Environmental Product Declaration

EPD®

In accordance with ISO 14025 and EN 15804 for:

Multi-coloured Glass-Glass Photovoltaic Module for Building Integration

from

ÜserHuus AG

Programme:	The International EPD® System, www.environdec.com
Programme operator:	EPD International AB
EPD registration number:	S-P-01817
Publication date:	2019-12-15
Valid until:	2024-12-17

Programme information

Programme:	The International EPD® System EPD International AB Box 210 60 SE-100 31 Stockholm Sweden www.environdec.com info@environdec.com

Product category rules (PCR): PCR 2012:01 Construction products and Construction services, Version 2.3, 2018-11-15, UN CPC code(s): 371 Glass and glass products The LCA study has been performed in accordance with the EN 15804.
PCR review was conducted by: The Technical Committee of the International EPD® System Chair: Maurizio Fieschi; contact via info@environdec.com
Independent third-party verification of the declaration and data, according to ISO 14025:2006: ☐ EPD process certification ☒ EPD verification
Third party verifier: Dr. Niels Jungbluth, ESU-services Ltd., Schaffhausen, Switzerland, signature: Approved by: The International EPD® System
Procedure for follow-up of data during EPD validity involves third party verifier: ☐ Yes ☒ No
LCA conducted by the University of Applied Sciences Northwestern Switzerland (FHNW), School for Life Sciences Institute for Ecopreneurship, Hofackerstrasse 30, 4132 Muttenz, www.fhnw.ch/lifesciences

The EPD owner has the sole ownership, liability, and responsibility for the EPD. EPDs within the same product category but from different programmes may not be comparable.

Company information

Owner of the EPD:
ÜserHuus AG, Seerosenweg 6, CH – 6052 Hergiswil (Nidwalden) Switzerland, Stephen Wittkopf, +41 (0) 79 917 81 31, Wittkopf4userhuus@gmail.com

Description of the organisation:
The mission of Üserhuus is the technology transfer from research to practice in the area of coloured photovoltaics for improved architectural integration. Üserhuus collaborates with research institutions such as Lucerne University of Applied Sciences (HSLU), Building Research Establishment (BRE London) as well as the Swiss Center for Electronics and Microtechnology (CSEM) to facilitate the development of prototypes of high technology readiness level and their public demonstration and test bedding in pilot- and demonstration projects. Projects include a terra cotta effect BIPV roof on Üserhuus' show house at the BRE Innovation Park, Watford (www.bregroup.com) and (www.userhuus.com/park), a terra cotta effect BIPV carport roof at Üserhuus' premises (www.userhuus.com/carport) in Hergiswil, Switzerland, the BIPV "Swissness" façade at the Umweltarena, Spreitenbach, Switzerland, (www.userhuus.com/spreitenbach-switzerland) and the coloured and structured BIPV balcony balustrades at the NEST building at EMPA (www.userhuus.com/coloured-and-structuredpv), Dübendorf, Switzerland.

Product-related or management system-related certifications:
The product can be considered complying to the type testing based upon the following aspects:

- IEC 61215-1:2016: Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements
- IEC 61215-1-1:2016: Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules
- IEC 61215-2:2016: Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures
- IEC 61730-1:2016: Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction
- IEC 61730-2:2016: Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing

Name and location of production site: GES Gebäude- Energiesysteme GmbH, Wiesenring 2 (Gewerbegebiet Korbwiesen), 07554 – Korbussen, Germany

Product information

Product name:
The declared product is a multi-coloured mono crystalline silicon (mc-si) photovoltaic module for building integration.

Product description:
This multi-coloured PV module is made of standard PV technology hidden behind a front glass, which is digitally printed with ceramic ink. Digital printing offers an unprecedented range of colours and patterns, which resulting electrical efficiency of the PV cell below is controlled by a patent filed method and Swiss registered trademark meta-c-print.

Building integrated photovoltaics (BIPV) contribute to achieving an increase of electricity supply from PV solar electricity by fully utilising building surfaces, such as roof, skylights or façades to maximise electricity generation.

Multi-coloured glass-glass photovoltaic modules have about 10-40% lower electricity generation yield than clear glass PV modules. The product takes over the function of a glass façade element and therefore must fulfil one or more requirements of EN 5050383-1 [1] such as mechanical rigidity or structural integrity,

primary weather protection, energy economy, fire protection etc.
The service lifetime for this type of photovoltaic module is about 30 years [3].
The following Table 1, Table 2 and Table 3 provide technical information about the declared product.

Table 1: Mechanical data

Mechanical data	ZRE285-295G4G4-60 Maw-L
Dimensions	1'000 x 1'650 x 11 mm
Weight	35 kg
Front glass thickness	4 mm
Back glass thickness	4 mm

Table 2: General data

General data	ZRE285-295G4G4-60 Maw-L
Cell type	mc-si (156 x 156 mm)
Number of cells	60
Number of cells for each diode	20
Connection	MC4
Cable	DC 1 m x 4 mm^2
Performance warranty	25 years on 80% of nom. performance

Table 3: Average electrical data of multi-coloured modules

Electrical data	ZRE285-295G4G4-60 Maw-L
Nominal power	275.7 W
Nominal current	7.24 A
Nominal Voltage	38.07 V
Short-circuit current	8.02 A
Maximum system voltage	1'000 V

Product identification:
The multi-coloured glass-glass photovoltaic module from Üserhuus considered in this EPD has the following identifier:
ZRE285-295G4G4-60Maw-L

UN CPC code:
371 Glass and glass products

Other codes for product classification:
In NACE/CPA classification, the declared product belongs to the class 27.90 "Manufacturing of other electrical equipment"

Geographical scope: Europe
The end-of-life performance was calculated for Europe, which is the target region for the use of the declared product.

Manufacturing:
The production site of the declared product is located at GES Gebäude- Energiesysteme GmbH in Germany and comprises the following steps:

- Cleaning front and back glasses
- Cutting the encapsulant
- Connecting the silicon cell laminates and busbars
- Laminating of the PV stack and cutting of encapsulant leftovers
- Mounting of the junction box, diode and cable
- Flashtesting
- Packaging

The multi-coloured front glass makes the product unique for architectural applications. Front and back glass are manufactured at Glas Trösch AG located in Bützberg in Switzerland. The production comprises the following steps:

- Cutting the raw glass
- Grinding the edges
- Washing off grinding sludge and drying
- Tempering to increase the strength of the solar glass
- Second washing (only for multi-coloured front glasses)
- Digital printing with ceramic ink and drying
- Packaging

The mc-si cells are sourced in Taiwan, the encapsulant in Germany and the other components in Europe. The production sites of these components are not known and may be global.

Environment and health aspects during manufacturing:
GES has no certified environmental management system. The glass supplier is certified in accordance with ISO 14001:2015. The supplier of the solar cells performs an environmental health and safety management and cooperate social responsibility policy.

End-of-life photovoltaic modules:
The European waste catalogue classifies end-of-life silicon photovoltaic modules as EWC 16 02 14 industrial waste from electrical and electronic equipment. The WEEE 2012/19/EU directive stipulates that end-of-life photovoltaic modules must be taken back and recycled [6].

Fractions remaining from the discarding process of end-of-life glass-glass modules are:

- Glass cullet
- Polymers (foil)
- Mixture of glass cullet, foil and metals (PV cells)
- Metals (copper, others)
- Others (e.g. plastics, sealing)

Glass cullet feedstock can be used in foam or fiberglass production, while the metals extracted during the process can be sold to metal recyclers and smelters. Foils coated with solar cell residues are disposed in waste-to-energy plants [7].

LCA information

Functional unit / declared unit:
The declared unit is 1 m^2 surface of the multi-coloured glass-glass photovoltaic module. The choice of this normalised functional unit allows a comparison of the environmental impact with other façade elements.

Time representativeness:
The period of the data collection at the solar glass supplier and module manufacturer was in 2018. The data represent the production conditions at the front and back glass supplier and the manufacture of the declared product in 2018.

Target group:
The target group of the EPD include architect, manufacturer, building owner, planner, and installer.

Database(s) and LCA software used:
For the elaboration of the LCA ecoinvent 3.5 (cut-off model) [2] and the SimaPro software version 9.0.035 were used.

System boundary:
This EPD of the declared product is a type cradle-to-gate with options. It covers information on the following life cycle modules:

- A1 – Raw material extraction and processing and the processing of secondary material input
- A2 – Transport of raw materials and secondary material inputs to the manufacturer
- A3 – Manufacturing of the front and back glass and the declared product and packaging
- C2 – Transportation of the end-of-life stage module
- C3 – Waste processing
- C4 – Disposal

The system boundary, site-specific and background processes for the LCA are shown in Figure 1.

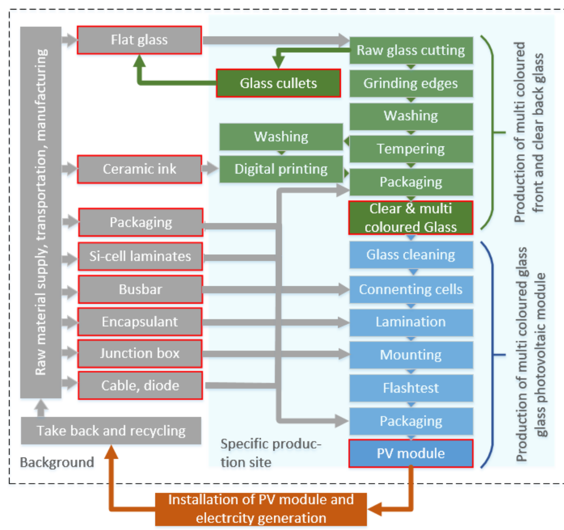

Figure 1: System boundary, background and site-specific processes used for the LCA of the declared product

Background data:
The background data used were taken from ecoinvent 3.5 database [2]. The data records from 2007 on mc-si cells and wafers were updated with literature values from 2014 [3] and values from the UVEK database on photovoltaic [4]. The data records in ecoinvent on raw glass for the front and back glass production were updated with data from 2017 of an EPD on raw glass [5]. Take back and recycling of glass-glass photovoltaic were taken from secondary sources [7].

Data quality:
Production data of the front and back glass and the assembling of the declared product are production site specific and were provided from

the companies. Both companies produce different products (flat glass products and solar photovoltaic modules). The production site managers allocated overall company's material and energy flows to the declared product. The allocation bases on energy measurements, data records, product and process specifications. Both companies have reported site-specific electricity supply mixes.

Assumption:
Amounts of energy and material flows used at the manufacturing of the declared product, which could not be delineated from other PV modules, were allocated by dividing the annual amount with the total m^2 of produced PV modules.
Site specific data on production of mc-si cell in Taiwan and other compounds were not available. Data were taken from reliable background literature, which also includes assumptions for the supply mix of prefabricates and electricity mixes.

Allocation:
Losses and breakages of raw glass cutting at front and back glass production are about 20%. The cullet is recycled directly in float glass production, which reduces the quantity of primary raw material and its energy consumption. The credits were considered in module A1-A3. Credits were neither given for energy recovery from the incineration of production waste of the module manufacturer nor for treatment and disposal of the end-of-life module.

Cut-off rules:
All data obtained from the survey at the solar glass supplier and module manufacturer were taken into consideration. It can be assumed that the total of all neglected percentage shares does not exceed 5% in the impact categories.

Renewable fuels:
The amount of renewable fuel in the supply chain of the declared product (module A1-A3) refer mainly to the biomass used to produce metallurgical grade silicon, a prefabricate to produce mc-si cells.

Renewable raw materials:
The amount of renewable material refers to the biomass used a) as construction material for infrastructure processes and b) as raw material to produce cardboard.

Secondary materials:
The modules A1 to A3 consider the amount of secondary copper and glass to produce the declared product.

The credits in module D consider the amount of recycled copper and glass from the end-of-life treatment of PV modules.

Secondary fuels:
No accountable amounts of renewable and non-renewable secondary fuels were identified. In module D, the secondary fuels derived from waste of end-of life treatment are not accountable for credits. The efficiency of energy recovery in unspecific incineration plants is lower than the required minimum value of 60%.

Net use of fresh water:
For the calculation of the net use of fresh water, the amount of lost evaporated water in the production, e.g. of silicon is considered.

Content declaration

Product

The declared product does not contain substances of very high concern.

Table 4 : Material composition of the declared product

Materials / chemical substances	[kg/m^2]	Percentage
Front and back glass	20.000	91.0%
EVA encapsulant	1.071	4.6%
Mono silicon cells	0.396	1.8%
PET foil	0.324	0.6%
Cell wires and busbars	0.183	0.8%
Cable	0.153	0.3%
Junction box	0.132	0.6%
Diode	0.035	0.2%
Silicon adhesive	0.012	0.1%

Packaging

The declared product is wrapped with a stretch foil. Several modules are piled in a cardboard box with polystyrene profiles. The cardboard is fixed with a strap on a wooden pellet.

Table 5: Material composition of the packaging

Material	Amount [kg/m^2]	Percentage
Wood	0.354	55.5%
Paper and cardboard	0.236	37.0%
Polystyrene	0.044	6.9%
LDPE foil	0.002	0.3%
Strap	0.002	0.3%

EWC classification of waste packaging materials:

- EWC 15 01 01 Paper and cardboard packaging
- EWC 15 01 02 Plastic packaging
- EWC 15 01 03 Wooden packaging

Recycled material

Pre-consumer:

Losses and breakages from the raw glass at cutting of solar glass production are about 20%. The cullet is recycled directly in float glass production, which reduces the quantity of the primary raw material. Breakages at tempering and quenching of the solar glass are about 5%. Cullet of different colours cannot be recycled and will be landfilled. The share of recycling copper in the cable, junction box, bus bars and cell wires add up to 29% [2].

Post-consumer:

The copper content of an end-of-life photovoltaic module can be recycled to a high material quality. The quality of the glass cullet, which is a mix of clear and coloured glass cullet, does not allow recycling in flat glass production. Flat glass is the raw material for solar glass. The cullet can be used in foam glass production [8].

Environmental performance of the declared product

Environmental indicator results for the modules A1–A3, C2-C3 and D on an aggregated basis are shown in the four tables Table 6 to Table 9 for the declared unit. The estimated impact results are only relative statements which do not indicate the end points of the impact categories, exceeding threshold values, safety margins or risks.

Table 6: Potential environmental impact

Parameter	Unit	A1-A3	C2	C3	C4	D
Global warming potential (GWP)	[kg CO_2-eq.]	2.79E+02	1.43E+00	2.64E+00	1.91E+00	-3.23E+00
Depletion potential of the stratospheric ozone layer (ODP)	[kg CFC11-eq.]	2.01E-05	2.68E-07	2.90E-07	2.47E-08	-2.97E-07
Acidification potential of land and water (AP)	[kg SO_2-eq.]	1.44E+00	7.32E-03	1.60E-02	1.45E-03	-3.70E-02
Eutrophication potential (EP)	[kg $(PO_4)^{3-}$-eq.]	2.59E-01	1.16E-03	2.35E-03	2.39E-04	-1.80E-02
Formation potential of tropospheric ozone (POCP)	[kg ethene-eq.]	9.86E-01	9.12E-03	7.23E-03	1.52E-03	-1.77E-02
Abiotic depletion potential – Elements (ADPE)	[kg Sb-eq.]	4.61E-03	4.09E-06	1.20E-06	3.00E-07	-3.99E-04
Abiotic depletion potential – Fossil resources (ADPF)	[MJ net calorific value]	3.25E+03	2.21E+01	2.90E+01	2.05E+00	-3.93E+01
Water scarcity potential (WSP)	[m^3 eq.]	2.83E+02	1.22E-01	7.34E-01	1.95E-01	-4.06E+00

Table 7: Use of resources

Parameter		Unit	A1-A3	C2	C3	C4	D
Primary energy resources – Renewable (PERR)	Use as energy carrier	[MJ net calorific value]	4.83E+02	2.18E-01	8.44E+00	3.12E-02	3.58E+00
	Use as raw materials	[MJ net calorific value]	2.25E+01	2.68E-02	8.26E-02	6.86E-03	1.29E+00
	Total	[MJ net calorific value]	5.05E+02	2.45E-01	8.52E+00	3.81E-02	4.87E+00
Primary energy resources – Non-renewable (PERNR)	Use as energy carrier	[MJ net calorific value]	4.32E+03	2.38E+01	5.73E+01	2.23E+00	4.39E+01
	Use as raw materials	[MJ net calorific value]	3.59E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Total	[MJ net calorific value]	4.35E+03	2.38E+01	5.73E+01	2.23E+00	4.39E+01
Secondary material		[kg]	5.48E+00	5.48E+00	0.00E+00	0.00E+00	1.82E+01
Renewable secondary fuels		[MJ net calorific value]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Non-renewable secondary fuels		[MJ net calorific value]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Net use of fresh water		[m^3]	8.70E+00	2.04E-03	3.01E-02	2.75E-03	-8.35E-02

Table 8: Waste production

Parameter	Unit	A1-A3	C2	C3	C4	D
Hazardous waste disposed	[kg]	1.57E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Non-hazardous waste disposed	[kg]	2.36E-01	0.00E+00	0.00E+00	2.22E+00	0.00E+00
Radioactive waste disposed	[kg]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 9: Output flows

Parameter	Unit	A1-A3	C2	C3	C4	D
Components for reuse	[kg]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.54E-01
Materials for recycling	[kg]	3.71E-01	0.00E+00	1.82E+01	0.00E+00	-2.15E+00
Materials for energy recovery	[kg]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported electrical energy	[MJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported thermal energy	[MJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

LCA interpretation

In the production phase (life cycle A1-A3) of the declared multi-coloured glass-glass mc-si photovoltaic module, the mc-si cells account between 71% (abiotic depletion potential – fossil resources) and 90% (water scarcity potential) of the total values of the impact categories. The value of global warming potential adds up to 86%. Even the proportion of the cells by mass is only 2%, its production is the major source for the environmental impact of the declared unit. The supply chain of mc-si cells includes energy and resource intensive production of prefabricates such as silicon single crystals. Therefore, the primary energy resources – non-renewable value for the mc-si cell contribute 84% and primary energy resources – renewable value 93% to the total values of the declared unit.

The multi-coloured front and clear back glass account 6% to the total global warming potential value, despite its proportion by mass accounts more than 90% of the product. The value for depletion potential of the stratospheric ozone layer for glass contributes 19% to the total value and stem from energy provision in the supply chain. The value of primary energy resources – non-renewable for glass production add up to 10% and the value for primary energy resources – renewable is up to 3%.

The copper containing compounds, that includes the cable, the cell connecting and junction box, account up to 11% of the total value for the category abiotic depletion potential – elements and 12% of the eutrophication potential. The other impact categories show lower values for these compounds.

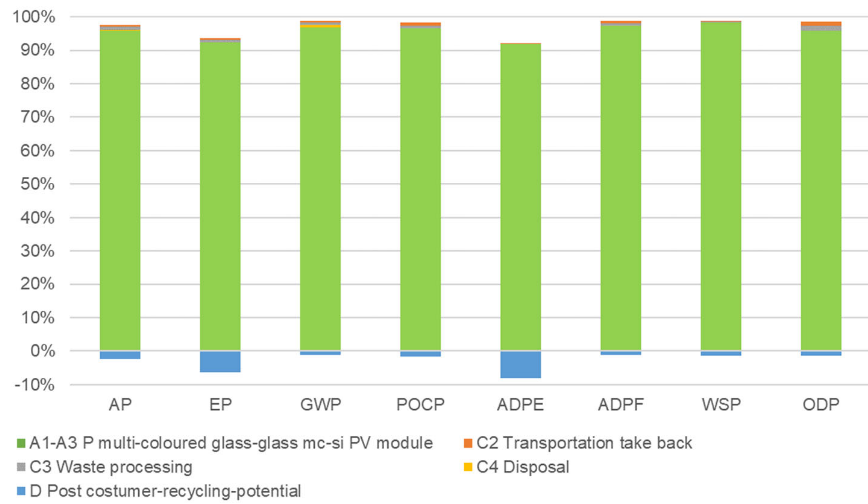

Figure 2 EPD impacts of the declared product through its life stages

In the end-of-life phase (life cycle C1-C4) of the declared product, the values in the impact categories are lower than 3% of the values of the life cycle A1–A3. The mass of disposed waste from end-of-life treatment contributes about 10% to the mass of the declared unit.

Copper and glass belong to the material fractions with post-consumer recycling potential (D). Main benefit is observed for the category abiotic depletion potential – elements. In relation to the life cycle A1–A3 the value accounts to 9%. In the category eutrophication potential, the benefit accounts to 7%. The benefits in the other impact categories are less than or equal to 3%.

Requisite evidence

This Environmental Product Declaration does not require any evidence in relation to the material composition in the product and its area of application.

Further Literature:

Jeeyoung Park, Dirk Hengevoss and Stephen Wittkopf. Industrial Data-Based Life Cycle Assessment of Architecturally Integrated Glass-Glass Photovoltaics. Buildings 2019, 9(1), 8; https://doi.org/10.3390/buildings9010008

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[2] Ecoinvent 3.5 Database https://www.ecoinvent.org/database/older-versions/ecoinvent-35/ecoinvent-35.html.

[3] Frischknecht, R.; Itten, R.; Sinha, P.; deWild-Scholten, M.; Zhang, J.; Fthenakis, V.; Kim, H.C.; Raugei, M.; Stucki, M. Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems.

Technical Report IEA-PVPS T12-04:2015, International Energy Agency Photovoltaic Power Systems Programme, 2015.

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[7] Philippe Stolz, Rolf Frischknecht. 2016. Life Cycle Assessment of Photovoltaic Module Recycling. In behalf of the Swiss Federal Office of Energy SFOE.

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