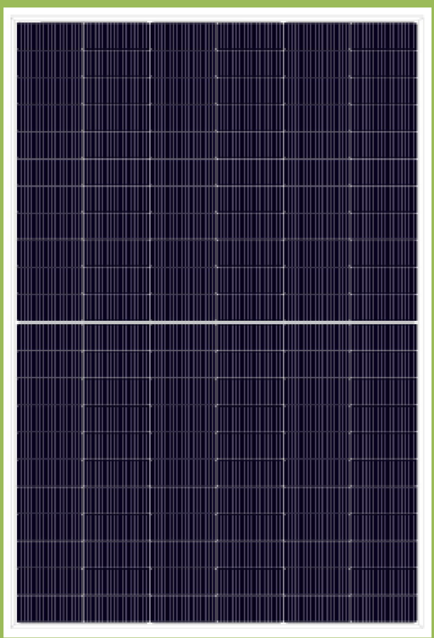
Environmental Product Declaration

as per ISO 14025 and EN 15804

Owner of the declaration:	Tongwei Co., Ltd.
Publisher:	Kiwa-Ecobility Experts
Programme operator:	Kiwa-Ecobility Experts
Registration number:	EPD-Kiwa-EE-000420-EN
Issue date:	27.11.2024
Valid to:	27.11.2029



TWMNH-48HD

TNC-G12R-48 Half Cell Bifacial Module

1. General information

Tongwei Co., Ltd.

Programme operator:
Kiwa-Ecobility Experts
Kiwa GmbH, Ecobility Experts
Wattstraße 11-13
13355 Berlin
Germany

Registration number:
EPD-Kiwa-EE-000420-EN

This declaration is based on the Product. Category Rules:
EPD-NORGE's:
NPCR PART A: Construction products and services Version 2.0, 2021-03-24

NPCR 029 Part B for photovoltaic modules used in the building and construction industry, including production of cell, wafer, ingot block, solar grade silicon, solar substrates, solar superstrates, and other solar grade semiconductor materials version 1.2, 2022-03-31.

Issue date:
27.11.2024

Valid to:
27.11.2029

Raoul Mancke
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TWMNH-48HD

Owner of the declaration:
Tongwei Co., Ltd.
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Declared product / declared unit:
1 m² of manufactured PV module.

Scope:
This EPD is based on the life cycle assessment of the photovoltaic module TWMNH-48HD which is produced and distributed by Tongwei Co., Ltd., located in Nantong City (P. R. China). The EPD refers to the specific product.

EPD type: Cradle to Grave + Module D

Kiwa-Ecobility Experts assumes no liability for manufacturer's information, LCA data and evidence.

Functional unit:
1 Wp of manufactured photovoltaic module, from cradle-to-grave, with activities needed for a study period for a defined reference service life (≥80% of the labelled power output).

Verification:
The European standard EN 15804+A2:2019 serves as the core PCR.

Independent verification of the declaration and data, according to EN ISO 14025:2010.

☐internal ☒external

Elisabet Amat
(Third party verifier)

2. Product

2.1 Product description

TWMNH-48HD is part of Tongwei G12R-TNC series of photovoltaic module products, which adopts the new efficient N-type TNC cell independently developed by Tongwei for module packaging, and integrates the industry-leading multi-main gate design to reduce hidden crack loss, non-destructive slicing technology to smooth and flat cutting surface, high-density packaging technology to improve the "screen ratio" of the module to ensure the perfect balance of efficiency and reliability. The product has the characteristics of market demand: small parts, high appearance level, high power, so that photovoltaic and building perfect integration. With fewer batteries, the G12R-48 product can connect more components to the same inverter at the same voltage, without the need for additional new strings, reducing the amount of DC cable, and easier wiring. The ultimate battery area design within 2 square meters, the "screen" is larger, more installed, reduce transportation costs, and bring higher product value to customers.
TWMNH-48HD has a power output range from 425W to 455W and a weight of 20.9 kg. 455W is chosen as the representative product power output.

2.2 Application (Intended Use of the product)

Tongwei solar PV modules installed on household roofs and deployed in various "PV+" applications, to meet the growing global demand for clean energy.

Reference service life: 25 years as per the NPCR 029 Part B Version: 1.2, 2022-03-31.

2.3 Technical data

The technical data of TWMNH-48HD is listed below in Table 1.

Table 1: Technical data for TWMNH-48HD

Characteristic	Unit	Value
Power output range	W	425-455
Dimension	mm^3	(1762±2)x(1134±2)x30
Weight	kg	20.9
Area	m^2	2.0
Converting factor	Wp/m^2	227.5
First year degradation	%	1
Annual degradation	%	0.4

2.4 Substances of very high concern

No substance present in the product with a contribution of more than 0.1 % of the total weight is present on the "List of Potentially Hazardous Substances" (SVHC) that are candidates for authorisation under REACH legislation.

2.5 Base materials / Ancillary materials

The used base and ancillary materials for one piece of manufactured module TWMNH-48HD are listed below in Table 2.

Table 2: Base and ancillary materials for TWMNH-48HD

Components, raw and anillary materials	Unit	Value
PV Cells (Monocrystalline Silicon)	kg/PC	0.535
Interconnection strip (Copper)	kg/PC	0.152
Busbar (Copper)	kg/PC	0.048
Solar Glass (Glass)	kg/PC	15.845
Encapsulation (EVA)	kg/PC	1.597
Frame (Aluminium Alloy)	kg/PC	1.946
Junction box	kg/PC	0.130
Silica gel	kg/PC	0.301
Flux	kg/PC	0.016

Where, 1 PC of Module = 2.0 m^2 (Area of module).

2.6 Manufacturing

The manufacturing site is located in No. 8, Bonded 10 Road, Economic Development Zone, Nantong City, Jiangsu Province, P. R. China.

The manufacturing process is depicted in the Figure 1:

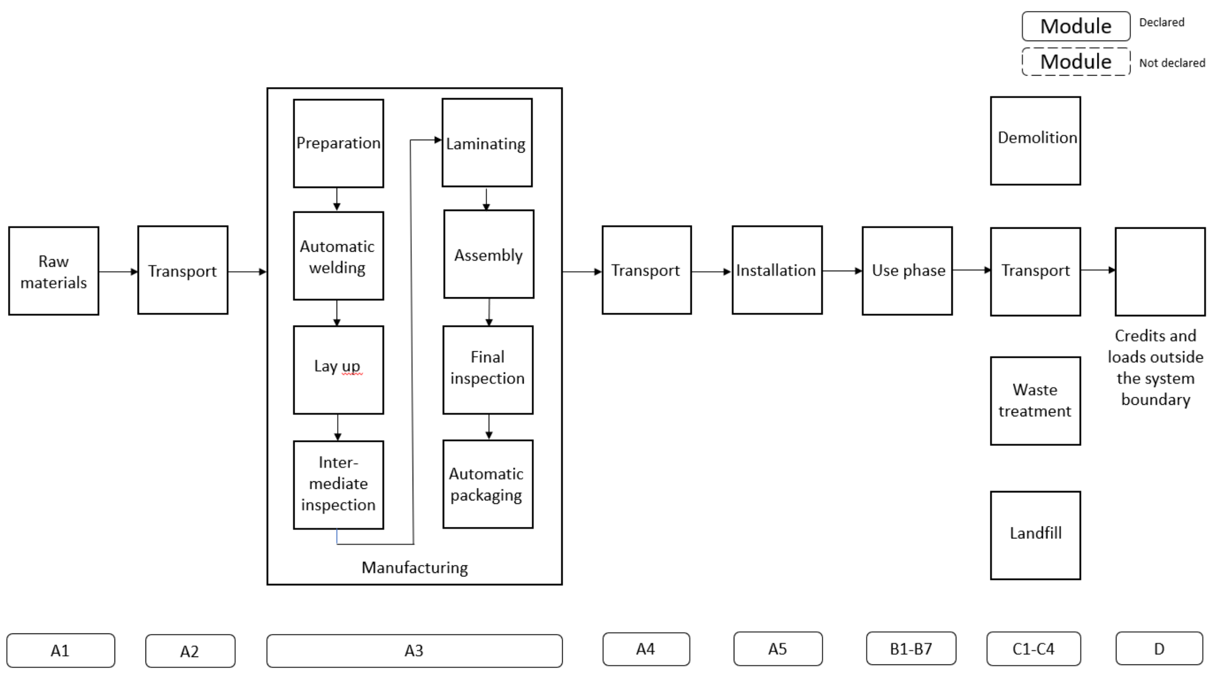

Figure 1: Process flow chart of the production of TWMNH-48HD.

The manufacturing process includes the following steps:

Step 1: Preparation:

The process starts with obtaining materials, followed by automatic glass feeding and loading of packaging film.

Step 2: Automatic Welding:

This includes cell cutting, automatic welding and cell string appearance and EL inspection.

Step 3: Lay Up:
This includes automatic typesetting of cell strings, automatic laying of insulation pad, automatic welding of bus bars as well as automatic laying of encapsulation film and backglass.

Step 4: Intermediate inspection:
This includes appearance and EL inspection before lamination.

Step 5: Laminating:
This includes laminating, automatic trimming and appearance inspection after lamination.

Step 6: Assembly:
This includes automatic frame mounting, installing welded junction boxes, automatic gluing, curing, angle rubbing, and cleaning.

Step 7: Final inspection:
This includes a safety testing, IV power testing, automatically attaching nameplates, and final appearance and EL inspection.

Step 8: Automatic packaging:
This step includes automatic packaging and packaging.

2.7 Other Information

For further information on this product please visit the webpage under the following link: Half-Cut Solar Modules - Tongwei Co., Ltd., (en.tongwei.com.cn/module.html)

3. LCA: Calculation rules

3.1 Functional unit

The functional unit is 1Wp (Watt- peak) of manufactured photovoltaic module, from cradle-to-grave, with activities needed for a study period for a defined reference service life (≥80% of the labelled power output).

3.2 Conversion factors

Table 3 Conversion Factors

Product	Value	Unit
Declared Unit	1	m^2
Weight per Declared unit (m^2)	10.28	kg
Functional Unit	1	Wp
Conversion factor for 1 m^2	227.5	Wp

3.3 Scope of declaration and system boundaries

Type of EPD: [cradle to grave+D]

Description of the system boundary																
Product stage			Construction process stage		Use stage							End of life stage				Benefits and loads beyond the system boundaries
Raw material supply	Transport	Manu-fac-turing	Transport from manu-	Constrution-installation	Use	Main-te-nance	Repair	Replacement	Refur-bish-ment	Operational energy use	Operational water use	De-construc-tion / demo-	Transport	Waste pro-cessing	Disposal	Reuse-Recovery-Recycling-po-tential
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X=Module declared | ND= Module not declared																

LCA method R<THiNK: Ecobility Experts | EN15804+A2
LCA software*: Simapro 9.1 (Simapro is used for calculating the characterized results of the Environmental profiles within R<THiNK)
Characterization method: EN 15804 +A2 Method v1.0
LCA database profiles: Ecoinvent version 3.6

3.4 Geographical reference area

The product is produced and manufactured in Nantong City, Jiangsu Province, P. R. China, and the main market areas are China, the European Union, the Middle East, Latin America, etc.
The geographical reference area is China and Europe.

3.5 Cut-off Criteria

No specific materials have been cut-off in this specific LCA. All materials provided by the manufacturer are properly modelled.

3.6 Allocation

The allocation is performed in accordance with the provisions of EN 15804. Incoming energy, water, and in-house waste production are equally allocated among all products using a power output allocation method. For the end-of-life allocation of background data (energy and materials), the "allocation cut-off by classification" model, as specified in the ISO standard, is applied. In the end-of-life stage of solar PV modules, the loads and benefits associated with reuse, recycling, and recovery processes are reported separately, as recommended by the PCR. Specific details regarding allocations within the background data can be found in the documentation of the Ecoinvent datasets.

3.7 Data collection and reference time period

The production data have been collected for the year 2024 (01/01/2024 – 31/07/2024) and are therefore up to date.

3.8 Estimates and assumptions

Transport to manufacturer (A2)

It was assumed that all transportation from suppliers is carried out using trucks. The environmental profile used for this purpose is "T0001 - Lorry (Truck), unspecified (default) | market group for (GLO)."

Production process (A3) | Production waste

The production waste data was based on the data sheets provided by the manufacturer. It is assumed that the waste scenarios for both production waste and end-of-life waste are similar.

Production process (A3) | Energy consumption

The energy consumption data was sourced from the manufacturer based on the onsite production data. Since the production takes place in China, the electricity grid mix for China is applied, using the environmental profile "Electricity, medium voltage {CN} | market group for | Cut-off, U."

3.9 Power Mix

Since the production site is in China, the environmental profile "Electricity, medium voltage {CN} | market group for | Cut-off, U" is used to account for electricity consumption during solar module production using location-based approach.

Where, Electricity Mix for company is 0.284 kg CO_2-equivalents per kWh (kg CO_2eq/kWh).

As the target market is Europe, a location-based approach was used. The environmental profile "[E0205] Electricity (EU) - low voltage (max 1kV)" was applied for Module A5, covering the construction stage.

3.11 Comparability

In principle, a comparison or assessment of the environmental impacts of different products is only possible if they have been prepared in accordance with EN 15804. For the evaluation of the comparability, the following aspects have to be considered in particular: PCR used , functional or declared unit, geographical reference, definition of the system boundary, declared modules, data selection (primary or secondary data, background database, data quality), scenarios used for use and disposal phases, and the life cycle inventory (data collection, calculation methods, allocations, validity period). PCRs and general program instructions of different EPDs programs may differ. A comparability needs to be evaluated. For further guidance see EN 15804+A2 (5.3 Comparability of EPD for construction products) and ISO 14025 (6.7.2 Requirements for comparability).

3.12 Data quality

The data quality of the study has been assessed in accordance with the "UN Environment Global Guidance on LCA Database Development," as referenced in EN 15804+A2.

Table 4 Data Quality

Quality Requirement	Specific Requirement	Data Quality Level	Notes
Time-Related Coverage	Age of data and minimum time - period for data collection.	TW Solar: 2024-01-01 to 2024-07-31	Very Good
Geographical Coverage	Upstream: Unit process for raw material should be collected for respective geographic region.	All raw material data were based on the respective geographic region.	Good
	Core: Unit process for production should represent the real site.	Production data is collected and provided by TW Solar.	Very Good
	Downstream: End-of-life disposal should represent the region of disposal.	Parameters from NMDstandards and generic data from the database were used for scenario development.	Good

Quality Require-ment	Specific Requirement	Data Quality Level	Notes
Technical Re-presenta-tiveness	Qualitative assessment of the degree to which the data set reflects the true population of interest (Technology)	Data for the processes and prod-ucts under study were collected using similar technology.	Good

4. LCA: Scenarios and additional technical information

4.1 Transportation to Construction site (A4)

Transport from production place to place of installation (A4): The manufactured PV modules were ex-ported to Europe and other global markets. In this scenario, it was assumed that the modules were transported 252 km by truck from the production site to the Shanghai port. From Shanghai, they were shipped to Amsterdam over a distance of 19,544 km. An additional 252 km was assumed for the transport from Amsterdam port to the storage location. As per the PCR requirements, a further 500 km of transportation was assumed from the storage location to the relevant market. The total transport distance amounts to 20,548 km, with specific distances calculated using SEADISTANCES.ORG and Google Maps.

Table 5 Transportation to construction site

Transport from production place to Installation site/user (A4)	Fuel type and consumption of vehicle	Capacity utilisation (including empty-returns) %	Distance (km)
Truck, EURO5, 16-32 metric ton	Diesel	36.7	252
Transocenic ship	Heavy oil	50	19544
Truck, EURO5, 16-32 metric ton	Diesel	36.7	752

4.2 Assembly (A5)

In accordance with NPCR 029 Part B, waste treatment of packaging materials and energy consumption during the installation phase must be considered. The electricity and diesel usage for installation were scaled based on data from the Ecoinvent database, which provides reference values of 36.03 kWh and 7673 MJ per 570 kWp system (from the process: "Photovoltaic plant, 570kWp, multi-Si, on open ground {GLO}| photovoltaic plant construction, 570kWp, multi-Si, on open ground | Cut-off, U"). These values were then adjusted to align with the power rating of the PV module being used (455 Wp).

Table 6 Construction consumption process (per Wp capacity)

Electricity	36.033 kWh electricity for 570 kWp as in the Ecoinvent da-taset ("Photovoltaic plant, 570 kWp, multi-Si, on open ground {GLO}| photovoltaic plant construction, 570 kWp, multi-Si, on open ground | Cut-off, U")	Conversion factor 0.06 kWh/kWp is applied
Diesel	7673 MJ diesel for 570 kWp as in the Ecoinvent dataset ("Photovoltaic plant, 570 kWp, multi-Si, on open ground {GLO}| photovoltaic plant construction, 570 kWp, multi-Si, on open ground | Cut-off, U")	Conversion factor 13.4MJ/kWp is applied.

The compositions of the packing waste were mainly waste pallet, waste corrugated sheet and waste kraft paper. The disposal was assumed to be 85% incineration, 10% landfill and 5% recycling for pallet. 25% incineration for the wooden pallet. 75% recycling and 25% incineration was assumed for waste corrugated sheet and waste kraft paper. The transportation distance to landfill, incineration and recycling was assumed to be 100 km, 150 km and 50 km respectively by a truck.

4.3 Use (B1)

There are no material or energy inputs, nor emissions during the use phase (B1) of the PV module.

4.4 Maintenance (B2) and Repair (B3)

The only maintenance required for PV modules is periodic cleaning. It was assumed that approximately 0.3 Liters of water is needed per module, with manual cleaning performed twice annually. During the Reference Service Life (RSL) of the module, no further maintenance. On a yearly basis, this equates to 0.3 kg of water per m^2 of module area, with 0.00741 kg of soap used for cleaning. It is assumed that the there was no repair.

4.5 Replacement (B4) and Refurbishment (B5)

It is assumed that neither replacement nor refurbishment of the PV module is necessary throughout its RSL.

4.6 Operational energy (B6) and water consumption (B7)

According to the NPCR 029 Part B v1.2, PV module does not require B6 and B7 respectively. The energy produced by a PV module depends on several factors, including installed power peak [Wp], degradation rate, geographic location, and the orientation/placement of the installation. The formulae for calculating energy production are as follows:

Energy Production in the First Year of Operation:

$$E_1 = S_{rad} \times A \times y \times PR \times (1 - deg)$$

Where:

- **S_{rad}**: Site specific annual average solar radiation on module (shadings not included), kWh/kWp/year. The annual radiation must take into consideration the specific inclination (slope, tilt) and orientation.
- **A**: Module area (m^2), stated in the EPD
- **y**: Module yield: electrical power, kWp for standard test conditions (STC) of the module divided by the area of the module (stated in the EPD).
- **PR**: Performance ratio (site-specific losses). Site specific performance ratio can be modelled with PV simulation software tools, such as PVSyst or similar.
- **deg**: Yearly degradation rate, stated in the EPD.

Energy Production Over Reference Service Life of the Module

$$E_{RSL} = E_1 \times (1 + \sum_{n=1}^{RSL-1} (1 - deg)^n)$$

Where:

- **n**: Year index.
- **RSL:** Reference service life for energy-producing unit, from functional unit (FU), stated in the EPD.

4.7 Deconstruction (C1)

Deconstruction primarily involves energy consumption for onsite dismantling, and it is assumed that this energy use is equivalent to that during the construction stage (A5).

This study refers to legal requirements issued by Waste Electrical and Electronic Equipment (WEEE) under the EU scenario. The required recycling rate for waste PV modules is 85% according to 2012/19/EU-Article 11 & ANNEX V.

4.8 Transportation end-of-life (C2)

The following distances and transport conveyance are assumed for transportation during end of life for the different types of waste processing.

Default transportation scenarios have been established as follows: 100 km for landfill, 150 km for incineration, and 50 km for recycling. Transportation is assumed to occur via truck, utilising the environmental profile [T0001] Lorry (Truck), unspecified (default) | market group for (GLO). These scenarios meet the requirements of the PCR, with a standard assumption of 50 km for transportation.

Table 7 Transportation – end-of-life

Parameters	Value and unit
Vehicle type used for transport	Lorry (Truck), unspecified (default) | market group for (GLO)
Fuel type and consumption of vehicle	Not available
Capacity utilisation (including empty returns)	50% (loaded up and return empty)
Bulk density of transported products	Inapplicable
Volume capacity utilisation factor	1

4.9 End of life (C3, C4)

The scenario(s) assumed for end of life of the product are given in the following tables. First the assumed percentages per type of waste processing are displayed, followed by the assumed amounts. As the waste disposal takes place in Europe, the NMD waste scenarios were taken as a reference for waste scenarios.

Table 8 Waste scenarios for end of life [%]

Waste Scenario	Not removed (stays in work) [%]	Land fill [%]	Incineration [%]	Recycling [%]	Re-use [%]
PV cells	0	20	0	80	0

Waste Scenario	Not re-moved (stays in work) [%]	Land fill [%]	Incineration [%]	Recycling [%]	Re-use [%]
Copper	0	5	0	95	0
Waste treatment for solar glass	0	15	0	85	0
Finishes (adhered to wood, plastic, metal) (NMD ID 2)	0	0	100	0	0
Aluminium, cast alloy for buildings (i.e. profiles, sheets, pipes) (NMD ID 4)	0	3	3	94	0
Waste scenario of Junction box	0	5	35	60	0

Table 9 Waste scenarios for end of life [kg]

Waste Scenario	Not removed (stays in work) [kg]	Land fill [kg]	Incinera-tion [kg]	Recycling [kg]	Re-use[kg]
PV cells	0	0.054	0.000	0.214	0.000
Copper	0	0.005	0.000	0.095	0.000
Waste treatment for solar glass	0	1.189	0.000	6.740	0.000
Finishes (adhered to wood, plastic, metal) (NMD ID 2)	0	0.000	0.950	0.000	0.000
Aluminium, cast alloy for buildings (i.a. profiles, sheets, pipes) (NMD ID 4)	0	0.029	0.029	0.915	0.000
Waste scenario of Junction box	0	0.003	0.023	0.039	0.000
Total	0	1.280	1.002	8.004	0.000

The end-of-life packaging assessment was conducted using the default waste scenarios in R<THiNK for the relevant environmental profiles (namely: NMD ID 35 according to EN16449 and PEF scenario).

4.10 Benefits and loads beyond the system boundary (D)

The presented Benefits and loads beyond the system boundary in this EPD are based on the following calculated Net output flows in kilograms and Energy recovery displayed in MJ Lower Heating Value.

Table 10 Benefits and loads beyond the system boundary.

Waste Scenario	Net output flow [kg]	Energy recovery [MJ]
PV cells	0.214	0.000
Copper	0.095	0.000
Waste treatment for solar glass	5.551	0.000
finishes (adhered to wood, plastic, metal) (NMD ID 2)	0.000	35.190
aluminium, cast alloy for buildings (i.a. profiles, sheets, pipes) (NMD ID 4)	0.915	0.000
Waste scenario of Junction box	0.039	1.002
Total	8.004	36.192

5. LCA: Results

The following tables show the results of the impact assessment indicators, resource use, waste and other output streams. The results presented here refer to the declared average product.

Disclaimer on ADP-e, ADP-f, WDP, ETP-fw, HTP-c, HTP-nc, SQP: The results of these environmental impact indicators must be used with caution, as the uncertainties in these results are high or as there is limited experience with the indicator.

Disclaimer on IR: This impact category mainly addresses the potential effect of low dose ionizing radiation on human health in the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents and occupational exposures, nor does it consider radioactive waste disposal in underground facilities. Potential ionizing radiation from soil, radon, and some building materials is also not measured by this indicator.

Note: Modules B1, B3, B4, B5, B6, and B7 have no relevant impact across all impact category results. Therefore, they are not included in the table below, but their values remain 0 in the results of all impact categories.

Table 11 Results declared per Functional unit (1Wp) – 1

LCA results - Indicators describing environmental impacts based on the impact assessment (LCIA): [1Wp of TWMNH-48HD] (EN 15804+A2)											
Parameter	**Unit**	**A1**	**A2**	**A3**	**A4**	**A5**	**B2**	**C1**	**C2**	**C3**	**C4**	**D**
Core environmental impact indicators (EN 15804+A2)												
GWP-total	kg CO_2 eqv	4.26E-01	1.71E-03	2.82E-03	1.57E-02	7.78E-03	9.01E-05	3.52E-03	4.03E-04	1.28E-02	1.09E-04	-9.80E-02
GWP-f	kg CO_2 eqv	4.26E-01	1.71E-03	2.82E-03	1.57E-02	7.78E-03	9.01E-05	3.52E-03	4.03E-04	1.28E-02	1.09E-04	-9.80E-02
GWP-b	kg CO_2 eqv	2.36E-03	7.87E-07	-4.20E-03	-6.77E-08	4.18E-03	-1.81E-03	3.56E-06	1.86E-07	2.53E-04	9.49E-07	-4.23E-04
GWP-luluc	kg CO_2 eqv	6.29E-04	6.24E-07	6.59E-06	8.57E-06	5.71E-07	1.12E-03	5.36E-07	1.48E-07	1.96E-06	3.39E-08	-2.98E-04
ODP	kg CFC 11 eqv.	4.13E-08	3.76E-10	3.39E-10	3.26E-09	7.60E-10	1.29E-10	7.43E-10	8.88E-11	1.72E-10	1.63E-11	-4.44E-09
AP	mol H^+ eqv.	2.68E-03	9.89E-06	4.84E-05	3.16E-04	4.97E-05	1.06E-05	4.88E-05	2.33E-06	1.21E-05	5.10E-07	-6.07E-04
EP-fw	kg CO_2 eqv	2.73E-05	1.72E-08	3.48E-07	9.93E-08	1.64E-08	1.03E-07	1.50E-08	4.06E-09	9.36E-08	1.47E-09	-3.41E-06
EP-m	kg CO_2 eqv	4.53E-04	3.49E-06	8.31E-06	7.91E-05	2.18E-05	1.05E-05	2.14E-05	8.22E-07	2.52E-06	1.67E-07	-9.10E-05
EP-T	kg CO_2 eqv	4.88E-03	3.84E-05	9.27E-05	8.79E-04	2.39E-04	3.83E-05	2.35E-04	9.05E-06	2.74E-05	1.83E-06	-1.06E-03
POCP	kg NMVOC eqv.	1.60E-03	1.10E-05	3.49E-05	2.32E-04	6.29E-05	5.01E-06	6.15E-05	2.59E-06	8.22E-06	5.05E-07	-3.02E-04
ADP-mm	kg Sb-eqv.	4.66E-05	4.32E-08	1.33E-06	2.45E-07	2.09E-08	5.36E-08	1.89E-08	1.02E-08	4.75E-08	5.45E-09	1.45E-05
ADP-f	MJ	5.41E+00	2.57E-02	7.65E-02	2.14E-01	4.84E-02	8.31E-03	4.70E-02	6.07E-03	2.43E-02	1.28E-03	-9.80E-01
WDP	m^3 world eqv.	3.34E-01	9.19E-05	3.22E-03	4.92E-04	6.33E-05	3.52E-03	4.97E-05	2.17E-05	3.16E-04	1.39E-05	-1.13E-02
Additional environmental impact indicators (EN 15804+A2)												
PM	disease incidence	2.45E-08	1.53E-10	5.23E-10	7.43E-10	8.04E-11	1.53E-10	6.95E-11	3.62E-11	1.35E-10	7.38E-12	-6.46E-09
IR	kBq U235 eqv.	1.68E-02	1.08E-04	1.55E-04	9.05E-04	2.11E-04	2.49E-05	2.07E-04	2.55E-05	1.14E-04	5.05E-06	-1.70E-03
ETP-fw	CTUe	1.45E+01	2.29E-02	3.02E-01	1.61E-01	3.25E-02	9.58E-02	3.07E-02	5.41E-03	1.60E-01	8.18E-02	-2.47E+00
HTP-c	CTUh	2.86E-10	7.43E-13	6.29E-12	7.3E-12	1.12E-12	2.69E-12	5.45E-13	1.75E-13	1.47E-11	8.7E-14	-1.34E-10
HTP-nc	CTUh	1.5E-08	2.51E-11	2.59E-10	1.47E-10	4.57E-11	6.55E-11	4.29E-11	5.93E-12	1.02E-10	3.39E-12	-2.77E-09
SQP	Pt	1.37E+00	2.23E-02	5.27E-01	8.31E-02	6.95E-03	8.35E-02	6.11E-03	5.27E-03	1.65E-02	2.39E-03	-4.33E-01

ADP-mm= Abiotic depletion potential for non-fossil resources | **ADP-f**=Abiotic depletion for fossil resources potential | **AP**= Acidification potential, Accumulated Exceedance | **EP-fw** = Eutrophication potential, fraction of nutrients reaching freshwater end compartment | **EP-m**= Eutrophication potential, fraction of nutrients reaching marine end compartment| **EP-T**= Eutrophication potential, Accumulated Exceedance | **GWP-b**=Global Warming Potential biogenic | **GWP-f**=Global Warming Potential fossil fuels | **GWP-luluc**=Global Warming Potential land use and land use change |**GWP-total**=Global Warming Potential total| **ODP**=Depletion potential of the stratospheric ozone layer |**POCP**=Formation potential of tropospheric ozone | **WDP**=Water (user) deprivation potential, deprivation- weighted water consumption | **ETP-fw**=Potential Comparative Toxic Unit for ecosystems | **HTP-c**=Potential Toxic Unit for Humans toxicity, cancer | **HTP-nc**= Potential Toxic Unit for humans, non-cancer | **IRP**=Potential Human exposure efficiency relative to U235, human health | **PM**=Potential incidence of disease due to Particulate Matter emissions | **SQP**=Potential soil quality index

Table 12 Results declared per Functional unit (1Wp) – 2

LCA results - Indicators describing resource use and environmental information derived from life cycle inventory (LCI): [1Wp of TWMNH-48HD] (EN 15804+A2)												
Parameter	**Unit**	**A1**	**A2**	**A3**	**A4**	**A5**	**B2**	**C1**	**C2**	**C3**	**C4**	**D**
PERE	MJ	8.63E-01	3.22E-04	4.75E-02	1.88E-03	4.05E-04	1.60E-02	3.74E-04	7.60E-05	2.55E-03	3.64E-05	-1.69E-01
PERM	MJ	0.00E+00	0.00E+00	3.51E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERT	MJ	8.63E-01	3.22E-04	8.26E-02	1.88E-03	4.05E-04	1.60E-02	3.74E-04	7.60E-05	2.55E-03	3.64E-05	-1.69E-01
PENRE	MJ	5.59E+00	2.73E-02	8.03E-02	2.27E-01	5.14E-02	1.05E-02	5.01E-02	6.45E-03	2.58E-02	1.36E-03	-1.04E+00
PENRM	MJ	1.67E-01	0.00E+00	6.66E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT	MJ	5.76E+00	2.73E-02	8.09E-02	2.27E-01	5.14E-02	1.05E-02	5.01E-02	6.45E-03	2.58E-02	1.36E-03	-1.04E+00
SM	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW	m^3	1.16E-02	3.13E-06	9.60E-05	1.70E-05	3.64E-06	1.33E-04	2.51E-06	7.39E-07	1.60E-05	1.20E-06	-6.39E-04
HWD	kg	1.91E-04	6.52E-08	1.08E-06	3.68E-07	1.38E-07	1.86E-08	1.35E-07	1.54E-08	2.66E-05	1.38E-09	3.23E-05
NHWD	kg	4.90E-02	1.63E-03	8.60E-04	5.00E-03	3.12E-04	2.06E-04	5.61E-05	3.85E-04	2.21E-03	5.87E-03	-1.58E-02
RWD	kg	1.39E-05	1.69E-07	1.42E-07	1.45E-06	3.39E-07	2.56E-08	3.32E-07	3.99E-08	1.12E-07	7.51E-09	-1.74E-06
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFR	kg	0.00E+00	0.00E+00	2.04E-06	0.00E+00	5.11E-04	0.00E+00	0.00E+00	0.00E+00	4.44E-03	0.00E+00	0.00E+00
MER	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EET	MJ	0.00E+00	0.00E+00	-2.01E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-5.71E-02
EEE	MJ	0.00E+00	0.00E+00	-1.17E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.32E-02

PERE=Use of renewable primary energy excluding renewable primary energy resources used as raw materials | **PERM**= Use of renewable primary energy resources used as raw materials | **PERT**=Total use of renewable primary energy resources | **PENRE**= Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials | **PENRM**= Use of non-renewable primary energy resources used as raw materials | **PENRT**= Total use of non-renewable primary energy resources | **SM**=Use of secondary material | **RSF**=Use of renewable secondary fuels | **NRSF**=Use of non-renewable secondary fuels | **FW**=Use of fresh water | **HWD**=Hazardous waste disposed | **NHWD**=Non-hazardous waste disposed | **RWD**=Radioactive waste disposed | **CRU**=Components for re-use | **MFR**=Materials for recycling | **MER**=Materials for energy recovery | **EET**=Exported energy, thermical | **EE**=Exported energy, electrical

LCA results - information on biogenic carbon content at the factory gate: [1Wp of TWMNH-48HD]] (EN 15804+A2)		
Parameter	**Value**	**Unit**
biogenic carbon content in product	0	kg C
biogenic carbon content in accompanying packaging	1.14E-03	kg C
NOTE 1 kg biogenic carbon is equivalent to 44/12 kg CO_2 eq.		

UPTAKE OF BIOGENIC CARBON DIOXIDE

The following amount of carbon dioxide uptake is taken into account. Related uptake and release of carbon dioxide in downstream processes are not taken into account in this number although they do appear in the presented results. One kilogram of biogenic Carbon content is equivalent to 44/12 kg of biogenic carbon dioxide uptake.

UPTAKE OF BIOGENIC CARBON DIOXIDE		
Parameter	**Amount**	**Unit**
Packaging	4.18E-03	kg CO_2eq. (biogenic)

6. LCA: Interpretation

Contribution analysis

From the Figure 2, it can be clearly seen that the module A1 has the major impact across all the categories. So, the major hotspot lies in the raw materials of the module. In the module (A1), major portion of the impact is attributed to manufacturing of PV cells (Monocrystalline cells) around 50% across all the impact categories.

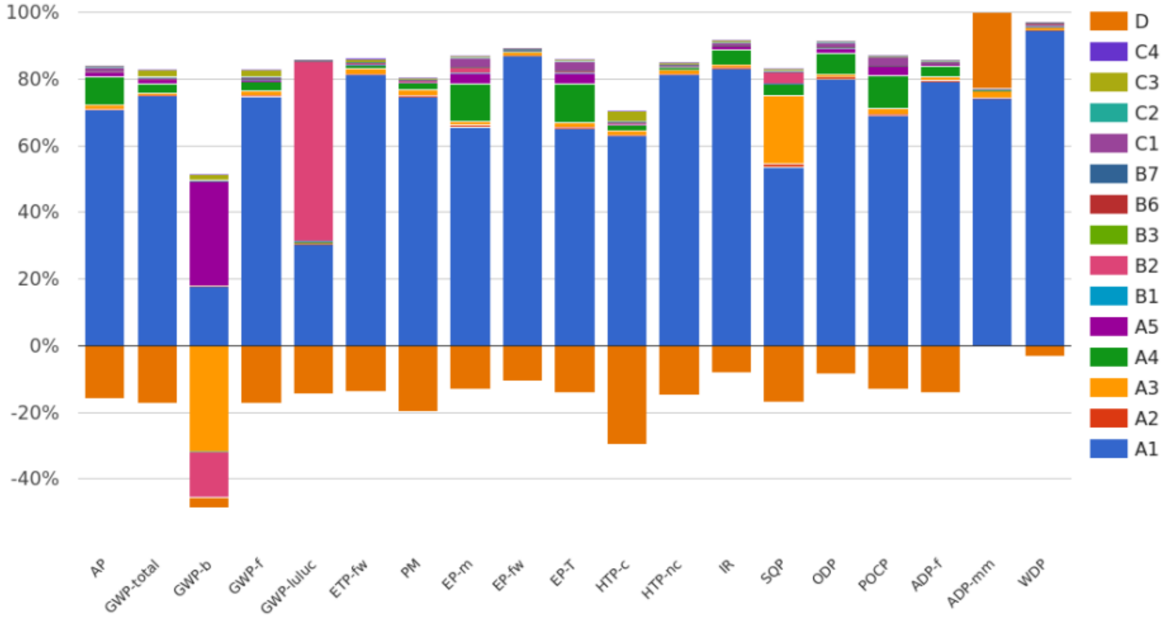

Figure 2 Contribution analysis of modules.

7. Annexure

The following tables show the results of the impact assessment indicators, resource use, waste and other output streams per declared unit (1m^2 of manufactured module). The results presented here refer to the declared average product.

Disclaimer on ADP-e, ADP-f, WDP, ETP-fw, HTP-c, HTP-nc, SQP: The results of these environmental impact indicators must be used with caution, as the uncertainties in these results are high or as there is limited experience with the indicator.

Disclaimer on IR: This impact category mainly addresses the potential effect of low dose ionizing radiation on human health in the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents and occupational exposures, nor does it consider radioactive waste disposal in underground facilities. Potential ionizing radiation from soil, radon, and some building materials is also not measured by this indicator.

Note: Modules B1, B3, B4, B5, B6, and B7 have no relevant impact across all impact category results. Therefore, they are not included in the table below, but their values remain 0 in the results of all impact categories

Table 13 Results declared per declared unit (1m² of manufactured module) – 1

LCA results - Indicators describing environmental impacts based on the impact assessment (LCIA): [1m2 of TWMNH-48HD] (EN 15804+A2)												
Parameter	**Unit**	**A1**	**A2**	**A3**	**A4**	**A5**	**B2**	**C1**	**C2**	**C3**	**C4**	**D**
Core environmental impact indicators (EN 15804+A2)												
GWP-total	kg CO_2 eqv	9.69E+01	3.88E-01	6.42E-01	3.57E+00	1.77E+00	2.05E-02	8.00E-01	9.16E-02	2.92E+00	2.47E-02	-2.23E+01
GWP-f	kg CO_2 eqv	9.69E+01	3.88E-01	6.42E-01	3.57E+00	1.77E+00	2.05E-02	8.00E-01	9.16E-02	2.92E+00	2.47E-02	-2.23E+01
GWP-b	kg CO_2 eqv	5.36E-01	1.79E-04	-9.56E-01	-1.54E-05	9.51E-01	-4.12E-01	8.09E-04	4.23E-05	5.76E-02	2.16E-04	-9.62E-02
GWP-luluc	kg CO_2 eqv	1.43E-01	1.42E-04	1.50E-03	1.95E-03	1.30E-04	2.54E-01	1.22E-04	3.36E-05	4.46E-04	7.72E-06	-6.79E-02
ODP	kg CFC 11 eqv.	9.39E-06	8.56E-08	7.72E-08	7.41E-07	1.73E-07	2.94E-08	1.69E-07	2.02E-08	3.91E-08	3.70E-09	-1.01E-06
AP	mol H^+ eqv.	6.10E-01	2.25E-03	1.10E-02	7.20E-02	1.13E-02	2.41E-03	1.11E-02	5.31E-04	2.76E-03	1.16E-04	-1.38E-01
EP-fw	kg CO_2 eqv	6.22E-03	3.91E-06	7.91E-05	2.26E-05	3.73E-06	2.34E-05	3.42E-06	9.24E-07	2.13E-05	3.34E-07	-7.76E-04
EP-m	kg CO_2 eqv	1.03E-01	7.93E-04	1.89E-03	1.80E-02	4.96E-03	2.38E-03	4.87E-03	1.87E-04	5.74E-04	3.79E-05	-2.07E-02
EP-T	kg CO_2 eqv	1.11E+00	8.74E-03	2.11E-02	2.00E-01	5.44E-02	8.71E-03	5.34E-02	2.06E-03	6.23E-03	4.17E-04	-2.41E-01
POCP	kg NMVOC eqv.	3.64E-01	2.50E-03	7.93E-03	5.27E-02	1.43E-02	1.14E-03	1.40E-02	5.89E-04	1.87E-03	1.15E-04	-6.86E-02
ADP-mm	kg Sb-eqv.	1.06E-02	9.83E-06	3.03E-04	5.57E-05	4.76E-06	1.22E-05	4.31E-06	2.32E-06	1.08E-05	1.24E-06	3.29E-03
ADP-f	MJ	1.23E+03	5.85E+00	1.74E+01	4.86E+01	1.10E+01	1.89E+00	1.07E+01	1.38E+00	5.53E+00	2.92E-01	-2.23E+02
WDP	m^3 world eqv.	7.60E+01	2.09E-02	7.33E-01	1.12E-01	1.44E-02	8.00E-01	1.13E-02	4.94E-03	7.20E-02	3.17E-03	-2.58E+00
Additional environmental impact indicators (EN 15804+A2)												
PM	disease incidence	5.58E-06	3.49E-08	1.19E-07	1.69E-07	1.83E-08	3.48E-08	1.58E-08	8.24E-09	3.07E-08	1.68E-09	-1.47E-06
IR	kBq U235 eqv.	3.83E+00	2.45E-02	3.52E-02	2.06E-01	4.81E-02	5.66E-03	4.70E-02	5.79E-03	2.59E-02	1.15E-03	-3.87E-01
ETP-fw	CTUe	3.31E+03	5.22E+00	6.88E+01	3.67E+01	7.39E+00	2.18E+01	6.98E+00	1.23E+00	3.63E+01	1.86E+01	-5.62E+02
HTP-c	CTUh	6.51E-08	1.69E-10	1.43E-09	1.66E-09	2.55E-10	6.11E-10	1.24E-10	3.99E-11	3.35E-09	1.98E-11	-3.05E-08
HTP-nc	CTUh	3.41E-06	5.71E-09	5.89E-08	3.34E-08	1.04E-08	1.49E-08	9.77E-09	1.35E-09	2.32E-08	7.72E-10	-6.31E-07
SQP	Pt	3.12E+02	5.07E+00	1.20E+02	1.89E+01	1.58E+00	1.90E+01	1.39E+00	1.20E+00	3.76E+00	5.43E-01	-9.86E+01

ADP-mm= Abiotic depletion potential for non-fossil resources | **ADP-f**=Abiotic depletion for fossil resources potential | **AP**= Acidification potential, Accumulated Exceedance | **EP-fw** = Eutrophication potential, fraction of nutrients reaching freshwater end compartment | **EP-m**= Eutrophication potential, fraction of nutrients reaching marine end compartment| **EP-T**= Eutrophication potential, Accumulated Exceedance | **GWP-b**=Global Warming Potential biogenic | **GWP-f**=Global Warming Potential fossil fuels | **GWP-luluc**=Global Warming Potential land use and land use change |**GWP-total**=Global Warming Potential total| **ODP**=Depletion potential of the stratospheric ozone layer |**POCP**=Formation potential of tropospheric ozone | **WDP**=Water (user) deprivation potential, deprivation- weighted water consumption | **ETP-fw**=Potential Comparative Toxic Unit for ecosystems | **HTP-c**=Potential Toxic Unit for Humans toxicity, cancer | **HTP-nc**= Potential Toxic Unit for humans, non-cancer | **IRP**=Potential Human exposure efficiency relative to U235, human health | **PM**=Potential incidence of disease due to Particulate Matter emissions | **SQP**=Potential soil quality index

Table 14 Results declared per declared unit (1m^2 of manufactured module) – 2

LCA results - Indicators describing resource use and environmental information derived from life cycle inventory (LCI): [1m^2 of CEJBB-48HD]] (EN 15804+A2)												
Parameter	**Unit**	**A1**	**A2**	**A3**	**A4**	**A5**	**B2**	**C1**	**C2**	**C3**	**C4**	**D**
PERE	MJ	1.96E+02	7.33E-02	1.08E+01	4.28E-01	9.22E-02	3.63E+00	8.50E-02	1.73E-02	5.81E-01	8.28E-03	-3.85E+01
PERM	MJ	0.00E+00	0.00E+00	7.98E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PERT	MJ	1.96E+02	7.33E-02	1.88E+01	4.28E-01	9.22E-02	3.63E+00	8.50E-02	1.73E-02	5.81E-01	8.29E-03	-3.85E+01
PENRE	MJ	1.27E+03	6.21E+00	1.83E+01	5.16E+01	1.17E+01	2.39E+00	1.14E+01	1.47E+00	5.86E+00	3.09E-01	-2.37E+02
PENRM	MJ	3.81E+01	0.00E+00	1.52E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT	MJ	1.31E+03	6.21E+00	1.84E+01	5.16E+01	1.17E+01	2.39E+00	1.14E+01	1.47E+00	5.88E+00	3.10E-01	-2.37E+02
SM	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW	m^3	2.63E+00	7.13E-04	2.18E-02	3.86E-03	8.28E-04	3.02E-02	5.72E-04	1.68E-04	3.65E-03	2.72E-04	-1.45E-01
HWD	kg	4.35E-02	1.48E-05	2.45E-04	8.37E-05	3.13E-05	4.23E-06	3.07E-05	3.50E-06	6.05E-03	3.13E-07	7.35E-03
NHWD	kg	1.12E+01	3.71E-01	1.96E-01	1.14E+00	7.09E-02	4.69E-02	1.28E-02	8.76E-02	5.02E-01	1.33E+00	-3.59E+00
RWD	kg	3.16E-03	3.84E-05	3.23E-05	3.29E-04	7.72E-05	5.83E-06	7.56E-05	9.07E-06	2.55E-05	1.71E-06	-3.96E-04
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFR	kg	0.00E+00	0.00E+00	4.65E-04	0.00E+00	1.16E-01	0.00E+00	0.00E+00	0.00E+00	1.01E+00	0.00E+00	0.00E+00
MER	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EET	MJ	0.00E+00	0.00E+00	-4.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.30E+01
EEE	MJ	0.00E+00	0.00E+00	-2.66E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-7.55E+00

PERE=Use of renewable primary energy excluding renewable primary energy resources used as raw materials | **PERM**= Use of renewable primary energy resources used as raw materials | **PERT**=Total use of renewable primary energy resources | **PENRE**= Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials | **PENRM**= Use of non-renewable primary energy resources used as raw materials | **PENRT**= Total use of non-renewable primary energy resources | **SM**=Use of secondary material | **RSF**=Use of renewable secondary fuels | **NRSF**=Use of non-renewable secondary fuels | **FW**=Use of fresh water | **HWD**=Hazardous waste disposed | **NHWD**=Non-hazardous waste disposed | **RWD**=Radioactive waste disposed | **CRU**=Components for re-use | **MFR**=Materials for recycling | **MER**=Materials for energy recovery | **EET**=Exported energy, thermical | **EE**=Exported energy, electrical

LCA results - information on biogenic carbon content at the factory gate: [1m² of TWMNH-48HD]] (EN 15804+A2)		
Parameter	**Value**	**Unit**
biogenic carbon content in product	0	kg C
biogenic carbon content in accompanying packaging	2.59E-01	kg C
NOTE 1 kg biogenic carbon is equivalent to 44/12 kg CO_2 eq.		

UPTAKE OF BIOGENIC CARBON DIOXIDE

The following amount of carbon dioxide uptake is taken into account. Related uptake and release of carbon dioxide in downstream processes are not taken into account in this number although they do appear in the presented results. One kilogram of biogenic Carbon content is equivalent to 44/12 kg of biogenic carbon dioxide uptake.

UPTAKE OF BIOGENIC CARBON DIOXIDE		
Parameter	**Amount**	**Unit**
Packaging	9.50E-01	kg CO_2eq. (biogenic)

8. References

Ecoinvent 2019	Ecoinvent Datenbank Version 3.6 (2019)
EN 15804	EN 15804:2012+A2:2019: Sustainability of construction works — Environmental Product Declarations — Core rules for the product category of construction products.
ISO 14025	ISO 14025:2010 Environmental labels and declarations — Type III environmental declarations — Principles and procedures
ISO 14040	ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework
ISO 14044	ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines
NMD 2019	NMD STICHTING NATIONAL ENVIRONMENTAL DATABASE: Environmental Performance Assessment Method for Construction; 1.1 (March 2022); Rijswijk
PCR A	Kiwa-Ecobility Experts, Berlin, 2022: PCR A – General Program Category Rules for Construction Products from the EPD programme of Kiwa-Ecobility Experts; Version 2.1
PCR B	NPCR 029:2022: Part B for photovoltaic modules used in the building and construction industry, including production of cell, wafer, ingot block, solar grade silicon, solar substrates, solar superstrates and other solar grade semiconductor materials; Version 1.2.
R<THiNK 2023	R<THiNK; Online-EPD-Tool by NIBE B.V.
SimaPro Software	Industry data LCA library; website: https://simapro.com/databases/industry-data-lca-library/
WEEE	WEEE Directive 2012/19/EU Article 4,11&15
IEA PVPS Task 12	Rolf Frischknecht, Philippe Stolz, Luana Krebs, Mariska de Wild-Scholten, Parikhit Sinha, Life Cycle Inventories and Life Cycle Assessment of Photovoltaic Systems, International Energy Agency (IEA) PVPS Task 12: PV Sustainability, Report IEA-PVPS Task12-19:2020 December 2020.

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