JA SOLAR TECHNOLOGY Co.,Ltd.

ENVIRONMENTAL PRODUCT DECLARATION

JAM72D10-XXX/MB
JAM72D20-XXX/MB
JAM72D30-XXX/MB

SHANGHAI
HEFEI
SHANGHAI, YIWU

in compliance with ISO 14025

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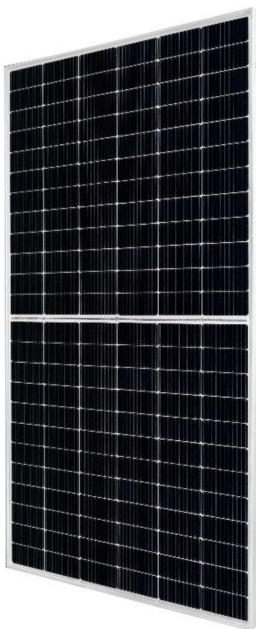

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1. Product Definition and Information

1.1. Description of Company/Organization

JA Solar was founded in 2005. The company's business ranges from silicon wafers, cells and modules to complete photovoltaic power systems, and its products are sold to 135 countries and regions. On the strength of its continuous technological innovation, sound financial condition, well-established global sales and customer service network, JA Solar has been highly recognized by authoritative associations in the industry as a leading global manufacturer of high-performance PV products.

1.2. Product Description

1.2.1 Product Identification

JA Solar produces more than a dozen series of mono-crystalline silicon photovoltaic (PV) modules.The module series under analysis can generate maximum power output of up to 540Wp, and up to 20.9% module efficiency, which is 40% higher than current mainstream products installed in utility projects. All the high energy density modules use innovative MBB bifacial PERCIUM cells and half-cell configuration technology to reach significantly improved performance with conversion efficiency. In addition to their unparalleled power generation performance and outstanding low-temperature coefficient, other advantages include less shading and lower resistive loss, and better mechanical loading tolerance. By greatly reducing LCOE compared to traditional modules, the high-efficiency module series paves the way for investors to generate higher power output.

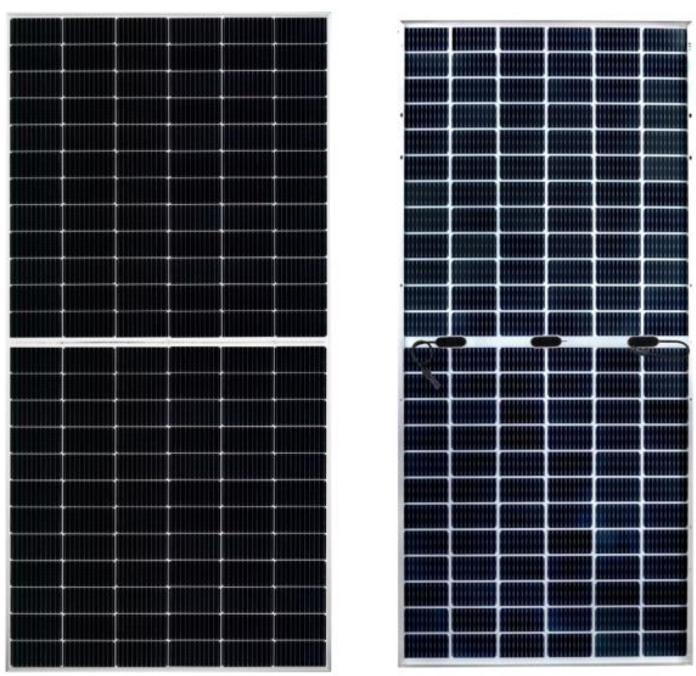

Figure 1 JA Solar PV Bifacial double glass modules

1.2.2 Product Specification

Within this report, in total there are 3 series of double glass series modules that are analyzed, including JAM72D10-

XXX/MB, JAM72D20-XXX/MB, JAM72D30-XXX/MB. The full list of the modules under analysis is shown in table 1 below.

Table 1 Different PV module products models

Series (brand name)	Production site	Dimensions (mm3)	Module efficiency (%)	Power output range (W)
JAM72D10-XXX/MB	Shanghai	2037±2×1005±2×30±1	20.0/20.3	405/420
JAM72D20-XXX/MB	Hefei	2117±2×1052±2×35±1	20.4/20.7	450/465
JAM72D30-XXX/MB	Shanghai, Yiwu	2285±2×1134±2×35±1	20.5/20.6	530/550

Note: 10/20/30: 158.75mm/168mm/182mm solar cells used in module.

1.3. Application

JA Solar PV modules are widely used to generate electricity on rooftop and ground solar farms.

1.4. Material Composition

Table 2 contains a list of materials and substances in different modules.

Table 2 Components in different PV modules

Materials	Main substance	CAS No. of main substance	Units	JAM72D10-XXX/MB	JAM72D20-XXX/MB	JAM72D30-XXX/MB-Shanghai	JAM72D30-XXX/MB-Yiwu
Tempering glass	Na2O·nSiO2	1344-09-8;106985-35-7	kg/pcs	20.289	22.125	25.700	24.346
Aluminum Frame	AlMg3	7429-90-5	kg/pcs	1.751	2.035	2.367	2.420
EVA	$(C_2H_4)x(C_4H_6O_2)y$	24937-78-8	kg/pcs	/	/	/	1.227
POE	Polyolefin elastomer		kg/pcs	2.262	2.251	2.461	1.227
Solar cell	Monocrystalline	7440-21-3	kg/pcs	0.68	0.742	0.936	0.910
Silica gel	SiO_2	112926-00-8	kg/pcs	0.3	0.574	0.307	0.356
Junction box	Fibre glass reinforced plastic		kg/pcs	0.35	0.26	0.350	0.254
Solder	Pb/Sn	7439-92-1/ 7440-31-5	kg/pcs	0.220	0.205	0.219	0.211
Backsheet	(C10H8O4)n		kg/pcs	/	/	/	/

1.5. Declaration of Methodological Framework

In this project, a full LCA approach was considered with some simplification on data modeling using generic data for most background systems. The EPD analysis uses a cradle-to-grave system boundary. No known flows are deliberately excluded from this EPD.

To calculate the LCA results for the product maintenance stage, a 30-year reference service life (RSL) was assumed for the declared products.

Additional details on assumptions, cut-offs and allocation procedures can be found in section 2.3,2.4,2.8, respectively.

1.6. Technical Requirements

The chart below lists all standards required for JA solar's PV modules.

Table 3 Standards required for JA Solar's PV modules

Product	Standards
JAM72D10-XXX/MB	IEC61215/IEC61730/IEC TS 62941
JAM72D20-XXX/MB	IEC61215/IEC61730/ UL61703/ UL61215/IEC TS 62941
JAM72D30-XXX/MB	IEC61215/IEC61730/ UL61703/ UL61215/IEC TS 62941

2. Life Cycle Assessment Background Information

2.1. Functional or Declared Unit

The functional unit and declared unit provide a reference by means of which the material flows(input and output data) for each information module of a product are normalized (in mathematical sense) to produce data, expressed on a common basis. It is important that the functional units of these products are equivalent so that the results may be interpreted clearly.

In this report, the functional unit is defined as 1 kWh of electricity generated as output from the solar photovoltaic plant.

To report the environmental impacts generated by the JA Solar PV modules during its life cycle in the declared unit, the total energy produced by the solar PV plant during the reference service life needs to be calculated. Once total energy 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

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

where:

E_{RSL} represents the total energy produced by the plant (or, in an extreme case, by the individual module) during its entire life cycle;

E_1 represents the energy produced in the first year by the plant. In the case of already installed plants, this figure can be calculated from the actual measurement of the energy produced;

n = year of operation, here 0<n<30;

deg = yearly degradation rate, assuming linear annual degradation;

RSL = Reference service life, 30years according to PCR.

In this study, the distribution loss is 1.58% from the station to the grid. And the electricity consumption for operation and maintenance is 201075 kWh per year. Therefore, the total electricity from the plant to the grid during RSL is listed in Table 4.

Table 4 Electricity generation during RSL

	Units	JAMD10-XXX/MB	JAM72D20-XXX/MB	JAM72D30-XXX/MB
Deg (first year)	%	2	2	2
Deg (rest years)	%	0.5	0.5	0.5
E_1	kWh	37951200	37951200	37951200
$E_{O\&M}$ (yearly)	kWh	201075	201075	201075
Distribution loss	%	1.58	1.58	1.58
$E_{RSL,net}$	kWh	1021876878	1021876878	1021876878

2.2. System Boundary

The system boundary considered in this LCA study is from cradle to grave. Figure 2 below illustrates the system boundaries for the JA Solar product, including raw material production and transportation, manufacture, delivery, solar plant installation and waste disposal.

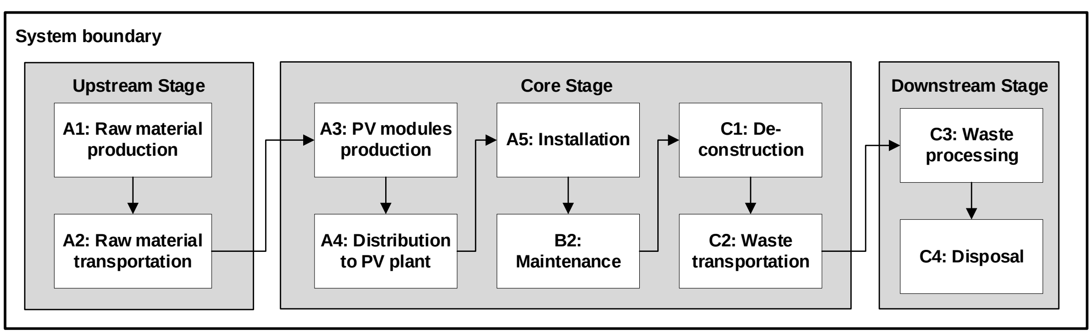

Figure 2 System boundaries

According to the PCR, the life cycle stage must refer to segmentation in the following three processes:

Upstream Stage for module: which includes all the processes upstream of the production of the photovoltaic module. 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.;

Core Stage for module: which includes all the relevant processes managed by the organization proposing the EPD. The core stage in this study includes manufacturing of 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), However, considering that the plant is still in operation, assumption is made on the life cycle inventory (LCI) data on the maintenance (B2) during the RSL (30 years) period, de-construction and demolition of the solar plant (C1), and transport to waste processing (C2).

Downstream Stage for module: which includes all the relevant processes that take place outside of the control of the organization proposing the EPD. In this study, the downstream stage includes waste processing (C3) and disposal (C4). 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.

2.3. Estimates and Assumptions

The key assumptions of this LCA study are as follows：

- For missing background data, substitution of missing data using similar background data approach was taken to shorten the gap;
- JA produced several types of silicon wafer and solar cells (158mm, 168mm, and 182mm), and it is difficult to acquire the inventory of a specific type of wafer or cell. Therefore, silicon wafer used for modeling solar cells and solar cells used for modeling PV module adopts the weight average inventory for each production site;
- The defects rate during module manufacturing is 0.4%, and the number of materials used for repairing and re-welding during module manufacturing is small (one or two pieces of cells or a small amount of solder). Thus, the impacts of additional materials required are assumed negligible;
- The PV plant (20MW) is an operated plant with JAM72S01-360/PR module installed. For the seven series module brands analyzed in this study, the number of PV modules employed in PV plant construction (A5) was calculated by dividing the total power capacity of the PV plant (20MW) by the peak power output of each PV module;
- Electricity and water consumption of PV plant maintenance during RSL are calculated based on the first-year operation real data provided by JA Solar, by multiplying them with RSL;
- The electricity consumption during the deconstruction of PV plant (C1) is assumed the same as the electricity consumption of construction stage (A5), and electricity consumption for PV module demolition at waste processing stage (C3) is assumed same to the electricity consumption of PV module manufacturing (A3);
- 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 is assumed to be 200 km for simplification purposes.

2.4. Cut-off Criteria

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;
- In case of insufficient input data or data gaps for a unit process, according to the PCR requirement, the cut-off criteria chosen is 2% of the total mass and energy of that unit process. (respectively, of the photovoltaic module's unit weight and the energy needed to produce and assemble it).

- The total neglected input flows of the cradle to grave stage, shall be a maximum of 2% of energy usage and mass, in this study, the neglected flow is demonstrated in table below.

Table 5 Cut off flows

Flow name	Process stage	Reason cut off	Total cut off mass % estimated
Packaging material for raw material e.g. wafer, cell and etc.	A1	Used repeatedly inside the plant	<0.1%
Raw materials (Bom) trace elements	A1	Mass <2%	0%-0.4%
Transportation and storage within the plant	A3	Energy<2%	0%-0.7%
Inspection during operation of solar plant	B	Cut off due to small impact according to PCR	<0.1%
Packaging material for waste transportation	C4	<2%	<1%
Total			<2%

2.5. Reference Service life and Estimated Building Service Life

The reference service life of products is 30 years.

2.6. Data Sources

In this LCA study, specific data related to materials or energy flows within the production was calculated and submitted by JA Solar, generic data for certain processes were sourced from databases in SimaPro 9. SimaPro is the world's most widely used LCA software and the data in it comes predominantly from Ecoinvent 3, the world's most complete and widely used set of data on industrial processes, material production, packaging production, transport and so on.

2.7. Data Quality

Steps were taken to ensure that the life cycle inventory data were reliable and representative. The type of data that was used is clearly stated in the Inventory Analysis, be it measured or calculated from primary sources or whether data are from the life cycle inventory databases.

The data quality requirements for this study were as follows:

• 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 occurred, e.g. electricity and transportation data from China.

• The technology represented the average technologies at the time of data collection.

2.8. 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.

Multi-input processes

For data sets in this study, the allocation of the inputs from coupled processes is generally carried out via the mass. The consumption of raw materials is allocated by mass ratio. The transportation of raw materials is allocated by mass. For PV module production, the total consumption of energy and water during manufacturing is equally allocated to per unit watt of energy yield capacity, no other approach of allocation of energy and water consumption for each model of PV module product is taken.

Multi-output processes

Multi-Output allocation is based on a quantitative calculation of the resource consumption and the emissions for example in relation to the distribution of functions, physical properties or economic aspects. Physical properties, such as mass, net calorific values, etc., shall be preferred, otherwise economic aspects, such as man-hours, operating hours or manufacturing cost may be used.

In this study, there is no other by products other than PV modules produced from the PV module production line, hence, there is quite little occasion that required allocation for multi-output processes. One allocation occurs on the environmental emissions allocation, especially in the area of waste treatment. The environmental emissions of PV module product are allocated by energy yield capacity (watt) to each unit module product.

Allocation for recovery processes

During the end-of-life stage of the solar plant, the extra benefit of recycling the waste modules as well as other equipment is 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 etc., is also allocated to the next life cycle of substituted products, but not the primary producers of PV module, hence no burden or benefit will be allocated to the primary producer of the PV module or solar plant (cut off approach).

2.9. Period under Review

The study used primary data collected from July 2020—July 2021.

2.10. Comparability and Benchmarking

No comparisons or benchmarking are included in this EPD. LCA results across EPDs can be calculated with different background databases, modeling assumptions, geographic scope and time periods, all of which are valid and acceptable according to the Product Category Rules (PCR) and ISO standards. The user of the EPD should take care when comparing EPDs from different companies. Assumptions, data sources, and assessment tools may all impact the uncertainty of the final results and make comparisons misleading.

2.11. Electricity power mix

In this EPD, different electricity mix data is taken where the process takes place based on grid mixes of China. The electricity inventory is based on the year 2018 for Chinese electricity generation (China Energy Statistics Yearbook 2019). China's electricity supply mix is depicted in figure 3 below.

Silicon ingot production takes place at Baotou and Qujing in China, and Vietnam. Therefore, Northern China grid mix and Southern China grid mix electricity are adopted for Baotou and Qujing, respectively. While Southern Asia electricity mix is used for Vietnam. Production of wafer takes place at Donghai, Langfang, and Vietnam, Eastern China grid mix is used for Donghai, Northern China grid mix is used for Langfang, while Southern Asia electricity mix is used for Vietnam. Production of solar cells takes place in Yangzhou, Yiwu, and Langfang in China, Eastern China grid mix is used for Yangzhou and Yiwu, and Northern China grid mix is used for Langfan. For PV module production, it takes place in Hefei, Shanghai, and Yiwu, Eastern China grid mix is used for these three sites. For PV plant construction and operation, the plant locates at Hebei province, Northern China grid electricity mix is used.

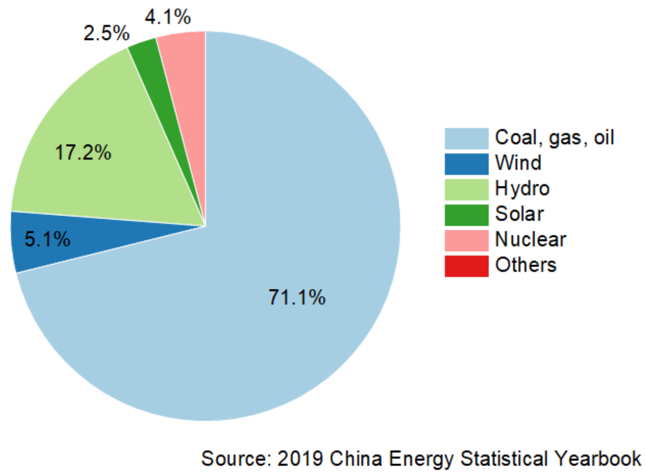

Figure 3 China's electricity production mix-2018

2.12. Units

SI units are used for all LCA results of JA Solar's products .

3. Life Cycle Assessment Scenarios

3.1. Manufacturing

The manufacturing process of JA Solar PV module mainly includes welding, layer, lamination, trimming, framing and junction box installation, curing and testing, final inspection and packaging, which involve raw materials, energy, water, emissions during the process.

A flowchart depicting the production process stages of JA Solar PV module products is shown in Figure 4 below. For simplification purpose, only main stages of manufacturing are presented, raw material, auxiliary processes considered in the LCA but not shown in the flow chart below 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

Step 1 Soldering: Welding machine is used to weld tin-plated belt on the main grid line using multi-point form. Welding heat source is generated from an infrared lamp powered by electricity.

Step 2 Lay-up: Solar cell string, glass, EVA and backing (TPO, or POE…) are laid accordingly for preparation of lamination. A layer of primer is pasted on the glass to strengthen bonding strength. Solar cell string, glass and other materials are properly positioned to prepare for lamination process.

Step 3 EL (electroluminescence) test: When the cell receives forward current, it can generate 1000nm-1200nm IR light, then CCD camera catches this light and forms the image. According to analysis of the image, it can effectively detect the material defect, printing defect, firing defect, process pollution and cell crack.

Step 4 Lamination: Solar string is laid into the laminating machine. The air between layers will be extracted out by vacuum process. A heating process is applied to melt EVA, cell string and backing so that they are bonded together.

Step 5 Framing: Aluminum frame is installed to the laminated piece to enhance the module strength and form a good sealing. The gap between aluminum frame and glass is filled with silicone glue. A horn button is used to connect frames. A junction box is welded on the back of solar module.

Step 7 Packing: The tested modules will be packed into a carton, and put them on the wooden pallet, so that they are convenient for storage and shipment.

Figure 4 Production Process Flowchart of JA Solar PV module products

3.2. Packaging

There are three main kinds of packaging materials, corrugated box (paper), wood board (wood), PE film (plastic).

3.3. Transportation

After the PV module is manufactured, the PV panels, along with other materials, such as brackets, cable, inverters are transported to the installation site(Kangbao, Hebei province). In this study a default value for the distance is given in table 6.

Table 6. Transport to the building site (A4)

NAME	VALUE	UNIT
Fuel type	Diesel	
Liters of fuel	31.11	l/100km
Vehicle type	Truck	
Transport distance	625	km
Capacity utilization (including empty runs, mass based	100	%
Gross density of products transported	N/A	kg/m^3
Weight of products transported (if gross density not reported)	1263052~1288200	kg
Volume of products transported (if gross density not reported)	N/A	m^3
Capacity utilization volume factor (factor: =1 or <1 or ≥ 1 for compressed or nested packaging products)	=1	-

Note: * This value represents the total weight range of different double-glass PV modules yielded to build the 20MW PV plant.

3.4. Production Installation

In terms of solar plant, the electricity generation data was taken from a real ground-mounted PV plant in Kangbao, Hebei province, with energy yield capacity at 20MW. The detailed information about the PV plant is listed in Table 7.

Table 7 Additional declared unit parameters – PV plant.

Parameters	Value		Source
	Amount	Unit	
Peak power of the plant	20	MW	JA Solar
Plant latitude and longitude	41°41'12.74″, 114°25'17.78″	°	JA Solar
Plant altitude	1359~1365	m	JA Solar
Nominal solar irradiance	1943367	Wh/m²/year	JA Solar

Table 8 listed the materials used for PV plant construction. The PV module installed in this PV plant is the brand JAM72S01-360/PR. For the number of PV module employed in PV plant, it is calculated by dividing the total power capacity of the PV plant (20MW) by the peak power output of each PV module.

Table 8 Components for solar plant installation (20MW capacity)

Components		Unit	Value	Distance/km
Module	JAM72D10-415/MB	pcs	51528	625
	JAM72D20-460/MB	pcs	46487	625

	JAM72D30-535/MB	pcs	39970	625
Inverter, 630kw		pcs	32	1407
Bracket (steel)		kg	971256	476
Cable, ZC-YJY23-1-3×150+1×70mm2		kg	1481	1215
Cable, ZRC-YJY23-0.6/1kV 2×70mm2		kg	23800	1215
Cable, PV1-F 1×4mm2		kg	15652	1215
Cable, ZRC-YJY23-0.6/1kV 2×95mm2		kg	3049	1215
Cable, ZRC-YJY23-0.6/1kV 2×50mm2		kg	13147	1215
Cable, ZRC-YJY23-26/35-3×50mm2		kg	4858	1215
Cable, ZRC-YJY23-26/35-3×70mm2		kg	1014	1215
Cable, ZRC-YJY23-26/35-3×95mm2		kg	5304	1215
Compact substation		kg	149000	1407
Transformer		kg	654.7	856
Grounding system		kg	15000	1578
Combiner box		Kg	8400	1479
Concrete foundation		kg	1300000	100
Steel foundation		kg	88000	100

3.5. Disposal

For the end-of-life stage, De-construction (C1) of the PV plant during the disposal stage is assumed mainly consuming electricity, and the electricity consumption is assumed the same as the construction stage (A5), 200km transportation distance from plant site to waste treatment site (C2) is assumed, electricity used for PV module demolition during waste processing (C3) stage is assumed the same as PV module manufacturing stage (A3), as all mentioned in section 4.5. For end-of-life disposal treatment process (C4), the infrastructures of PV plants such as inverters are considered fully reused and following the end-of-life load and benefit allocation approach, is then cut off from the analysis. Since there is lack of existing data of recycling rate for PV module, this study refers to legal requirements issued by Waste Electrical and Electronic Equipment (WEEE). In 2012/19/EU-Article 11 & ANNEX V, the required recycling rate for waste PV module is 85%. Therefore, 15% of waste PV module end up with waste disposal, waste management scenario of 20% landfill and 80% incineration was adopted.

4. Life Cycle Assessment Results

Table 9. Description of the system boundary modules

	PRODUCT STAGE			CONSTRUCT-ION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY
	A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
EPD Type: cradle-to-grave	Raw material supply	Transport	Manufacturing	Transport from gate to site	Assembly/Install	Use	Maintenance	Repair	Replacement	Refurbishment	Building Operational Energy Use During Product Use	Building Operational Water Use During Product Use	Deconstruction	Transport	Waste processing	Disposal	Reuse, Recovery, Recycling Potential
	X	X	X	X	X	MND	X	MND	MND	MND	MND	MND	X	X	X	X	MND

4.1. Life Cycle Impact Assessment Results

Based on the model of PV module products, the EN 15804 result is calculated and the tables below show the results. Note that impact results are calculated based on 1 kWh electricity generated by the PV plant. The results have been demonstrated through different processes according to the PCR, namely upstream, core, and downstream stages.

Table 10. Life Cycle Impact Assessment Results- JAM72D10-Shanghai

IMPACT CATEGORY	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
Climate change -total	kg CO2 eq	1.00E-02	6.97E-03	4.75E-04	1.75E-02
Climate change - fossil	kg CO2 eq	1.02E-02	6.98E-03	4.78E-04	1.77E-02
Climate change - biogenic	kg CO2 eq	-2.30E-04	-2.11E-05	-3.49E-06	-2.55E-04
Climate change - land use and change in land use	kg CO2 eq	4.78E-06	4.57E-06	6.97E-08	9.42E-06
Ozone depletion	kg CFC-11 eq	5.77E-10	7.54E-10	3.39E-12	1.33E-09
Acidification	moles H+ eq	7.19E-05	7.02E-05	2.73E-06	1.45E-04
Eutrophication of water	kgPO_4eq	2.36E-06	8.45E-06	5.78E-08	1.09E-05
Photochemical ozone formation	kg NMVOC eq	3.55E-05	3.04E-05	1.33E-06	6.72E-05
Consumption of abiotic resources - minerals and materials	kg Sb eq	4.37E-06	1.14E-06	2.81E-09	5.51E-06
Consumption of abiotic resource use – fossil resources	MJ, calculated using lower calorific values	1.03E-01	7.18E-02	3.46E-03	1.78E-01
Water consumption	m3 eq	2.48E-03	1.43E-03	1.53E-05	3.92E-03

Table 11. Life Cycle Impact Assessment Results- JAMD20-Hefei

IMPACT CATEGORY	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
Climate change -total	kg CO2 eq	9.74E-03	6.89E-03	4.32E-04	1.71E-02
Climate change - fossil	kg CO2 eq	1.00E-02	6.91E-03	4.35E-04	1.74E-02
Climate change - biogenic	kg CO2 eq	-3.01E-04	-2.06E-05	-3.17E-06	-3.25E-04
Climate change - land use and change in land use	kg CO2 eq	4.66E-06	4.54E-06	6.73E-08	9.27E-06
Ozone depletion	kg CFC-11 eq	5.87E-10	7.47E-10	3.18E-12	1.34E-09
Acidification	moles H+ eq	7.02E-05	6.96E-05	2.48E-06	1.42E-04
Eutrophication of water	$kgPO_4eq$	2.24E-06	8.39E-06	5.27E-08	1.07E-05
Photochemical ozone formation	kg NMVOC eq	3.48E-05	3.01E-05	1.21E-06	6.62E-05
Consumption of abiotic resources - minerals and materials	kg Sb eq	4.20E-06	1.13E-06	2.58E-09	5.34E-06
Consumption of abiotic resource use – fossil resources	MJ, calculated using lower calorific values	9.97E-02	7.10E-02	3.15E-03	1.74E-01
Water consumption	m3 eq	2.42E-03	1.42E-03	1.40E-05	3.85E-03

Table 12. Life Cycle Impact Assessment Results -JAM72D30-Shanghai

IMPACT CATEGORY	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
Climate change -total	kg CO2 eq	1.04E-02	6.93E-03	4.76E-04	1.78E-02
Climate change - fossil	kg CO2 eq	1.06E-02	6.94E-03	4.79E-04	1.80E-02
Climate change - biogenic	kg CO2 eq	-2.13E-04	-2.09E-05	-3.50E-06	-2.37E-04
Climate change - land use and change in land use	kg CO2 eq	4.88E-06	4.54E-06	6.83E-08	9.49E-06
Ozone depletion	kg CFC-11 eq	5.78E-10	7.48E-10	3.35E-12	1.33E-09
Acidification	moles H+ eq	7.32E-05	6.98E-05	2.74E-06	1.46E-04
Eutrophication of water	$kgPO_4eq$	2.31E-06	8.39E-06	5.80E-08	1.08E-05
Photochemical ozone formation	kg NMVOC eq	3.64E-05	3.02E-05	1.33E-06	6.79E-05
Consumption of abiotic resources - minerals and materials	kg Sb eq	4.26E-06	1.13E-06	2.80E-09	5.39E-06
Consumption of abiotic resource use – fossil resources	MJ, calculated using lower calorific values	1.04E-01	7.13E-02	3.47E-03	1.78E-01
Water consumption	m3 eq	2.51E-03	1.42E-03	1.54E-05	3.94E-03

Table 13. Life Cycle Impact Assessment Results- JAM72D30-Yiwu

IMPACT CATEGORY	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
Climate change -total	kg CO2 eq	1.01E-02	6.80E-03	2.95E-04	1.72E-02
Climate change - fossil	kg CO2 eq	1.03E-02	6.81E-03	2.97E-04	1.74E-02
Climate change - biogenic	kg CO2 eq	-2.16E-04	-1.99E-05	-2.16E-06	-2.38E-04
Climate change - land use and change in land use	kg CO2 eq	4.89E-06	4.53E-06	6.09E-08	9.49E-06
Ozone depletion	kg CFC-11 eq	5.74E-10	7.46E-10	2.55E-12	1.32E-09

Acidification	moles H+ eq	7.14E-05	6.91E-05	1.69E-06	1.42E-04
Eutrophication of water	kgPO$_4$eq	2.27E-06	8.38E-06	3.60E-08	1.07E-05
Photochemical ozone formation	kg NMVOC eq	3.53E-05	2.99E-05	8.30E-07	6.61E-05
Consumption of abiotic resources - minerals and materials	kg Sb eq	4.22E-06	1.13E-06	1.87E-09	5.35E-06
Consumption of abiotic resource use – fossil resources	MJ, calculated using lower calorific values	1.01E-01	7.02E-02	2.17E-03	1.73E-01
Water consumption	m3 eq	2.46E-03	1.41E-03	9.63E-06	3.88E-03

Table 14. TRACI Results- JAM72D10-Shanghai

Impact Category	Unit	Upstream	Core Stream	Downstream	Total
Ozone depletion	kg CFC-11 eq	7.05E-10	8.49E-10	6.93E-12	1.56E-09
Global warming	kg CO2 eq	9.71E-03	6.60E-03	4.49E-04	1.68E-02
Smog	kg O3 eq	6.96E-04	5.09E-04	2.89E-05	1.23E-03
Acidification	kg SO2 eq	6.07E-05	5.72E-05	2.34E-06	1.20E-04
Eutrophication	kg N eq	1.92E-05	6.37E-05	4.84E-07	8.34E-05
Carcinogenics	CTUh	4.38E-10	4.14E-09	1.09E-11	4.59E-09
Non carcinogenics	CTUh	3.44E-09	1.62E-08	4.59E-11	1.97E-08
Respiratory effects	kg PM2.5 eq	6.69E-06	9.23E-06	2.53E-07	1.62E-05
Ecotoxicity	CTUe	7.68E-02	3.86E-01	1.49E-03	4.64E-01
Fossil fuel depletion	MJ surplus	6.85E-03	5.26E-03	6.98E-05	1.22E-02

Table 15. TRACI Results- JAMD20-Hefei

Impact Category	Unit	Upstream	Core Stream	Downstream	Total
Ozone depletion	kg CFC-11 eq	7.12E-10	8.46E-10	6.42E-12	1.56E-09
Global warming	kg CO2 eq	9.50E-03	6.54E-03	4.09E-04	1.65E-02
Smog	kg O3 eq	6.82E-04	5.05E-04	2.64E-05	1.21E-03
Acidification	kg SO2 eq	5.94E-05	5.67E-05	2.13E-06	1.18E-04
Eutrophication	kg N eq	1.82E-05	6.33E-05	4.40E-07	8.19E-05
Carcinogenics	CTUh	4.34E-10	4.12E-09	1.01E-11	4.57E-09
Non carcinogenics	CTUh	3.21E-09	1.61E-08	4.18E-11	1.93E-08
Respiratory effects	kg PM2.5 eq	6.58E-06	9.15E-06	2.30E-07	1.60E-05
Ecotoxicity	CTUe	7.24E-02	3.82E-01	1.36E-03	4.56E-01
Fossil fuel depletion	MJ surplus	6.56E-03	5.25E-03	6.40E-05	1.19E-02

Table 16. TRACI Results- AM72D30-Shanghai

Impact Category	Unit	Upstream	Core Stream	Downstream	Total
Ozone depletion	kg CFC-11 eq	7.08E-10	8.47E-10	6.90E-12	1.56E-09
Global warming	kg CO2 eq	1.00E-02	6.57E-03	4.50E-04	1.70E-02
Smog	kg O3 eq	7.15E-04	5.07E-04	2.90E-05	1.25E-03
Acidification	kg SO2 eq	6.20E-05	5.68E-05	2.35E-06	1.21E-04

Eutrophication	kg N eq	1.88E-05	6.34E-05	4.85E-07	8.26E-05
Carcinogenics	CTUh	4.43E-10	4.12E-09	1.09E-11	4.58E-09
Non carcinogenics	CTUh	3.24E-09	1.61E-08	4.59E-11	1.94E-08
Respiratory effects	kg PM2.5 eq	6.85E-06	9.17E-06	2.54E-07	1.63E-05
Ecotoxicity	CTUe	7.38E-02	3.83E-01	1.48E-03	4.58E-01
Fossil fuel depletion	MJ surplus	6.68E-03	5.25E-03	6.98E-05	1.20E-02

Table 17. TRACI Results- JAM72D30-Yiwu

IMPACT CATEGORY	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
Ozone depletion	kg CFC-11 eq	7.02E-10	8.44E-10	4.81E-12	1.55E-09
Global warming	kg CO2 eq	9.75E-03	6.45E-03	2.79E-04	1.65E-02
Smog	kg O3 eq	6.97E-04	5.00E-04	1.81E-05	1.22E-03
Acidification	kg SO2 eq	6.04E-05	5.62E-05	1.46E-06	1.18E-04
Eutrophication	kg N eq	1.84E-05	6.32E-05	3.01E-07	8.19E-05
Carcinogenics	CTUh	4.40E-10	4.12E-09	7.65E-12	4.56E-09
Non carcinogenics	CTUh	3.18E-09	1.61E-08	2.90E-11	1.92E-08
Respiratory effects	kg PM2.5 eq	6.72E-06	9.10E-06	1.57E-07	1.60E-05
Ecotoxicity	CTUe	7.24E-02	3.82E-01	9.59E-04	4.55E-01
Fossil fuel depletion	MJ surplus	6.44E-03	5.23E-03	4.56E-05	1.17E-02

4.2. Resource Consumption and Waste Generation Results

The resource consumption and waste generation results are demostrated in tables below.

Table 18. Resource Use- JAM72D10-Shanghai

PARAMETER	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
PENRE:Non-renewable primary resources used as an energy carrier (fuel)	MJ	1.32E-01	8.85E-02	5.59E-03	2.26E-01
PERE:Renewable primary energy used as energy carrier (fuel)	MJ	2.76E-02	7.40E-03	2.28E-04	3.52E-02
PENRM:Non-renewable primary resources with energy content used as material	MJ	1.59E-02	0.00E+00	0.00E+00	1.59E-02
PERM:Renewable primary resources with energy content used as material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT:Total use of non-renewable primary energy resources	MJ	1.48E-01	8.85E-02	5.59E-03	2.42E-01
PERT:Total use of renewable primary energy resources	MJ	2.76E-02	7.40E-03	2.28E-04	3.52E-02
FW:Use of net fresh water	m3	6.53E-05	3.46E-05	3.66E-07	1.00E-04
MS: Use of secondary raw materials	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF:Use of renewable secondary fuels	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF:Use of none renewable secondary fuels	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 19. Output Flows and Waste Categories- JAM72D10-Shanghai

PARAMETER	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL

HWD:Hazardous waste disposed	kg	5.83E-10	8.27E-05	0.00E+00	8.27E-05
NHWD:Non-hazardous waste disposed	kg	3.00E-10	3.00E-06	1.20E-04	1.23E-04
RWD:Radioactive waste disposed	kg	7.38E-19	6.01E-12	0.00E+00	6.01E-12
MER: Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MRF:Materials for recycling	kg	0.00E+00	0.00E+00	1.11E-03	1.11E-03
CRU:Components for re-use	kg	0.00E+00	7.31E-05	0.00E+00	7.31E-05
ETE: Exported thermal energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EEE: Exported electricity energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 20. Resource Use- JAMD20-Hefei

PARAMETER	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
PENRE:Non-renewable primary resources used as an energy carrier (fuel)	MJ	1.29E-01	8.76E-02	5.09E-03	2.22E-01
PERE:Renewable primary energy used as energy carrier (fuel)	MJ	2.79E-02	7.22E-03	2.08E-04	3.53E-02
PENRM:Non-renewable primary resources with energy content used as material	MJ	1.51E-02	0.00E+00	0.00E+00	1.51E-02
PERM:Renewable primary resources with energy content used as material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT:Total use of non-renewable primary energy resources	MJ	1.44E-01	8.76E-02	5.09E-03	2.37E-01
PERT:Total use of renewable primary energy resources	MJ	2.79E-02	7.22E-03	2.08E-04	3.53E-02
FW:Use of net fresh water	m3	6.40E-05	3.43E-05	3.35E-07	9.86E-05
MS: Use of secondary raw materials	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF:Use of renewable secondary fuels	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF:Use of none renewable secondary fuels	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 21. Output Flows and Waste Categories- JAMD20-Hefei

PARAMETER	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
HWD:Hazardous waste disposed	kg	5.70E-10	8.09E-05	0.00E+00	8.09E-05
NHWD:Non-hazardous waste disposed	kg	2.93E-10	2.94E-06	1.51E-04	1.54E-04
RWD:Radioactive waste disposed	kg	7.22E-19	5.43E-12	0.00E+00	5.43E-12
MER: Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MRF:Materials for recycling	kg	0.00E+00	0.00E+00	1.09E-03	1.09E-03
CRU:Components for re-use	kg	0.00E+00	1.04E-04	0.00E+00	1.04E-04
ETE: Exported thermal energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EEE: Exported electricity energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 22. Resource Use- JAM72D30-Shanghai

PARAMETER	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
PENRE:Non-renewable primary resources used as an energy carrier (fuel)	MJ	1.35E-01	8.80E-02	5.61E-03	2.29E-01
PERE:Renewable primary energy used as energy carrier (fuel)	MJ	2.86E-02	7.34E-03	2.29E-04	3.62E-02
PENRM:Non-renewable primary resources with energy content used as material	MJ	1.51E-02	0.00E+00	0.00E+00	1.51E-02

PERM:Renewable primary resources with energy content used as material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT:Total use of non-renewable primary energy resources	MJ	1.51E-01	8.80E-02	5.61E-03	2.44E-01
PERT:Total use of renewable primary energy resources	MJ	2.86E-02	7.34E-03	2.29E-04	3.62E-02
FW:Use of net fresh water	m3	6.64E-05	3.44E-05	3.67E-07	1.01E-04
MS: Use of secondary raw materials	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF:Use of renewable secondary fuels	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF:Use of none renewable secondary fuels	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 23. Output Flows and Waste Categories- JAM72D30-Shanghai

PARAMETER	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
HWD:Hazardous waste disposed	kg	6.18E-10	8.78E-05	0.00E+00	8.78E-05
NHWD:Non-hazardous waste disposed	kg	3.18E-10	3.18E-06	1.51E-04	1.54E-04
RWD:Radioactive waste disposed	kg	7.83E-19	6.03E-12	0.00E+00	6.03E-12
MER: Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MRF:Materials for recycling	kg	0.00E+00	0.00E+00	1.09E-03	1.09E-03
CRU:Components for re-use	kg	0.00E+00	6.69E-05	0.00E+00	6.69E-05
ETE: Exported thermal energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EEE: Exported electricity energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 24. Resource Use- JAM72D30-Yiwu

PARAMETER	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
PENRE:Non-renewable primary resources used as an energy carrier (fuel)	MJ	1.32E-01	8.64E-02	3.48E-03	2.22E-01
PERE:Renewable primary energy used as energy carrier (fuel)	MJ	2.80E-02	7.16E-03	1.44E-04	3.53E-02
PENRM:Non-renewable primary resources with energy content used as material	MJ	1.40E-02	0.00E+00	0.00E+00	1.40E-02
PERM:Renewable primary resources with energy content used as material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRT:Total use of non-renewable primary energy resources	MJ	1.46E-01	8.64E-02	3.48E-03	2.36E-01
PERT:Total use of renewable primary energy resources	MJ	2.80E-02	7.16E-03	1.44E-04	3.53E-02
FW:Use of net fresh water	m3	6.52E-05	3.42E-05	2.33E-07	9.96E-05
MS: Use of secondary raw materials	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF:Use of renewable secondary fuels	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF:Use of none renewable secondary fuels	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 25. Output Flows and Waste Categories- JAM72D30-Yiwu

PARAMETER	UNIT	UPSTREAM	CORE STREAM	DOWNSTREAM	TOTAL
HWD:Hazardous waste disposed	kg	6.01E-10	7.12E-05	0.00E+00	7.12E-05
NHWD:Non-hazardous waste disposed	kg	3.09E-10	2.58E-06	1.43E-04	1.45E-04
RWD:Radioactive waste disposed	kg	7.61E-19	3.69E-12	0.00E+00	3.69E-12
MER: Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MRF:Materials for recycling	kg	0.00E+00	0.00E+00	1.09E-03	1.09E-03

CRU:Components for re-use	kg	0.00E+00	6.36E-05	0.00E+00	6.36E-05
ETE: Exported thermal energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EEE: Exported electricity energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

5. LCA Interpretation

The contribution analysis of the PV module products on various impact categories reveals that PV module including raw materials stage (A1) and PV plant installation stage (A5) are the main contributions to environmental impact categories. In terms of raw materials stage, solar cell, glass and frame are three key impact components, and for the PV plant installation stage, cable, bracket and inverter used for PV plant infrastructure are the key impact components.

6. Additional Environmental Information

6.1. Additional Environmental Indicators

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 on Table 26.

The calculation of RoE is done using the following formula:

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

where: $E_{invested}$ =PENRT+PERT, $E_{produced,annual}$ = total amount of electricity generated in a year by the solar park

Table 26. RoE results of JA Solar PV modules

MODULE	JAM72D10-XXX/MB	JAM72D20-XXX/MB	JAM72D30-XXX/MB—SHANGHAI	JAM72D30-XXX/MB—YIWU
RoE	2.31	2.27	2.33	2.26

6.2. Environmental Activities and Certifications

Green Supply Chain

JA Solar has incorporated environmental, social, ethical factors as well as health, and human rights, etc. into corporate procurement decisions, building green supply chain. JA Solar won the "Silver Award for recognition of corporate social responsibility achievements" in 2021. Among the evaluated electric equipment manufacturing enterprises, JA Solar ranks among the top 12% in terms of comprehensive ranking and the top 1% in terms of "sustainable procurement".

Supplier and User of Green Electricity

JA Solar has produced 63GW of battery modules, which is equivalent to an annual reduction of about 69 million tons of carbon dioxide. JA solar holds more than 30 photovoltaic projects, with an annual green power generation of about 840 million kWh. It is the supplier and user of green power.

Certifications

Plants of JA Solar comply with the following standards:

- ISO 9001:2015 Quality Management System
- ISO 14001:2015 Environmental Management System
- ISO 45001:2018 Occupational Health and Safety Management System

7. Supporting Documentation

Additional information about JA Solar's products can be found on the website: https://www.jasolar.com/

8. References

BS EN 50693:2019, Product category rules for life cycle assessments of electronic and electrical products and systems.

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