudolf, at buildir	CH	1	m2						1			
technosphere	PV facade installation, single-Si, laminated, integrated, MFH Schaffhauserplatz, all orientations, at building	CH	1	m2				1.00E+0			1	3.01	(3,1,1,1,1,1); PV facade installation
	photovoltaic panel, CIS, Sto, Ventec Artline invisible, at plant	DE	1	m2	9.10E-1						1	3.01	(3,1,1,1,1,1); PV panel
	photovoltaic panel, CIS, Solar Frontier, at plant	JP	1	m2		1.00E+0					1	3.01	(3,1,1,1,1,1); PV panel
	photovoltaic panel, single-Si, MFH Setz, at plant	AT	1	m2					1.00E+0		1	3.01	(3,1,1,1,1,1); PV panel
	photovoltaic panel, facade, single-Si, LOF Solar, at plant	TW	1	m2			5.32E-1				1	3.01	(3,1,1,1,1,1); PV panel
	photovoltaic panel, roof, single-Si, LOF Solar, at plant	TW	1	m2			3.33E-1				1	3.01	(3,1,1,1,1,1); PV panel
	photovoltaic panel, single-Si, Meyer Burger, at plant	CH	1	m2						1.00E+0	1	3.01	(3,1,1,1,1,1); PV panel
	photovoltaic panel, blind, CIS, Sto, Ventec Artline invisible, at plant	DE	1	m2	9.00E-2						1	3.01	(3,1,1,1,1,1); PV panel blind
	photovoltaic panel, blind, CIS, Solar Frontier, at plant	JP	1	m2		0					1	3.01	(3,1,1,1,1,1); PV panel blind
	photovoltaic panel, blind, single-Si, MFH Setz, at plant	AT	1	m2					0		1	3.01	(3,1,1,1,1,1); PV panel blind
	photovoltaic panel, facade, blind, single-Si, LOF Solar, at plant	TW	1	m2			8.31E-2				1	3.01	(3,1,1,1,1,1); PV panel blind
	photovoltaic panel, roof, blind, single-Si, LOF Solar, at plant	TW	1	m2			5.21E-2				1	3.01	(3,1,1,1,1,1); PV panel blind
	photovoltaic panel, blind, single-Si, Meyer Burger, at plant	CH	1	m2						0	1	3.01	(3,1,1,1,1,1); PV panel blind
	takeback and recycling, c-Si PV module	RER	0	kg			2.85E+1		1.86E+1	1.49E+1	1	1.11	(3,1,1,1,1,1); disposal PV panel
	takeback and recycling, CdTe PV module	DE	0	kg	1.68E+01	1.63E+01					1	1.11	(3,1,1,1,1,1); disposal PV panel
	facade substructure, integrated, Sto, Ventec Artline invisible, at plant	DE	1	m2	9.10E-1						1	3.01	(3,1,1,1,1,1); facade substructure
	facade substructure, integrated, medium, GFT, at plant	CH	1	m2		1.00E+0	6.15E-1				1	3.01	(3,1,1,1,1,1); facade substructure
	roof substructure, integrated, small, GFT, at plant	CH	1	m2			3.85E-1				1	3.01	(3,1,1,1,1,1); roof substructure
	facade substructure, integrated, Meyer Burger, at plant	CH	1	m2						1.00E+0	1	3.01	(3,1,1,1,1,1); facade substructure
	facade substructure, integrated, MFH Setz, at plant	CH	1	m2					1.00E+0		1	3.01	(3,1,1,1,1,1); facade substructure
	disposal, facade substructure, integrated, Ventec Artline invisible, Sto, to final disposal	CH	1	m2	9.10E-1						1	3.01	(3,1,1,1,1,1); disposal facade substructure
	disposal, facade substructure, integrated, medium, GFT, to final disposal	CH	1	m2		1.00E+0	6.15E-1				1	3.01	(3,1,1,1,1,1); disposal facade substructure
	disposal, roof construction, integrated, small, GFT, to final disposal	CH	1	m2			3.85E-1				1	3.01	(3,1,1,1,1,1); disposal roof substructure
	disposal, facade substructure, integrated, Meyer Burger, to final disposal	CH	1	m2						1.00E+0	1	3.01	(3,1,1,1,1,1); disposal facade substructure
	disposal, facade substructure, integrated, MFH Setz, to final disposal	CH	1	m2					1.00E+0		1	3.01	(3,1,1,1,1,1); disposal facade substructure
	electric installation, 440 kWp photovoltaic plant, Grosspeter Tower, at plant	CH	1	unit	2.08E-4						1	3.05	(4,1,1,1,1,1); electric installation
	electric installation, photovoltaic plant, at plant	CH	1	unit		4.76E-2					1	3.01	(3,1,1,1,1,1); electric installation
	electric installation, 34.56 kWp photovoltaic plant, MFH Rudolf, at plant	CH	1	unit						4.13E-3	1	3.01	(3,1,1,1,1,1); electric installation
	electric installation, 71.7 kWp photovoltaic plant, Solaris, at plant	CH	1	unit			1.22E-3				1	3.01	(3,1,1,1,1,1); electric installation
	electric installation, 3.24 kWp photovoltaic plant, Sanierung EFH Aven, at plant	CH	1	unit					5.25E-2		1	3.01	(3,1,1,1,1,1); electric installation
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	3.82E+1	3.45E+1	6.06E+1		1.86E+1	3.30E+0	1	2.05	(4,1,1,1,1,1); Transport of substructures and PV panels
	transport, transoceanic freight ship	OCE	0	tkm	0	3.38E+2	6.17E+2		0	0	1	2.05	(4,1,1,1,1,1); Transport of substructures and PV panels
	inverter, 10 kW, average, at plant	RER	1	unit	1.20E-2	7.10E-2	4.26E-2		1.15E-1	2.18E-2	1	3.01	(3,1,1,1,1,1); inverter
	electricity, low voltage, at grid	CH	0	kWh	1.90E-3	1.90E-3	1.90E-3		1.90E-3	1.90E-3	1	1.11	(3,1,1,1,1,1); Energy use for installation; scaled from a 3kWp plant based on area of PV modules
	chromium-nickel steel sheet 18/8, recycling share 2000 (37% Rec.)	CH	0	kg			1.47E+0				1	1.11	(3,1,1,1,1,1); edge seals
	synthetic rubber, at plant	RER	0	kg					3.13E-1		1	1.11	(3,1,1,1,1,1); EPDM joints, data provided by BFH, 2019
resource, in ground	Iron, resource correction	-	-	kg			-4.39E-1				1	1.11	(3,1,1,1,1,1);
	Chromium, resource correction	-	-	kg			-2.20E-1				1	1.11	(3,1,1,1,1,1);
	Nickel, resource correction	-	-	kg			-2.66E-1				1	1.11	(3,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	6.86E-3	6.86E-3	6.86E-3		6.86E-3	6.86E-3	1	1.28	(3,4,3,1,1,5); calculated with electricity use

Tab. 4.2 Life cycle inventory data of the production of 1 kWh electricity with the PV façade installations of the six selected buildings.

	Name	Location	Infrastructure Process	Unit	electricity, PV, at facade installation, CIS, Grosspeter Tower	electricity, PV, at facade installation, CIS, Flumroc	electricity, PV, at facade installation, single-Si, Solaris	electricity, PV, at facade installation, single-Si, Viridén	electricity, PV, at facade installation, single-Si, MFH Setz	electricity, PV, at facade installation, single-Si, MFH Rudolf	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH	CH	CH	CH	CH			
	Infrastructure Process				0	0	0	0	0	0			
	Unit				kWh	kWh	kWh	kWh	kWh	kWh			
product	electricity, PV, at facade installation, CIS, Grosspeter Tower	CH	0	kWh	1								
	electricity, PV, at facade installation, CIS, Flumroc	CH	0	kWh		1							
	electricity, PV, at facade installation, single-Si, Solaris	CH	0	kWh			1						
	electricity, PV, at facade installation, single-Si, Viridén	CH	0	kWh				1					
	electricity, PV, at facade installation, single-Si, MFH Setz	CH	0	kWh					1				
	electricity, PV, at facade installation, single-Si, MFH Rudolf	CH	0	kWh						1			
technosphere	PV facade installation, CIS, integrated, 440 kWp, Grosspeter Tower, at building	CH	1	unit	1.96E-7						1	3.01	(3,1,1,1,1,1);
	PV facade installation, CIS, integrated, 57.3 kWp, Flumroc, at building	CH	1	unit		9.01E-7					1	3.01	(3,1,1,1,1,1);
	PV facade and roof installation, single-Si, integrated, 71.7 kWp, Solaris, at building	CH	1	unit			9.52E-7				1	3.01	(3,1,1,1,1,1);
	PV facade installation, single-Si, integrated, 159 kWp, Viridén, at building	CH	1	unit				7.25E-7			1	3.01	(3,1,1,1,1,1);
	PV facade installation, single-Si, integrated, 3.57 kWp, MFH Setz, at building	CH	1	unit					1.62E-5		1	3.01	(3,1,1,1,1,1);
	PV roof installation, single-Si, integrated, 34.56 kWp, MFH Rudolf, at building	CH	1	unit						9.98E-7	1	3.01	(3,1,1,1,1,1);
	tap water, at user	CH	0	kg	1.88E-2	7.46E-3	1.22E-2	2.35E-2	6.78E-3	4.83E-3	1	1.11	(3,1,1,1,1,1); Estimation 20l/m2 panel
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	1.88E-5	7.46E-6	1.22E-5	2.35E-5	6.78E-6	4.83E-6	1	1.11	(3,1,1,1,1,1); Estimation 20l/m2 panel
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	1.11	(3,1,1,1,1,1); Energy loss in the system is included
emission air	Heat, waste	-	-	MJ	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	1	1.11	(3,1,1,1,1,1); Calculation

4.2.1 Grosspeter Tower, Basel

The active glass façade of Grosspeter Tower in Basel covers an area of 4’800 m^2 and has a power output of 440 kWp. The annual electricity yield of 170’000 kWh/a results in a yield of 386.4 kWh/kWp. A share of 91 % of the total façade area is covered with active PV modules while the remaining 9 % is covered with blind PV modules. Replacement modules and rejects are not considered in the inventory.

The active glass façade system by Sto AG consists of frameless CIS glass-glass PV modules produced by NICE Solar Energy GmbH in Germany (Tab. B. 1) and Ventec ARTline invisible substructure manufactured by Verotec GmbH (Tab. A. 1). The front and back glass thickness is 4 mm and 3 mm, respectively. The PVB encapsulation has a thickness of 0.76 mm. The weight of the module is around 18.5 kg/m^2.

The BOS includes one inverter with a power output of 350 kW and 42 power optimizers with a power output of 5.5 kW (Tab. C 1). No information was available on the weight of the fuse box, which is why it was neglected in the inventory. Cable lengths and diameters were adapted according to building specific data.

4.2.2 Flumroc, Flums

The active glass façade of the Flumroc office building in Flums with an area of 414 m^2 and a power output of 57.3 kWp, has an annual electricity yield of 37’000 kWh/a. This results in an electricity yield of 645.7 kWh/kWp. Replacement modules and rejects are not considered in the inventory. No blind modules are used in the building.

The façade substructure is manufactured by gft (Tab. A. 2, for medium size panels). The cadmium-free CIS PV panels have an aluminium frame and are produced by Solar Frontier in Japan (Tab. B. 2). The front glass thickness is 3.2 mm. The backglass thickness was assumed to be 1 mm. EVA is used for the encapsulation for which a thickness of 2.5 mm was assumed. The weight of the module is 16.3 kg/m^2.

The BOS includes three inverters with a power output of 17 kW and 100 power optimizers with a power output of 0.7 kW (Tab. C 1). Apart from the inverters and the power optimizers, no information on the BOS was available. The electric installation (including cables, fuse box, etc.) was therefore approximated with the life cycle inventory for the electric installation of a 3 kWp PV system described in Frischknecht et al. (2020) and scaled over the area.

4.2.3 Viridén, Zürich

The active glass façade of the apartment building Viridén in Zurich covers an area of 1’620 m^2 and has a power output of 159 kWp. The annual electricity yield of 46’000 kWh/a results in a yield of 289 kWh/kWp (BFE 2018). The facades in all orientations as well as the balcony niches are covered with active PV modules. Thus, 98 % of the total façade area is covered with active PV modules while the remaining 2 % is covered with blind PV modules. The inventory takes into account a replacement module requirement of 2% over the entire lifetime. In addition, it is assumed that 1 % of the modules were rejects.

The active glass façade consists of frameless mono-Si glass-glass PV modules produced by Kioto Photovoltaics GmbH in Austria (Tab. B. 3) and façade substructure manufactured by gft (Tab. A. 2, for medium size panels). The front glass and the back glass have a thickness of 4 mm. The EVA encapsulation has a thickness of 0.4 mm. The weight of the module is 22.7 kg/m^2.

The BOS includes seven inverters with a power output of 17 kW/25 kW and 335 power optimizers with a power output of 0.7 kW. Cable lengths, cable diameters and the weight of the fuse box were adapted according to building specific data (Tab. C 1).

4.2.4 Solaris 416, Zürich

The active glass façade (roof and façade) of the apartment building in Zurich Wollishofen with an area of 640 m^2 and a power output of 71.7 kWp, has an annual electricity yield of 35'000 kWh/a. This results in an electricity yield of 488.1 kWh/kWp. An area of 135 m^2 is covered with blind PV modules. The façade and roof have an area of 502 m^2 and 315 m^2 of which 86 % are covered with active modules. A replacement module requirement and reject rate of 14% for the active PV modules was considered in the inventory.

The façade substructure is manufactured by gft (Tab. A. 2, for medium size panels). The frameless mono-Si PV panels are produced by LOF Solar in Taiwan (Tab. B. 8). The PV panels used for the façade differ from the roof panels. The façade panels have a front and back glass with a thickness of 10 mm and 5 mm, respectively. The front and back glass thickness of the roof panels is 5 mm. PVB is used for the encapsulation with a thickness of 0.76 mm. The weight of the façade panel is 39.5 kg/m^2, while the weight of the roof panel is 24.5 kg/m^2.

The BOS includes four inverters with a power output of 12 kW and 318 power optimizers with a power output of 0.35 kW. Cable lengths, cable diameters and the weight of the fuse box were adapted according to building specific data (Tab. C 1).

The sheet metal edges were modelled as chromium-nickel steel sheets with a recycling share of 37 %.

4.2.5 Setz, Möriken

The south façade of the apartment building Setz in Möriken partly consists of a façade integrated PV system with an area of 21 m^2 and a power output of 3.6 kWp. The annual electricity yield is 2060 kWh/a, which results in a yield of 578 kWh/kWp. Replacement modules and rejects are not considered in the inventory. No blind modules are used in the building.

The façade substructure is manufactured by BE Netz AG (Tab. A. 7). The mono-Si PV modules are manufactured by Kioto Photovoltaics GmbH in Austria and have a weight of 18.6 kg/m^2 (Tab. B. 7). The front and back glass thickness is 3 mm. EVA is used for the encapsulation with a thickness of 2 mm.

The BOS includes one inverter with a power output of 10 kW, one inverter with a power output of 25 kW and 11 power optimizers with a power output of 0.5 kW. The cabling was approximated with a life cycle inventory describing the electric installation of a PV system of a single-family house with a similar power output (3.24 kWp; Tab. C 1). The data was scaled according to the power output.

The inventory of the PV system includes the material for the joints over 18 m horizontally and 14 m vertically (56 x rubber sealing profiles EPDM à 0.0575 kg; 28 x rubber standing profiles EPDM à approx. 0.120 kg). The sheet metal edges (20 m) were modelled as chromium-nickel steel sheets with 37 % recycling share.

4.2.6 Rudolf, Thun

The apartment building Rudolf in Thun has a roof integrated PV system with an area of 242 m^2 and a power output of 34.6 kWp. The electricity yield is 966 kWh/kWp (with an annual electricity yield of 33’400 kWh/a). Replacement modules and rejects are not considered in the inventory. No blind modules are used in the building.

The façade substructure (Tab. A. 6) and mono-Si PV modules (Tab. B. 9) are produced by Meyer Burger Technology AG. The front glass has a thickness of 5 mm. The back sheet is modelled as PVF. The EVA encapsulation has a thickness of 1 mm.

Two inverters with a power output von 15 kW are used. No information was available on the weight of the fuse box, which is why it was neglected in the inventory. Cable lengths and diameters were adapted according to building specific data (Tab. C 1).

4.3 Façade constructions

The inventories of six façade construction systems exhibited at the UmweltArena in Spreitenbach (including systems developed by Eternit, Sto, Kioto Photovoltaics / gft, René Schmid Architekten AG / Max Vogelsang AG, Ecolite and Solaxess / gft) comprise the PV modules and the substructures. The manufacturers of substructures include Eternit (Schweiz) AG, Verotec GmbH, gft Fassaden AG, Max Vogelsang AG and Ecolite AG. The manufacturers of the PV modules include Kioto Photovoltaics GmbH and NICE Solar Energy GmbH. A separate life cycle inventory was set up for each substructure as well as the according PV module. Tab. 4.3 shows the life cycle inventories of the assessed façade construction systems.

Tab. 4.3 Life cycle inventory data of 1m² of the PV façade constructions exhibited at the UmweltArena in Spreitenbach.

	Name	Location	Infrastructure Process	Unit	facade construction, Eternit, at regional storage	facade construction, Sto Ventec ARTline inlay, at regional storage	facade construction, Sto Ventec ARTline invisible, at regional storage	facade construction, Kioto Solar/GFT, at regional storage	facade construction, Vogelsang, at regional storage	facade construction, concrete substrate, Ecolite, at regional storage	facade construction, brick substrate, Ecolite, at regional storage	facade construction, average, Ecolite, at regional storage	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH	CH	CH	CH	CH	CH	CH			
	Infrastructure Process				1	1	1	1	1	1	1	1			
	Unit				m2	m2	m2	m2	m2	m2	m2	m2			
product	facade construction, Eternit, at regional storage	CH	1	m2	1										
	facade construction, Sto Ventec ARTline inlay, at regional storage	CH	1	m2		1									
	facade construction, Sto Ventec ARTline invisible, at regional storage	CH	1	m2			1								
	facade construction, Kioto Solar/GFT, at regional storage	CH	1	m2				1							
	facade construction, Vogelsang, at regional storage	CH	1	m2					1						
	facade construction, concrete substrate, Ecolite, at regional storage	CH	1	m2						1					
	facade construction, brick substrate, Ecolite, at regional storage	CH	1	m2							1				
	facade construction, average, Ecolite, at regional storage	CH	1	m2								1			
technosphere	photovoltaic panel, single-Si, Eternit Sunskin Facade, at plant	AT	1	m2	1.00E+0								1	3.01	(3,1,1,1,1,1,BU:3); PV panel
	photovoltaic panel, CIS, Sto, Ventec Artline inlay, at plant	DE	1	m2		1.00E+0							1	3.01	(3,1,1,1,1,1,BU:3); PV panel
	photovoltaic panel, CIS, Sto, Ventec Artline invisible, at plant	DE	1	m2			1.00E+0						1	3.01	(3,1,1,1,1,1,BU:3); PV panel
	photovoltaic panel, single-Si, Kioto Solar PVP-GExxxM, at plant	AT	1	m2				1.00E+0					1	3.01	(3,1,1,1,1,1,BU:3); PV panel
	photovoltaic panel, single-Si, Vogelsang-Kioto Solar, at plant	AT	1	m2					1.00E+0				1	3.01	(3,1,1,1,1,1,BU:3); PV panel
	photovoltaic panel, single-Si, at plant	RER	1	m2						1.00E+0	1.00E+0	1.00E+0	1	3.01	(3,1,1,1,1,1,BU:3); PV panel
	takeback and recycling, c-Si PV module	RER	0	kg	2.07E+1			2.20E+1	2.25E+1	2.31E+1	2.31E+1	2.31E+1	1	1.11	(3,1,1,1,1,1,BU:1.05); disposal PV panel
	takeback and recycling, CdTe PV module	DE	0	kg		2.05E+1	1.85E+1						1	1.11	(3,1,1,1,1,1,BU:1.05); disposal PV panel
	facade substructure, integrated, Eternit, at plant	AT	1	m2	1.00E+0								1	3.01	(3,1,1,1,1,1,BU:3); facade substructure
	facade substructure, integrated, Sto, Ventec Artline inlay, at plant	DE	1	m2		1.00E+0							1	3.01	(3,1,1,1,1,1,BU:3); facade substructure
	facade substructure, integrated, Sto, Ventec Artline invisible, at plant	DE	1	m2			1.00E+0						1	3.01	(3,1,1,1,1,1,BU:3); facade substructure
	facade substructure, integrated, medium, GFT, at plant	CH	1	m2				1.00E+0					1	3.01	(3,1,1,1,1,1,BU:3); facade substructure
	facade substructure, integrated, Vogelsang, at plant	CH	1	m2					1.00E+0				1	3.01	(3,1,1,1,1,1,BU:3); facade substructure
	facade substructure, integrated, concrete substrate, Ecolite, at plant	CH	1	m2						1.00E+0			1	3.01	(3,1,1,1,1,1,BU:3); facade substructure
	facade substructure, integrated, brick substrate, Ecolite, at plant	CH	1	m2							1.00E+0		1	3.01	(3,1,1,1,1,1,BU:3); facade substructure
	facade substructure, integrated, average, Ecolite, at plant	CH	1	m2								1.00E+0	1	3.01	(3,1,1,1,1,1,BU:3); facade substructure
	disposal, facade substructure, integrated, Eternit, to final disposal	CH	1	m2	1.00E+0								1	3.01	(3,1,1,1,1,1,BU:3); disposal facade substructure
	disposal, facade substructure, integrated, Ventec Artline inlay, Sto, to final disposal	CH	1	m2		1.00E+0							1	3.01	(3,1,1,1,1,1,BU:3); disposal facade substructure
	disposal, facade substructure, integrated, Ventec Artline invisible, Sto, to final disposal	CH	1	m2			1.00E+0						1	3.01	(3,1,1,1,1,1,BU:3); disposal facade substructure
	disposal, facade substructure, integrated, medium, GFT, to final disposal	CH	1	m2				1.00E+0					1	3.01	(3,1,1,1,1,1,BU:3); disposal facade substructure
	disposal, facade substructure, integrated, Vogelsang, to final disposal	CH	1	m2					1.00E+0				1	3.01	(3,1,1,1,1,1,BU:3); disposal facade substructure
	disposal, facade substructure, integrated, concrete substrate, Ecolite, to final disposal	CH	1	m2						1.00E+0			1	3.01	(3,1,1,1,1,1,BU:3); disposal facade substructure
	disposal, facade substructure, integrated, brick substrate, Ecolite, to final disposal	CH	1	m2							1.00E+0		1	3.01	(3,1,1,1,1,1,BU:3); disposal facade substructure
	disposal, facade substructure, integrated, average, Ecolite, to final disposal	CH	1	m2								1.00E+0	1	3.01	(3,1,1,1,1,1,BU:3); disposal facade substructure
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	1.89E+1	5.49E+0	5.18E+0	1.93E+1	2.29E+1	1.53E+1	1.56E+1	1.54E+1	1	2.05	(4,1,1,1,1,1,BU:2); transport services

4.3.1 Eternit

The data used for the life cycle inventory of the façade construction system Sunskin Façade by Eternit refer to a façade construction with frameless, mono-Si PV modules with an area of 1.11 m². The substructure is manufactured by Eternit (Schweiz) AG in Austria (Tab. A. 3). It is made of powder coated aluminium, chromium steel, EPDM rubber and wood. To calculate the area of the aluminium profiles which is powder coated, we assumed that their thickness is 2 mm. The wood was assumed to have a humidity of 10 %.

The mono-Si glass-glass PV modules are frameless and manufactured by Kioto Photovoltaics GmbH (Tab. B. 6). The front and back glass thickness is 4 mm and 3.2 mm, respectively. The POE encapsulation has a thickness of 1.3 mm. The weight of the module is 20.7 kg/m².

4.3.2 Sto

Sto AG manufactures two product lines of façade constructions, i.e. StoVentec ARTline invisible and StoVentec ARTline inlay which were both modelled. The substructures are manufactured by Verotec GmbH in Germany. Materials used for the substructure include blank and anodised aluminium, chromium steel, zinc-coated steel and nylon (Tab. A. 1). To calculate the area of the aluminium profiles that is anodised, we assumed the profile thickness to be 1 mm.

The PV modules used are CIS PV modules produced by NICE Solar Energy in Germany with an area of 0.72 m^2 (Tab. B. 1). The PV modules for the system Sto Ventec ARTline invisible are frameless while those used for the system Sto Ventec ARTline inlay have an aluminium frame. The thickness is 4 mm for the front glass and 3 mm for the back glass. The PVB encapsulation has a thickness of 0.76 mm. The weight of the module for the product line StoVentec ARTline invisible is between 18 and 19 kg/m^2. The panel for the product line StoVentec ARTline inlay has a weight of 20 – 21 kg/m^2.

4.3.3 Kioto Photovoltaics / gft

The active façade construction system exhibited at the UmweltArena in Spreitenbach by Kioto Photovoltaics GmbH consists of PV panels manufactured by Kioto Photovoltaics GmbH with a substructure of gft. Life cycle inventory data for systems with three different PV module sizes (0.8, 1.4 and 2.0 m^2 area) was collected.

Materials used for the substructures comprise blank and anodised aluminium, PVC, EPDM, glass fibre reinforced plastic, chromium steel and silicone adhesive (Tab. A. 2). To calculate the surface area of the anodised aluminium profiles, the profiles were assumed to have a thickness of 1 mm. No specific information on the composition of the used silicone adhesive was available. Therefore, the dataset “silicone product” from the ecoinvent data v2.2 (ecoinvent Centre 2010) was used as an approximation.

The frameless mono-Si glass-glass PV modules are manufactured by Kioto Photovoltaics GmbH (Tab. B. 4). The front and back glass thickness is 4 mm. The POE encapsulation has a thickness of 1 mm. The weight of the module is 22 kg/m^2.

4.3.4 René Schmid Architekten AG / Max Vogelsang AG

The façade construction exhibited at the UmweltArena Spreitenbach developed by René Schmid Architekten AG / Max Vogelsang AG consists of a wooden substructure manufactured by Max Vogelsang AG and mono-Si PV modules manufactured by Kioto Photovoltaics GmbH.

The substructures consist mainly of wood and chromium steel (Tab. A. 4). The frameless glass-glass PV modules have an area of 0.44 m^2 (Tab. B. 5). The front and back glass thickness is 4 mm. The EVA encapsulation has a thickness of 1 mm. The weight of the module is 22.5 kg/m^2.

4.3.5 Ecolite

The façade construction system with substructures manufactured by Ecolite as exhibited at the UmweltArena Spreitenbach consists of a substructure manufactured by Ecolite in Switzerland and mono-Si PV modules. The PV modules are modelled as the standard modules inventories described in Frischknecht et al. (2020).

Ecolite provided data for the substructure system KA Solar installed on a concrete substrate as well as on a brick substrate (Tab. A. 5). It is supposed that façade constructions on a brick substrate are slightly more material-intensive, as fixing must take place in the brick and not in the mortar. According to Ecolite, 60 % of the façade constructions are installed on a brick substrate, while 40 % are installed on a concrete substrate. Using this information, we calculated the market average for Ecolite substructures. Ecolite uses blank aluminium, chromium steel, EPDM, Polyoxymethylene and glass fibre reinforced plastic. The aluminium used is blank, coated, or anodised (no exact shares were provided). As an approximation, we assumed that the same shares of blank and anodised aluminium are used as gft Fassaden AG uses. In the life cycle inventory, polyoxymethylene was approximated with polymethyl methacrylate.

5 Life cycle impact assessment: Active glass façades

5.1 Overview

The life cycle assessment quantifies the environmental impacts of the building-integrated PV systems of six buildings per 1 m^2. Tab. 5.1 shows the gross environmental impacts (all impacts attributed to electricity production) as well as the net environmental impacts (impacts of front glass and substructure attributed to the building, remaining impacts attributed to electricity production) per m^2 active glass façade. The gross and net environmental impacts per 1 kWh produced electricity are shown in Tab. 5.2.

The lowest environmental impacts according to non-renewable CED and UBP per m^2 active glass façade/roof are caused by the roof-integrated PV system of the apartment building Rudolf. The façade-integrated PV system of the Grosspeter Tower causes the lowest greenhouse gas emissions per m^2.

Tab. 5.1 Overview of the environmental impacts of the active glass façades of the six selected buildings per m^2 (gross: all impacts attributed to electricity production; net: impacts of front glass and substructure attributed to the building, remaining impacts attributed to electricity production).

		unit	Overall environmental impact	Cumulative energy demand			Greenhouse gas emissions
				total	non-renewable	renewable	
			UBP	kWh oil-eq	kWh oil-eq	kWh oil-eq	kg CO_2-eq
Grosspeter Tower	gross	m^2	583'000	683	619	63.7	145
	net	m^2	526'000	461	428	33.0	99.1
Flumroc	gross	m^2	804'000	1'050	948	105	221
	net	m^2	741'000	802	731	71.0	170
Solaris	gross	m^2	445'000	1'150	1'050	107	291
	net	m^2	357'000	807	745	62.0	218
Viridén	gross	m^2	409'000	1'080	992	92.4	237
	net	m^2	344'000	824	766	58.0	183
Setz	gross	m^2	611'000	1'420	1'270	151	316
	net	m^2	526'000	1'050	956	94.0	245
Rudolf	gross	m^2	256'000	693	610	82.3	162
	net	m^2	212'000	551	499	52.0	132

The lowest gross environmental impacts (according to all impact assessment indicators) per kWh produced electricity are caused by the roof-integrated PV system of the apartment building Rudolf. The highest cumulative energy demand per kWh produced electricity is associated to the façade-integrated PV system of the apartment building Viridén. According to the ecological scarcity method, the highest impacts per kWh produced electricity are caused by the façade-integrated PV system of the Grosspeter Tower. 1 kWh electricity produced with the façade- and roof-integrated PV system of the apartment building Solaris causes the highest greenhouse gas emissions.

Tab. 5.2 Overview of the gross environmental impacts of 1 kWh electricity caused by the active glass façades of the six buildings (gross: all impacts attributed to electricity production; net: impacts of front glass and substructure attributed to the building, remaining impacts attributed to electricity production).

		unit	Overall environmental impact	Cumulative energy demand			Greenhouse gas emissions
				total	non-renewable	renewable	
			UBP	kWh oil-eq	kWh oil-eq	kWh oil-eq	kg CO_2-eq
Grosspeter Tower	**gross**	kWh	553	1.71	0.583	1.13	0.136
	net	kWh	499	1.50	0.402	1.10	0.093
Flumroc	**gross**	kWh	304	1.46	0.354	1.11	0.082
	net	kWh	280	1.37	0.273	1.10	0.063
Solaris	**gross**	kWh	347	1.97	0.815	1.15	0.226
	net	kWh	280	1.70	0.579	1.12	0.169
Viridén	**gross**	kWh	485	2.34	1.16	1.18	0.278
	net	kWh	408	2.04	0.900	1.14	0.215
Setz	**gross**	kWh	211	1.55	0.430	1.12	0.107
	net	kWh	182	1.43	0.324	1.10	0.083
Rudolf	**gross**	kWh	65.6	1.24	0.147	1.09	0.039
	net	kWh	55.0	1.20	0.120	1.08	0.032

The net environmental impacts of 1 kWh electricity produced by the active glass façades of the six buildings are between 8 % and 32 % lower (depending on the impact indicator and building) than the gross environmental impacts.

5.2 Ecological scarcity method 2013

The overall environmental impacts are assessed with the Swiss eco-factors 2013 according to the ecological scarcity method and expressed in eco-points (UBP, Umweltbelastungspunkte). The highest gross overall environmental impacts caused by 1 m^2 active glass façade is 804’000 UBP/m^2 (Flumroc), while the lowest is 256’000 UBP/m^2 (Rudolf).

CIS PV panels (used at Grosspeter Tower, Flumroc) generally cause higher overall environmental impacts than mono-Si panels due to the use of Indium as raw material. The PV panels thus account for 61 % and 74 % of the overall environmental impacts caused by 1 m^2 active glass façade of Flumroc and Grosspeter Tower, respectively. The substructures are responsible for a comparibly low share of the overall environmental impacts.

Large differences among the selected buildings can be seen in terms of the overall environmental impacts caused by the inverters and power optimisers. The highest contributions can be seen in the buildings Viridén and Setz, where they cause 38 % and 51 % of the overall environmental impacts per m^2, respectively. In both buildings the power optimisers (not the inverters) are mainly responsible for this large contribution.

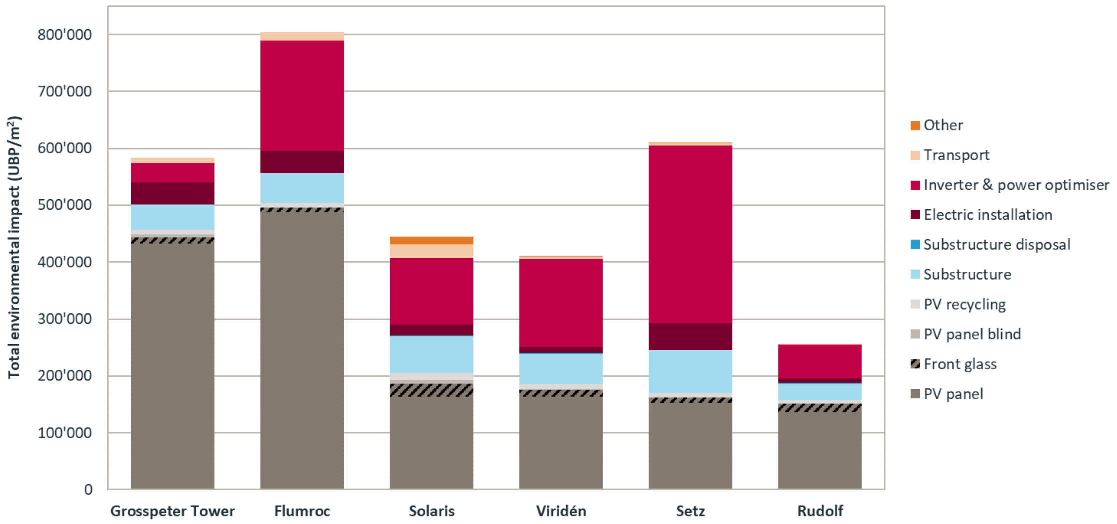

Fig. 5.1 Gross overall environmental impacts in UBP per m² active glass façade of the six selected buildings divided into the impacts associated to PV panels, blind PV panels, substructure, disposals of PV panels and substructures, BOS, transport and other (edge seals, joints).

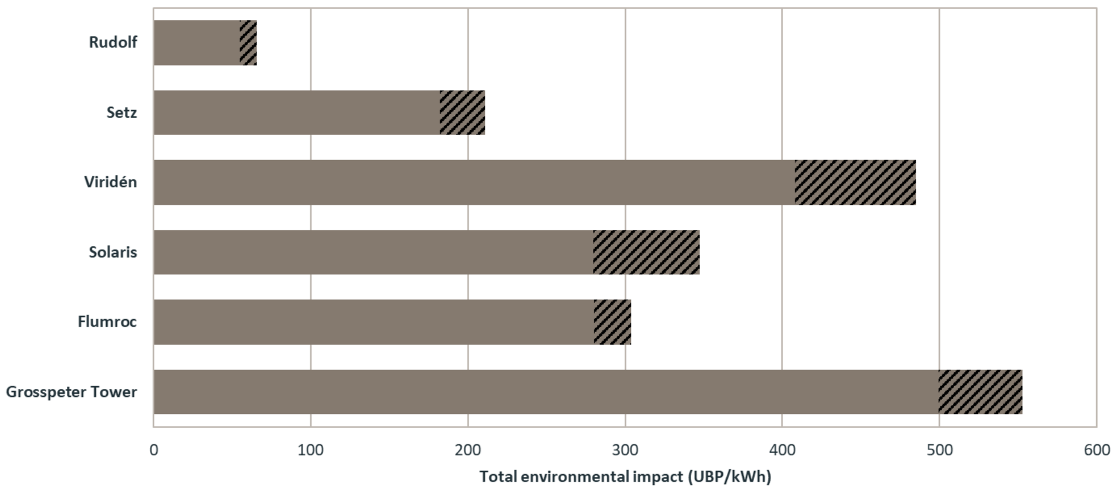

Fig. 5.2 Gross overall environmental impacts in UBP per kWh electricity produced by the active glass façades of the six buildings. The shaded area can be attributed to the building and not the electricity production.

The highest gross overall environmental impacts per kWh produced electricity is caused by the façade-integrated PV system of the Grosspeter Tower (553 UBP/kWh). This is due to a comparably low specific electricity yield of 386 kWh/kWp. The same is applicable for the building Viridén, which has a specific electricity yield of 289 kWh/kWp, causing the comparably high gross overall environmental impacts per kWh (485 UBP/kWh), even though the overall environmental impacts per m² active glass façade are at the lower end compared to the remaining buildings. The comparibly low specific electricity yield per kWp and thus also the high overall environmental impacts per kWh can be explained by the fact, that the entire façade (including parts with low solar irradiation such as the north façade and balcony niches) is covered with active PV panels.

The front glass and substructure, which can be attributed to the weather protection layer of the building make up between 8 % and 20 % of the overall environmental impacts per m^2 façade construction and kWh produced electricity. The building Solaris has the highest share which can be attributed to the building, reducing the overall environmental impact per kWh produced electricity by 68 UBP/kWp.

5.3 Cumulative energy demand

The cumulative energy demand is determined according to the approach developed by Frischknecht et al. (2015b). The non-renewable cumulative energy demand per 1 m^2 active glass façade and per kWh produced electricity varies largely among the six buildings (Fig. 5.3, Fig. 5.4). The highest gross non-renewable CED per m^2 is caused by the apartment building Setz (1’270 kWh oil-eq/m^2). The apartment building Rudolf causes the lowest gross non-renewable CED with 610 kWh oil-eq/m^2 and 0.147 kWh oil-eq/kWh.

The PV panels, substructures and power optimisers (Flumroc, Solaris, Viridén, Setz) are the main contributors to the non-renewable cumulative energy demand per m^2 active glass façade of the buildings. The supply of CIS PV panels (used at Grosspeter Tower, Flumroc) is slightely less energy intense than the supply of mono-Si PV panels (used at Solaris, Viridén, Setz, Rudolf).

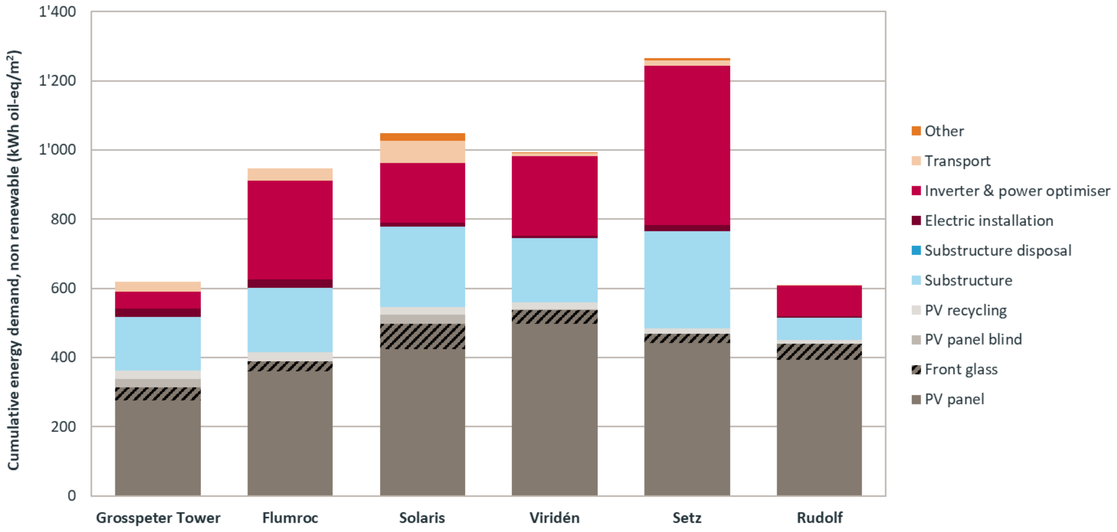

Fig. 5.3 Gross cumulative energy demand, non-renewable (in kWh oil-eq) per m^2 active glass façade of the six selected buildings divided into the impacts associated to PV panels, blind PV panels, substructure, disposals of PV panels and substructures, BOS, transport and other (edge seals, joints).

The highest non-renewable cumulative energy demand per kWh produced electricity is caused by the façade-integrated PV system of the apartment building Viridén (1.16 kWh oil-eq/kWh). It needs to be taken into consideration, that the life cycle inventory data of the PV panels used at the building Viridén are based on a previous update of the study used for the rest of the PV panels. This might lead to a slight overestimation of the CED, and the environmental impacts in general, of the PV-panels used at Viridén.

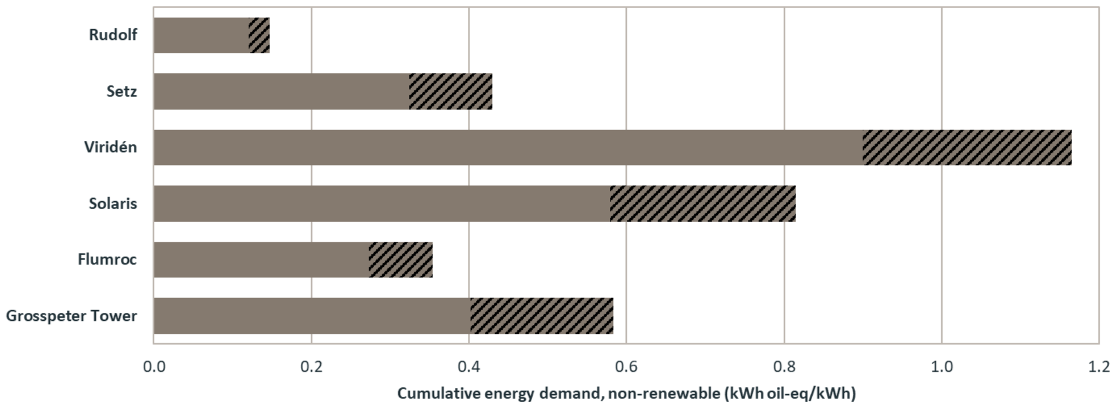

Fig. 5.4 Gross cumulative energy demand, non-renewable (in kWh oil-eq) per kWh electricity produced by the active glass façades of the six buildings. The shaded area can be attributed to the building and not the electricity production.

The front glass and substructure, which can be attributed to the weather protection layer of the building make up between 18 % and 31 % of the overall environmental impacts per m^2 and kWh. The Grosspeter Tower has the highest share which can be attributed to the building, reducing the overall environmental impact per kWh produced electricity to 0.402 kWh oil-eq/kWp.

5.4 Greenhouse gas emissions

The impact indicator greenhouse gas emissions includes all greenhouse gases, which are regulated within the Kyoto Protocol. They are weighted according to their global warming potential (GWP) specified in the latest IPCC report (IPCC 2013) over a time horizon of 100 years and summed up. The building-integrated PV systems of the apartment buildings Setz and Solaris cause the highest gross greenhouse gas emissions per m^2 (316 kg CO_2-eq/m^2 and 291 kg CO_2-eq/m^2, respectively). The lowest greenhouse gas emissions per m^2 are around 50 % lower (145 kg CO_2-eq/m^2, Grosspeter Tower).

As for the environmental impact indicators CED and UBP, the results according to the indicator GHG are mainly characterized by the components PV panel, substructures and power optimizers (Flumroc, Solaris, Viridén, Setz). Generally, in the production of CIS PV panels less greenhouse gases are emitted than in the production of mono-Si PV panels.

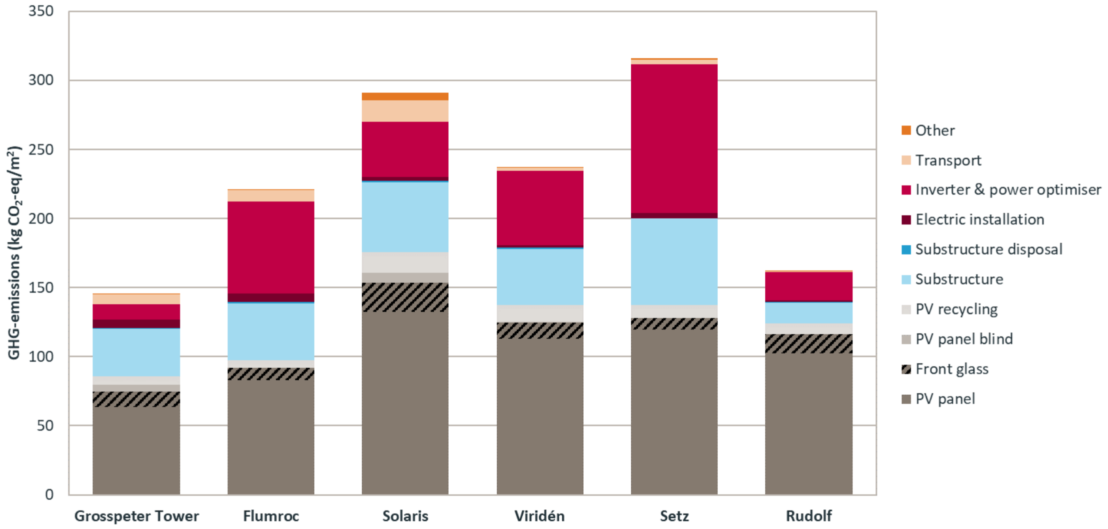

Fig. 5.5 Gross greenhouse gas emissions (in kg CO_2-eq) per m² active glass façade of the six selected buildings divided into the impacts associated to PV panels, blind PV panels, substructure, disposals of PV panels and substructures, BOS, transport and other (edge seals, joints).

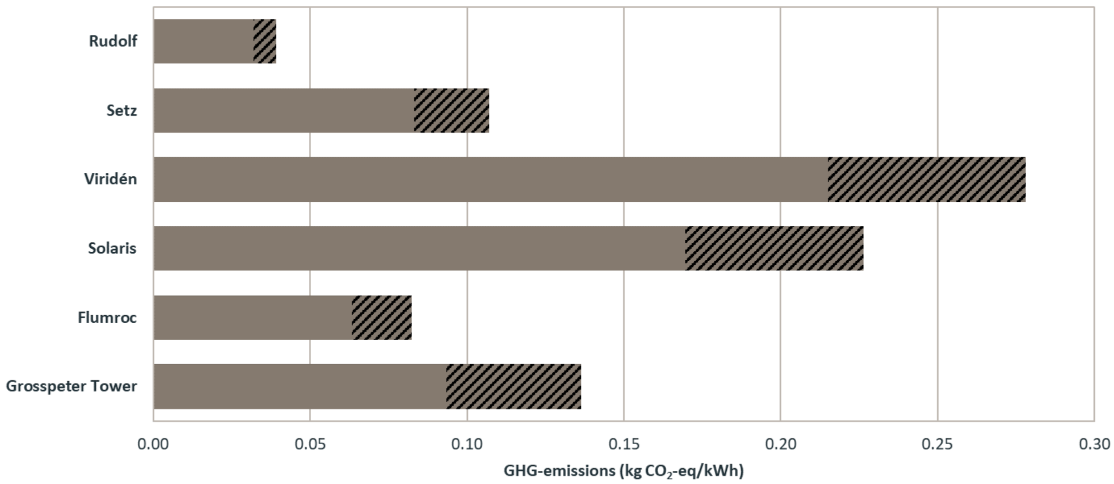

Fig. 5.6 Gross greenhouse gas emissions (in kg CO_2-eq) per kWh electricity produced by the active glass façades of the six buildings. The shaded area can be attributed to the building and not the electricity production.

The front glass and substructure, which can be attributed to the weather protection layer of the building make up between 18 % and 32 % of the overall environmental impacts per m² and kWh. The Grosspeter Tower has the highest share which can be attributed to the building, reducing the overall environmental impact per kWh produced electricity to 0.093 kg CO_2-eq/kWp.

6 Life cycle impact assessment: Façade constructions

6.1 Overview

The environmental impacts per m^2 of the analised façade construction systems are summarized in Tab. 6.1.

Tab. 6.1 Overview of the environmental impacts of the active glass façade construction systems (and the contributions of the substructures and PV panels thereof) exhibited at the UmweltArena in Spreitenbach per m^2 façade construction.

	unit	Overall environmental impact	Cumulative energy demand			Greenhouse gas emissions
			total	non-renewable	renewable	
		UBP	kWh oil-eq	kWh oil-eq	kWh oil-eq	kg CO_2-eq
Eternit	m^2	180'000	554	504	50.3	144
thereof substructure	m^2	3'320	16.2	12.1	4.17	2.70
thereof PV panel	m^2	172'000	523	477	45.4	138
Sto Ventec ARTline inlay	m^2	552'000	614	552	62.3	132
thereof substructure	m^2	38'600	144	123	21.1	27.7
thereof PV panel	m^2	512'000	466	425	41.0	104
Sto Ventec ARTline invisible	m^2	546'000	604	544	59.5	126
thereof substructure	m^2	49'700	202	170	31.8	38.3
thereof PV panel	m^2	495'000	398	370	27.4	87.2
Kioto Solar/GFT	m^2	231'000	760	680	79.9	184
thereof substructure	m^2	53'200	220	187	33.5	42.0
thereof PV panel	m^2	173'000	525	479	45.7	139
René Schmid Architekten AG / Max Vogelsang AG	m^2	205'000	681	557	124	157
thereof substructure	m^2	26'100	133	55.9	77.2	13.0
thereof PV panel	m^2	173'000	529	483	46.1	140
Ecolite concrete substrate	m^2	240'000	829	739	90.9	193
thereof substructure	m^2	61'700	263	224	38.8	50.2
thereof PV panel	m^2	174'000	555	503	51.6	140
Ecolite brick substrate	m^2	251'000	875	778	96.8	202
thereof substructure	m^2	72'500	308	263	44.7	59.4
thereof PV panel	m^2	174'000	555	503	51.6	140
Ecolite average	m^2	246'000	857	762	94.5	199
thereof substructure	m^2	68'200	290	247	42.3	55.7
thereof PV panel	m^2	174'000	555	503	51.6	140

6.2 Ecological scarcity method 2013

The two active glass façade construction systems developed by Sto AG (Sto Ventec ARTline inlay and invisible) with CIS modules produced by NICE Solar Energy in Germany cause the highest overall environmental impact according to the ecological scarcity method 2013 (552’000 UBP/m^2 and 546’000 UBP/m^2, Fig. 6.1). This can be associated to the generally higher environmental impacts of CIS PV modules compared to mono-Si modules due to the use of Indium as raw material. All analysed mono-Si PV panels cause a very similar overall environmental impact (between 160’000 and 170’000 UBP/m^2).

The lowest impact is caused by system Sunskin Façade by Eternit (180’000 UBP/m^2) due to the substructure which, thanks to a very lightweight structure, causes a very low environmental impact, contributing only 3’320 UBP/m^2. Compared with the PV modules, the substructures are generally responsible for a rather low share of the overall environmental impacts of the active glass façade constuction systems (between 2 % and 29 %).

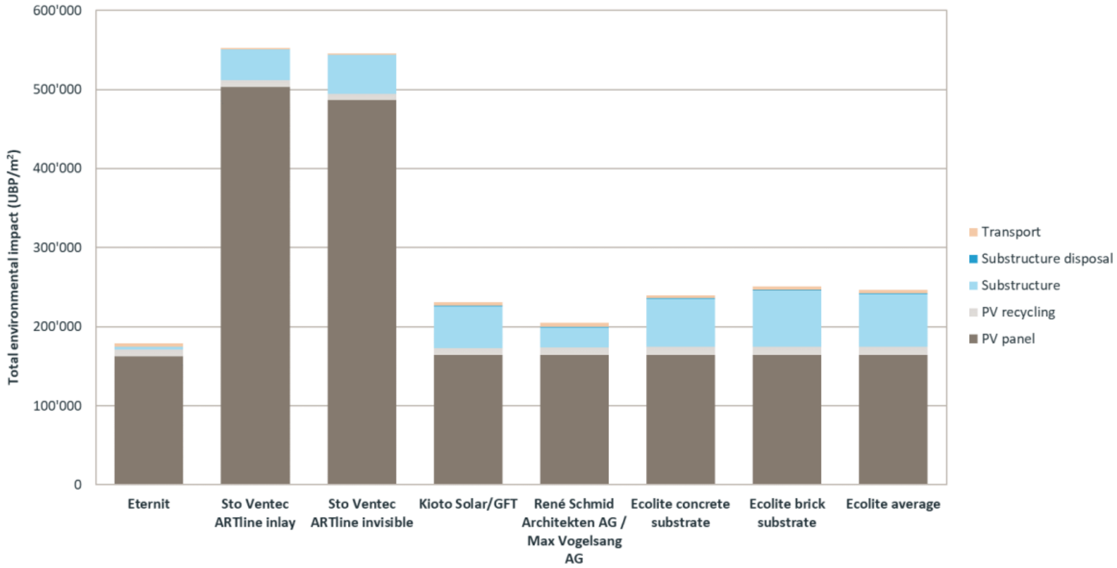

Fig. 6.1 Overall environmental impacts (in UBP) per m^2 active glass façade construction divided into the impacts associated to PV panels, substructure, end of life treatment of PV panels and substructures and transport.

6.3 Cumulative energy demand

The lowest non-renewable cumulative energy demand can be attributed to the façade construction system Sunskin Façade by Eternit (504 kWh oil-eq/m^2, Fig. 6.2). The highest non-renewable cumulative energy demand is caused by the façade construction system developed by Ecolite on brick substrate (778 kWh oil-eq/m^2)

The non-renewable cumulative energy demand of systems with CIS PV panels and systems with mono-Si PV panels does not differ as much as for the overall environmental impact. However, CIS PV panels are generally less energy intensive in the production compared to mono-Si PV panels. With regard to the manufacture of the substructures, it is noticeable that the substructures of Eternit (lightweight) and René Schmid Architekten AG / Max Vogelsang AG (wooden) cause considerably lower cumulative energy demands.

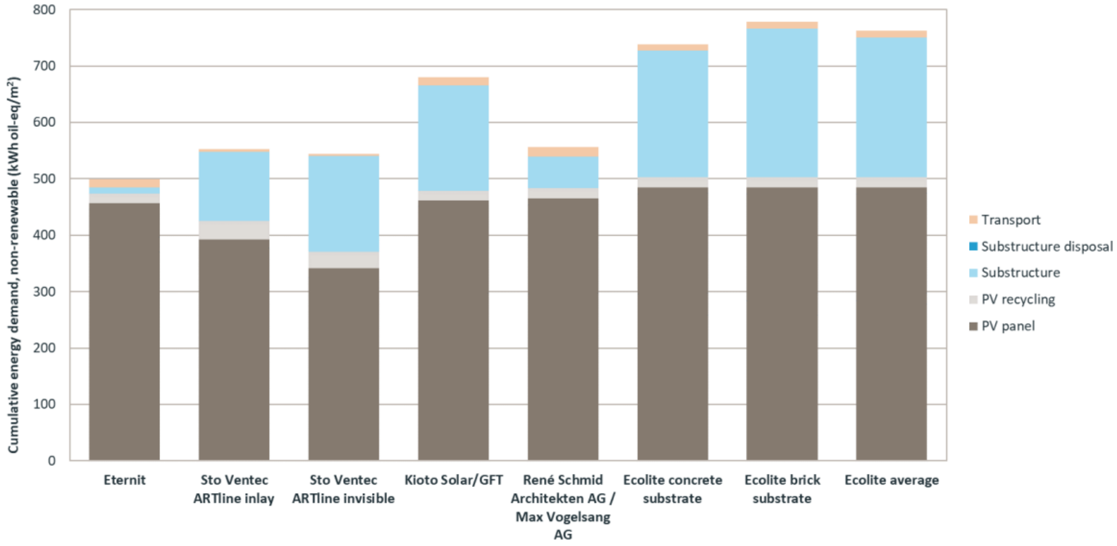

Fig. 6.2 Cumulative energy demand, non-renewable (in kWh oil-eq) per m^2 active glass façade construction divided into the impacts associated to PV panels, substructure, end of life treatment of PV panels and substructures and transport.

6.4 Greenhouse gas emissions

The lowest greenhouse gas emissions per m^2 are caused by the façade constructions systems Sto Ventec ARTline inlay and invisible (132 kg CO_2-eq/m^2 and 126 kg CO_2-eq/m^2, respectively, Fig. 6.3). This can be mainly attributed to the lower greenhouse gas emissions of CIS PV panels compared to mono-Si panels. The highest GHG emissions are attributed to the façade construction system by Ecolite (193 – 202 kg CO_2-eq/m^2). Generally, the PV modules are the main contributors to the greenhouse gas emissions of the active glass façade constuction systems (between 70 % and 98 %).

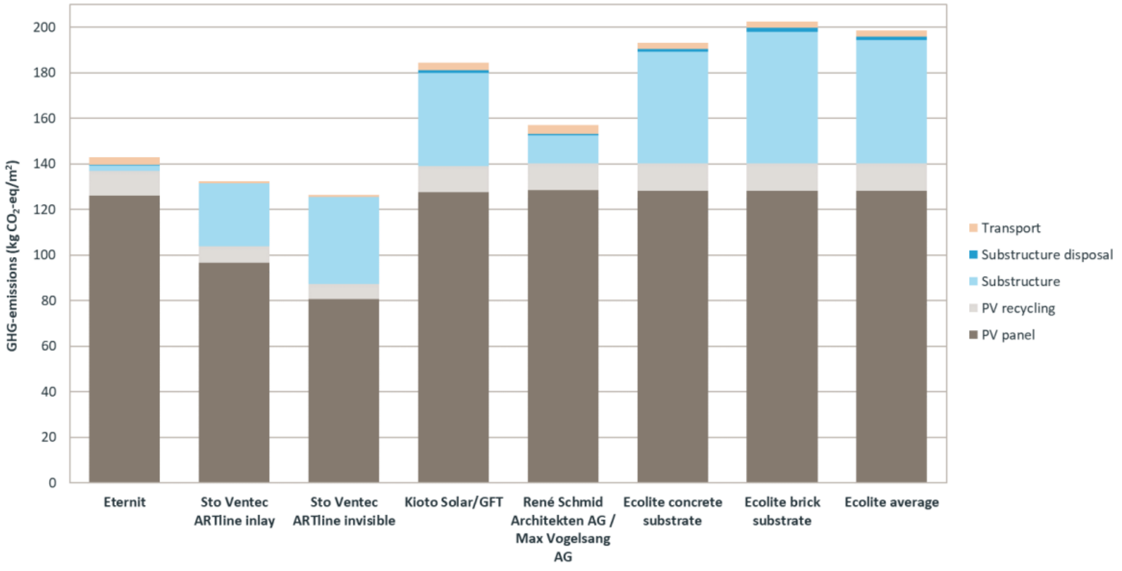

Fig. 6.3 Greenhouse gas emissions (in kg CO_2-eq) per m^2 active glass façade construction divided into the impacts associated to PV panels, substructure, end of life treatment of PV panels and substructures and transport.

7 Data quality and uncertainty

The data quality is generally considered to be good as it was collected directly from architects, installers and manufacturers.

Only limited data was available on electric installations. These depend strongly on the specific PV system (in particular length of cables for PV module strings and connections to the solar inverter and fuse box, presence of power optimisers and micro-inverters). Life cycle inventory data is missing for microinverters and power optimisers, which were therefore modelled with life cycle inventories of solar inverters, and scaled by mass.

Furthermore, no information was available on the digital printing of the PV modules. The impacts were claimed to be negligible by the manufactureres in most cases. The relative efficiency loss due to the digital printing of the PV modules is a source of uncertainty. It depends on colour and coverage ratio (higher efficiency loss with brighter colours and increasing coverage ratio).

The calculated weigth per area of the modelled PV panels does not exactly meet the information given by the producers. The panels were modelled based on life cycle inventories described in Frischknecht et al. (2020) and adapted according to manufacturer-specific information on frame, front glass thickness, thickness of back glass or polyvinyl flouride (PVF) foil used as back sheet, and encapsulation material. These components make up a large fraction of the total panel weight however there might be weight differences in other components of the panels, which might lead to over- or underestimation of the environmental impacts of a specific PV panel. The difference between the modelled weight and the weigth given by the producers is between – 3.5 % and + 0.3 %.

8 Consolidation of life cycle inventories of PV systems

The life cycle inventories of PV supply chains and module manufacture were updated and consolidated and ducumented in an updated version of the PVPS Task 12 LCI Report (Frischknecht et al. 2020). The following data were updated and consolidated:

- c-Si supply chain (update of market situation and key parameters)
- CIS PV modules (update of key parameters)
- CdTe PV modules (Series 4 and Series 6; updated based on information and data from FirstSolar)
- Perovskite-silicon tandem PV modules (compiled by Mariska de Wild-Scholten, incorporated into UVEK LCA data DQRv2:2018 by treeze)
- Residential scale solar inverters (updated by treeze, Tschümperlin et al. 2016b)
- National PV electricity mixes / PV module efficiencies (updated by treeze, Stolz & Frischknecht 2019)
- PV module recycling (compiled by treeze, Stolz et al. 2018)
- Water footprint (to be applied on updated LCIs of PV modules, Stolz & Frischknecht 2017)

The corresponding EcoSpoldv1 files with updated metadata are available for download.[8]

[8] https://iea-pvps.org/key-topics/life-cycle-inventories-and-life-cycle-assessments-of-photovoltaic-systems, accessed on 21 December 2021.

9 Conclusions and Recommendations

9.1 Conclusions

The environmental impacts of BIPV building elements are mainly influenced by PV technology (crystalline silicon versus thin film PV panels), the amount of glass used in the PV panels and the presence of power optimisers. Same is valid for the environmental impacts of BIPV electricity which is additionally strongly influenced by the specific yield of the PV system.

In general, between 7 % and 31 % (depending on the impact indicator and building) of the environmental impacts can be allocated to the weather protection layer of the building. However, the environmental benefits of the multifunctionality of BIPV elements (weather protection and electricity production) is compensated by reduced yields due to colouring and partly suboptimal orientation of the panels.

The consolidated life cycle inventories of PV panels and their supply chains resulted in substantially lower specific environmental impacts (Frischknecht et al. 2020).

9.2 Recommendations

To reduce the environmental impacts of BIPV electricity, we recommend to develop and apply colour coatings with less impact on the PV panel efficiency. The specific yield of the PV systems could thereby be increased which would lead to a reduction of the environmental impacts per kWh produced electricity. Furthermore, we recommend to cross-check the material efficiency of BIPV panels in particular in terms of glass thickness.

Due to their high contribution to the total environmental impacts in the current study, we recommend to establish life cycle inventories of microinverters and power optimisers. This would open up the possibility to assess their environmental benefits (increased electricity production) in comparison to the environmental impacts caused by their supply.

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A Annex: Façade substructures

Tab. A. 1 Life cycle inventory data of the manufacture and disposal of Sto substructures as used at Grosspeter Tower.

	Name	Location	Infrastructure Process	Unit	facade substructure, integrated, Sto, Ventec Artline inlay, at plant	facade substructure, integrated, Sto, Ventec Artline invisible, at plant	disposal, facade substructure, integrated, Ventec Artline inlay, Sto, to final disposal	disposal, facade substructure, integrated, Ventec Artline invisible, Sto, to final disposal	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				DE	DE	CH	CH			
	Infrastructure Process				1	1	1	1			
	Unit				m2	m2	m2	m2			
product	facade substructure, integrated, Sto, Ventec Artline inlay, at plant	DE	1	m2	1						
	facade substructure, integrated, Sto, Ventec Artline invisible, at plant	DE	1	m2		1					
	disposal, facade substructure, integrated, Ventec Artline inlay, Sto, to final disposal	CH	1	m2			1				
	disposal, facade substructure, integrated, Ventec Artline invisible, Sto, to final disposal	CH	1	m2				1			
technosphere	aluminium profile, uncoated	CH	0	kg	3.13E+0	5.22E+0			1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Sto, 2019
	anodising, aluminium sheet	RER	0	m2	5.03E-1	0			1	1.21	(4,1,1,1,1,1,BU:1.05); assumption of aluminium profile thickness: 1 mm; data provided by Sto, 2019
	chromium steel sheet 18, recycling share 2000 (37% Rec.)	CH	0	kg	1.12E+0	1.12E+0			1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Sto, 2019
	chromium steel product manufacturing, average metal working	RER	0	kg	1.12E+0	1.12E+0			1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	steel, low-alloyed, at plant	RER	0	kg	3.40E-1	3.40E-1			1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Sto, 2019
	steel product manufacturing, average metal working	RER	0	kg	3.40E-1	3.40E-1			1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	zinc coating, pieces	RER	0	m2	2.04E-2	2.04E-2			1	1.21	(4,1,1,1,1,1,BU:1.05); assumption mean surface area = 0.06 m2 / kg;
	nylon 6, at plant	RER	0	kg	3.40E-2	3.40E-2			1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Sto, 2019
	transport, freight, lorry, fleet average	RER	0	tkm	4.63E-01	6.72E-01			1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
	transport, freight, rail	DE	0	tkm	1.51E+0	1.93E+0			1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
resource, in ground	Aluminium, resource correction	-	-	kg	-1.60E+0	-2.67E+0			1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Zinc, resource correction	-	-	kg	-2.14E-2	-2.14E-2			1	1.21	(4,1,1,1,1,1,BU:1.05); 1.05 kg Zinc / m2;
	Iron, resource correction	-	-	kg	-5.39E-1	-5.39E-1			1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Chromium, resource correction	-	-	kg	-1.68E-1	-1.68E-1			1	1.21	(4,1,1,1,1,1,BU:1.05); ;
technosphere	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg			4.01E-2	4.01E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); ;

Tab. A. 2 Life cycle inventory data of the manufacture and disposal of gft substructures for three different panel sizes (average size small: 0.8 m^2; medium: 1.4 m^2; large: 2 m^2) for façade and roof as used in the façade constructions system Kioto Photovoltaics / gft and the buildings Flumroc, Viridén, and Solaris.

	Name	Location	Infrastructure Process	Unit	facade substructure, integrated, small, GFT, at plant	facade substructure, integrated, medium, GFT, at plant	facade substructure, integrated, large, GFT, at plant	roof substructure, integrated, small, GFT, at plant	disposal, facade substructure, integrated, small, GFT, to final disposal	disposal, facade substructure, integrated, medium, GFT, to final disposal	disposal, facade substructure, integrated, large, GFT, to final disposal	disposal, roof construction, integrated, small, GFT, to final disposal	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH	CH	CH	CH	CH	CH	CH			
	Infrastructure Process				1	1	1	1	1	1	1	1			
	Unit				m2	m2	m2	m2	m2	m2	m2	m2			
product	facade substructure, integrated, small, GFT, at plant	CH	1	m2	1										
	facade substructure, integrated, medium, GFT, at plant	CH	1	m2		1									
	facade substructure, integrated, large, GFT, at plant	CH	1	m2			1								
	roof substructure, integrated, small, GFT, at plant	CH	1	m2				1							
	disposal, facade substructure, integrated, small, GFT, to final disposal	CH	1	m2					1						
	disposal, facade substructure, integrated, medium, GFT, to final disposal	CH	1	m2						1					
	disposal, facade substructure, integrated, large, GFT, to final disposal	CH	1	m2							1				
	disposal, roof construction, integrated, small, GFT, to final disposal	CH	1	m2								1			
technosphere	aluminium profile, uncoated	CH	0	kg	1.08E+1	5.20E+0	4.33E+0	8.79E+0					1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by gft Fassaden AG, 2019
	anodising, aluminium sheet	RER	0	m2	2.83E+0	1.46E+0	1.49E+0	2.71E+0					1	1.21	(4,1,1,1,1,1,BU:1.05); assumption of aluminium profile thickness: 1 mm; data provided by gft
	chromium steel sheet 18, recycling share 2000 (37% Rec.)	CH	0	kg	4.98E-1	4.82E-1	3.22E-2	8.60E-2					1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by gft Fassaden AG, 2019
	chromium steel product manufacturing, average metal working	RER	0	kg	4.98E-1	4.82E-1	3.22E-2	8.60E-2					1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	polyvinylchloride, at regional storage	RER	0	kg	4.95E-2	9.83E-3	0	0					1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by gft Fassaden AG, 2019
	injection moulding	RER	0	kg	4.95E-2	9.83E-3	0	0					1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	synthetic rubber, at plant	RER	0	kg	0	6.10E-3	1.07E-2	0					1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by gft Fassaden AG, 2019
	silicone product, at plant	RER	0	kg	9.05E-1	3.70E-1	3.16E-1	7.13E-1					1	1.21	(4,1,1,1,1,1,BU:1.05); approximation for silicone adhesive; data provided by gft Fassaden AG, 2019
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	4.88E-2	5.00E-2	0	0					1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by gft Fassaden AG, 2019
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	6.13E-1	3.06E-1	2.34E-1	4.80E-1					1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
	transport, freight, rail, electricity with shunting	CH	0	tkm	2.66E+0	1.42E+0	9.51E-1	1.95E+0					1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
resource, in ground	Aluminium, resource correction	-	-	kg	-5.54E+0	-2.67E+0	-2.22E+0	-4.50E+0					1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Iron, resource correction	-	-	kg	-2.39E-1	-2.32E-1	-1.54E-2	-4.13E-2					1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Chromium, resource correction	-	-	kg	-7.47E-2	-7.23E-2	-4.82E-3	-1.29E-2					1	1.21	(4,1,1,1,1,1,BU:1.05); ;
technosphere	disposal, polyvinylchloride, 0.2% water, to municipal incineration	CH	0	kg					4.95E-2	9.83E-3	0	0	1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg					1.13E+0	5.03E-1	3.86E-1	8.42E-1	1	1.11	(3,1,1,1,1,1,BU:1.05); ;

Tab. A. 3 Life cycle inventory data of the manufacture and disposal of Eternit substructures as used in the façade construction system Sunskin Façade by Eternit.

	Name	Location	Infrastructure Process	Unit	facade substructure, integrated, Eternit, at plant	disposal, facade substructure, integrated, Eternit, to final disposal	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				AT	CH			
	Infrastructure Process				1	1			
	Unit				m2	m2			
product	facade substructure, integrated, Eternit, at plant	AT	1	m2	1				
product	disposal, facade substructure, integrated, Eternit, to final disposal	CH	1	m2		1			
technosphere	aluminium sheet, uncoated	CH	0	kg	4.00E-1		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Eternit (Schweiz) AG, 2019
	powder coating, aluminium sheet	RER	0	m2	7.43E-2		1	1.21	(4,1,1,1,1,1,BU:1.05); assumption of aluminium profile thickness: 2 mm;
	chromium steel sheet 18, recycling share 2000 (37% Rec.)	CH	0	kg	1.00E-2		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Eternit (Schweiz) AG, 2019
	chromium steel product manufacturing, average metal working	RER	0	kg	1.00E-2		1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	sawnwood, beam, softwood, dried (u=10%), planed, at sawmill	AT	0	m3	7.31E-4		1	1.11	(3,1,1,1,1,1,BU:1.05); density: 465 kg / m3; data provided by Eternit (Schweiz) AG, 2019
	synthetic rubber, at plant	RER	0	kg	1.50E-2		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Eternit (Schweiz) AG, 2019
	transport, freight, lorry, fleet average	RER	0	tkm	4.25E-02		1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
	transport, freight, rail	AT	0	tkm	8.91E-2		1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
resource, in ground	Aluminium, resource correction	-	-	kg	-2.05E-1		1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Iron, resource correction	-	-	kg	-4.80E-3		1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Chromium, resource correction	-	-	kg	-1.50E-3		1	1.21	(4,1,1,1,1,1,BU:1.05); ;
technosphere	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg		1.77E-2	1	1.11	(3,1,1,1,1,1,BU:1.05); ;

Tab. A. 4 Life cycle inventory data of the manufacture and disposal of René Schmid Architekten AG / Max Vogelsang AG substructures as used in the façade construction René Schmid Architekten AG / Max Vogelsang AG.

	Name	Location	Infrastructure Process	Unit	facade substructure, integrated, Vogelsang, at plant	disposal, facade substructure, integrated, Vogelsang, to final disposal	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH			
	Infrastructure Process				1	1			
	Unit				m2	m2			
product	facade substructure, integrated, Vogelsang, at plant	CH	1	m2	1				
	disposal, facade substructure, integrated, Vogelsang, to final disposal	CH	1	m2		1			
technosphere	steel, low-alloyed, at plant	RER	0	kg	5.00E-1		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Max Vogelsang, 2019
	steel product manufacturing, average metal working	RER	0	kg	5.00E-1		1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	chromium steel sheet 18, recycling share 2000 (37% Rec.)	CH	0	kg	1.80E+0		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Max Vogelsang, 2019
	chromium steel product manufacturing, average metal working	RER	0	kg	1.80E+0		1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	sawnwood, beam, softwood, dried (u=10%), planed, at sawmill	CH	0	m3	2.69E-2		1	1.11	(3,1,1,1,1,1,BU:1.05); density: 465 kg / m3; data provided by Max Vogelsang, 2019
	synthetic rubber, at plant	RER	0	kg	1.00E-1		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Max Vogelsang, 2019
	polyester resin, unsaturated, at plant	RER	0	kg	1.00E-1		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Max Vogelsang, 2019
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	1.26E-01		1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
	transport, freight, rail, electricity with shunting	CH	0	tkm	1.22E+0		1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
resource, in ground	Iron, resource correction	-	-	kg	-1.10E+0		1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Chromium, resource correction	-	-	kg	-2.70E-1		1	1.21	(4,1,1,1,1,1,BU:1.05); ;
technosphere	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg		2.36E-1	1	1.11	(3,1,1,1,1,1,BU:1.05); ;

Tab. A. 5 Life cycle inventory data of the manufacture and disposal of Ecolite substructures as used in the façade constructions Ecolite.

	Name	Location	Infrastructure Process	Unit	facade substructure, integrated, concrete substrate, Ecolite, at plant	facade substructure, integrated, brick substrate, Ecolite, at plant	facade substructure, integrated, average, Ecolite, at plant	disposal, facade substructure, integrated, concrete substrate, Ecolite, to final disposal	disposal, facade substructure, integrated, brick substrate, Ecolite, to final disposal	disposal, facade substructure, integrated, average, Ecolite, to final disposal	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH	CH	CH	CH	CH			
	Infrastructure Process				1	1	1	1	1	1			
	Unit				m2	m2	m2	m2	m2	m2			
product	facade substructure, integrated, concrete substrate, Ecolite, at plant	CH	1	m2	1								
	facade substructure, integrated, brick substrate, Ecolite, at plant	CH	1	m2		1							
	facade substructure, integrated, average, Ecolite, at plant	CH	1	m2			1						
	disposal, facade substructure, integrated, concrete substrate, Ecolite, to final disposal	CH	1	m2				1					
	disposal, facade substructure, integrated, brick substrate, Ecolite, to final disposal	CH	1	m2					1				
	disposal, facade substructure, integrated, average, Ecolite, to final disposal	CH	1	m2						1			
technosphere	aluminium profile, uncoated	CH	0	kg	6.20E+0	7.10E+0	6.74E+0				1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Ecolite AG, 2019
	anodising, aluminium sheet	RER	0	m2	1.83E+0	2.10E+0	1.99E+0				1	1.21	(4,1,1,1,1,1,BU:1.05); assumption that share of anodised aluminium is equal to average of gft substructures; assumption of aluminium profile thickness: 1 mm;
	chromium steel sheet 18, recycling share 2000 (37% Rec.)	CH	0	kg	2.00E-1	3.00E-1	2.60E-1				1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Ecolite AG, 2019
	chromium steel product manufacturing, average metal working	RER	0	kg	2.00E-1	3.00E-1	2.60E-1				1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	synthetic rubber, at plant	RER	0	kg	5.00E-3	5.00E-3	5.00E-3				1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Ecolite AG, 2019
	polymethyl methacrylate, sheet, at plant	RER	0	kg	5.00E-3	5.00E-3	5.00E-3				1	1.11	(3,1,1,1,1,1,BU:1.05); approximation for Polyoxymethylene; data provided by Ecolite AG, 2019
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	4.00E-1	6.00E-1	5.20E-1				1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Ecolite AG, 2019
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	3.41E-01	4.01E-01	3.77E-01				1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
	transport, freight, rail, electricity with shunting	CH	0	tkm	1.44E+0	1.72E+0	1.61E+0				1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
resource, in ground	Aluminium, resource correction	-	-	kg	-3.18E+0	-3.64E+0	-3.45E+0				1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Iron, resource correction	-	-	kg	-9.60E-2	-1.44E-1	-1.25E-1				1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Chromium, resource correction	-	-	kg	-3.00E-2	-4.50E-2	-3.90E-2				1	1.21	(4,1,1,1,1,1,BU:1.05); ;
technosphere	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg				4.84E-1	7.20E-1	6.26E-1	1	1.11	(3,1,1,1,1,1,BU:1.05); ;

Tab. A. 6 Life cycle inventory data of the manufacture and disposal of Meyer Burger substructures used at the MFH Rudolf.

	Name	Location	Infrastructure Process	Unit	facade substructure, integrated, Meyer Burger, at plant	disposal, facade substructure, integrated, Meyer Burger, to final disposal	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH			
	Infrastructure Process				1	1			
	Unit				m2	m2			
product	facade substructure, integrated, Meyer Burger, at plant	CH	1	m2	1				
product	disposal, facade substructure, integrated, Meyer Burger, to final disposal	CH	1	m2		1			
technosphere	chromium steel sheet 18, recycling share 2000 (37% Rec.)	CH	0	kg	2.93E+0		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by Meyer Burger, 2019
	chromium steel product manufacturing, average metal working	RER	0	kg	2.93E+0		1	1.11	(3,1,1,1,1,1,BU:1.05); ;
	sawnwood, beam, softwood, dried (u=10%), planed, at sawmill	CH	0	m3	8.26E-3		1	1.11	(3,1,1,1,1,1,BU:1.05); density: 465 kg / m3; data provided by Meyer Burger, 2019
	synthetic rubber, at plant	RER	0	kg	1.00E-1		1	1.11	(3,1,1,1,1,1,BU:1.05); assumption based on data provided by Max Vogelsang AG for similar substructures;
	polyester resin, unsaturated, at plant	RER	0	kg	1.00E-1		1	1.11	(3,1,1,1,1,1,BU:1.05); assumption based on data provided by Max Vogelsang AG for similar substructures;
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	1.57E-01		1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
	transport, freight, rail, electricity with shunting	CH	0	tkm	1.80E+0		1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
resource, in ground	Iron, resource correction	-	-	kg	-1.40E+0		1	1.21	(4,1,1,1,1,1,BU:1.05); ;
	Chromium, resource correction	-	-	kg	-4.38E-1		1	1.21	(4,1,1,1,1,1,BU:1.05); ;
technosphere	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg		2.36E-1	1	1.11	(3,1,1,1,1,1,BU:1.05); ;

Tab. A. 7 Life cycle inventory data of the manufacture and disposal of BE Netz AG substructures used at the MFH Setz.

	Name	Location	Infrastructure Process	Unit	facade substructure, integrated, MFH Setz, at plant	disposal, facade substructure, integrated, MFH Setz, to final disposal	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH			
	Infrastructure Process				1	1			
	Unit				m2	m2			
product	facade substructure, integrated, MFH Setz, at plant	CH	1	m2	1				
	disposal, facade substructure, integrated, MFH Setz, to final disposal	CH	1	m2		1			
technosphere	aluminium profile, uncoated	CH	0	kg	2.68E+0		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by BFH, 2019
	anodising, aluminium sheet	RER	0	m2	7.92E-1		1	1.11	(3,1,1,1,1,1,BU:1.05); assumption that share of anodised aluminium is equal to average of gft
	aluminium sheet, uncoated	CH	0	kg	6.86E+0		1	1.11	(3,1,1,1,1,1,BU:1.05); ; data provided by BFH, 2019
	powder coating, aluminium sheet	RER	0	m2	1.28E+0		1	1.11	(3,1,1,1,1,1,BU:1.05); assumption of aluminium profile thickness: 2 mm;
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	4.77E-01		1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
	transport, freight, rail, electricity with shunting	CH	0	tkm	1.91E+0		1	2.05	(4,1,1,1,1,1,BU:2); based on standard distances ecoinvent 2, report 1;
resource, in ground	Aluminium, resource correction	-	-	kg	-4.89E+0	0	1	1.21	(4,1,1,1,1,1,BU:1.05); ;

B Annex: PV panels

Tab. B. 1 Life cycle inventory data of the manufacture of CIS PV panels for the Sto Ventec ARTline inlay and invisible systems, manufactured by NICE Solar Energy GmbH in Germany used at Grosspeter Tower. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available (entries in red letters).

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, CIS, Sto, Ventec Artline inlay, at plant	photovoltaic panel, CIS, Sto, Ventec Artline invisible, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE	DE			
	InfrastructureProcess				1	1			
	Unit				m2	m2			
product	photovoltaic panel, CIS, Sto, Ventec Artline inlay, at plant	DE	1	m2	1	0			
	photovoltaic panel, CIS, Sto, Ventec Artline invisible, at plant	DE	1	m2	0	1			
technosphere	electricity, medium voltage, at grid	DE	0	kWh	4.47E+01	4.47E+1	1	1.07	(1,1,1,1,1,3); company information, coating, air-conditioning, water purification, etc.
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	1.55E+01	1.55E+1	1	1.07	(1,1,1,1,1,3); Raugei, literature
	photovoltaic panel factory	GLO	1	unit	4.00E-06	4.00E-6	1	3.02	(1,4,1,3,1,3); Assumption
	aluminium alloy, AlMg3, at plant	RER	0	kg	2.20E+00	0	1	1.07	(1,1,1,1,1,3); data provided by Sto, 2019
	copper, at regional storage	RER	0	kg	9.77E-03	9.77E-3	1	1.07	(1,1,1,1,1,3); company information
	wire drawing, copper	RER	0	kg	9.77E-03	9.77E-3	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	aluminium, production mix, at plant	RER	0	kg	4.44E-02	4.44E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	flat glass, uncoated, at plant	RER	0	kg	7.50E+00	7.50E+0	1	1.07	(1,1,1,1,1,3); data provided by Sto, 2019
	diode, unspecified, at plant	GLO	0	kg	1.44E-03	1.44E-3	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	silicone product, at plant	RER	0	kg	4.04E-01	4.04E-1	1	1.07	(1,1,1,1,1,3); company information; Kleber
	molybdenum, at regional storage	RER	0	kg	6.06E-03	6.06E-3	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	indium, at regional storage	RER	0	kg	2.82E-03	2.82E-3	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	cadmium sulphide, semiconductor-grade, at plant	US	0	kg	2.69E-04	2.69E-4	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	gallium, semiconductor-grade, at regional storage	RER	0	kg	8.99E-04	8.99E-4	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	selenium, at plant	RER	0	kg	5.60E-03	5.60E-3	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	tin, at regional storage	RER	0	kg	1.23E-02	1.23E-2	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	solar glass, low-iron, at regional storage	RER	0	kg	1.00E+01	1.00E+1	1	1.07	(1,1,1,1,1,3);
	tempering, flat glass	RER	0	kg	1.00E+01	1.00E+1	1	1.07	(1,1,1,1,1,3); Assumption
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	4.00E-02	4.00E-2	1	1.07	(1,1,1,1,1,3); Raugei, literature
	flux, wave soldering, at plant	GLO	0	kg	1.23E-2	1.23E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	zinc oxide, at plant	RER	0	kg	9.09E-3	9.09E-3	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.36E-1	3.36E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	4.84E-2	4.84E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyvinylbutyral foil, at plant	RER	0	kg	1.03E+0	1.03E+0	1	1.07	(1,1,1,1,1,3); data provided by Sto, 2019
	polyphenylene sulfide, at plant	GLO	0	kg	8.59E-2	8.59E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	tap water, at user	RER	0	kg	1.31E+2	1.31E+2	1	1.07	(1,1,1,1,1,3); company information
	argon, liquid, at plant	RER	0	kg	1.90E-2	1.90E-2	1	1.07	(1,1,1,1,1,3); protection gas, company information
	butyl acrylate, at plant	RER	0	kg	1.01E-1	1.01E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	diborane, at plant	GLO	0	kg	2.01E-4	2.01E-4	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	sulphuric acid, liquid, at plant	RER	0	kg	3.31E-2	3.31E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrogen sulphide, H2S, at plant	RER	0	kg	1.91E-1	1.91E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	3.34E-2	3.34E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrogen peroxide, 50% in H2O, at plant	RER	0	kg	2.31E-2	2.31E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	9.94E-2	9.94E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	nitrogen, liquid, at plant	RER	0	kg	1.57E+1	1.57E+1	1	1.07	(1,1,1,1,1,3); protection gas, company information
	ammonia, liquid, at regional storehouse	RER	0	kg	9.29E-2	9.29E-2	1	1.07	(1,1,1,1,1,3); dip coating for CdS, company information
	urea, as N, at regional storehouse	RER	0	kg	1.15E-3	1.15E-3	1	1.16	(3,1,3,1,1,3); dip coating for CdS, Ampenberg 1998
	EUR-flat pallet	RER	0	unit	5.00E-2	5.00E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	transport, freight, lorry, fleet average	RER	0	tkm	3.84E+0	3.62E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km
	transport, freight, rail	RER	0	tkm	2.28E+1	2.15E+1	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, waste, Si waferprod., inorg, 9.4% water, to residual material landfill	CH	0	kg	2.02E-2	2.02E-2	1	1.24	(3,1,1,1,3,3); company information, amount of deposited waste, own estimation for type
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.81E+0	1.81E+0	1	1.07	(1,1,1,1,1,3); Calculation for plastic parts burned after recycling
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	6.50E-1	6.50E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	disposal, glass, 0% water, to municipal incineration	CH	0	kg	4.64E+0	4.64E+0	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	1.31E-1	1.31E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
emission air, high population density	Heat, waste	-	-	MJ	1.61E+2	1.61E+2	1	1.07	(1,1,1,1,1,3); Calculation
	Cadmium	-	-	kg	2.10E-8	2.10E-8	1	5.09	(3,4,3,3,1,5); Rough estimation

Tab. B. 2 Life cycle inventory data of the manufacture of CIS PV panels of Solar Frontier used at the office building Flumroc. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available (entries in red letters).

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, CIS, Solar Frontier, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				JP			
	InfrastructureProcess				1			
	Unit				m2			
product	photovoltaic panel, CIS, Solar Frontier, at plant	JP	1	m2	1			
technosphere	electricity, medium voltage, at grid	JP	0	kWh	4.47E+1	1	1.07	(1,1,1,1,1,3); company information, coating, air-conditioning, water purification, etc.
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	1.55E+1	1	1.07	(1,1,1,1,1,3); Raugei, literature
	photovoltaic panel factory	GLO	1	unit	4.00E-6	1	3.02	(1,4,1,3,1,3); Assumption
	aluminium alloy, AlMg3, at plant	RER	0	kg	2.20E+0	1	1.07	(1,1,1,1,1,3); Assumption
	copper, at regional storage	RER	0	kg	9.77E-3	1	1.07	(1,1,1,1,1,3); company information
	wire drawing, copper	RER	0	kg	9.77E-3	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	aluminium, production mix, at plant	RER	0	kg	4.44E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	flat glass, uncoated, at plant	RER	0	kg	2.50E+0	1	1.07	(1,1,1,1,1,3); company information
	diode, unspecified, at plant	GLO	0	kg	1.44E-3	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	silicone product, at plant	RER	0	kg	4.04E-1	1	1.07	(1,1,1,1,1,3); data provided by Flumroc, 2019; Kleber
	molybdenum, at regional storage	RER	0	kg	6.06E-3	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	indium, at regional storage	RER	0	kg	2.82E-3	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	gallium, semiconductor-grade, at regional storage	RER	0	kg	8.99E-4	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	selenium, at plant	RER	0	kg	5.60E-3	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	tin, at regional storage	RER	0	kg	1.23E-2	1	1.13	(3,2,2,1,1,3); company information and assumption for share of metals
	solar glass, low-iron, at regional storage	RER	0	kg	8.00E+0	1	1.07	(1,1,1,1,1,3); data provided by Flumroc, 2019
	tempering, flat glass	RER	0	kg	8.00E+0	1	1.07	(1,1,1,1,1,3); Assumption
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	4.00E-2	1	1.07	(1,1,1,1,1,3); Raugei, literature
	ethylvinylacetate, foil, at plant	RER	0	kg	2.50E+0	1	1.07	(1,1,1,1,1,3); company information
	flux, wave soldering, at plant	GLO	0	kg	1.23E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	zinc oxide, at plant	RER	0	kg	9.09E-3	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.36E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	4.84E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyvinylbutyral foil, at plant	RER	0	kg	1.89E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyphenylene sulfide, at plant	GLO	0	kg	8.59E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	tap water, water balance according to MoeK 2013, at user	JP	0	kg	1.31E+2	1	1.07	(1,1,1,1,1,3); company information
	argon, liquid, at plant	RER	0	kg	1.90E-2	1	1.07	(1,1,1,1,1,3); protection gas, company information
	butyl acrylate, at plant	RER	0	kg	1.01E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	diborane, at plant	GLO	0	kg	2.01E-4	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	sulphuric acid, liquid, at plant	RER	0	kg	3.31E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrogen sulphide, H2S, at plant	RER	0	kg	1.91E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	3.34E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrogen peroxide, 50% in H2O, at plant	RER	0	kg	2.31E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	9.94E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	nitrogen, liquid, at plant	RER	0	kg	1.57E+1	1	1.07	(1,1,1,1,1,3); protection gas, company information
	ammonia, liquid, at regional storehouse	RER	0	kg	9.29E-2	1	1.07	(1,1,1,1,1,3); dip coating for CdS, company information
	urea, as N, at regional storehouse	RER	0	kg	1.15E-3	1	1.16	(3,1,3,1,1,3); dip coating for CdS, Ampenberg 1998
	EUR-flat pallet	RER	0	unit	5.00E-2	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	transport, freight, lorry, fleet average	RER	0	tkm	3.33E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km
	transport, freight, rail	RER	0	tkm	1.96E+1	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, waste, Si waferprod., inorg, 9.4% water, to residual material landfill	CH	0	kg	2.02E-2	1	1.24	(3,1,1,1,3,3); company information, amount of deposited waste, own estimation for type
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	3.78E+0	1	1.07	(1,1,1,1,1,3); Calculation for plastic parts burned after recycling
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	6.50E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	disposal, glass, 0% water, to municipal incineration	CH	0	kg	2.78E+0	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	1.31E-1	1	1.07	(1,1,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
emission air, high population density	Heat, waste	-	-	MJ	1.61E+2	1	1.07	(1,1,1,1,1,3); Calculation

Tab. B. 3 Life cycle inventory data of the manufacture of mono-Si PV panels of Kioto Photovoltaics GmbH used at the MFH Viridén. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available.

	Name	Location	InfrastructureProcess	Unit	photovoltaic laminate, single-Si, PVP Photovoltaik, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				AT			
	InfrastructureProcess				1			
	Unit				m2			
	photovoltaic laminate, single-Si, PVP Photovoltaik, at plant	AT	1	m2	1			
technosphere	electricity, medium voltage, at grid	AT	0	kWh	7.28E+0	1	1.14	(3,3,1,1,1,3); PVP Photovoltaik
	natural gas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	0	1	1.14	(3,3,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diesel, burned in building machine, average	CH	0	MJ	8.75E-3	1	2.09	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic panel factory	GLO	1	unit	4.00E-6	1	3.02	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, single-Si, Gintech Energy, at plant	TW	0	m2	8.78E-1	1	1.13	(1,4,1,3,1,3); PVP Photovoltaik; 48 cells with an area of 0.156x0.156 m2; Module size: 0.99x1.39 m2
	aluminium alloy, AlMg3, at plant	RER	0	kg	0	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	copper, at regional storage	RER	0	kg	1.03E-1	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	wire drawing, copper	RER	0	kg	1.03E-1	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	silicone product, at plant	RER	0	kg	1.22E-1	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	nickel, 99.5%, at plant	GLO	0	kg	0	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	brazing solder, cadmium free, at plant	RER	0	kg	0.00E+00	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tin, at regional storage	RER	0	kg	1.29E-2	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	lead, at regional storage	RER	0	kg	7.25E-4	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	silver, at regional storage	RER	0	kg	0	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	solar glass, low-iron, at regional storage	RER	0	kg	1.02E+1	1	1.24	(1,4,1,3,3,3); PVP Photovoltaik; Front glass of 0.004 m thickness; Density glass: 2500 kg/m3; Production in Slowenia
	flat glass, uncoated, at plant	RER	0	kg	1.02E+1	1	1.24	(1,4,1,3,3,3); PVP Photovoltaik; back glass of 0.004 m thickness ; Density glass: 2500 kg/m3; Production in Slowenia
	tempering, flat glass	RER	0	kg	1.02E+1	1	1.13	(1,4,1,3,1,3); PVP Photovoltaik; Front glass of 0.004 m thickness; Density glass: 2500 kg/m3; Production in Slowenia
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	ethylvinylacetate, foil, at plant	RER	0	kg	7.81E-1	1	1.13	(1,4,1,3,1,3); PVP Photovoltaik; 2 EVA layers of 0.0004 m thickness; Density EVA: 955 kg/m3; Production in Belgium
	polyvinylfluoride film, at plant	US	0	kg	1.12E-1	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tap water, at user	RER	0	kg	5.03E+0	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	acetone, liquid, at plant	RER	0	kg	0	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	methanol, at regional storage	CH	0	kg	0	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	vinyl acetate, at plant	RER	0	kg	0	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	lubricating oil, at plant	RER	0	kg	0	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	1-propanol, at plant	RER	0	kg	1.59E-2	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	isopropanol, at plant	RER	0	kg	1.47E-4	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	soap, at plant	RER	0	kg	1.16E-2	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	EUR-flat pallet	RER	0	unit	5.00E-2	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	transport, freight, lorry, fleet average	RER	0	tkm	5.73E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100 km, cells 380 km, glass 430 km, EVA 580 km
	transport, freight, rail	RER	0	tkm	9.05E+0	1	2.09	(4,5,na,na,na,na); Standard distance 600 km, glass 430 km, EVA 580 km
	transport, transoceanic freight ship	OCE	0	tkm	3.85E+0	1	2.09	(4,5,na,na,na,na); Transport of cells from Taiwan to Croatia (8030 km)
	transport, aircraft, freight	RER	0	tkm	0	1	2.09	(4,5,na,na,na,na);
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	1	1.13	(1,4,1,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.68E-2	1	1.13	(1,4,1,3,1,3); Production losses
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, waste, Si waferprod., inorg, 9.4% water, to residual material landfill	CH	0	kg	2.89E-2	1	1.13	(1,4,1,3,1,3); Production losses
	disposal, glass, 0% water, to inert material landfill	CH	0	kg	4.40E-1	1	1.13	(1,4,1,3,1,3); Production losses
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	5.03E-3	1	1.13	(1,4,1,3,1,3); Calculation, water use
emission air, high population density	Heat, waste	-	-	MJ	1.34E+1	1	1.29	(3,4,3,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	1	1.61	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	1	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)

Tab. B. 4 Life cycle inventory data of the manufacture of mono-Si PV panels of Kioto Photovoltaics GmbH as used in the façade constructions Kioto Photovoltaics / gft. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available (entries in red letters).

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, single-Si, Kioto Solar PVP-GExxxM, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				AT			
	InfrastructureProcess				1			
	Unit				m2			
	photovoltaic panel, single-Si, Kioto Solar PVP-GExxxM, at plant	AT	1	m2	1			
technosphere	photovoltaic cell, single-Si, at regional storage	RER	0	m2	9.35E-1	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	copper, at regional storage	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	wire drawing, copper	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	silicone product, at plant	RER	0	kg	1.22E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	tin, at regional storage	RER	0	kg	1.29E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	lead, at regional storage	RER	0	kg	7.25E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	solar glass, low-iron, at regional storage	RER	0	kg	1.00E+1	1	1.33	(1,4,4,3,3,3); front glass; data provided by Kioto Solar, 2019
	tempering, flat glass	RER	0	kg	1.00E+1	1	1.24	(1,4,4,3,1,3); data provided by Kioto Solar, 2019
	flat glass, uncoated, at plant	RER	0	kg	1.00E+1	1	1.33	(1,4,4,3,3,3); back glass; data provided by Kioto Solar, 2019
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	sealing sheeting polyolefin (TPO), at plant	CH	0	kg	9.00E-1	1	1.24	(1,4,4,3,1,3); data provided by Kioto Solar, 2019
	polyvinylbutyral foil, at plant	RER	0	kg	1.89E-1	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	polyphenylene sulfide, at plant	GLO	0	kg	8.59E-2	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	tap water, water balance according to MoeK 2013, at user	RER	0	kg	5.03E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	1-propanol, at plant	RER	0	kg	1.59E-2	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	isopropanol, at plant	RER	0	kg	1.47E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	soap, at plant	RER	0	kg	1.16E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	EUR-flat pallet	RER	0	unit	5.00E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	electricity, medium voltage, at grid	AT	0	kWh	1.40E+1	1	1.09	(2,2,1,1,1,3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	diesel, burned in building machine, average	CH	0	MJ	8.75E-3	1	2.12	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	photovoltaic panel factory	GLO	1	unit	4.00E-6	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	transport, freight, lorry, fleet average	RER	0	tkm	2.34E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	1.38E+1	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	1	1.24	(1,4,4,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	2.17E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.53E-3	1	1.24	(1,4,4,3,1,3); Calculation, water use
emission air, high population density	Heat, waste	-	-	MJ	5.03E+1	1	1.60	(3,4,5,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
	Carbon dioxide, fossil	-	-	kg	2.18E-2	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table
emission air, unspecified	Water, RER	-	-	kg	5.03E-1	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table

Tab. B. 5 Life cycle inventory data of the manufacture of mono-Si PV panels of Kioto Photovoltaics GmbH used in the façade construction system of René Schmid Architekten AG / Max Vogelsang AG. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available (entries in red letters).

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, single-Si, Vogelsang-Kioto Solar, at plant	UncertaintyType	StandardDeviation95 %	GeneralComment
	Location				AT			
	InfrastructureProcess				1			
	Unit				m2			
	photovoltaic panel, single-Si, Vogelsang-Kioto Solar, at plant	AT	1	m2	1			
technosphere	photovoltaic cell, single-Si, at regional storage	RER	0	m2	9.35E-1	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	copper, at regional storage	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	wire drawing, copper	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	silicone product, at plant	RER	0	kg	1.22E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tin, at regional storage	RER	0	kg	1.29E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	lead, at regional storage	RER	0	kg	7.25E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	solar glass, low-iron, at regional storage	RER	0	kg	1.00E+1	1	1.33	(1,4,4,3,3,3); front glass; company information 2019
	tempering, flat glass	RER	0	kg	1.00E+1	1	1.24	(1,4,4,3,1,3); company information 2019
	flat glass, uncoated, at plant	RER	0	kg	1.00E+1	1	1.33	(1,4,4,3,3,3); back glass; company information 2019
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	ethylvinylacetate, foil, at plant	RER	0	kg	1.00E+0	1	1.24	(1,4,4,3,1,3); company information 2019
	polyvinylbutyral foil, at plant	RER	0	kg	1.89E-1	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	polyphenylene sulfide, at plant	GLO	0	kg	8.59E-2	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	tap water, water balance according to MoeK 2013, at user	RER	0	kg	5.03E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	1-propanol, at plant	RER	0	kg	1.59E-2	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	isopropanol, at plant	RER	0	kg	1.47E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	soap, at plant	RER	0	kg	1.16E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	EUR-flat pallet	RER	0	unit	5.00E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	electricity, medium voltage, at grid	AT	0	kWh	1.40E+1	1	1.09	(2,2,1,1,1,3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	diesel, burned in building machine, average	CH	0	MJ	8.75E-3	1	2.12	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic panel factory	GLO	1	unit	4.00E-6	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	transport, freight, lorry, fleet average	RER	0	tkm	2.35E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	1.39E+1	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	1	1.24	(1,4,4,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	2.29E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.53E-3	1	1.24	(1,4,4,3,1,3); Calculation, water use
emission air, high population density	Heat, waste	-	-	MJ	5.03E+1	1	1.60	(3,4,5,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
emission air, unspecified	Water, RER	-	-	kg	5.03E-1	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)

Tab. B. 6 Life cycle inventory data of the manufacture of mono-Si PV panels of Eternit Sunskin Façade manufactured by Kioto Photovoltaics GmbH as used in the façade construction system Sunskin Façade by Eternit. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available (entries in red letters).

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, single-Si, Eternit Sunskin Facade, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				AT			
	InfrastructureProcess				1			
	Unit				m2			
	photovoltaic panel, single-Si, Eternit Sunskin Facade, at plant	AT	1	m2	1			
technosphere	photovoltaic cell, single-Si, at regional storage	RER	0	m2	9.35E-1	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	copper, at regional storage	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	wire drawing, copper	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	silicone product, at plant	RER	0	kg	1.22E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tin, at regional storage	RER	0	kg	1.29E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	lead, at regional storage	RER	0	kg	7.25E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	solar glass, low-iron, at regional storage	RER	0	kg	1.00E+1	1	1.33	(1,4,4,3,3,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tempering, flat glass	RER	0	kg	1.00E+1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	flat glass, uncoated, at plant	RER	0	kg	8.00E+0	1	1.33	(1,4,4,3,3,3);
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	sealing sheeting polyolefin (TPO), at plant	CH	0	kg	1.17E+0	1	1.24	(1,4,4,3,1,3);
	polyvinylbutyral foil, at plant	RER	0	kg	1.89E-1	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	polyphenylene sulfide, at plant	GLO	0	kg	8.59E-2	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	tap water, water balance according to MoeK 2013, at user	RER	0	kg	5.03E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	1-propanol, at plant	RER	0	kg	1.59E-2	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	isopropanol, at plant	RER	0	kg	1.47E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	soap, at plant	RER	0	kg	1.16E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	EUR-flat pallet	RER	0	unit	5.00E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	electricity, medium voltage, at grid	AT	0	kWh	1.40E+1	1	1.09	(2,2,1,1,1,3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	diesel, burned in building machine, average	CH	0	MJ	8.75E-3	1	2.12	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic panel factory	GLO	1	unit	4.00E-6	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	transport, freight, lorry, fleet average	RER	0	tkm	2.17E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	1.28E+1	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	1	1.24	(1,4,4,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	2.49E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.53E-3	1	1.24	(1,4,4,3,1,3); Calculation, water use
emission air, high population density	Heat, waste	-	-	MJ	5.03E+1	1	1.60	(3,4,5,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
emission air, unspecified	Water, RER	-	-	kg	5.03E-1	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)

Tab. B. 7 Life cycle inventory data of the manufacture of mono-Si PV panels used at the MFH Setz manufactured by Kioto Photovoltaics GmbH. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available (entries in red letters).

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, single-Si, MFH Setz, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				AT			
	InfrastructureProcess				1			
	Unit				m2			
	photovoltaic panel, single-Si, MFH Setz, at plant	AT	1	m2	1			
technosphere	photovoltaic cell, single-Si, at regional storage	RER	0	m2	9.35E-1	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	copper, at regional storage	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	wire drawing, copper	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	silicone product, at plant	RER	0	kg	1.22E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tin, at regional storage	RER	0	kg	1.29E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	lead, at regional storage	RER	0	kg	7.25E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	solar glass, low-iron, at regional storage	RER	0	kg	7.50E+0	1	1.33	(1,4,4,3,3,3); front glass; company information 2019
	tempering, flat glass	RER	0	kg	7.50E+0	1	1.24	(1,4,4,3,1,3); company information 2019
	flat glass, uncoated, at plant	RER	0	kg	7.50E+0	1	1.33	(1,4,4,3,3,3); back glass; company information 2019
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	ethylvinylacetate, foil, at plant	RER	0	kg	2.00E+0	1	1.24	(1,4,4,3,1,3); company information 2019
	polyvinylbutyral foil, at plant	RER	0	kg	1.89E-1	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	polyphenylene sulfide, at plant	GLO	0	kg	8.59E-2	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	tap water, water balance according to MoeK 2013, at user	RER	0	kg	5.03E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	1-propanol, at plant	RER	0	kg	1.59E-2	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	isopropanol, at plant	RER	0	kg	1.47E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	soap, at plant	RER	0	kg	1.16E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	EUR-flat pallet	RER	0	unit	5.00E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	electricity, medium voltage, at grid	AT	0	kWh	1.40E+1	1	1.09	(2,2,1,1,1,3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	diesel, burned in building machine, average	CH	0	MJ	8.75E-3	1	2.12	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic panel factory	GLO	1	unit	4.00E-6	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	transport, freight, lorry, fleet average	RER	0	tkm	1.97E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	1.15E+1	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	1	1.24	(1,4,4,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	3.47E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.53E-3	1	1.24	(1,4,4,3,1,3); Calculation, water use
emission air, high population density	Heat, waste	-	-	MJ	5.03E+1	1	1.60	(3,4,5,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
emission air, unspecified	Water, RER	-	-	kg	5.03E-1	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)

Tab. B. 8 Life cycle inventory data of the manufacture of mono-Si PV panels of LOF Solar for façade and roof used at the MFH Solaris. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available (entries in red letters).

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, facade, single-Si, LOF Solar, at plant	photovoltaic panel, roof, single-Si, LOF Solar, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				TW	TW			
	InfrastructureProcess				1	1			
	Unit				m2	m2			
	photovoltaic panel, facade, single-Si, LOF Solar, at plant	TW	1	m2	1	0			
	photovoltaic panel, roof, single-Si, LOF Solar, at plant	TW	1	m2	0	1			
technosphere	photovoltaic cell, single-Si, at plant	CN	0	m2	9.35E-1	9.35E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	copper, at regional storage	RER	0	kg	1.03E-1	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	wire drawing, copper	RER	0	kg	1.03E-1	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	2.81E-3	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	silicone product, at plant	RER	0	kg	1.22E-1	1.22E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tin, at regional storage	RER	0	kg	1.29E-2	1.29E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	lead, at regional storage	RER	0	kg	7.25E-4	7.25E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	solar glass, low-iron, at regional storage	RER	0	kg	2.50E+1	1.00E+1	1	1.33	(1,4,4,3,3,3); data provided by LOF Solar, 2019
	tempering, flat glass	RER	0	kg	2.50E+1	1.00E+1	1	1.24	(1,4,4,3,1,3); data provided by LOF Solar, 2019
	flat glass, uncoated, at plant	RER	0	kg	1.25E+1	1.25E+1	1	1.33	(1,4,4,3,3,3); data provided by LOF Solar, 2019
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	2.95E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	3.46E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	2.38E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyvinylbutyral foil, at plant	RER	0	kg	8.36E-1	8.36E-1	1	1.24	(1,4,4,3,1,3); data provided by LOF Solar, 2019
	polyvinylbutyral foil, at plant	RER	0	kg	1.89E-1	1.89E-1	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	polyphenylene sulfide, at plant	GLO	0	kg	8.59E-2	8.59E-2	1	1.24	(1,4,4,3,1,3); used for back glass; assumption
	tap water, water balance according to MoeK 2013, at user	CN	0	kg	5.03E+0	5.03E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	6.24E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	1-propanol, at plant	RER	0	kg	1.59E-2	1.59E-2	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	isopropanol, at plant	RER	0	kg	1.47E-4	1.47E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	5.14E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	soap, at plant	RER	0	kg	1.16E-2	1.16E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	7.63E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	EUR-flat pallet	RER	0	unit	5.00E-2	5.00E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	electricity, medium voltage, at grid	TW	0	kWh	1.40E+1	1.40E+1	1	1.09	(2,2,1,1,1,3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	diesel, burned in building machine, average	CH	0	MJ	8.75E-3	8.75E-3	1	2.12	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic panel factory	GLO	1	unit	4.00E-6	4.00E-6	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	transport, freight, lorry, fleet average	RER	0	tkm	4.08E+0	2.58E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	2.43E+1	1.53E+1	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	3.00E-2	1	1.24	(1,4,4,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	2.10E+0	2.10E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1.61E-3	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.53E-3	4.53E-3	1	1.24	(1,4,4,3,1,3); Calculation, water use
emission air, high population density	Heat, waste	-	-	MJ	5.03E+1	5.03E+1	1	1.60	(3,4,5,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	2.18E-2	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
emission air, unspecified	Water, CN	-	-	kg	5.03E-1	5.03E-1	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)

Tab. B. 9 Life cycle inventory data of the manufacture of mono-Si PV panels of Meyer Burger used at the MFH Rudolf. The inventory is based on the life cycle inventory described in Frischknecht et al. (2015a) and adapted where specific information was available (entries in red letters).

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, single-Si, Meyer Burger, at plant	UncertaintyType	StandardDeviation95 %	GeneralComment
	Location				CH			
	InfrastructureProcess				1			
	Unit				m2			
	photovoltaic panel, single-Si, Meyer Burger, at plant	CH	1	m2	1			
technosphere	photovoltaic cell, single-Si, at regional storage	RER	0	m2	9.35E-1	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	copper, at regional storage	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	wire drawing, copper	RER	0	kg	1.03E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	silicone product, at plant	RER	0	kg	1.22E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tin, at regional storage	RER	0	kg	1.29E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	lead, at regional storage	RER	0	kg	7.25E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	solar glass, low-iron, at regional storage	RER	0	kg	1.25E+1	1	1.33	(1,4,4,3,3,3); data provided by Meyer Burger, 2019
	tempering, flat glass	RER	0	kg	1.25E+1	1	1.24	(1,4,4,3,1,3); data provided by Meyer Burger, 2019
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	ethylvinylacetate, foil, at plant	RER	0	kg	1.00E+0	1	1.24	(1,4,4,3,1,3); data provided by Meyer Burger, 2019
	polyvinylfluoride film, at plant	US	0	kg	1.12E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tap water, at user	CH	0	kg	5.03E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	1-propanol, at plant	RER	0	kg	1.59E-2	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	isopropanol, at plant	RER	0	kg	1.47E-4	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	soap, at plant	RER	0	kg	1.16E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	EUR-flat pallet	RER	0	unit	5.00E-2	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	electricity, medium voltage, production CH, at grid	CH	0	kWh	1.40E+1	1	1.09	(2,2,1,1,1,3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	diesel, burned in building machine, average	CH	0	MJ	8.75E-3	1	2.12	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic panel factory	GLO	1	unit	4.00E-6	1	3.06	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	transport, freight, lorry, fleet average	RER	0	tkm	1.58E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	9.28E+0	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	1	1.24	(1,4,4,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, polyvinylfluoride, 0.2% water, to municipal incineration	CH	0	kg	1.12E-1	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.97E+0	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1	1.24	(1,4,4,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.53E-3	1	1.24	(1,4,4,3,1,3); Calculation, water use
emission air, high population density	Heat, waste	-	-	MJ	5.03E+1	1	1.60	(3,4,5,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
emission air, unspecified	Water, CH	-	-	kg	5.03E-1	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)

C Annex: Balance of system

Tab. C 1 Life cycle inventory data of the balance of system of the six selected buildings.

	Name	Location	InfrastructureProcess	Unit	electric installation, 440 kWp photovoltaic plant, Grosspeter Tower, at plant	electric installation, 34.56 kWp photovoltaic plant, MFH Rudolf, at plant	electric installation, 71.7 kWp photovoltaic plant, Solaris, at plant	electric installation, 159 kWp photovoltaic plant, Viridén, at plant	electric installation, 85.55 kWp photovoltaic plant, 2MFH Zurich-Oerlikon, at plant	electric installation, 3.24 kWp photovoltaic plant, Sanierung EFH Aven, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	CH	CH	CH	CH	CH			
	InfrastructureProcess				1	1	1	1	1	1			
	Unit				unit	unit	unit	unit	unit	unit			
product	electric installation, 440 kWp photovoltaic plant, Grosspe	CH	1	unit	1	-	-	-	-	-			
	electric installation, 34.56 kWp photovoltaic plant, MFH R	CH	1	unit	-	1	-	-	-	-			
	electric installation, 71.7 kWp photovoltaic plant, Solaris,	CH	1	unit	-	-	1	-	-	-			
	electric installation, 159 kWp photovoltaic plant, Viridén, a	CH	1	unit	-	-	-	1	-	-			
	electric installation, 85.55 kWp photovoltaic plant, 2MFH Z	CH	1	unit	-	-	-	-	1	-			
	electric installation, 3.24 kWp photovoltaic plant, Sanierui	CH	1	unit	-	-	-	-	-	1			
technosphere	aluminium, production mix, wrought alloy, at plant	RER	0	kg	-	-	-	-	-	-	1	1.36	(2,1,3,1,1,5); distributor box and control electronics
	copper, at regional storage	RER	0	kg	3.31E+3	3.62E+1	2.89E+2	3.11E+2	5.76E+2	1.65E+1	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	brass, at plant	CH	0	kg	0	0	6.82E-2	2.05E-1	5.46E-1	0	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	zinc, primary, at regional storage	RER	0	kg	0	0	1.36E-1	4.09E-1	1.09E+0	0	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	steel, low-alloyed, at plant	RER	0	kg	9.78E+0	3.80E-1	2.85E+0	1.00E+1	2.46E+1	3.36E-1	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	diode, glass-, through-hole mounting, at plant	GLO	0	kg	-	-	-	-	-	-	1	1.36	(2,1,3,1,1,5); diode and glass epoxy share for cotrol electronics
	concrete, normal, at plant	CH	0	m3	-	-	-	-	-	-	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	nylon 6, at plant	RER	0	kg	0	0	7.84E-1	2.35E+0	6.28E+0	0	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	sulphuric acid, liquid, at plant	RER	0	kg	-	-	-	-	-	-	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	lead, at regional storage	RER	0	kg	-	-	-	-	-	-	1	1.36	(2,1,3,1,1,5); for control electronics
	polyethylene, HDPE, granulate, at plant	RER	0	kg	3.14E+3	2.59E+1	2.58E+2	2.95E+2	4.38E+2	6.42E+0	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	polyethylene, LDPE, granulate, at plant	RER	0	kg	-	-	-	-	-	-	1	1.36	(2,1,3,1,1,5); halogen free polyolefin cable insulation
	polyvinylchloride, bulk polymerised, at plant	RER	0	kg	8.80E+2	2.41E+0	3.04E+1	6.68E+1	1.54E+1	6.49E-01	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	polycarbonate, at plant	RER	0	kg	0.00E+00	0.00E+00	6.82E-3	2.05E-2	5.46E-2	0	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
	epoxy resin, liquid, at plant	RER	0	kg	0.00E+00	0.00E+00	6.82E-3	2.05E-2	5.46E-2	0	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
manufacturing	wire drawing, copper	RER	0	kg	3.31E+3	3.62E+1	2.89E+2	3.11E+2	5.76E+2	1.65E+1	1	1.36	(2,1,3,1,1,5); Scaled from smaller plants over cabling length and fuse box weight
transport	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	4.40E+2	3.90E+0	3.49E+1	4.12E+1	6.37E+1	1.43E+0	1	2.16	(4,5,na,na,na,na); Standard distance 60km incl. disposal
	transport, freight, lorry, fleet average	RER	0	tkm	-	-	-	-	-	-	1	2.16	(4,5,na,na,na,na); Standard distance 60km incl. disposal
	transport, freight, rail, electricity with shunting	CH	0	tkm	2.80E+3	2.76E+1	233.22	2.66E+2	4.53E+2	1.15E+1	1	2.16	(4,5,na,na,na,na); Standard distances 200km (metals 600km)
	transport, freight, rail	RER	0	tkm	-	-	-	-	-	-	1	2.16	(4,5,na,na,na,na); Standard distances 200km (metals 600km)
disposal	disposal, plastic, industr. electronics, 15.3% water, to	CH	0	kg	4.75E+3	3.35E+1	3.41E+2	4.30E+2	5.43E+2	8.35E+0	1	1.36	(2,1,3,1,1,5); Estimation
	disposal, building, electric wiring, to final disposal	CH	0	kg	0	0	2.05E-1	6.14E-1	1.64E+0	0	1	1.36	(2,1,3,1,1,5); Estimation