Environmental Product Declaration

In accordance with ISO 14025

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Jolywood

N-type Bifacial Double Glass Photovoltaic Modules

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 2007:08 Electricity, steam and hot water generation and distribution (Version 4.2)*
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Independent third-party verification of the declaration and data, according to ISO 14025:2006: ☐ EPD process certification ☒ EPD verification	
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Version history

This document has been issued in the following versions:

- 2020-11-01: Version 1.0
- 2021-08-19: Version 2.0. The background electricity data was updated using the updated China Grid Electricity data in 2018
- 2022-04-27: Version 3.0. Company name was changed. Product series name changed, raw material and manufacturing data changed.
- 2023-03-02: The system diagram and the description of life cycle processes have been changed. The processes results have also been reallocated according to the corrected system boundary.

Company information

Owner of the EPD:
Jolywood (Jiangsu) Light Energy Technology Co., Ltd
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Description of the organisation:
Founded in 2008, Jolywood is a national high-tech enterprise. It was successfully listed in 2014 (stock code: 300393). The company focuses on innovative R&D and high-quality manufacturing of photovoltaic auxiliary materials, solar cell and module, system integration and other products. As the world largetst N-type bifacial solar cell and module manufacturer with 6.6GW production capacity, and world largest backsheet manufacturer with 30% market share, Jolywood was awarded financial health Top3 by Photon.

Jolywood (Taizhou) Solar Technology Co.,Ltd is the world's largest manufacturer of N-type TOPCon bifacial solar panel, with a registered capital of 1.5 billion yuan, N-type TOPCon bifacial solar panel of more than 3GW capacity. In the N-type TOPCon bifacial solar panel process, Jolywood has complete independent intellectual property rights. Up to now, it has applied for 99 related patents, including 58 granted patents and PCT5 items and maintain long-term research cooperation with the international renowned IMEC Institute, Sun Yat-sen University, Shanghai Jiaotong University.

Figure 1 Jolywood (Taizhou) Solar Technology Co., Ltd

Product information

Product name:
Jolywood N-type Bifacial Double Glass Photovoltaic Modules

UN CPC code:
171 Electrical Energy

Geographical scope: Global

Product description:
With higher efficiency, higher bifaciality (up to 85%), lower degradation, and lower temperature co-efficiency (≤0.32%), the N-Type solar systems can generate 10-30% extra power than p-type mono facial products, therefore reducing solar projects LCOE, bringing better investment return for customers. Bifacial modules combine leading NTOPCon technology, 11BB and half-cell. The Jolywood N-type Bifacial Half-cell Module can reach power output up to 575W. N-type material has zero LID/LeTID risk, which makes the modules to be more reliable, to have higher bifacility, higher efficiency, lower temperature coefficient and longer lifetime.

Within this project, in total there are 4 models of double glass PV modules that were analyzed:

- HD144N(P)-182
- HD108N(P)-182
- HD144N(P)-166
- HD120N(P)-166

Note: H: Half-cells; D: Double glass; N(P): N/P-type cells; 182: cell size (mm).

Product Application:

Jolywood N-Type bifacial modules can be widely used in rooftop and ground solar farms. Also, the products have wider application areas, such as high temperature regions, heavy snow regions, water surface systems, agriculture greenhouses, etc..

Product identification:

Table 1 Product technical specifications

Series (brand name)	Power output range (W)	Dimensions(mm^3)	Module efficiency (%)	Weight (kg)
HD144N(P)-182	550-575	2285×1134×30	21.23-22.19	32.5
HD108N(P)-182	410-430	1728×1134×30	20.92-21.94	24.5
HD144N(P)-166	445-470	2095×1039×30	20.44-21.59	28.0
HD120N(P)-166	375-395	1756×1039×30	20.55-21.65	23.0

Manufacturing Process:

The manufacturing process of PV modules includes solar cells production and PV modules production. Figure 2 and Figure 3 below are flowcharts depicting the production process stages of the declared products. For simplification purpose, only main stages of manufacturing are presented. Raw material, auxiliary processes that were considered in the LCA but not shown in the flowcharts include:

- Raw and auxiliary material production and transportation
- Recycling of waste materials;
- Waste water and off-gas treatment;
- Water recycling and reuse system;
- Supply of natural gas/water/electricity

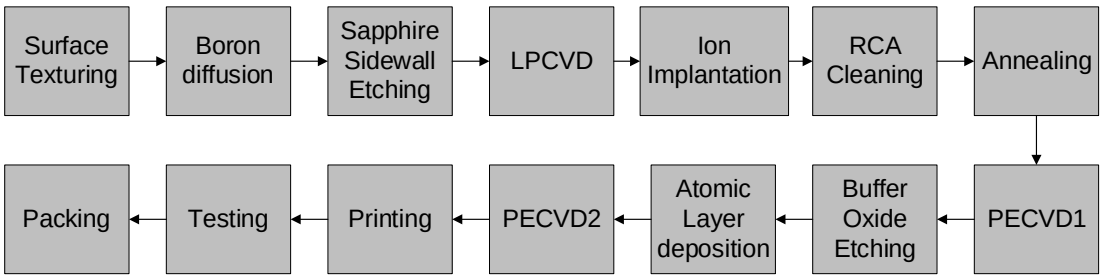

Figure 2 Manufacturing process flowchart of solar cells

Solar cells production

Step 1: Surface Texturing

In order to reduce the reflection of incident light for enhancing the conversion efficiency of solar cells, a texturing structure needs to be formed at the surface of the wafer by using chemical etching processing.

Step 2: Boron diffusion

Boron gases are introduced into the tube and pass through the wafers so that a layer of boron doped layer is formed on the wafer surfaces. The following high temperature process drives the boron into the surface areas of the wafers and a P-N junction is formed at the surface region.

Step 3: Sapphire Sidewall Etching

During the Boron diffusion for P-N junction formation, a layer of silicate glass is coated at the surface of the wafers. It is necessary to remove the silicate glass before further processing for solar cells. The removal processing is composed of diluted hydrofluoric (HF) etching and rinse.

Step 4: Low pressure chemical vapor deposition (LPCVD)

Silicon nitride films were prepared by low pressure chemical vapor deposition (LPCVD) at 800 ℃ with different process gas flow ratios.

Step 5: Ion Implantation
The doping of N + and P + region is realized by boron ion implantation.

Step 6: RCA Cleaning
Removal of particulate matter and metal ions from the surface of silicon wafer by multi-channel cleaning.

Step 7: Annealing
By heating and drying the back passivated silicon wafer, the water vapor can be completely removed through negative pressure ventilation, and the impurities in the silicon wafer can be more fully separated out and defects can be reduced by gradient cooling.

Step 8: Plasma enhanced chemical vapor deposition 1 (PECVD1)
The plasma enhanced chemical vapor deposition (PECVD) method was used to coat the surface of silicon wafer with a layer of SixNy by conducting the graphite boat at 480 ℃ in vacuum.

Step 9: Buffer Oxide Etching (BOE)
BOE solution, namely buffer oxide etching solution, is a mixture of hydrofluoric acid and ammonium fluoride. The volume ratio of hydrofluoric acid and ammonium fluoride in the mixed solution is 1:6 to clean the secondary suede.

Step 10: Atomic Layer deposition
Advanced atomic layer deposition (ALD) aluminum oxide (Al_2O_3) method was used to passivate the front surface of battery.

Step 11: Plasma enhanced chemical vapor deposition 2 (PECVD2)
The plasma enhanced chemical vapor deposition (PECVD) method was used to coat the surface of silicon wafer with a layer of SixNy by conducting the graphite boat at 480 ℃ in vacuum.

Step 12: Printing
The printing process is based on the principle that the part of the screen pattern is permeated with the paste through the mesh and the non-permeable part is impervious to the paste. Using screen printing process, the corresponding metal electrodes are printed on the upper and lower surfaces of the fabricated P-N junction silicon wafer to collect and conduct the photocurrent generated by illumination.

Step13: Testing
Under standard test condition (STC), test the solar cells by sunlight simulator after production completed, and then sort them into varied class.

Step 14: Packing
Pack the tested cells according to different grades and efficiencies.

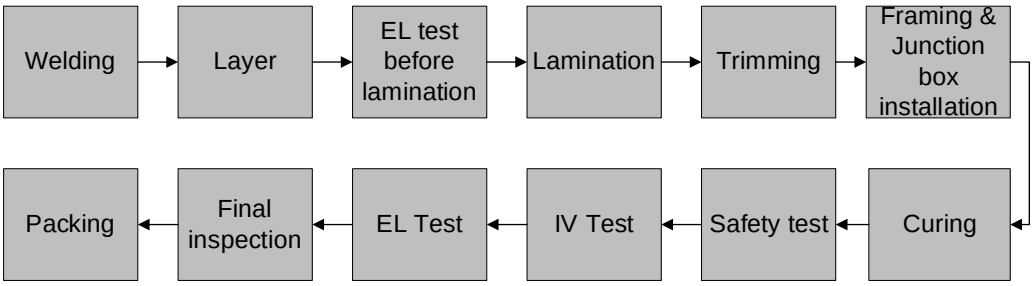

Figure 3 Manufacturing process flowchart for PV modules

PV modules production

Step 1: Welding
The bus bar is welded to the main grid line on the front and back of the cell. The bus bar is tinned copper strip. The welding machine can spot-weld the strip on the main grid line in the form of multiple points.

Step 2: Layer
Connect the cells in series to form a PV layer. The positioning of the cell mainly depends on the template.

Step 3: Electroluminescent (EL) Imaging test before lamination
Conduct appearance and EL imaging inspection on the PV modules before lamination.

Step 4: Lamination
The assembled PV modules are put into the laminating machine, the air in the modules is extracted by vacuuming, and then the Ethylene Vinyl Acetate (EVA)/ Polyolefin Encapsulant (POE) is melted by heating, and the battery, glass and backplane are bonded together.

Step 5: Trimming
During lamination, EVA melts and extends outward due to pressure to form burr, so it should be cut off after lamination.

Step 6: Framing & junction box installation
Aluminum frame is installed on the glass module to increase the strength of the module, further seal the battery module and prolong the service life of the Cell. Weld a box at the back lead of the module to facilitate the connection between the battery and other devices or batteries.

Step 7: Curing
Under the condition of 25 ± 5 ℃ and more than 60% humidity, curing the PV Modules frame glue and junction box glue.

Step 8: Safety test
A certain voltage is applied between the frame and the electrode lead to test the withstand voltage and insulation strength of the module to ensure that the module will not be damaged under adverse natural conditions (such as lightning strike). Test the grounding performance of modules to ensure the safety of modules.

Step 9: IV Test
standard test condition (STC), the output power of the module is calibrated and its output characteristics are tested.

Step 10: EL Test
Electroluminescent imaging technology is used to detect the potential defects and control the product quality.

Step 11: Final inspection
Inspect the appearance of the modules and judge its grade.

Step 12: Packing
Package the modules after testing according to the standard.

Content declaration
Raw materials of the different PV modules are mostly the same, including solar cells, solar glass, aluminum frame, silica gel, junction box and packaging etc. The type and ratio of raw materials per 10000 pcs PV modules are listed in Table 2.

Table 2 Raw materials of double glass PV modules

Materials	Units	HD144N(P)-182	HD108N(P)-182	HD144N(P)-166	HD120N(P)-166
Cell_166	kg/1000pcs	0	0	711.504	592.920
Cell_182	kg/1000pcs	864.000	648.000	0	0
Glass	kg/1000pcs	25900.000	19621.212	21776.700	18254.320

POE	kg/1000pcs	2590.000	1962.121	2247.400	1883.170
Frame	kg/1000pcs	2067.000	1565.909	1759.100	1569.200
Silica gel	kg/1000pcs	324.880	246.121	311.590	285.500
Solder	kg/1000pcs	289.440	219.273	289.423	241.186
Junction box	kg/1000pcs	104.990	104.990	104.990	104.990
Corrugated box	kg/1000pcs	725.143	549.351	640.000	600.000
Pallet	kg/1000pcs	1301.400	985.909	1660.000	1200.000
Packaging film	kg/1000pcs	84.969	84.969	79.608	73.349
Flux	kg/1000pcs	39.376	22.254	29.371	24.476
Ethanol	kg/1000pcs	3.000	3.000	3.000	3.000
Tin	kg/1000pcs	1.000	1.000	1.000	1.000

Transportation

The transportation mainly takes place on the upstream of raw material supply and downstream of PV modules and other equipment delivery to the solar PV plant.

According to Jolywood, the production of solar cells and PV modules are taken place in Taizhou, Jiangsu province. The raw materials are mainly sourced from Jiangsu and Zhejiang province, and delivered by lorry. The transportation distance is provided by Jolywood. For packaging materials, Jolywood purchased from several local markets, the largest transportation distance of 100 km is used. For all vehicles, since it is not specified, 20t lorry was used for LCA modeling.

Product Installation

The specific data regarding solar PV plant installation was taken from a real PV plant in Qingjiang, Qinghai in China, with an energy yield capacity of 150MW. The detailed information about the PV plant is listed in table below.

Table 3 PV plant information

Parameters	Value		Source
	Amount	Unit	
Peak power of the plant	150,000	kW	Jolywood
Plant latitude and longitude	36.20°N, 100.61°E	°	Jolywood
Plant altitude	2,904	m	Jolywood
Nominal solar irradiance	1,724,600	Wh/m²/year	Jolywood

Use, Maintenance, and Reference Service Life

In terms of electricity generation during RSL (30 years), as provided by Jolywood, the electricity generation in the first year is calculated with the aid of PVSYST V6.88. Total electricity generation during RSL can be calculated with following equation:

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

where E_{RSL} is electricity generation during RSL, E_1 is electricity generation for the first year of operation, deg is yearly degradation rate (%), 0.4% was used in this study. n (n=30) is RSL. Table 4 lists the E_1 (calculated with PVSYST V6.88) and E_{RSL}.

Table 4 Electricity generation during RSL for all PV modules

Module series	Module Power output	E_1/kWh	PR	Albedo	Deg	E_{RSL}/kWh
HD144N(P)-182	570Wp	331,491,700	93.86%	35%	0.4%	9,253,440,900
HD108N(P)-182	430Wp	329,063,100	93.44%	35%	0.4%	9,198,717,300
HD144N(P)-166	470Wp	329,018,400	93.33%	30%	0.4%	9,197,904,400
HD120N(P)-166	395Wp	329,130,000	93.36%	30%	0.4%	9,200,831,300

Reuse, Recycling, Energy Recovery, and Disposal

For the end-of-life stage, De-construction (C1) of the PV plant during the disposal stage was assumed to consume mainly electricity, and the electricity consumption was assumed to be the same as the construction stage (A5), 100km transportation distance from the plant site to waste treatment site (C2) was assumed, electricity used for PV module demolition during waste processing (C3) stage was assumed the same as PV module manufacturing

stage (A3). For the end-of-life disposal treatment process (C4), the infrastructures of PV plants such as inverters are considered fully reused, most of the PV modules will be collected and recycled. However, the PV plant has just operated, there is a lack of existing data of recycling rate vs. disposal rate for PV module. At present, any regulations about PV recycle rate could hardly be found in China. Thus, this study refers to legal requirements issued by Waste Electrical and Electronic Equipment (WEEE) under the EU scenario. In 2012/19/EU-Article 11 & ANNEX V, the required recycling rate for waste PV module is 85%. Therefore, 15% of waste PV modules end up with waste disposal, mostly are waste glass. A waste management scenario of 20% landfill and 80% incineration was adopted for the waste disposal. A sensitivity analysis was further conducted to see the various disposal scenarios' impact on the results. Following the end-of-life load and benefit allocation approach, reuse, recovery, and/or recycling potentials (D) was not declared in this study.

LCA information

Functional unit:
In this report, the functional unit is defined as 1 kWh net of electricity generated by PV modules and thereafter distributed to the customer.

Time representativeness:
The study used primary data collected from July 2021 to December 2021.

Database(s) and LCA software used:
Generic data including material, energy as well as waste disposal and transportation are taken from the LCI-database Ecoinvent 3.7 with regional energy and material mix data coming from adapted China local LCI data (1mi1,2020). For the modeling and calculation, the LCA-software SimaPro version 9.2 was used.

The data quality requirements for this study were as follows:

- *Foreground data* of the considered system: such as materials or energy flows that enter the production system). These data were calculated and submitted by Jolywood;
- *Generic data* related to the life cycle impacts of the material or energy flows that enter the production system. These data were sourced from the databases in SimaPro 9.2;
- Existing LCI data were, at most, 10 years old. Newly collected LCI data were current or up to 3 years old;
- The LCI data related to the geographical locations where the processes took place, e.g. electricity and transportation data from China, disposal data from China and Europe were utilized;
- The scenarios represented the average technologies at the time of data collection.

System diagram:

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; ND = MODULE NOT DECLARED)																		
Upstream	**Core infrasctructure**					**Core operation**											**Downstream**	**Resource recovery stage**
Infrastructures of auxiliary substances	Raw Material	Transport	Manufacturing	Transport	Assembly / Install	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction and demolition	Transport	Waste processing	disposal	Distribution system	Reuse-Recovery-Recycling-potential
-	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	-	D
X	X	X	X	X	X	ND	X	ND	ND	ND	ND	ND	X	X	X	X	X	ND

The system boundary considered in this LCA study is from cradle to grave, except use by end consumer. According to the PCR, the life cycle stage must refer to segmentation in the following three processes:

1. *Upstream process*: which include infrastructures of auxiliary substances.

2. *Core process*: which include extraction and processing of raw materials (A1), transportation of the raw material to the factory (A2), manufacturing of the solar cells and PV modules (A3) with the supply of the energy and auxiliary material inputs, and emissions, and distribution of PV modules to solar PV plant (A4); the construction of the solar plant (A5), the maintenance (B2) during the RSL (30 years) period; de-construction and demolition of the solar PV plant (C1); transport to waste processing (C2), waste processing (C3), and disposal (C4). However, considering the studied PV plant has not operated for 30 years, for simplification purposes, assumption was made on the LCI data during the modeling of core processes. According to the PCR, the benefit and avoided loads in module D are not declared (reported in "ND") in the present study following the polluter pay principle (PPP);

3. *Downstream process*: which includes all the relevant processes that take place outside of the control of the organization proposing the EPD. In this study, the downstream processes include distribution loss of electricity to the customer, and operation and maintenance of the distribution systems. According to Jolywood, the distance of transmission network allows the generated electricity to be delivered to the grid is 15km.

Figure 4 below illustrates the system boundaries for Jolywood's PV module products, including raw material production and transportation, manufacture, delivery, solar plant installation and End-of-life.

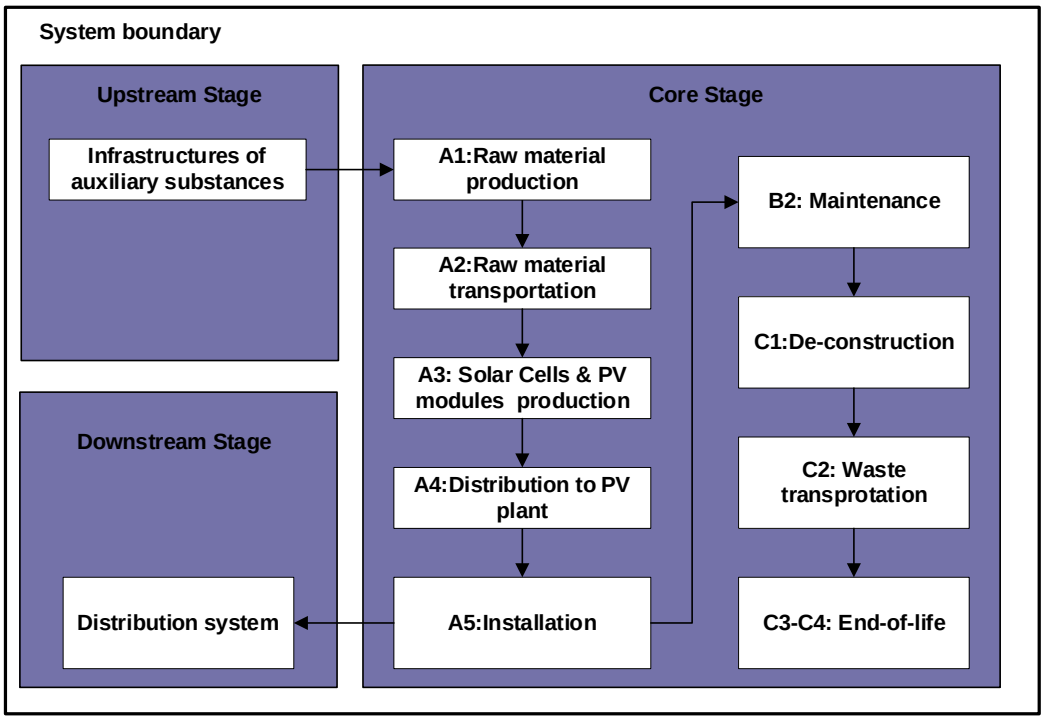

Figure 4 System boundary of PV module products

Excluded Processes:
The following steps/stages were not included in the system boundary due to the reason that the elements below are considered irrelevant or not within the boundary to the LCA study of PV module products:

- The load and benefit of recycling waste solar module as well as waste equipment from solar plant were excluded from the analysis.
- The packaging for silicon wafer and solar cells is reused internally and its impact was excluded from the system;
- Emissions during the solar PV plant construction and operation as these activities are mainly done by manual and electrical machinery.
- Storage phases and sales of PV products due to no observable impact;

- Product losses due to abnormal damage such as natural disaster or fire accident. These losses would mostly be accidental;
- Recycling process of defective products;
- Handling operations at the distribution center and retail outlet due to small contribution and negligible impact.

Assumption and limitations:
In order to carry out the LCA study, the following main assumptions were made:

- For missing background data, substitution of missing data using similar background data approach was taken to shorten the gap. A sensitivity analysis was conducted.
- For the PV module produced by Jolywood, two types of cells (namely N-type cell and P-type cell) are used depending on the customer's choice. Generally, the production of N-type cell requires more raw materials and more energy than P-type cell (LCI is listed in ANNEX3 in the LCA study report). For simplification, LCI of N-type cell was used for assessment in this study to represent the impact of two types of cells;
- Life cycle inventory (LCI) data of silicon ingot and the silicon wafer was difficult to obtain at the stage, thus an average LCI data for China in IEA PVPS Task 12, 2020 was used for modeling;
- The PV plant data inventory from a real solar farm in Qingjiang, Qinghai, with a capacity of 150MW was referred to. The electricity generation during RSL was modeled with a real plant via PVSYST V6.88, by taking the highest power output for each brand series as the representative;
- Water used for cleaning the PV panels during maintenance was assumed to be 0.23L (source: www.polywater.com) per module per time and twice a year;
- The electricity consumption during the deconstruction of the PV plant (C1) was assumed to be the same as the electricity consumption of the construction stage (A5), and electricity consumption for PV module dismantling at the waste processing stage (C3) was assumed the same as the electricity consumption of PV module assembling;
- During the end-of-life stage, the transportation of the waste PV modules and other equipment from the solar PV plant to treatment facilities including recycling, landfill, or incineration center was assumed to be 200 km for simplification purposes. A sensitivity analysis was conducted.

Allocation:
Allocation refers to partitioning of input or output flows of a process or a product system between the product systems under study and one or more other product systems. In this study, there are three types of allocation procedures considered:

Multi-input processes

For data sets in this study, the allocation of the inputs from coupled processes was generally carried out via the mass. The consumption of raw materials and the transportation of raw materials was allocated by mass ratio.

Multi-output processes

During the production of Solar Cells and PV modules, the total consumption of energy and water during manufacturing was equally allocated to per unit mass. There are no by-products that need to be allocated.

Allocation for recovery processes

For the allocation of residuals, the model "allocation cut-off by classification (ISO standard) (called "Allocation Recycled Content", alloc rec, by Ecoinvent) 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.

During the end-of-life stage of the solar plant, the extra benefit of recycling the waste modules as well as other equipment was cut off from the boundary, following the PCR's recommendation on end-of-life scenario. Along with the benefit, the load from waste treatment for recycling purpose such as de-pollution and crushing and etc.,

was also allocated to the next life cycle of substituted products, but not the primary producers, hence no burden or benefit was allocated to the primary producer of the PV module or solar PV plant (cut-off approach).

Cut-off rules:

The following procedure was followed for the exclusion of inputs and outputs:

- All inputs and outputs to a (unit) process will be included in the calculation for which data is available. Data gaps may be filled by conservative assumptions with average or generic data. Any assumptions for such choices will be documented;
- According to PCR, data for elementary flows to and from the product system contributing to a minimum of 99% of the declared environmental impacts shall be included. Therefore, the cut off criteria was set to 1% in this study. The neglected flows are demonstrated in Table 5 below.

Table 5 Cut-off flows

Flow name	**Process stage**	**Mass %**	**Reason to cut off**
Additives	A1	0.15	<1%
Screen	A1	0.0004	<1%
Trimethyl aluminum	A1	0.0008	<1%
Boron tribromide	A1	0.01	<1%
Phosphine	A1	0.0004	<1%
Auxiliary materials (tie, tape)	A5	0.09	<1%
Inspection during operation of solar plant	B	N/A	Cut off due to small impact according to PCR
Total cut off mass % estimated		**0.16**	**<1%**

Environmental performance

The result was allocated by stages, as shown in tables below.

Table 6 Environmental impacts of HD144N(P)-182

Parameter	Unit	Upstream	Core infrastructure	Core operation	Downstream	Total
Global warming potential – Fossil (GWP-fossil)	kg CO_2 eq.	1.25E-04	1.02E-02	4.51E-04	1.67E-04	1.10E-02
Global warming potential – Biogenic (GWP-biogenic)	kg CO_2 eq.	1.34E-06	1.04E-04	2.33E-08	2.06E-07	1.06E-04
Global warming potential - Land use and Land transformation (GWP-luluc)	kg CO_2 eq.	1.15E-07	2.63E-05	2.87E-08	2.54E-07	2.67E-05
Global warming potential (GWP) - Total	kg CO_2 eq.	1.26E-04	1.04E-02	4.51E-04	1.67E-04	1.11E-02
Acidification potential (AP)	Kg SO_2 eq.	9.17E-07	5.98E-05	2.72E-06	8.65E-07	6.43E-05
Eutrophication potential (EP)	kg PO_4^{3-} eq.	3.18E-07	2.39E-05	3.75E-07	2.98E-07	2.49E-05
Photochemical oxidant formation potential (POFP)	kg di NMVOC eq.	5.91E-07	4.02E-05	1.71E-06	7.11E-07	4.32E-05
Particulate matter	kg PM2.5 eq.	1.26E-07	7.94E-06	1.75E-07	1.38E-07	8.38E-06
Abiotic depletion potential – Elements	Kg Sb eq.	4.12E-09	1.14E-06	3.59E-10	8.76E-09	1.15E-06
Abiotic depletion potential – Fossil fuels	MJ, net calorific value	1.23E-03	1.13E-01	3.98E-03	1.61E-03	1.20E-01
Water scarcity footprint	m^3 H_2O eq.	3.78E-05	1.16E-02	3.59E-05	4.34E-05	1.17E-02

Table 7 Environmental impacts of HD108N(P)-182

Parameter	Unit	Upstream	Core infrastructure	Core operation	Downstream	Total
Global warming potential – Fossil (GWP-fossil)	kg CO_2 eq.	1.26E-04	1.10E-02	4.59E-04	1.67E-04	1.18E-02
Global warming potential – Biogenic (GWP-biogenic)	kg CO_2 eq.	1.35E-06	1.27E-04	2.56E-08	2.08E-07	1.28E-04
Global warming potential - Land use and Land transformation (GWP-luluc)	kg CO_2 eq.	1.16E-07	2.73E-05	3.17E-08	2.55E-07	2.77E-05
Global warming potential (GWP) - Total	kg CO_2 eq.	1.28E-04	1.12E-02	4.59E-04	1.68E-04	1.19E-02
Acidification potential (AP)	Kg SO_2 eq.	9.24E-07	6.54E-05	2.76E-06	8.71E-07	7.00E-05

Parameter	Unit	Upstream	Core infrastructure	Core operation	Downstream	Total
Eutrophication potential (EP)	kg PO_4^{3-} eq.	3.21E-07	2.78E-05	3.82E-07	3.00E-07	2.88E-05
Photochemical oxidant formation potential (POFP)	kg di NMVOC eq.	5.96E-07	4.41E-05	1.75E-06	7.15E-07	4.71E-05
Particulate matter	kg PM2.5 eq.	1.27E-07	8.79E-06	1.79E-07	1.39E-07	9.23E-06
Abiotic depletion potential – Elements	Kg Sb eq.	4.15E-09	1.38E-06	3.85E-10	8.81E-09	1.39E-06
Abiotic depletion potential – Fossil fuels	MJ, net calorific value	1.24E-03	1.22E-01	4.10E-03	1.62E-03	1.29E-01
Water scarcity footprint	m^3 H_2O eq.	3.81E-05	1.19E-02	4.17E-05	4.37E-05	1.20E-02

Table 8 Environmental impacts of HD144N(P)-166

Parameter	Unit	Upstream	Core infrastructure	Core operation	Downstream	Total
Global warming potential – Fossil (GWP-fossil)	kg CO_2 eq.	1.28E-04	1.10E-02	5.12E-04	1.68E-04	1.18E-02
Global warming potential – Biogenic (GWP-biogenic)	kg CO_2 eq.	1.37E-06	1.20E-04	2.59E-08	2.08E-07	1.22E-04
Global warming potential - Land use and Land transformation (GWP-luluc)	kg CO_2 eq.	1.18E-07	2.88E-05	3.21E-08	2.55E-07	2.92E-05
Global warming potential (GWP) - Total	kg CO_2 eq.	1.30E-04	1.11E-02	5.12E-04	1.68E-04	1.19E-02
Acidification potential (AP)	Kg SO_2 eq.	9.40E-07	6.49E-05	3.09E-06	8.71E-07	6.98E-05
Eutrophication potential (EP)	kg PO_4^{3-} eq.	3.26E-07	2.71E-05	4.25E-07	3.00E-07	2.81E-05
Photochemical oxidant formation potential (POFP)	kg di NMVOC eq.	6.06E-07	4.37E-05	1.94E-06	7.15E-07	4.69E-05
Particulate matter	kg PM2.5 eq.	1.29E-07	8.64E-06	1.99E-07	1.39E-07	9.11E-06
Abiotic depletion potential – Elements	Kg Sb eq.	4.22E-09	1.34E-06	4.03E-10	8.81E-09	1.35E-06
Abiotic depletion potential – Fossil fuels	MJ, net calorific value	1.26E-03	1.22E-01	4.50E-03	1.62E-03	1.29E-01
Water scarcity footprint	m^3 H_2O eq.	3.87E-05	1.19E-02	4.20E-05	4.37E-05	1.20E-02

Table 9 Environmental impacts of HD120N(P)-166

Parameter	Unit	Upstream	Core infrastructure	Core operation	Downstream	Total
Global warming potential – Fossil (GWP-fossil)	kg CO_2 eq.	1.29E-04	1.16E-02	5.18E-04	1.67E-04	1.25E-02
Global warming potential – Biogenic (GWP-biogenic)	kg CO_2 eq.	1.38E-06	1.38E-04	2.76E-08	2.08E-07	1.40E-04
Global warming potential - Land use and Land transformation (GWP-luluc)	kg CO_2 eq.	1.19E-07	2.97E-05	3.42E-08	2.55E-07	3.01E-05
Global warming potential (GWP) - Total	kg CO_2 eq.	1.31E-04	1.18E-02	5.19E-04	1.68E-04	1.26E-02
Acidification potential (AP)	Kg SO_2 eq.	9.49E-07	6.94E-05	3.12E-06	8.70E-07	7.44E-05
Eutrophication potential (EP)	kg PO_4^{3-} eq.	3.29E-07	3.00E-05	4.31E-07	3.00E-07	3.10E-05
Photochemical oxidant formation potential (POFP)	kg di NMVOC eq.	6.12E-07	4.67E-05	1.97E-06	7.15E-07	5.00E-05
Particulate matter	kg PM2.5 eq.	1.31E-07	9.36E-06	2.02E-07	1.39E-07	9.83E-06
Abiotic depletion potential – Elements	Kg Sb eq.	4.26E-09	1.52E-06	4.21E-10	8.81E-09	1.54E-06
Abiotic depletion potential – Fossil fuels	MJ, net calorific value	1.28E-03	1.29E-01	4.60E-03	1.62E-03	1.37E-01
Water scarcity footprint	m^3 H_2O eq.	3.91E-05	1.23E-02	4.64E-05	4.36E-05	1.24E-02

Use of resources

Table 10 Resource use of HD144N(P)-182

Parameter		Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Primary energy resources – Renewable	Use as energy carrier	MJ, net calorific value	3.21E-04	2.46E-02	7.79E-04	1.33E-04	2.58E-02
	Used as raw materials	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	MJ, net calorific value	3.21E-04	2.46E-02	7.79E-04	1.33E-04	2.58E-02
Primary energy resources – Non-renewable	Use as energy carrier	MJ, net calorific value	1.48E-03	1.43E-01	6.02E-03	2.05E-03	1.52E-01
	Used as raw materials	MJ, net calorific value	0.00E+00	1.28E-02	0.00E+00	0.00E+00	1.28E-02
	TOTAL	MJ, net calorific value	1.48E-03	1.56E-01	6.02E-03	2.05E-03	1.65E-01
Secondary material		kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
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	1.16E-06	2.95E-04	9.11E-07	1.43E-06	2.98E-04

Table 11 Resource use of HD108N(P)-182

Parameter		Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Primary energy resources – Renewable	Use as energy carrier	MJ, net calorific value	3.24E-04	2.11E-02	7.82E-04	1.34E-04	2.23E-02

	Used as raw materials	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	MJ, net calorific value	3.24E-04	2.11E-02	7.82E-04	1.34E-04	2.23E-02
Primary energy resources – Non-renewable	Use as energy carrier	MJ, net calorific value	1.49E-03	1.09E-01	6.14E-03	2.06E-03	1.19E-01
	Used as raw materials	MJ, net calorific value	0.00E+00	1.30E-02	0.00E+00	0.00E+00	1.30E-02
	TOTAL	MJ, net calorific value	1.49E-03	1.26E-01	6.14E-03	2.06E-03	1.36E-01
Secondary material		kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
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	1.17E-06	2.62E-04	1.06E-06	1.44E-06	2.65E-04

Table 12 Resource use of HD144N(P)-166

Parameter		Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Primary energy resources – Renewable	Use as energy carrier	MJ, net calorific value	3.30E-04	2.63E-02	8.70E-04	1.34E-04	2.76E-02
	Used as raw materials	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	MJ, net calorific value	3.30E-04	2.63E-02	8.70E-04	1.34E-04	2.76E-02
Primary energy resources – Non-renewable	Use as energy carrier	MJ, net calorific value	1.51E-03	1.53E-01	6.84E-03	2.06E-03	1.64E-01
	Used as raw materials	MJ, net calorific value	0.00E+00	1.34E-02	0.00E+00	0.00E+00	1.34E-02
	TOTAL	MJ, net calorific value	1.51E-03	1.68E-01	6.84E-03	2.06E-03	1.79E-01
Secondary material		kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

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	1.19E-06	3.06E-04	1.06E-06	1.44E-06	3.09E-04

Table 13 Resource use of HD120N(P)-166

Parameter		Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Primary energy resources – Renewable	Use as energy carrier	MJ, net calorific value	3.33E-04	2.70E-02	8.74E-04	1.34E-04	2.84E-02
	Used as raw materials	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	MJ, net calorific value	3.33E-04	2.70E-02	8.74E-04	1.34E-04	2.84E-02
Primary energy resources – Non-renewable	Use as energy carrier	MJ, net calorific value	1.53E-03	1.63E-01	6.93E-03	2.06E-03	1.74E-01
	Used as raw materials	MJ, net calorific value	0.00E+00	1.36E-02	0.00E+00	0.00E+00	1.36E-02
	TOTAL	MJ, net calorific value	1.53E-03	1.82E-01	6.93E-03	2.06E-03	1.93E-01
Secondary material		kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
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	1.20E-06	3.14E-04	1.17E-06	1.44E-06	3.18E-04

Waste production and output flows

Table 14 Waste production of HD144N(P)-182

Parameter	Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Hazardous waste disposed	kg	0	1.40E-04	0.00E+00	0.00E+00	1.40E-04
Non-hazardous waste disposed	kg	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Radioactive waste disposed	kg	0	2.04E-11	0.00E+00	0.00E+00	2.04E-11

Table 15 Output flows of HD144N(P)-182

Parameter	Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Components for reuse	kg	0.00E+00	4.00E-02	0.00E+00	0.00E+00	4.00E-02
Material for recycling	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 16 Waste production of HD108N(P)-182

Parameter	Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Hazardous waste disposed	kg	0.00E+00	1.40E-04	0.00E+00	0.00E+00	1.40E-04
Non-hazardous waste disposed	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Radioactive waste disposed	kg	0.00E+00	2.04E-11	0.00E+00	0.00E+00	2.04E-11

Table 17 Output flows of HD108N(P)-182

Parameter	Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Components for reuse	kg	0.00E+00	4.12E-02	0.00E+00	0.00E+00	4.12E-02
Material for recycling	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 18 Waste production of HD144N(P)-166

Parameter	Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Hazardous waste disposed	kg	0.00E+00	1.96E-04	0.00E+00	0.00E+00	1.96E-04
Non-hazardous waste disposed	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Radioactive waste disposed	kg	0.00E+00	2.16E-11	0.00E+00	0.00E+00	2.16E-11

Table 19 Output flows of HD144N(P)-166

Parameter	Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Components for reuse	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material for recycling	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for energy recovery	kg	0.00E+00	6.12E-02	0.00E+00	0.00E+00	6.12E-02

Table 20 Waste production of HD120N(P)-166

Parameter	Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Hazardous waste disposed	kg	0.00E+00	2.37E-04	0.00E+00	0.00E+00	2.37E-04
Non-hazardous waste disposed	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Radioactive waste disposed	kg	0.00E+00	2.17E-11	0.00E+00	0.00E+00	2.17E-11

Table 21 Output flows of HD120N(P)-166

Parameter	Unit	Upstream	Core infrastructure	Core operation	Down-stream	Total
Components for reuse	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material for recycling	kg	0.00E+00	5.39E-02	0.00E+00	0.00E+00	5.39E-02
Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Additional environmental information

Radiology, Electro Magnetic Fields and Noise

The impact of photovoltaic power generation is mainly the noise of power generation equipment such as inverters and transformers, the low-level radiation generated by photovoltaic cells, and electromagnetism. The noise is within a controllable range and below the legally set limits. The radiation has little impact on the human body and the environment, similar to the battery of mobile phones and cameras. The electromagnetic field and the radio and TV interferences that will be generated by the operation of the connection line will not exceed the recommended limits. For the end-of-life stage of the photovoltaic power station, the battery components need to be recycled. In China, crystalline silicon battery components are widely used, therefore producing very little pollution.

Environmental risks

The manufacturing of silicon material and silicon wafer is the most energy-consuming part in the production process of the entire industrial chain. During the production of crystalline silicon, a large amount of silicon tetrachloride ($SiCl_4$) and dichloro-dihydro silicon (SiH_2Cl_2) are produced, and these by-products can be treated through resource reuse. The recycling process is strictly controlled.

During the manufacturing of solar cells and photovoltaic modules. The pollution comes mainly from the cell production process. Chemicals like hydrofluoric, hydrochloric acid, isopropanol, hydrogen peroxide, etc. are used, and the discharge of exhaust gas will also affect the environment. Jolywood strictly controls the discharge of waste water and exhaust gas, and has been awarded the “National green factory” title by the Ministry of Industry and Information Technology of the Chinese government. Assembling the solar cells into photovoltaic modules does not consume chemicals and basically does not cause pollution to the environment.

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