ENVIRONMENTAL PRODUCT DECLARATION

PRODUCT :
DMEGC bifacial Monocrystalline photovoltaic module (N-type cells)

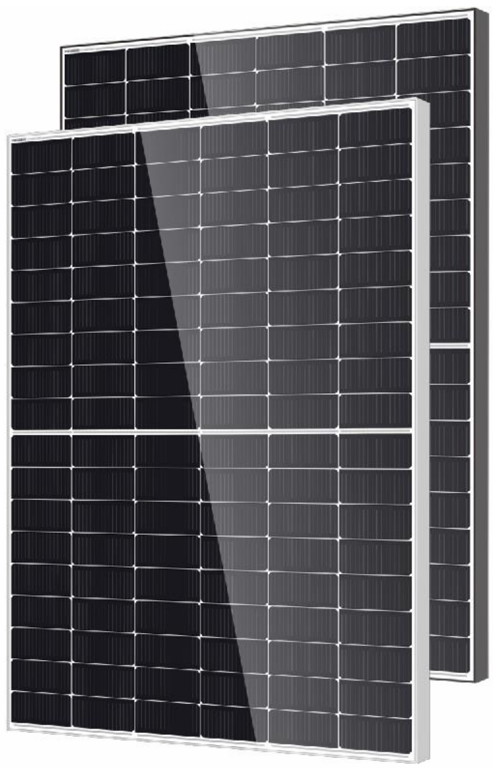
PLANT:
Jiangsu Dongci New Energy Technology Co.,Ltd

In accordance with ISO 14025

Program Operator	EPDItaly
Publisher	The Norwegian EPD Foundation

Declaration Number	DMEGC04
Registration Number	EPDITALY0440 / NEPD-30-24-MRA

Issue Date	30/01/2024
Valid to	30/07/2025



DMXXXM10T-B54XXX module

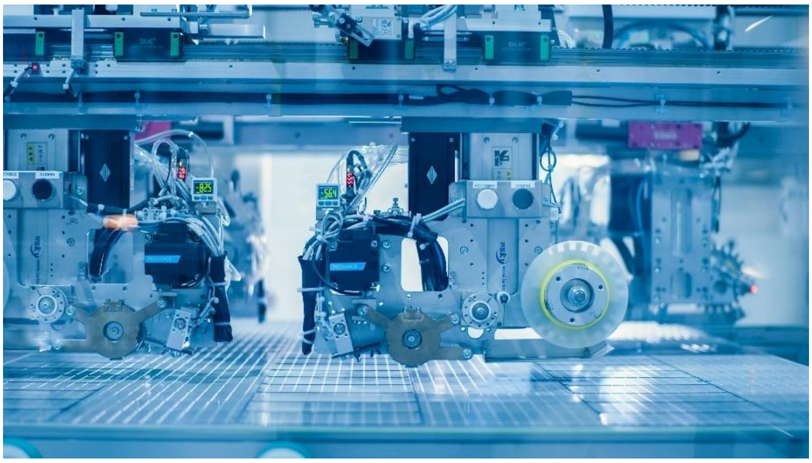
1. Company introduction

Founded in 1980, DMEGC Solar is committed to be the world's leading renewable energy company, possessing five manufacturing bases with an annual capacity of 8GW cells and 7GWmodules, and cumulative shipments are over 30GW. With industry-leading technology R&D, manufacturing technologies, quality management and service, DMEGC Solar provides high-efficiency and reliable PV products and all application solutions for global customers.

- Top 10 PV Module suppliers in 2022 (PVTECH)
- Bloomberg "Tier 1 Solar Panels Manufacturers
- EUPD Research "Top Brand PV Modules" since 2018
- Top Performer in PVEL PV Module Reliability Scorecard
- Leading Altman-Z score ranking in Global Solar Industry

We are one of the earliest PV manufacturers whose have passed French low -carbon certification for module life cycle and leading brand of black modules and European distributed market.

More information can be found on our website https://www.dmegcsolar.com/



Source: DMEGC

2. General information

EPD owner and address	Hengdian Group DMEGC Magnetics Co.,Ltd Adress :Hengdian Industrial Zone, Dongyang City, Jinhua City, Zhejiang Province, China Contact person : Allison (allison@dmegc.com.cn)
Production site and address	Jiangsu Dongci New Energy Technology Co.,Ltd No. 9, Wulijiang East Road,Sihong county economic development Zone, Sihong County, Suqian City, Jiangsu Province, China
Product name	Bi-facial M10 N-type monocrystalline silicon photovoltaic (PV) modules
Application	Electricity generation
CPC code	171 "Electrical energy"
External audit - Third party verifier	This declaration has been prepared with reference to EPDItaly, in accordance with the General Programme Guide; further information can be found at www.epditaly.it. Independent Verification Statement: Independent verification of the declaration and data, carried out according to ISO 14025: 2010. ☐ Internal ☒ External Third party verification carried out by: ICMQ S.p.A., via Gaetano De Castillia n ° 10 - 20124 Milan, Italy. Accredited by Accredia.
LCA Consultant	The LCA and report is written by: Kapstan https://www.kapstan.fr/ Address: 28 Rue Bellicard, 69003 Lyon Contact person: Yazid Charkani (Yazidcharkani@kapstan.fr)
Liability	The owner of the declaration is responsible for the information and supporting evidence. The LCA consultant has no responsibility for the further use of this report for other applications. EPDItaly disclaims all liability in relation to the manufacturer's information.
Comparability	EPDs from different programs are not necessarily comparable. Full compliance with the PCR only allows EPD comparability if all stages of the life cycle have been considered. Nevertheless, discrepancies are possible. Note that different LCA software and background LCI data sets may lead to different results.
PCR	EPDItaly014 Rev 1.1 (Core PCR for ELECTRICITY PRODUCED BY PHOTOVOLTAIC MODULES; 08/02/2022)
Further information	For further informations about EPDItaly regulations, you can refer to the EPDItaly webstite www.epditaly.com

3. Scope and type of EPD

3.1 Scope of EPD

The present EPD is based on a cradle to grave scope e.i from raw material extraction to the disposal of waste.

The lifecycle stages are illustrated in figure 1 based on PCR segmentation and EN15804 equivalent life cycle stages.

Life cycle stages according to PCR 014	Life cycle stages according to EN15804	Scope
Upstream stage	A1 – Raw material supply	X
	A2 – Raw material transportation	X
Core process	A3 – Manufacturing	X
	A4 – Transport to Pv plant	X
	A5 - Installation	X
	B1- Use	X
	B2- Maintenance	X
	B3- Repair	X
	B4- Replacement	X
	B5- Refurbishment	X
	B6- Operational energy use	X
	B7- Operational water use	X
	C1- Deconstruction	X
	C2- Transport to waste processing	X
Downstream stage	C3- Waste processing	X
	C4- Disposal	X
	Electricity distributed to the grid	X
	D- Benefits and loads beyond the system boundary	MND
Caption : X = modules declared in the Table of modules , MND = modules not declared in the Tables of modules.		

Figure 1 : EPD scope

In compliance with PCR014 the module D (benefits and loads beyond the system boundary) is not considered in the EPD.

3.2 Type of EPD

The present EPD is an <u>average EPD</u> including the following products:

- DMXXXM10T-B54HXX
- DMXXXM10T-B66HXX
- DMXXXM10T-B72HXX
- DMXXXM10T-B78HXX

3.3 Geographical coverage

The manufacturing of the modules and upstream intermediate products is in China, expect for polysi which part of it comes from Europe. Therefore, the present study is representative of pv modules manufactured in China. The present EPD study is based on the scenario that the PV power plant is installed in the city of Rome in Italy. The end-of-life of PV modules is considered to be in Italy.

3.4 Applied Database

Generic data for raw materials for PV module manufacturing and packaging; natural resources, such as water, energy, waste disposal and transport were taken from the database Ecoinvent 3.8, allocation, Cut-off by classification with adaptation of regional energy and material data collected by Kapstan.

3.5 Software

The EPD was conducted with the life cycle assessment software Simapro 9.4.0.2

4. Detailed product description

4.1 Functional unit and reference service life

In the EPD study, the functional unit is 1 kWh of electricity generated as output from the solar photovoltaic plant during 30 years in Rome, Italy. The environmental impact from this study was calculated and reported per functional unit.

Following the EPDItaly PCR for pv modules, the reference service life was defined as 30 years.

4.2 Product description

The present EPD study includes a range of 4 mono-crystalline pv modules with n-type Topcon technology cells, the peak power goes up to 625Wp for the largest modules, and a max efficiency of 22.5%. The modules include M10 cells size.

Modules references	Power output range in Wp	Dimensions in mm	Module efficiency in %
DMXXXM10T-B54HXX	410-430	1722*1134	22.0%
DMXXXM10T-B66HXX	505-525	2094*1134	22.1%
DMXXXM10T-B72HXX	565-580	2278*1134	22.5%
DMXXXM10T-B78HXX	610-625	2465*1134	22.4%

Table 1 : Product specification

4.3 Material composition

Components	Main substances	CAS No. of main substance	Units	DMXXXM10T-B54HXX	DMXXXM10T-B66HXX	DMXXXM10T-B72HXX	DMXXXM10T-B78HXX
Solar cell	Si	7440-21-3	pcs	54.000	66.000	72.000	78.000
Junction box	Cu	7440-50-8	kg/pcs	0.204	0.204	0.204	0.204
Ribbon string	Cu	7440-50-9	kg/pcs	0.151	0.151	0.165	0.223
Ribbon interconnection	Cu	7440-50-10	kg/pcs	0.043	0.043	0.043	0.043
Aluminium frame	Al	7429-90-5	kg/pcs	2.310	2.610	2.760	3.030
Solar glass	Na2O·nSiO2	1344-09-8; 106985-35-7	kg/pcs	19.356	23.553	25.628	27.738
Backsheet	(C10H8O4)n	25038-59-9	kg/pcs	0.000	0.000	0.000	0.000
EPE	(C2H4)n	9002-88-4	kg/pcs	1.549	1.884	2.050	2.219
EVA	(C2H4)x.(C4H6O2)y	24937-78- 8	kg/pcs	1.025	1.247	1.357	1.469
Silicon	SiO2	112926-00-8	kg/pcs	0.219	0.344	0.350	0.357
Flux for soldering	Sn	7440-31-5	kg/pcs	0.022	0.021	0.023	0.030

Table 2 : Material composition

4.5 EPD Average

The present EPD is a declaration relating to the average product amongst several products in a specific facility by a specific manufacturer (DMEGC).
The selected products can be considered from the same family since:

- Their purpose is the same (producing electricity through photovoltaic technology)
- They share the same technology (TopCon cells)
- The manufacturing process is identical.
- They are manufactured in the same factory.

The only difference is the number and the size of the cells included in each product.

EPD4	
Modules references	DMXXXM10T-B54HXX
	DMXXXM10T-B66HXX
	DMXXXM10T-B72HXX
	DMXXXM10T-B78HXX

Table 3 : EPD average

The variation of the impact results in the product average have been calculated for all the mandatory indicators based on PCR specifications, as presented below:

Average EPD	Impacts variation							
	GWP total	Ozone depletion	Acidification	Eutrophication of water	Photochemical ozone formation	Resource use - minerals and materials	Resource use - fossil resources	Water consumption
EPD4	0.94%	0.68%	1.01%	1.04%	0.81%	1.18%	0.83%	0.74%

Table 4 : Product average impact results variation

For all the impact indicators the variations of the results are under 10%. The average variation of the results across all mandatory indicators is 0.90%, therefore the EPD was considered as representative of the selected products.
The processes selected for the variation calculations contribute to at least 90% of the life cycle impacts.

4.5 Production processes

The 8 modules included in the EPD shares the same manufacturing process and life cycle stages, only the cell size and quantity are different, this leads to differences in module dimensions.
Photovoltaic modules are fabricated by electrically connecting typically 54 to 78 solar cells together in a so-called PV module. A PV module (or panel) is an assembly of solar cells in a sealed, weather-proof packaging and is the fundamental building block of photovoltaic (PV) systems.
The manufacturing of a PV module is primarily a mechanical assembly process.

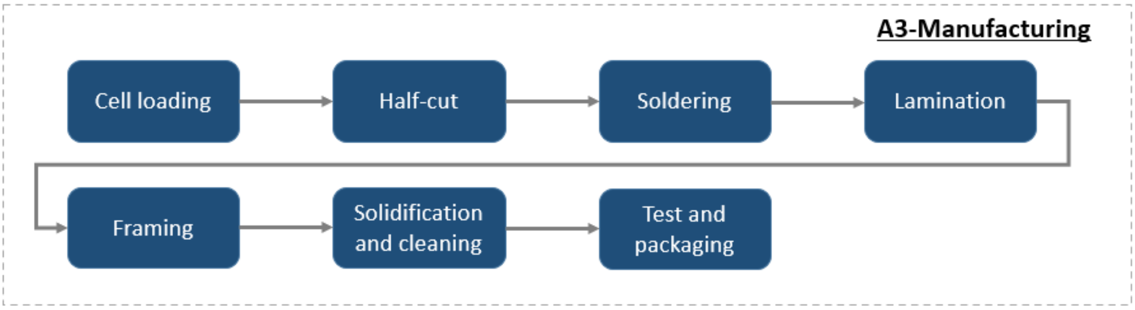


Figure 2 : PV Modules manufacturing process

The different processes are explained in section 7.

4.6 Installation

The pv plant installation have been modelled based on a ground based pv plant, the specifications of the pv plant are based on a real operating pv plant with DMEGC modules. The default ecoinvent model have been adapted with the specific characteristics of the real plant. More details can be found in the section 7.

4.7 End of life

The end-of-life stage includes the deconstruction of the pv plant (C1) and the waste processing, treatment, and disposal (C2-C4) of pv modules.

The end-of-life treatment of the pv modules is based on the published life cycle inventory of a pilot recycling unit in Italy, the recycling process follows an innovative route of module delamination, that allows a higher level of material and energy recovery.

5. LCA results

This EPD study follows the PCR EPDItaly014 photovoltaic modules guidelines and use the recommended impact method, the EN 15804+A2:2019 (version 1.04) was used in this report. The results are calculated for each impact categories for life cycle impact assessment, resource use, and output flows, the results are expressed per functional unit, a kWh of electricity generated by the pv plant.

Furthermore, the results are expressed by life cycle stage according to EN15804+A2.

5.1 LCA Results – Environmental impact per functional unit

Impact categories	Unit	Total	Upstream module		Core module						Downstream module	
			A1-Raw material supply	A2-transport to manufacturing site	A3-Manufacturing	A4- Transport to Pv plant	A5- Installation pv plant	B1-B7 use stage	C1 - Deconstruction	C2 - Transport to waste plant	C3-C4 End of life stage	Electricity distributed to the grid
Climate change - total	kg CO2 eq	**1.71E-02**	1.69E-02	9.63E-03	7.16E-05	5.05E-04	5.03E-03	3.78E-04	1.71E-05	1.48E-04	4.50E-04	1.71E-04
Climate change - fossil	kg CO2 eq	**1.69E-02**	1.67E-02	9.58E-03	7.11E-05	5.03E-04	4.95E-03	3.77E-04	1.71E-05	1.48E-04	4.50E-04	1.69E-04
Climate change - biogenic	kg CO2 eq	**6.94E-05**	6.87E-05	4.46E-05	3.24E-08	1.52E-06	2.12E-05	5.63E-07	8.21E-09	6.83E-08	4.70E-07	6.94E-07
Climate change - land use and change in land use	kg CO2 eq	**6.59E-05**	6.52E-05	6.59E-06	5.03E-07	2.85E-07	5.67E-05	5.80E-07	1.74E-09	7.11E-08	9.43E-08	6.59E-07
Ozone depletion	kg CFC11 eq	**2.09E-09**	2.07E-09	1.43E-09	1.51E-11	8.34E-12	3.41E-10	5.97E-11	3.64E-12	3.33E-11	3.68E-11	2.09E-11
Acidification	mol H+ eq	**1.30E-04**	1.29E-04	6.25E-05	3.92E-07	2.88E-06	4.93E-05	3.33E-06	1.76E-07	5.89E-07	1.17E-06	1.30E-06
Eutrophication of water	kg PO_4 eq	**7.61E-06**	7.54E-06	3.70E-06	5.87E-09	1.06E-07	3.44E-06	2.00E-07	6.05E-10	1.13E-08	3.16E-08	7.61E-08
Photochemical ozone formation	kg NMVOC eq	**8.72E-05**	2.43E-05	1.38E-05	1.40E-07	6.36E-07	5.65E-06	5.25E-07	7.76E-08	1.71E-07	1.24E-06	8.72E-07
Consumption of abiotic resources - minerals and materials	kg Sb eq	**1.39E-06**	2.45E-04	1.27E-04	1.51E-06	7.17E-06	7.17E-05	5.86E-06	8.50E-07	1.86E-06	6.82E-06	1.39E-08
Consumption of abiotic resources - fossil resources	MJ	**1.90E-01**	8.64E-05	5.13E-05	4.35E-07	1.79E-06	2.06E-05	1.92E-06	2.34E-07	5.75E-07	3.34E-06	1.90E-03
Water use	m3 depriv.	**6.05E-03**	1.38E-06	8.72E-07	2.43E-10	2.54E-09	4.57E-07	4.33E-08	1.20E-11	6.90E-10	1.19E-09	6.05E-05

Table 5 : LCA results

5.2 LCA Results – Resource use per functional unit

Resource categories	Unit	Total	Upstream module		Core module						Downstream module	
			A1-Raw material supply	A2-transport to manufacturing site	A3-Manufacturing	A4- Transport to Pv plant	A5- Installation pv plant	B1-B7 use stage	C1 Deconstruction	C2 - Transport to waste plant	C3-C4 End of life stage	Electricity distributed to the grid
Renewable primary energy excl. RM	MJ, net CV	**3.73E-02**	1.88E-02	1.84E-05	2.19E-03	1.53E-02	2.72E-04	2.98E-06	3.80E-05	1.67E-04	1.11E-04	3.73E-04
Renewable primary energy used as RM	MJ, net CV	**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
Total renewable primary energy	MJ, net CV	**3.73E-02**	1.88E-02	1.84E-05	2.19E-03	1.53E-02	2.72E-04	2.98E-06	3.80E-05	1.67E-04	1.11E-04	3.73E-04
Non renewable primary energy excl. RM	MJ, net CV	**1.90E-01**	1.02E-01	1.07E-03	4.76E-03	6.07E-02	5.23E-03	2.36E-04	2.22E-03	2.43E-03	9.29E-03	1.90E-03
Non renewable primary energy used as RM	MJ, net CV	**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
Total non renewable primary energy	MJ, net CV	**1.90E-01**	1.02E-01	1.07E-03	4.75E-03	6.07E-02	5.23E-03	2.36E-04	2.22E-03	2.43E-03	9.29E-03	1.90E-03
Use of secondary material	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
Use of renewable secondary fuels	MJ, net CV	**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
Use of non renewable secondary fuels	MJ, net CV	**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
Net use of fresh water	m3	**1.98E-04**	1.02E-04	1.14E-07	3.42E-06	8.49E-05	2.12E-06	1.57E-08	2.63E-07	1.83E-06	7.97E-07	1.98E-06

Caption : PERE = Use of renewable primary energy excluding renewable primary energy resources used as raw material, PERM = Use of renewable primary energy resources used as raw material, PERT = Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials), PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw material, PENRM = Use of non-renewable primary energy resources used as raw material, PENRT = Total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials)

Table 6: Resource use results

5.3 LCA results– Output flows and waste categories per functional unit

Output flows categories	Unit	Total	Upstream module		Core module						Downstream module	
			A1-Raw material supply	A2-transport to manufacturing site	A3-Manufacturing	A4- Transport to Pv plant	A5- Installation pv plant	B1-B7 use stage	C1 Deconstruction	C2 - Transport to waste plant	C3-C4 End of life stage	Electricity distributed to the grid
Hazardous landfill waste (HWD)	kg	**2.44E-03**	6.10E-04	1.12E-06	3.34E-05	1.52E-03	2.90E-05	1.87E-07	1.88E-06	2.07E-04	7.50E-06	2.44E-05
Non-hazardous waste disposed (NHWD)	kg	**2.28E-02**	1.05E-02	8.23E-05	5.89E-04	9.23E-03	7.62E-04	1.07E-06	1.12E-04	9.08E-04	3.95E-04	2.28E-04
Radioactive waste disposed (RWD)	kg	**5.17E-07**	1.59E-07	7.04E-09	4.69E-09	2.16E-07	2.75E-08	1.61E-09	1.48E-08	1.77E-08	6.33E-08	5.17E-09
Components for reuse (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
Material for recycling (MFR)	kg	**1.15E-03**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-03	0.00E+00	1.15E-05
Materials for energy recovery (MER)	kg	**8.38E-05**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.30E-05	0.00E+00	8.38E-07
Exported electricity energy (EEE)	MJ	**3.16E-04**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.13E-04	0.00E+00	3.16E-06
Exported thermal energy (ETE)	MJ	**6.39E-04**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.32E-04	0.00E+00	6.39E-06

Table 7: Output flows and wastes

Interpretation

Regarding lifecycle results, the A1 life cycle stage (raw material supply) is for all the impact categories the most impactful stage (> 50%), mainly driven by the Pv cells cradle to gate impacts, closely followed by the installation of the pv plant, specifically the construction of the mounting structure, which is material intensive.
The third most impactful stage is the transport of the products to the pv plant, this is linked to the long-distance transport from manufacturing plant in China to the pv plant in Italy.

6. Calculation rules

6.1 Functional unit

In the EPD study, the functional unit is 1 kWh of electricity generated as output from the solar photovoltaic plant during 30 years in Rome, Italy. The environmental impact of this study was calculated and reported per functional unit.

To report the environmental impacts generated by each DMEGC Solar photovoltaic (PV) module during its life cycle in the functional unit, the total energy produced by the solar PV plant during the reference service life (RSL) needs to be calculated.

Once the total energy of the solar plant has been calculated, the overall environmental impacts generated throughout the entire life cycle are divided by this value to return the results in the individual kWh produced.

The total energy produced by the plant will therefore be equal to

$$Etot[kWh] = Eyear * RSL$$

Where:

Etot represents the total energy produced by the plant (or, in an extreme case, by the individual module) during its entire life cycle.
Eyear represents the energy produced annually by the plant.

Following the EPDItaly PCR, the reference service life (RSL) of DMEGC Solar modules is assumed to be 30 years.

$$\boldsymbol{E_{RSL} = E1 * \left(1 + \sum_{n=1}^{RSL-1} (1 - Deg)^n \right)}$$

The pv plant characteristics are given below :

Parameter	Unit	EPD4
Peak power of the plant	KWp	160.0
Plant latitude and longtitude	DMS	41.89332°N, 012.482932°E
Plant altitude	m	49
Nominal solar irradiance	KWh/m2/year	1868
Number of modules	pcs	296
Specific power	Wp	540
Production	KWh	7 353 047

Table 8 : Pv plant characteristics

The nominal solar irradiance is based on global solar atlas data, more specifically it is the global tilted irradiation at optimal angle value.

6.2 Period under study

The study is based on primary data from April to June 2023.

6.3 System boundary

The system boundary considered for this study is cradle to grave.

According to the PCR, the life cycle stages must refer to segmentation in the following three modules:

1. Upstream module which includes all the processes upstream of the production of the photovoltaic module and/or solar park. In this study the upstream ends at the beginning of PV modules manufacturing, including extraction and processing of raw materials including silicon, ingot block, wafer, PV cell with packaging (A1), and the transportation of the raw material to the factory (A2) etc.

2. Core module which includes all the relevant processes managed by the Organization proposing the EPD. The core module in this study includes manufacturing of the solar cells and PV modules (A3) with the supply of the raw material, energy and auxiliary material input, and treatment and emission of off gas, wastewater and solid wastes during the PV module manufacturing; considering that the functional unit is energy generated by solar plant utilizing the PV modules, the core module is extended to include the transportation of PV modules to solar plant (A4), the construction of the solar plant (A5), the use (B1), maintenance (B2), repair (B3), replacement (B4), refurbishment (B5) and the operational energy use (B6) and water use (B7) during the RSL (30 years) period, de-construction and demolition of the solar plant (C1), transport to waste processing (C2).

3. Downstream module which includes all the relevant processes that take place outside of the control of DMEGC. In this study, the downstream module includes waste processing (C3) and disposal (C4). According to the PCR, the benefit and avoided loads beyond the product system boundary were not reported in module D separately within this study, neither were the benefit and loads be reported in other stages by following a cut off allocation approach. Since it will take 30 years to enter the end-of-life stage for the PV modules, scenarios must be developed for end-of-life treatment. For simplification purpose, assumption was made during the modelling of downstream modules.

6.4 Assumptions

To conduct this EPD study many assumptions had to be taken, the key assumptions are listed below:

- This EPD study is based on the scenario that the DMEGC modules are installed in a pv plant located in Rome Italy, the solar irradiation, transport distances and pv plant installation data have been adapted to this assumption.
- The nominal solar irradiance was based on an optimal modules orientation at 180° azimuth and 34° tilt.
- Energy is needed to de-construct the PV power plant. The energy consumption during the deconstruction of the PV plant (C1) was assumed the same as the energy consumption during the construction stage (A5).
- The pv modules were assumed to be auto-cleaning with rainwater.
- The mounting structure of the pv plant is assumed to be composed of the same materials than the generic ecoinvent dataset.
- The end-of-life treatment route for pv modules is assumed to include delamination, with glass and frame recovery.
- The bifacial gain is assumed to be 5%.

6.5 Data quality

This EPD is based on DMEGC LCA's for the manufacturing processes of ingot/wafers/cells, those LCA's are already validated by ADEME, the French environmental agency, the LCA's have been conducted with 2021 inventory data. The data used in this EPD are based on the life cycle inventories performed in those LCA's.
The data quality has been assessed as follows:

- Technological representativeness: Good in overall.
- Geographical representativeness: Correct for Aluminium frame and glass, very good for the rest of data.
- Time representativeness: Very good for data based on LCA (Ingot to cell processes), very good for the rest of data, the data used have a validity of less than 3 years.
- Precision/uncertainty: Excellent for the processes based on LCA's that are validated by ADEME, indeed the data have been measured, cross-checked, and externally reviewed.

A data quality rating was conducted based on the PEF method.
The DQR is calculated based on the most-relevant process and elementary flows:

- Silicon solar grade (modified datasets based on generic datasets)
- Photovoltaic cell, single-Si (DMEGC LCA)
- Silicon, ingot (DMEGC LCA)
- Aluminium frame (modified dataset based on generic datasets)
- Solar glass (generic dataset)
- Single-Si Wafer (DMEGC LCA)
- Pv plant construction (modified dataset based on generic datasets)
- End of life stage (custom LCA based on literature)
- Transport to pv plant (generic dataset)

The DQR of the whole study is based on the DQR of each individual items above and weighted with GWP impact % as a reference. The items above represents at least 80% of the total GHG impact of the product averages in the EPDs.

The DQR is calculated at around 1.84, which is very good.

6.5 Allocations

Multi-input processes:

The allocation of inputs (water, electricity) has been done based on surface area of the modules produced, the electricity ratios have been adjusted with the lamination electricity consumption, which was calculated per module, based on lamination power and duration.

Multi-output processes:

Module manufacturing is a mono product process, meaning that modules are the only product produced, with no co-products, therefore there was no need of an allocation for multi-output processes.

Allocation for recovery processes

For the allocation of residuals, the model "allocation cut-off by classification" in ecoinvent database was used. The underlying philosophy of this approach is that primary (first) production of materials is always allocated to the primary user of a material. If a material is recycled, the primary producer does not receive any credit for the provision of any recyclable materials. Consequently, recyclable materials are available burden-free for recycling processes, and secondary (recycled) materials bear only the impacts of the recycling processes.

6.6 Excluded processes

The following processes were excluded from the system boundary, the items below were considered either irrelevant or out of the system boundary of pv modules:

- The load and benefit of recycling waste solar module as well as waste equipment from solar plant was excluded from the analysis.
- Storage phase of pv modules
- The transport of workers to the pv plant for construction
- The packaging of the different equipment's in the construction of the pv plant stage
- The recycling of defecting modules
- The electricity, water, and heat consumption of support functions not linked directly to manufacturing.

6.7 Cut-off rules

To exclude inputs and outputs, the procedures below were followed:

- All inputs and outputs of a (unit) process were included in the calculation if data were available. Data gaps were completed with conservative assumptions, using average or general data. All the assumptions used were documented.
- In case of insufficient input data or data gaps, a cut-off criterion was chosen following the PCR requirement. These cut-off criteria were 2% of the total mass and energy of that unit process. (According to the specific weight of the photovoltaic module and the energy required to manufacture and assemble it.)
- The overall neglected input flow of the cradle-to-grave stages should be no more than 2% of the energy consumption and mass per module.

The neglected flows of this EPD study are shown in the following table:

Flow name	Process stage	Justification for cut-off	Total cut-off mass estimated in %
Transport of mounting system/inverter to the pv plant	A5	<2%	<1%

Table 9 : Cut-off rules

The energy need for the transportation of the mounting system and inverter to the pv plant is assumed to be lower than 2% of the total energy needed to produce the pv modules calculated as 3196 MJ.

7. Scenarios

The detailed processes of A1-A3 stages are presented in figure 3:

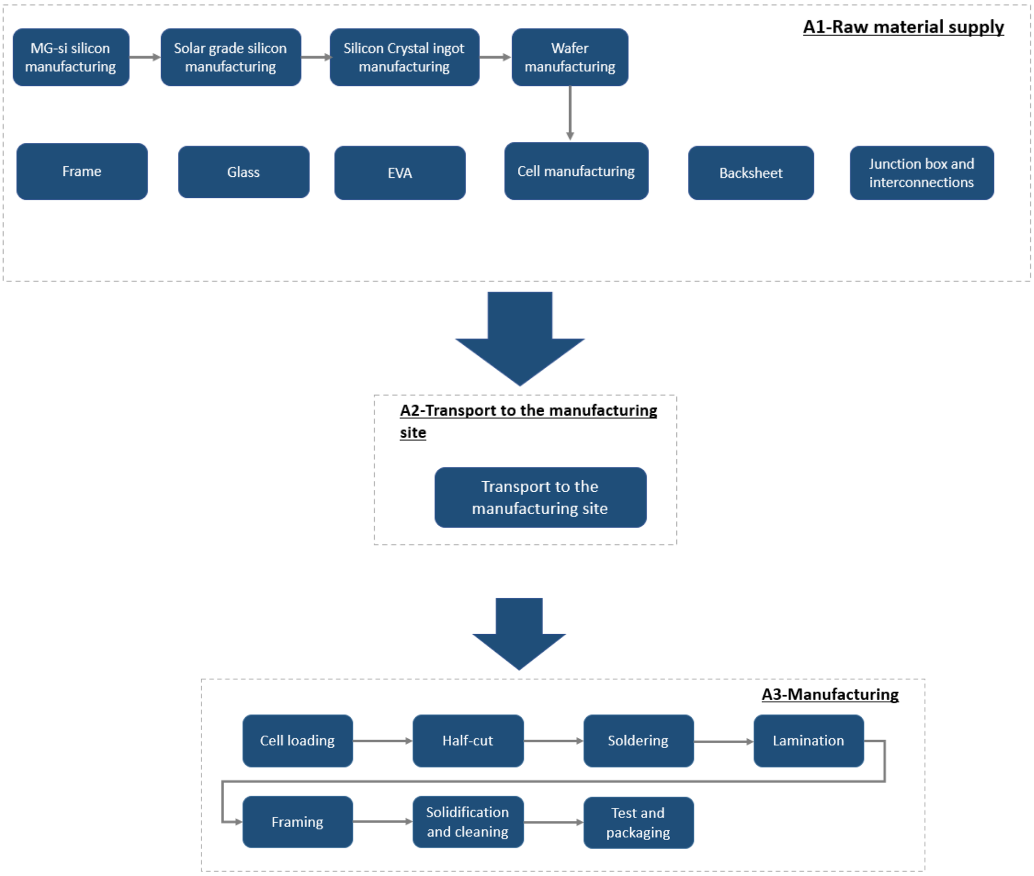


Figure 3 : A1-A3 life cycle stages

A1 Raw material supply

The pv modules are complex products requiring multiple production stages up-stream, involving several actors along the supply chain. The first stage is the reduction of silica material into MG-Si (metallurgical silicon) with a purity of 98-99%, this step consumes high amount of charcoal to separate oxygen from silica (carboreduction), generic dataset was used to model this process, the next step is the purification of the MG-si into solar grade silicon, through the siemens process, this produces silicon with high purity (9N) grade. Generic datasets were used for this process, the geographical location was adapted based on the current polysi supplychain of DMEGC. The third step is the manufacturing of crystal silicon ingot with the Czochralski method, the ingot is then squared into bricks and sliced to wafers, DMEGC own LCA have been used for these processes. The LCA is based on DMEGC factory located in Qixian city, Shanxi province, China, the data is less than 3 years old.

The wafers are then processed into pv cells, through multiple chemical processes, that are mainly listed below:

1. **Saw damage etching:** The first step is to remove the residual contaminants from the ingot sawing, this is done with a wet alkaline solution of Sodium hydroxide of potassium hydroxide diluted in deionized water.
2. **Surface Texturing:** In this process the wafer surface is roughened to increase its ability to absorb light, a mixture of acid is applied to the silicon, the results is a pyramid structure surface.
3. **Diffusion:** In this process the p-n junction is created through the diffusion of phosphorus using POCl3 ((Phosphorus Oxychloride) at high temperature.

4. **Edge isolation:** During diffusion, phosphorous may diffuse to the back of the wafer through its edge, removal of these edges is necessary to prevent short-circuit. This is commonly done using a mixture of HF (Hydrofluoric acid) and HNO3 (Nitric acid).
5. **Anti-reflection coating:** in this process an anti-reflective film, as silicon nitride is deposited into the silicon surface through PECVD (plasma enhanced chemical vapor deposition).
6. **Screen-printing:** in this process a metallic conductor (silver/aluminium) is screen printed on top and at the bottom of the cell to collect the photocurrent.

The LCI data from Dongyang cell factory, have been used to model cell manufacturing. The data is less than 3 years old.

For all the other components (EVA/Backsheet/Glass/Frame/Junction box), secondary data were used from Ecoinvent database. The frame and junction box datasets were adapted to fit the specific materials used in the modules.

A2 Transport to the manufacturing site

All the components used in the pv modules manufacturing process are supplied from China, by road transportation (lorry trucks), in lack of specific data on vehicles technology, a conservative "Unspecified" dataset was used.

A3 Manufacturing

The modules manufacturing is essentially an assembly process, the first step is the loading of cells that are half-cut by laser. The string interconnection composed of copper tabs is then soldered between the cells, afterwards comes the lamination process, which is the most energy consuming process for modules assembly, the different layers composed of EVA encapsulant, back sheet, cells and glass are bonded together by melting the EVA layer at high temperature. The manufacture process continues with the integration of the aluminium frame. The modules finally follow several mechanical (strength) and electrical tests before being packed in cardboard boxes.

A4 Transport to pv plant

The modules are transported to pv plant site by a mix of road and ship transportation, the main route from manufacturing gate to the pv plant site in Rome in Italy is presented below:

Origin and destination	km
Jiangsu factory to Ningbo port	622
Ningbo port to rotterdam	19 000
Rotterdam - Oslo	1 500

Table 10 : Transport distances to pv plant site

For road transportation the distances have been taken from google services, as being more conservative, for ship transportation the distance has been taken from sea rates database.

There were no data on vehicle technology or load factors, thus the conservative average generic dataset has been selected.

A5 Installation

For the open ground mounted pv plant model, the generic dataset has been adapted to be aligned with the following parameters known before construction:

- The weight of the structure is 8.17 kg/m2.
- The power density of the inverter is 1.905 kWp /kg.
- The inverter is changed once in the RSL.
- In lack of data on the materials of the structure, the material composition (steel/aluminium) of the generic dataset have been selected.

Use phase (B1-B7)

B1 – Use

Not concerned, no water/air emissions during use stage.

B2 – Maintenance

It has been assumed that distance from the inspection office to the pv plant is 50km, and that the pv plant is inspected 2 times per year.

B3 – Replacement

The inverter is replaced once per RSL.

B4-Repair

Not concerned, no repair planned.

B4-Repair

Not concerned.

B5- Refurbishment

Not concerned.

B6-operational energy use

Not concerned, energy produced RSL.

B7-Water use

Not concerned, assumed to be autocleaning with rainwater, as the tilt is high.

End of life stages (C3-C4)

For the end-of life of pv modules, the modules are assumed to be recycled with the upcycling route as shown below:

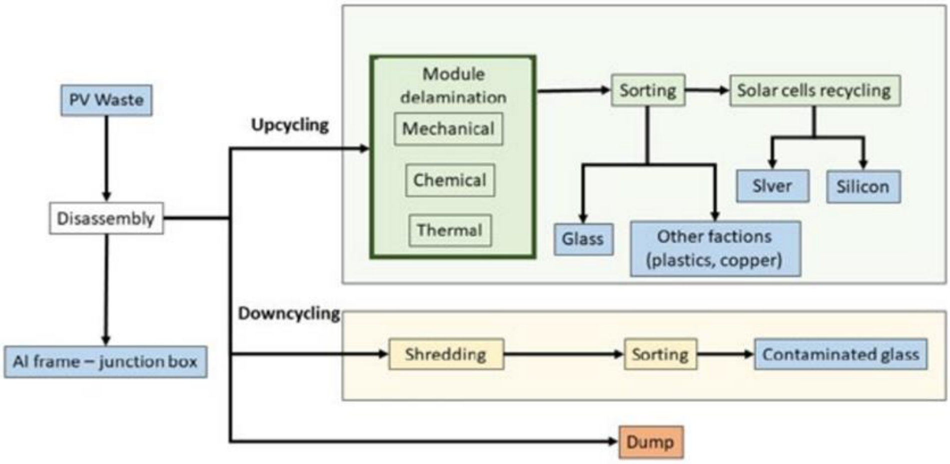


Figure 4 : PV recycling routes (Source : P.Cerchier 2022)

The different layers are separated through a mechanical and thermal process, the glass is recycled except the contaminated glass, which is landfilled, the plastic components of the sandwich layers (encapsulant and backsheet) are incinerated, the silicon/Copper/aluminium are separated, sorted, and made available for recycling. The LCI is based on the published LCA of a pilot unit of the FRELP (full recovery end-of-life photovoltaic) project in northern Italy. This recycling route is not yet operational due to lack of commercial interest explained by insufficient pv waste. However, regarding the long lifetime of pv modules (at least 20 years), it is assumed that at the time the products of this EPD will reach end of life, sufficient pv waste will be available for a commercial operational unit.

The LCI and subsequent assumptions can be found online in the published paper "Life Cycle Assessment of an innovative recycling process for crystalline silicon photovoltaic panels" by Latunussa et al 2016.

The transport distances considered in this study are:

Transport distances	
From pv plant to collection point	100 km
From collection point to recyling plant	400 km
From recyling plant to the incineration plant	200 km
From incineration plant to special landfill forhazardous waste	50 km

Table 11 : Transport distances for end of life treatment

AC losses and electricity infrastructure

The voltage dissipation between the inverter and the grid is assumed to be 1%.
Electricity infrastructure includes Inverters and electrical cables and installation, which are already included in the Installation (A5) stage, there is no MV transformer the electricity is directly fed into the grid.

8. Additional environmental information

An additional indicator is the Return on Energy (RoE). This parameter gives an estimate of the efficiency of the photovoltaic park's solar energy production. The results are shown in table 15.

The calculation of RoE is done using the following formula:

$$RoE\ [years] = E_{invested}/E_{produced,annual}$$

Where:
$E_{invested}$ = total amount of energy (thermal and electrical) required to produce the photovoltaic module (or solar park).

$E_{produced,annual}$ = total amount of electricity generated in a year by the photovoltaic module (or solar park).

The results are shown below for each product average:

Item	Unit	Value
Return on energy	years	**1.89**

Table 12 : Return on energy results

8. REFERENCES

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Ademe, FEDEREC. (2017) Évaluation environnementale du recyclage en France selon la méthodologie de l'analyse de cycle de vie

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R. Frischknecht, P. Stolz, L. Krebs, M. de Wild-Scholten, P. Sinha, V. Fthenakis, H.C. Kim, M. Raugei, M. Stucki, 2020, Life Cycle Inventories and Life Cycle Assessment of Photovoltaic Systems, International Energy Agency (IEA) PVPS Task 12, Report T12-19:2020.

Zampori, L. and Pant, R., Suggestions for updating the Product Environmental Footprint (PEF) method, EUR 29682 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-00654-1, doi:10.2760/424613, JRC115959.

LCA reports:

Qixian factory: Life cycle assessment for CRE tenders - Crystalline silicon ingot, Brick, recycling and wafers produced by DMEGC Qixian, China (written by Kapstan in 2021).

Jiangsu factory : Life cycle assessment for CRE tenders - Crystalline silicon modules produced by DMEGC Jiangsu, China (written by Kapstan in 2022).

ANNEX 1

ANNEX 1: Self declaration from EPD owner

Specific requirements

Applied electricity data set used in the manufacturing phase

The electricity mix for the electricity used in manufacturing (A3) is the electricity grid mix 0,284 kg CO_2 eqv/MJ

Transport from the place of manufacture to a central warehouse

Transport distance, and CO_2-eqv./FU from transport of the product from factory gate to central warehouse in Oslo shall be given. The following table shall be included in the EPD:

Type	Capacity utilisation (incl. return) %	Type of vehicle	Distance km	Fuel/Energy use	Unit	Value (l/t)	Kg CO2-eqv./FU
Boat	70%	Container ship	19000	2.63E-3	l/tkm	49.97	2.2E-03
Truck	36.7	Euro 6 16-32 ton	2100	4.44E-02	l/tkm	92.4	5.4E-03
Total							7.6E-03

3. Impact on the indoor environment

- ☐ Indoor air emission testing has been performed; specify test method and reference; M1, ______________________________
- ☐ No test has been performed
- ✓ Not relevant; specify ___Not relevant for pv products