Environmental Life Cycle Assessment of Electricity from PV systems, version 2020

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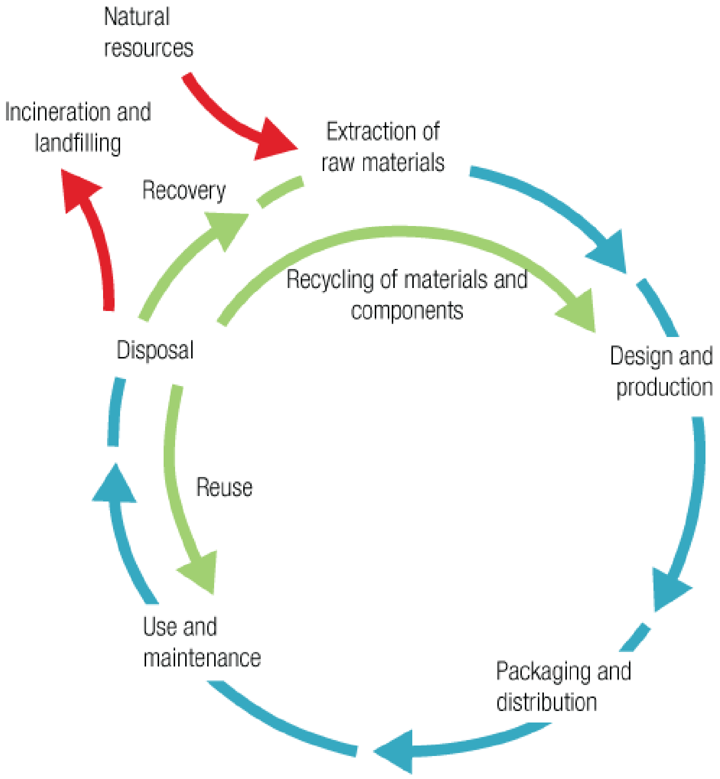
Environmental Life Cycle Assessment

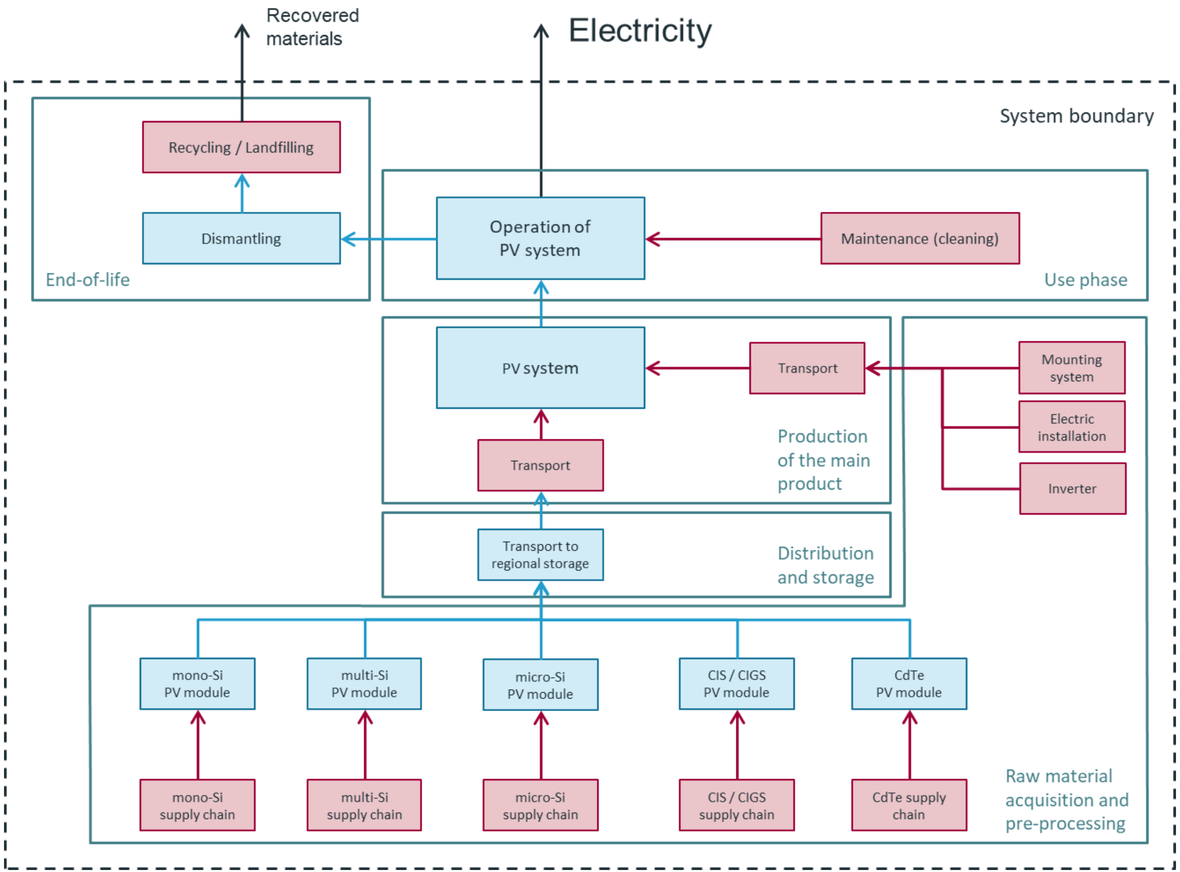
Life Cycle Assessment (LCA) is a structured, comprehensive method of quantifying material and energy flows, including the associated emissions caused in the life cycle of goods and services.

The life cycle of goods and services covers raw material and primary energy extraction, material and energy supply, manufacture, use and end of life, including transport and waste management services where needed.



www.lifecycleinitiative.org

Product System and System Boundary PV Electricity Generation



Company-specific data

Company-specific or secondary data

Company specific data:
Data from PV panel manufacturer and companies operating supply chain activities such as cell manufacturing

Secondary data:
Data derived from scientific publications, reports and statistics or industry average data

IEA PVPS Report T12-19:2020

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Environmental Footprint PV: Scope

- **Reference flow:**
  1 kWh AC electricity (at connection point with the network), produced with a 3 kWp PV system, rooftop mounted
- **Annual production (Europe):**
  975 kWh/kWp, including degradation (linear, 0.7 %/year [1])
- **Service life:**
  30 years (Panel), 15 years (inverter)
- **PV technologies and efficiencies**
  - Cadmium-Tellurid (CdTe), 18.0 %
  - Copper-Indium-Gallium-Selenid (CIS/CIGS), 16.0 %
  - Multicrystalline Silicon (multi-Si, BSF) [2], 18.0 %
  - Monocrystalline Silicon (mono-Si, BSF) [2], 19.5 %

[1] As per current Task 12 LCA methodology (IEA-PVPS T12-18:2020), though research on recent systems suggests degradation rates in the order of 0.5-0.6 %/year (Jordan et al. 2016). Results presented here can be adjusted by assuming a linear relationship with the degradation rate dependent yield. For a degradation rate of 0.5 %/year simply multiply results by a factor of 0.968; while for a degradation rate of 0.9 %/year multiply results by a factor of 1.053.

[2] LCI data on more recent technologies such as PERC are not yet available

Key Parameters and Key Data

Update 2020	mono-Si [1]	multi-si [1]	CIS	CdTe
Module efficiency	19.5 %	18.0 %	16.0 %	18.0 %
Wafer thickness	170 µm	180 µm	n.a.	n.a.
Kerf loss	65 mm	65 µm	n.a.	n.a.
Further losses	20.5 µm	27.5 µm	n.a.	n.a.
Glass thickness	3.2 mm	3.2 mm	3.2 mm	3.2+3.2 mm [2] 2.1+2.8 mm [3]
Electricity consumption				
- MG silicon	11 kWh/kg			
- polysilicon production	49 kWh/kg		n.a.	n.a.
- CZ monocrystal / casting	32 kWh/kg	7.0 kWh/kg	n.a.	n.a.
- wafer manufacturing	4.8 kWh/m^2	5.6 kWh/m^2	n.a.	n.a.
- cell manufature	17.7 kWh/m^2		n.a.	n.a.
- Panel manufacturing	14.0 kWh/m^2		45 kWh/m^2	34 kWh/m^2
Year of key production and market data	2017-2019		2010	2018-2019

[1] Standard technology
Back Surface Field, BSF

[2] Series 4
[3] Series 6

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Environmental Impacts of 1 kWh AC Electricity

	unit	Mono-Si	Multi-Si	CIS	CdTe
Greenhouse gas emissions	g CO_2-eq	42.5	42.3	36.3	26.5
Resource use, fossil fuels	MJ	0.54	0.54	0.54	0.38
resource use, minerals and metals	mg Sb_{eq}	5.28	5.35	4.65	5.26
particulate matter	10^{-9} disease incidences	3.63	3.51	1.38	1.08
acidification	mmol H+ eq	0.36	0.36	0.23	0.19
water scarcity	l water-eq	7.49	6.71	4.88	3.08
module efficiency	%	19.5	18.0	16.0	18.0
Data		2017-2019		2010	2018-2019

1 kWh AC electricity. Annual yield (Europe): 975 kWh/kW_p, including degradation (linear, 0.7%/a). To adjust results for a degradation rate of 0.5 %/year multiply results by 0.968; while for a degradation rate of 0.9 %/year, multiply results by a factor of 1.053.
Service life: 30 years (Panel), 15 years (inverter)

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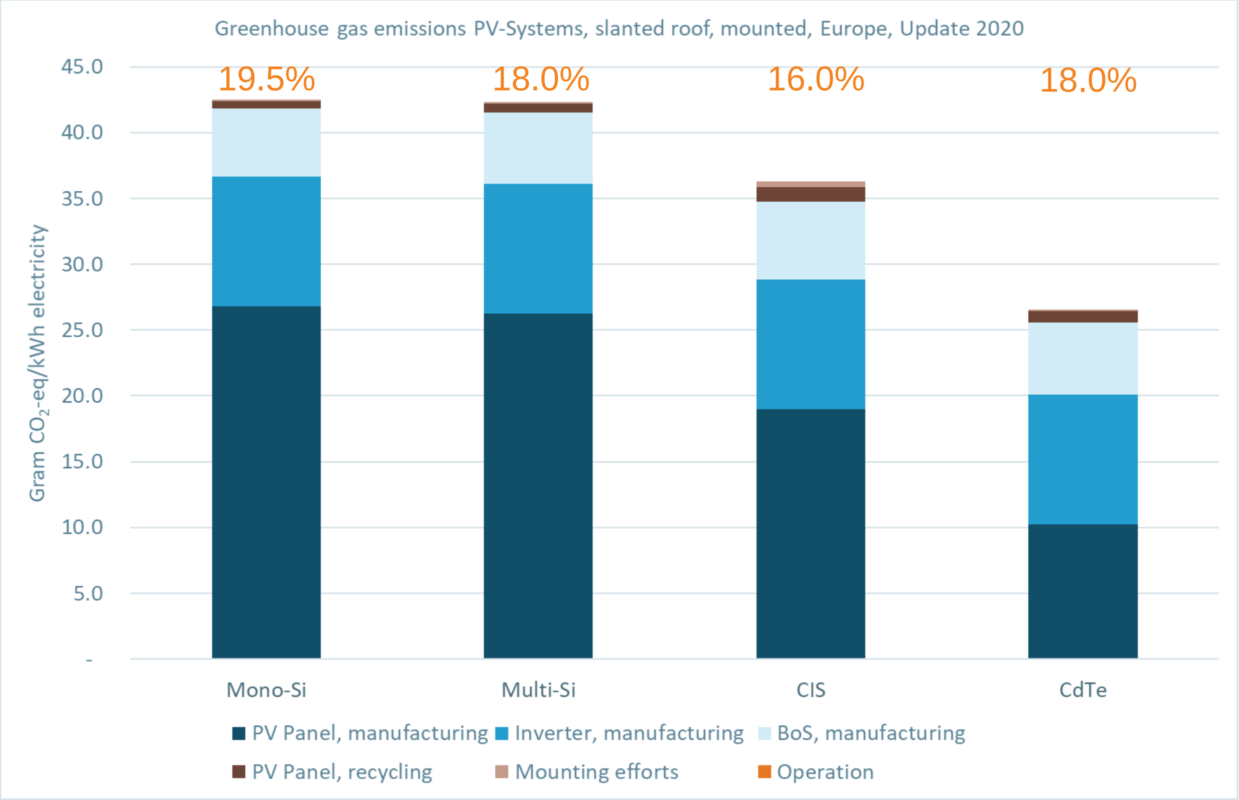
Environmental Impacts of 2018 Systems Relative to 2011 Systems

	Mono-Si	Multi-Si	CIS	CdTe
Greenhouse gas emissions	40.2%	63.7%	79.0%	94.8%
Resource use, fossil fuels	44.6%	66.1%	79.6%	95.9%
resource use, minerals and metals	139.2%	108.0%	254.9%	185.3%
particulate matter	30.2%	55.1%	75.1%	82.2%
acidification	36.6%	59.0%	80.8%	79.2%
water scarcity	24.6%	38.7%	81.1%	98.8%
module efficiency	19.5	18.0	16.0	18.0

1 kWh AC electricity. Annual yield (Europe): 975 kWh/kW_p, including degradation (linear, 0.7%/a).
Service life: 30 years (Panel), 15 years (inverter).
Impacts of 2011 system equal 100%

Greenhouse Gas Emissions 1 kWh PV-System 3kWp



module efficiency

1 kWh AC electricity. Annual yield (Europe): 975 kWh/kW_p, including degradation (linear, 0.7%/a). To adjust results for a degradation rate of 0.5 %/year multiply results by 0.968; while for a degradation rate of 0.9 %/year, multiply results by a factor of 1.053. Service life: 30 years (Panel), 15 years (inverter)

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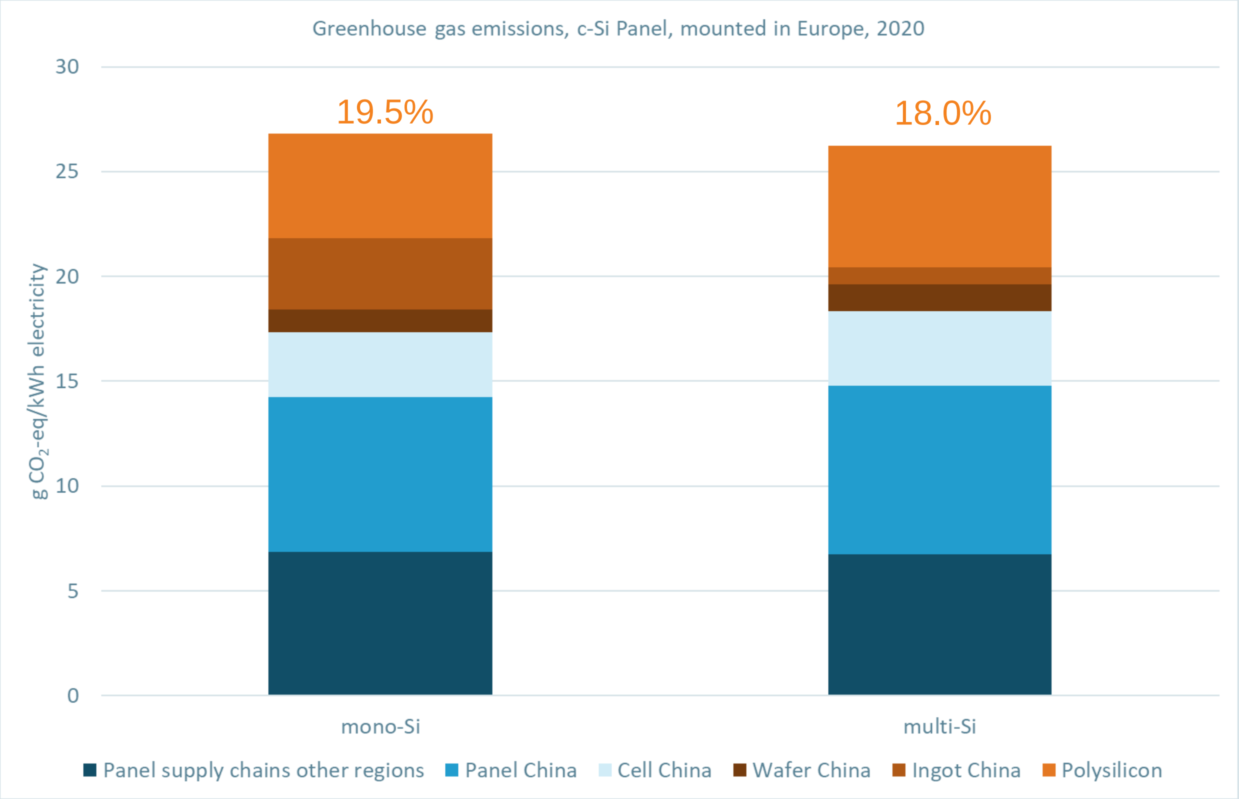
c-Si Panels Supplied to Europe: Supply Chain Contributions



module efficiency

1 kWh AC electricity. Annual yield (Europe): 975 kWh/kW_p, including degradation (linear, 0.7%/a). To adjust results for a degradation rate of 0.5 %/year multiply results by 0.968; while for a degradation rate of 0.9 %/year, multiply results by a factor of 1.053. Service life: 30 years (Panel), 15 years (inverter)

Non Renewable Energy Payback Time

NREPBT

Non renewable energy payback time is defined as the period required for a renewable energy system to generate the same amount of energy (in terms of non renewable primary energy equivalent) that was used to produce the system itself.

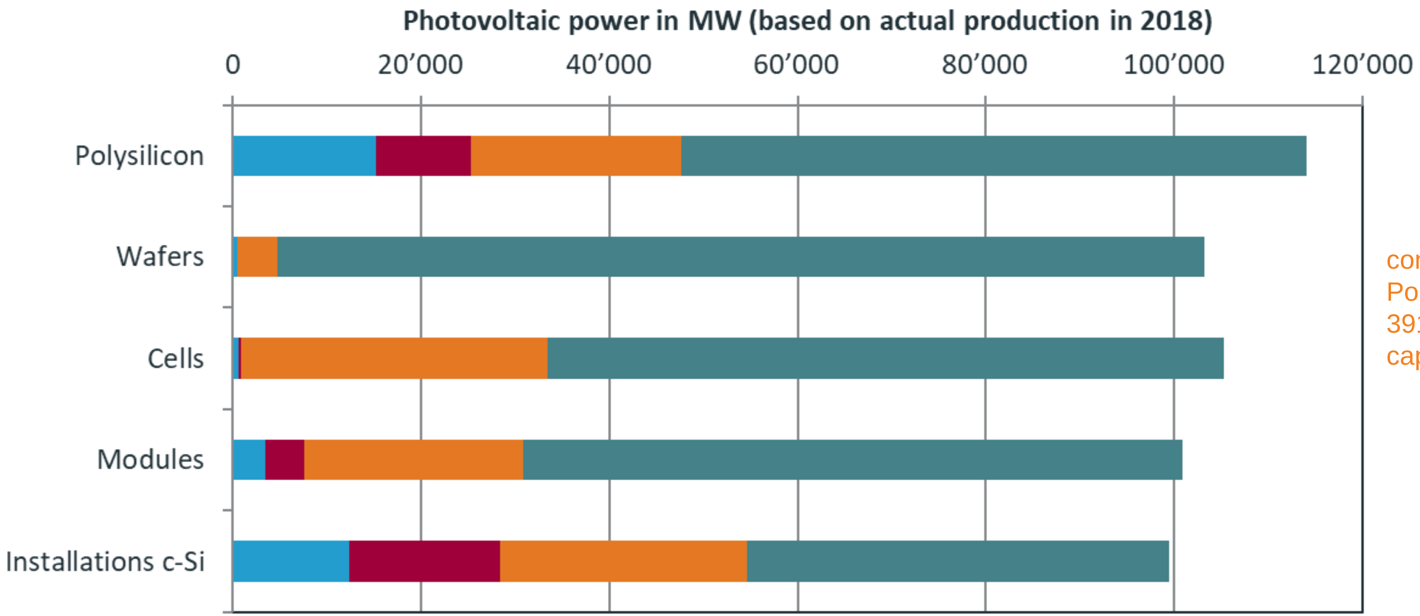
	unit	Mono-Si	Multi-Si	CIS	CdTe
NREPBT	year	1.2	1.2	1.3	0.9
module efficiency	%	19.5	18.0	16.0	18.0

1 kWh AC electricity. Annual yield (Europe): 975 kWh/kW_p, including degradation (linear, 0.7%/a).
Service life: 30 years (Panel), 15 years (inverter).
Reference electricity mix: mix of power plants using non renewable energy sources (coal, oil, natural gas, uranium) in Europe.

Bill of Materials

Material			otovoltaic module (laminate/unframed and panel/frame			
			Mono-Si	Multi-Si	CI(G)S	CdTe
Source			PVPS Task 12 2020	PVPS Task 12 2020	Jungbluth et al. 2012	PVPS Task 12 2020
Laminate/unframed	**Subtotal wafer / semiconductor**		**5.89%**	**6.11%**	**0.06%**	**0.15%**
	Wafer / semiconductor	silicon for photovoltaics	5.89%	6.11%	0.00%	0.00%
		indium	0.00%	0.00%	0.02%	0.00%
		cadmium telluride	0.00%	0.00%	0.00%	0.14%
		cadmium sulphide	0.00%	0.00%	0.00%	0.00%
		gallium	0.00%	0.00%	0.01%	0.00%
		selenium	0.00%	0.00%	0.04%	0.00%
	Subtotal metals		**1.47%**	**1.46%**	**0.55%**	**0.09%**
	Metals	aluminium	0.39%	0.39%	0.00%	0.00%
		aluminium, production mix	0.00%	0.00%	0.30%	0.00%
		copper	0.92%	0.92%	0.07%	0.08%
		lead	0.01%	0.01%	0.00%	0.00%
		molybdenum	0.00%	0.00%	0.04%	0.00%
		silver	0.03%	0.03%	0.00%	0.00%
		chromium steel	0.00%	0.00%	0.00%	0.01%
		tin	0.12%	0.12%	0.08%	0.00%
		zinc oxide	0.00%	0.00%	0.06%	0.00%
	Subtotal plastics		**13.31%**	**13.28%**	**12.20%**	**3.28%**
	Plastics	ethylvinylacetate	7.88%	7.86%	5.05%	2.38%
		polyvinylfluoride film	1.01%	1.00%	0.00%	0.00%
		polyvinylbutyral foil	0.00%	0.00%	1.27%	0.00%
		polyphenylene sulfide	0.00%	0.00%	0.58%	0.00%
		polyethylene terephthalate, PET	3.11%	3.10%	2.26%	0.00%
		polyethylene, HDPE	0.21%	0.21%	0.33%	0.00%
		glass fibre reinforced plastic, polyamide	0.00%	0.00%	0.00%	0.67%
		silicone product	1.10%	1.09%	2.72%	0.23%
	Subtotal solar glass		**79.34%**	**79.15%**	**87.19%**	**96.48%**
	Solar glass	flat glass	0.00%	0.00%	35.43%	46.75%
		solar glass	79.34%	79.15%	51.76%	49.73%
Panel/ frame	**Subtotal metals panel**		**19.13%**	**19.09%**	**14.79%**	**2.03%**
	Metals	aluminium alloy	19.13%	19.09%	14.79%	2.03%
Total laminate/unframed			**100.00%**	**100.00%**	**100.00%**	**100.00%**
Total panel/framed			**119.13%**	**119.09%**	**114.79%**	**102.03%**

Market Situation Crystalline Silicon 2018 in MW PV Power Capacity



	Installations c-Si	Modules	Cells	Wafers	Polysilicon
Europe	12'383	3'468	582	455	15'244
Americas	16'004	4'103	308	0	10'105
Asia & Pacific	26'204	23'245	32'483	4'225	22'304
China	44'847	70'120	71'996	98'546	66'434

conversion from tons of Polysilicon to MW power with 3910 kg per MW PV power capacity

IEA PVPS Report T12-19:2020, based on IHS Markit Report 2019

Methodology and Database

- **Methodology protocol**
  IEA PVPS Task 12 Methodology guidelines, 4th edition (IEA PVPS Report T12-04)
- **System model**
  Attributional LCI
- **Allocation**
  - Multifunctional processes: economic relationships
  - Recycling: recycled content approach
- **Background data**
  UVEK LCI data DQRv2:2018
- **LCA software**
  SimaPro v9.1

Environmental Footprint PV: Environmental Indicators

Selection of indicators from Life Cycle Impact Assessment Method "Environmental Footprint v3":

- **Climate change:**
  Greenhouse gas emissions, kg CO_2-eq;
  IPCC (2013)
- **Resource use, minerals and metals:**
  Abiotic depletion potential (ADP, ultimate reserves), kg Sb-eq;
  CML 2002 (Guinée et al. 2001) and (van Oers et al. 2002)
- **Resource use, fossils:**
  Abiotic resource depletion – fossil fuels (ADP-fossil), MJ, CML 2002;
  (Guinée et al. 2001) and (van Oers et al. 2002)
- **Acidification:**
  Accumulated Exceedance (AE), mol H^+-eq;
  (Posch et al. 2008; Seppälä et al. 2006)
- **Particulate matter:**
  Impact on human health, disease incidence;
  (Fantke et al. 2016)
- **Water use:**
  User deprivation potential (deprivation-weighted water consumption); m^3 water-eq;
  Boulay et al. (2017)

Scope of the Update 2020 of LCI Report T12-04:2015

- **Crystalline Silicon (mono-Si, multi-Si)**
  - Market situation supply chains
  - Electricity consumption manufacturing, wafer thickness, kerf loss, further material losses
  - Panel efficiency
  - Main information sources: NREL 2019, IEA-PVPS 2019, VDMA 2020 (ITRPV)
- **CdTe**
  - Manufacturing efforts and emissions
  - Panel efficiency
  - Main information source: Industry data FirstSolar, module series 4 and 6
- **Inverter**
- **End of Life treatment/recycling**
- **water consumption in the supply chains**

Main References

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- Fraunhofer ISE, Photovoltaics Report (16 September 2020), Freiburg, Germany, 2020
- Frischknecht R., Stolz P., Krebs L., de Wild-Scholten M., Sinha P. and Raugei M. (2020) Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems, Report T12-19:2020. International Energy Agency, IEA, Paris.
- Frischknecht R., Stolz P., Heath G., Raugei M., Sinha P. and de Wild-Scholten M. (2020) Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity, 4th edition, IEA-PVPS T12-18:2020. International Energy Agency, IEA, Paris.
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- G. Masson and I. Kaizuka, Trends in Photovoltaic Applications 2019, IEA PVPS Task 1, Report T1-36:2019, 2019
- VDMA, International Technology Roadmap for Photovoltaic (ITRPV) - 2019 Results, Vol. Eleventh Edition, VDMA Photovoltaic equipment, 2020
- M. Woodhouse, B. Smith, A. Ramdas, and R. Margolis, Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing: 1H 2018 Benchmark and Cost Reduction Road Map, NREL, Golden, CO, USA, 2019

What is PVPS Task 12 – PV Sustainability

The goal of Task 12 is to foster international collaboration and knowledge creation in PV environmental sustainability and safety, as crucial elements for the sustainable growth of PV as a major contributor to global energy supply and emission reductions of the member countries and the world. In doing so, Task 12 aims to facilitate a common understanding of PV Sustainability, with a focus on Environment Health and Safety (EH&S), among the various country-members and disseminate the Task's outcomes and knowledge to stakeholders, energy and environmental policy decision makers, and the general public.

Task 12 is operated jointly by the National Renewable Energy Laboratory (NREL) and University of New South Wales (UNSW). Support from the United States' Department of Energy (DOE) and the Australian University of New South Wales (UNSW) are gratefully acknowledged.

Task 12 Subtasks

- End of Life of PV systems
- Environmental Life Cycle Assessment (LCA)
- Other PV sustainability topics

Task 12 Operating agents

- Garvin Heath, NREL, USA
- Jose Bilbao, UNSW, Australia

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PVPS Task 12 Reports

- T12-19:2020: Frischknecht R., Stolz P., Krebs L., de Wild-Scholten M., Sinha P. and Raugei M. (2020) Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems, IEA-PVPS Task 12, Report T12-19:2020. International Energy Agency, IEA, Paris.
- T12-18:2020: Frischknecht R., Stolz P., Heath G., Raugei M., Sinha P. and de Wild-Scholten M. (2020) Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity, 4th edition, IEA-PVPS Task 12, Report IEA-PVPS T12-18:2020. International Energy Agency, IEA, Paris.
- T12-17:2020: Krebs L., Frischknecht R., Stolz P., Heath G., Komoto K., Sinha P. and Wade A. (2020) Environmental Life Cycle Assessment of residential PV and battery storage system. IEA-PVPS Task 12, Report IEA-PVPS T12-17:2020, International Energy Agency, IEA, Paris.
- T12-16:2020: Sinha P., Heath G., Wade A., Komoto K. (2020) Human Health Risk Assessment, Part 3: Module Disposal Risks, PVPS Task 12, Report T12-16:2020, International Energy Agency, IEA, Paris.
- T12-15:2019: Sinha P., Heath G., Wade A., Komoto K. (2019) Human Health Risk Assessment, Part 2: Breakage Risks, PVPS Task 12, Report T12-15:2019, International Energy Agency, IEA, Paris.
- T12-14:2018: Sinha P., Heath G., Wade A., Komoto K. (2018) Human Health Risk Assessment, Part 1: Fire Risks, PVPS Task 12, Report T12-14:2018, International Energy Agency, IEA, Paris.
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- see https://iea-pvps.org/research-tasks/pv-sustainability/ for further publications of IEA PVPS Task 12

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