



Task 12 PV Sustainability

PVPS

# Life Cycle Inventories of Photovoltaic Systems

## 2026



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The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The Technology Collaboration Programme (TCP) was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of 6.000 experts across government, academia, and industry dedicated to advancing common research and the application of specific energy technologies.

The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the TCPs within the IEA and was established in 1993. The mission of the programme is to “enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems.” To achieve this, the Programme’s participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct ‘Tasks,’ that may be research projects or activity areas.

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## What is IEA PVPS Task 12?

The goal of Task 12 is to foster international cooperation and knowledge sharing on the sustainable aspects of PV technology, emphasizing environmental and social factors. Its mission is to provide essential information to stakeholders, enhancing consumer and policy-maker confidence in PV systems, and thereby accelerating the shift towards sustainable energy. The objectives of Task 12 are to: (1) Quantify PV electricity’s environmental profile to enhance supply chain sustainability and enable comparisons with other energy technologies. (2) Enhance PV technology and materials circularity through novel analysis, legislative tracking, and technical standards development. (3) Investigate synergies between PV system deployment and its environmental and ecosystem impacts. (4) Identify and tackle both real and perceived social and socio-economic challenges to PV market growth. (5) Share analytical findings with technical experts, policymakers, and the public.

Task 12 is operated jointly by the National Laboratory of the Rockies (NLR) and TotalEnergies. Support from the U.S. Department of Energy and TotalEnergies is gratefully acknowledged.

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Götz, M., Deuber, R., Gazbour, N., Brailovsky, P.H., Nold, S., Marchand-Lasserre, M., Frischknecht, R., Khan, A.A., Bovo, G. Stucki, M. (2026). Heath, G. (Ed.), *Life Cycle Inventories of Photovoltaic Systems* (Report No. T12-33:2026). IEA PVPS Task 12, <https://iea-pvps.org/key-topics/t12-lci-pv-systems-2026/> DOI: 10.69766/WJTE1771

### COVER PICTURE

Credits: JA Solar

INTERNATIONAL ENERGY AGENCY  
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

# **Life Cycle Inventories of Photovoltaic Systems**

## **IEA PVPS Task 12 PV Sustainability**

Report IEA-PVPS T12-33:2026  
July 2026

ISBN: 978-1-923734-08-1  
DOI: 10.69766/WJTE1771

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## Previous version

Frischknecht, R., Stolz, P., Krebs, L., De Wild-Scholten, M., & Sinha, P. (2020). Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems (IEA-PVPS T12-19:2020; IEA PVPS Task 12 Report). International Energy Agency (IEA) PVPS Task 12. <https://iea-pvps.org/wp-content/uploads/2020/12/IEA-PVPS-LCI-report-2020.pdf>



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## ACKNOWLEDGEMENT

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This report received valuable contributions from several IEA-PVPS Task 12 members and other international experts. Funding support from the Swiss Federal Office of Energy is gratefully acknowledged (SFOE contract SI/502610-01). The integration of bottom-up process based LCI in Chapter 4 was partly funded by the Federal Ministry for Economic Affairs and Climate Action of Germany (BMWK) within the project “OekodesignPV” (contract 03EE1218).

The authors thank all the providers of primary inventory data including Marie Sauze and Jérémie Schuhmann from ADEME, Raphael Joliviet from MINES ParisTech, First Solar Inc., two anonymised inverter manufacturers, and Andrea Danelli from RSE for material data on a inverters and trackers. Valuable support provided by Maya Ezzeddine from Schneider Electric is greatly acknowledged.

The LCI data and report was reviewed and approved by the experts from the IEA PVPS Task 12. It was finalized based on valuable feedback from Garvin Heath (NLR), Karen Drozdiak (First Solar), Pierpaolo Girardi (RSE), Saeed Rahimpour (VITO), Rachel Woods-Robinson (University of Washington), and Moonyong Kim (University of New South Wales).

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## LIST OF ABBREVIATIONS

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APAC	Asia and Pacific
BOS	Balance of system
BOM	Bill of materials
CdTe	Cadmium telluride
CEA	Commissariat à l'énergie atomique et aux énergies alternatives
Cl(G)S	Copper indium (gallium) selenide
CH	Switzerland
CH <sub>3</sub> NH <sub>3</sub> I	Methylammonium iodide
CN	China
c-Si	Crystalline silicon
CO <sub>2</sub>	Carbon dioxide
CPV	Concentrating photovoltaics
DE	Germany
ENTSO	European Network of Transmission Systems Operators for Electricity
EPD	Environmental Product Declaration
GLO	Global
Hg	Mercury
IEA	International Energy Agency
KR	Korea
kW	Kilowatt
kWp	Kilowatt peak
LCA	Life cycle assessment
LCI	Life cycle inventory
Li-ion	Lithium ion
LPCVD	Low-pressure chemical vapor deposition
mc-Si	Multi-crystalline silicon
MG	Metallurgical grade
MW	Megawatt
MY	Malaysia
NO	Norway
NO <sub>x</sub>	Nitrogen oxides



NORDEL	Nordic Countries Power Association
O <sub>3</sub>	Ozone
OCE	Oceanic
Pb	Lead
PbI <sub>2</sub>	Lead iodide
PECVD	Plasma-enhanced chemical vapor deposition
PERC	Passivated emitter and rear cell
PM	Particulate matter
PV	Photovoltaics
RAS	Asia
RER	Europe (continental)
c-Si	crystalline silicon
Si	Silicon
SiH <sub>4</sub>	Silane
SiHCl <sub>3</sub>	Trichlorosilane
SO <sub>2</sub>	Sulphur dioxide
TOPCon	Tunnel Oxide Passivated Contact
US	United States of America
VTD	Vapor transport deposition
W	Watt



## EXECUTIVE SUMMARY

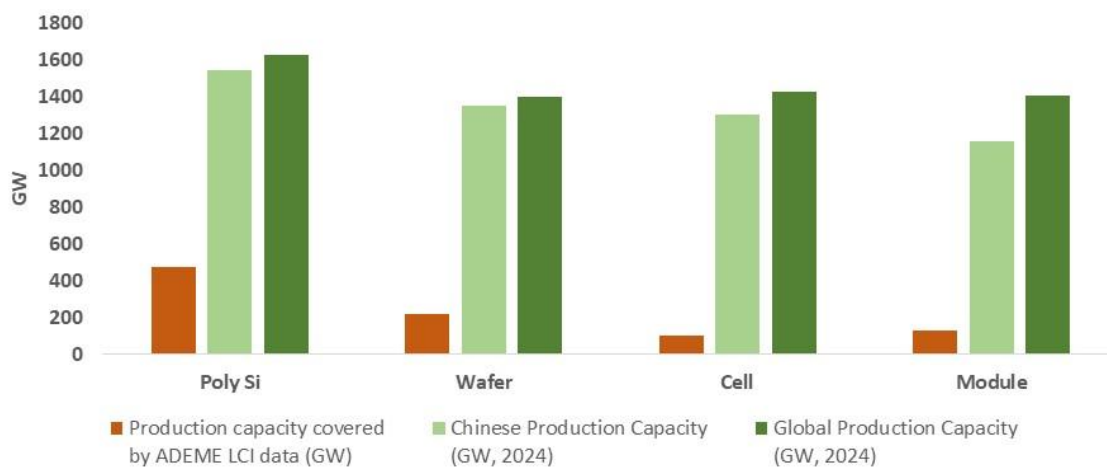
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Life cycle assessment (LCA) is a structured method for quantifying material and energy flows, emissions, resource use, and associated environmental impacts over the life cycle of products and services. In photovoltaic (PV) systems, robust life cycle inventories (LCIs) are a prerequisite for credible LCA results and are often the main barrier to consistent, transparent, and comparable environmental assessments. One of the core objectives of the International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS) Task 12 (PV Sustainability) is therefore to provide internationally reviewed LCI data for PV technologies and system components, supporting consistent LCA of PV electricity generation across technologies, regions, and applications.

This report updates and expands the previous IEA PVPS Task 12 LCI report published in 2020. It provides updated LCI datasets for selected monocrystalline silicon PV supply chains, including PERC and TOPCon cell technologies, thin-film cadmium telluride (CdTe) PV modules, selected string inverters, and country-specific PV mixes. It also includes LCIs for balance-of-system components, PV module recycling, reference residential, commercial, and utility-scale PV systems, and PV installations. Some datasets from previous editions are retained without substantial update, including multi-crystalline silicon PV, CI(G)S modules, perovskite–silicon tandem PV, Li-ion battery storage, selected mounting structures, and medium-large PV installations in Europe. Users should therefore verify the reference year and update status of each dataset before using the data in comparative LCA studies. Updated LCI data tables are provided in sections 3 and 4, with electronic versions available at IEA PVPS (<https://iea-pvps.org/research-tasks/pv-sustainability>) and ZHAW (<https://doi.org/10.21256/zhaw-2586>).

This edition represents a substantial update of the IEA PVPS Task 12 LCI report series. The update is particularly significant for the monocrystalline silicon supply chain, where LCI data are based on a large set of LCAs collected in the context of the French PV tender process operated by ADEME between 2022 and 2025. In total, after screening, consistency checks, and exclusion of datasets that were non-coherent or insufficiently representative, 83 LCAs of different factories producing different PV supply chain components across the PV value chain were retained for the final aggregation. These data cover key supply chain stages from polysilicon, ingot and brick production to wafer, cell, laminate, and module manufacturing. The resulting datasets are aggregated and anonymised to protect confidential company information while enabling public use in LCA.

The market coverage of the updated monocrystalline silicon industry data is high for public PV LCI datasets. Relative to global production capacity, the 83 datasets obtained from ADEME represent approximately 29% of polysilicon production capacity, 16% of wafer production capacity, 7% of cell production capacity, and 9% of module production capacity (see Figure 1).



**Figure 1: Production capacity covered by industry data from French tenders compared against the Chinese and global c-Si production capacity [1; 2]**

The CdTe module datasets were updated using LCI data provided by First Solar and replace the CdTe datasets included in the 2020 report. Because First Solar accounts for more than 90% of global CdTe module production, these datasets can be considered highly representative of the current CdTe PV market.

The quality assurance process differs by dataset type. The monocrystalline silicon datasets benefit from the extensive ADEME/CERTISOLIS/Mines Paris–PSL/CEA workflow described below and from aggregation across many company LCAs. The CdTe dataset is based on primary manufacturer data from the dominant global CdTe producer and were reviewed in the Task 12 process. The inverter and tracker datasets draw on primary or component-level data from selected manufacturers and contributors but should not be interpreted as full market-average datasets.

The LCI presented in this report followed a multi-step quality assurance process behind the updated datasets. For the monocrystalline silicon supply chain, the underlying LCAs were first developed within the French PV tender framework, which requires documented production data, process descriptions, material and energy flows, allocation assumptions, and supporting evidence. CERTISOLIS performed technical and administrative verification of submitted dossiers, including consistency checks of supporting documentation. ADEME then provided the final attestation required for the French tender process; on-site audits on a random subsample of submissions were also conducted to verify procurement flows, manufacturing operations, and supporting records. For the public Task 12 datasets, further data control and aggregation were performed by Mines Paris–PSL, while CEA and CERTISOLIS contributed expert review, analysis, anonymization, and consistency checks. The full report and datasets were then reviewed and approved by IEA PVPS Task 12 experts and revised based on comments from international reviewers from research organisations, industry, and public institutions.

This report also introduces a new category of Task 12 LCI data: detailed LCI data based on bottom-up simulations. These datasets, developed by Fraunhofer ISE, represent simulated monocrystalline silicon PERC and TOPCon production for 2024–2025 and include detailed modelling of advanced manufacturing processes, production infrastructure, water management, and waste treatment as validated by industry. They are not equivalent to the industry-average datasets derived from measured production data. Instead, they provide complementary inventories for analysing advanced or leading-edge manufacturing scenarios, process optimisation, and prospective technology development. Users should explicitly state whether they use industry-representative measured data or data from bottom-up simulation.

Several caveats are important for correct interpretation. First, the monocrystalline silicon industry data originate from the French tender system, where carbon performance is an explicit criterion. The underlying datasets may therefore be biased toward lower-carbon supply chains compared with the full global PV market. Second, the data are not all representative of the same year. The monocrystalline silicon data mainly cover 2022–2025, CdTe data



cover production years up to 2023, and several not updated datasets originate from older report editions. Third, continuous improvements in PV manufacturing efficiency, material utilisation, energy efficiency, and carbon performance mean that some data may already be conservative relative to the best products currently entering the market.

The main uncertainties in the LCI datasets arise from five sources: variability in manufacturing routes and plant-level performance; regional electricity mixes and upstream supply-chain assumptions; differences in reference years across technologies and components; and incomplete market coverage for BOS components and older technologies. Additional uncertainty arises from assumptions on recycled silicon shares, closed-loop silicon scrap treatment, wafer thickness, kerf losses, cell efficiencies, and module formats. These uncertainties do not undermine the usefulness of the datasets, but they define their appropriate use: the industry-representative measured LCIs are well suited as generic background data, screening datasets, and harmonised reference inventories. For comparative LCAs of specific manufacturers, product lines, or procurement decisions, specific foreground data should be used wherever available.

### Key messages

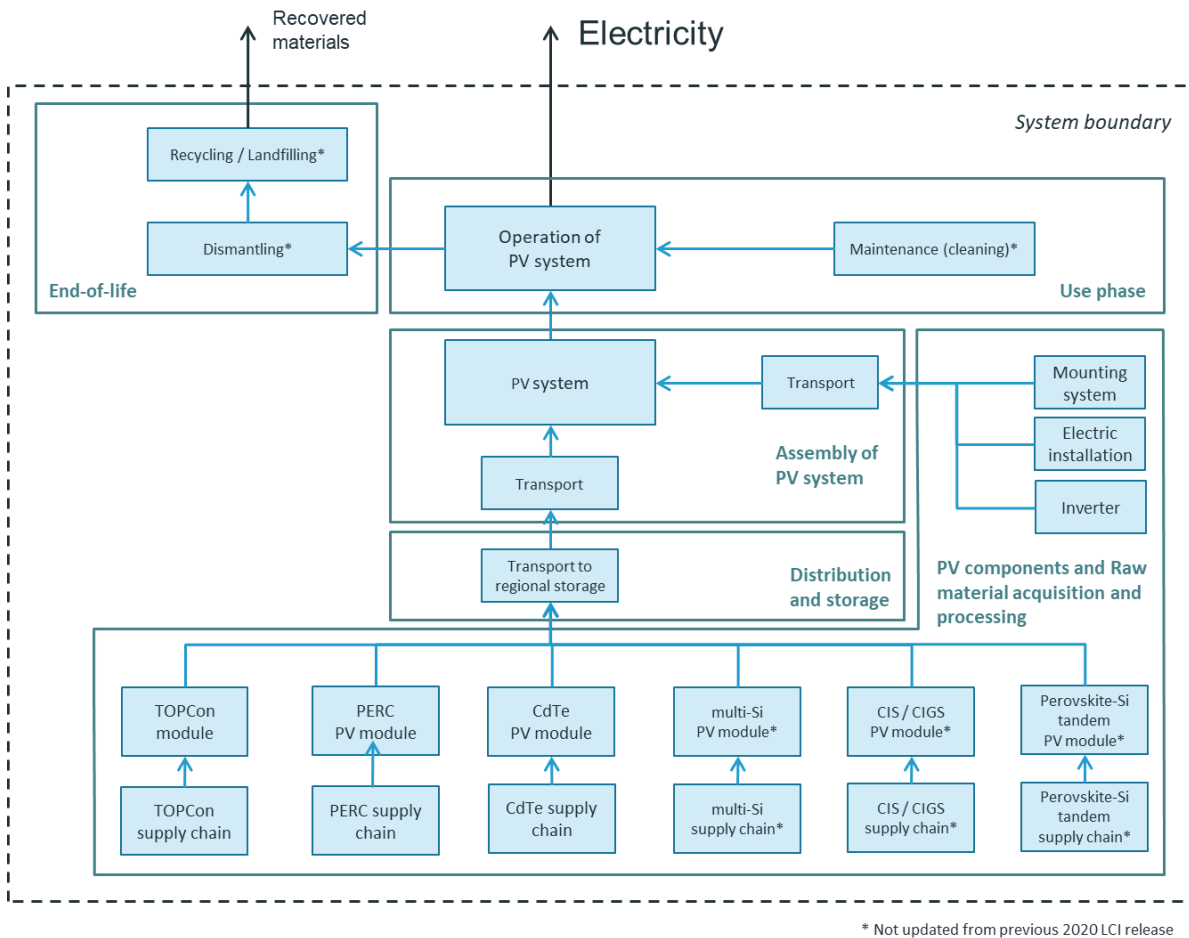
- **This is the most comprehensive IEA PVPS Task 12 LCI update in more than a decade.** The monocrystalline silicon supply chain update for TOPCon cell technology is based on 83 screened LCAs of different components from the French PV tender process and provides unusually high market coverage for public PV LCI data, including approximately 29% of global polysilicon, 16% of global wafer, 7% of global cell, and 9% of global module production capacity. CdTe data are based on primary data from the dominant global CdTe producer, representing more than 90% of the CdTe module market. Additionally, new LCI data on string inverters have been added.
- **The updated datasets have undergone a robust, multi-step quality assurance process.** For instance, the monocrystalline silicon, the data passed through French tender LCA documentation requirements, CERTISOLIS verification, ADEME attestation, expert aggregation and anonymisation by Mines Paris–PSL, CEA and CERTISOLIS, and final IEA PVPS Task 12 expert review.
- **Users must distinguish between dataset types.** This report includes industry-representative measured LCI data, selected product-line industry data (CdTe modules), retained datasets from earlier report editions, generic BOS component inventories, and—for the first time—industry-validated, modelled LCI data for advanced monocrystalline silicon manufacturing. These categories have different appropriate uses and should not be treated as interchangeable.
- **Representativeness is strong but not uniform.** The monocrystalline silicon and CdTe datasets have high credibility and strong market relevance, while BOS datasets and older technology datasets should be used more cautiously as generic inventories. For manufacturer-specific comparative LCA, specific foreground data remain necessary.



# 1 INTRODUCTION

Life Cycle Assessment (LCA) enables consideration of all life cycle stages, from cradle to grave, in quantifying environmental impacts and resource consumption of products or services. There has been continuous and remarkable progress in photovoltaic (PV) technologies during the last decades as governments and the industry stepped up investments in solar energy. Economies of scale and improvements in material utilization and process and module efficiencies have contributed to substantial reductions in production costs and to reduced environmental impacts per unit of electricity generated. In this report, we present life cycle inventory data (LCI) of commercial PV technologies that are the basis for LCA of PV electricity. This report provides updated data of selected monocrystalline silicon (Si) and cadmium telluride (CdTe) PV technologies, along with additional not or only partially updated inventory data on balance-of-system (BOS) components and recycling. Inventory data of multi-crystalline silicon (Si), copper indium gallium selenide (CIGS/CIS), and perovskite–silicon tandem PV technologies were updated in earlier reports but not in this one. For additional information, refer to the annex.

The life cycle of PV systems comprises raw material extraction, manufacturing of PV cells, modules and BOS components, transport, system installation and operation, and end-of-life treatment, including disposal or recycling (Figure 1). All processes of PV systems can be combined to a full LCI model that delivers impact assessment results following the LCA methodology guideline of Task 12 [3].



**Figure 2: Product system of PV electricity production, adapted from TS PEF Pilot PV [4]**

The mining of raw materials, for example, quartz sand for crystalline silicon PV technologies, is followed by further processing and purification stages, to achieve the required high purities. The silica in the quartz sand is reduced in



an arc furnace to metallurgical-grade silicon, which must be purified further into solar grade silicon. There is no single globally harmonised definition of solar-grade polysilicon or its required purity. The most widely referenced industry specification, SEMI PV17-1012 (Reapproved 2019), defines four grades of virgin silicon feedstock based on element-specific impurity limits covering electron acceptors (B, Al), electron donors (P, As, Sb), transition metals (Ti, Cr, Fe, Ni, Cu, Zn, Mo), alkali and earth alkali metals (Na, K, Ca), and atmospheric elements (H, C, O, Cl) [5]. In commercial practice, solar-grade polysilicon for n-type monocrystalline silicon production is supplied in a near-intrinsic, essentially undoped state, enabling precise phosphorus doping during the Czochralski pulling process to achieve the target n-type wafer resistivity of 1–3  $\Omega\cdot\text{cm}$  required for TOPCon cell architectures [6]. This purification is predominantly performed using the modified Siemens process, while fluidized bed reactor (FBR) technology has gained increasing usage as a potentially more energy- and cost-efficient alternative. Cadmium and tellurium used in CdTe PV are primarily obtained as byproducts of zinc and copper production, respectively, and require additional purification to reach solar-grade purity ( $\geq 99.9999\%$ ) [7]. Similarly, the metals used in CIGS PV are sourced from byproducts, with indium derived from zinc smelting, gallium recovered primarily as a byproduct of bauxite processing, and selenium mainly recovered from copper production [8; 9].

The raw materials considered also include those required for encapsulation such as silica for glass and aluminium for frames, and BOS components such as copper ore for cables, as well as iron and zinc ores for mounting structures. After polysilicon refining, the manufacture of a crystalline silicon PV device is typically divided into four main stages: ingot, wafer, cell, and module production. Cylindric solar-grade monocrystalline silicon ingots are commonly grown using the advanced processes of Czochralski (Cz) method, and in the wafer stage, ingots are squared, cut into blocks and sliced into wafers with a thickness typically between 110  $\mu\text{m}$  and 150  $\mu\text{m}$ . During the cell stage, a p–n junction is formed through dopant diffusion or via direct deposition of doped layers, the surfaces of the wafers are deposited with passivation layers, and the electrical contacts are created by applying and sintering metallization pastes. In the module stage, individual cells are electrically interconnected and subsequently encapsulated using polymeric materials and glass.

The manufacturing stage for thin-film PV technologies (of which CdTe has greatest market share but also includes CIGS) is generally less material-intensive and involves fewer discrete processing steps. It typically involves the deposition of semiconductor layers, followed by cell definition and module fabrication steps such as encapsulation, which are similar to those used for silicon PV modules.

During the PV system installation stage, support structures are erected, PV modules are mounted, and electrical components, including cables, power conditioning units and, where applicable, energy storage systems, are integrated. At the end of their service life, PV systems are decommissioned, with valuable components and materials potentially recovered through treatment and recycling or are appropriately disposed.

Methodology guidelines for conducting LCAs and net energy analyses of PV systems have been developed by IEA PVPS Task 12 [3; 10]. Life cycle impact category indicators include climate change, primary energy demand, water scarcity, land-use impacts on biodiversity, and abiotic resource depletion. In the interpretation phase of a LCA, system-level energy payback time, and energy return on investment are often applied. Most life cycle impact category indicators are aligned with methods used in the EU Product Environmental Footprint (PEF) framework [4].

The life cycle inventories presented in this report update or incorporate those last published in 2020:

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

The datasets provided in this report are fully compatible with the recently published open-source database BAFU:2025 [11]. BAFU:2025 is the Swiss Federal Administration Life Cycle Inventory database coordinated and published by the Swiss Federal Office for the Environment (BAFU/FOEN). The database provides open and freely accessible life cycle inventory data for use in life cycle assessment (LCA) and environmental product information. It includes many datasets across relevant economic sectors, including energy, mobility, construction, materials,



chemicals, agriculture, food and consumer goods. BAFU:2025 is designed to improve the transparency, consistency and accessibility of environmental background data and can be used with established LCA software environments.

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*Updated data tables are provided here with electronic versions available at IEA PVPS (<https://iea-pvps.org/research-tasks/pv-sustainability>) and the Zurich University of Applied Sciences <https://doi.org/10.21256/zhaw-2586>*

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## 2 LIFE CYCLE INVENTORIES

The life cycle inventory (LCI) phase of an LCA involves the compilation of data on material and energy inputs, as well as emissions and product outputs, across the complete life cycle of the system under study. For PV systems, these data are collected or modelled separately for the PV modules and the balance-of-system (BOS) components.

### 2.1 PV modules

For the current LCI update, the life cycle inventory data of the monocrystalline silicon (mono-c-Si) PV module supply chain are largely based on data collected within the French PV tender process operated by ADEME (French Agency for Ecological Transition) over the period 2022–2025 which represents approximately 29 % for polysilicon, 16 % for wafer, 7 % for cell and 9 % for module production capacities compared to the global production capacities (see Figure 3).

These data were provided to IEA PVPS Task 12 in horizontally aggregated and anonymized form. In addition, for the first time, this report includes simulation-based data from Fraunhofer ISE (Fraunhofer Institute for Solar Energy Systems) representing an optimized and integrated c-Si module manufacturing process, including minimized liquid discharge and waste valorisation [12]. These inventories are included as complementary and parallel datasets to the IEA PVPS Task 12 inventories derived from industry- and market-based data. The life cycle inventory of thin-film cadmium telluride (CdTe) PV modules was updated using LCI data provided by First Solar, the manufacturer accounting for > 90 % of global CdTe module production [13]. Average technology-specific module efficiency values were taken from the ITRPV Report [14]. The supply chain life cycle inventories of other PV module technologies included in previous versions of this report, namely multi-Si, CIGS, and perovskite–silicon tandem PV, were not updated in the present revision, as these technologies do not represent relevant shares of the current global PV market or are no longer being produced. Information and life cycle inventory data on these PV technologies are provided in Annex and in previous reports [15].

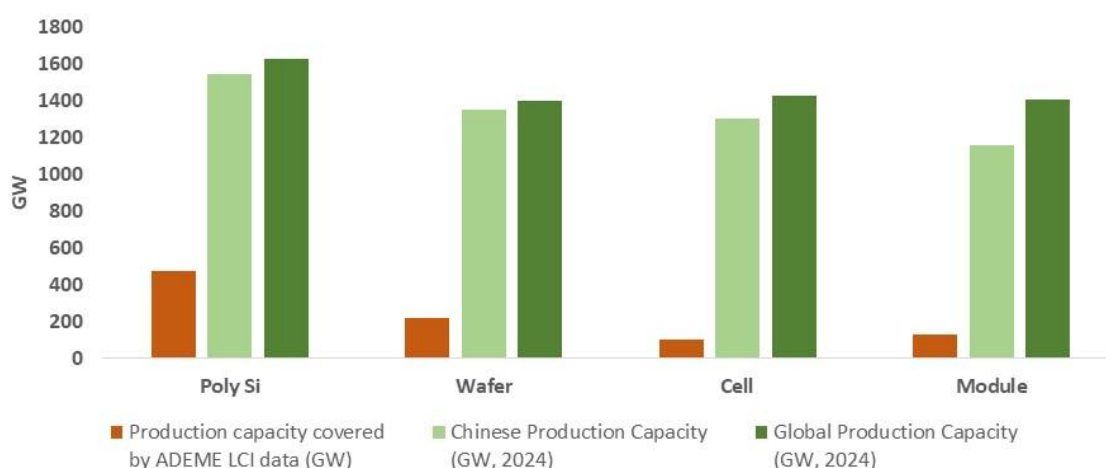


Figure 3: Production capacity covered by industry data from French tenders compared against the Chinese and global c-Si production capacity [1; 2]



### 2.1.1 Monocrystalline–Si PV – industry data

The LCI data provided in this report encompass the entire c-Si production pathway, from raw material extraction to c-Si module manufacturing. At the upstream stage of the PV supply chain, high-purity quartz is processed to metallurgical-grade silicon (~98–99 % purity) and subsequently purified to solar-grade polysilicon, with purity defined by element-specific impurity limits as specified in SEMI PV17-1012 [5]. This purification step is predominantly based on trichlorosilane-based modified Siemens processes. Silane-based fluidised bed reactor (FBR) routes, which produce granular polysilicon, accounted for approximately 10 % of total global polysilicon production volume in 2024, with GCL Technology as the sole remaining significant FBR producer following the shutdown of REC Silicon's US FBR operations in early 2025 [14; 16; 17].

In the trichlorosilane ( $\text{SiHCl}_3$ )–based modified Siemens process, high-purity polysilicon is deposited from the gas phase onto electrically heated silicon seed rods at temperatures typically in the range of 1050°C–1150 °C. The less widely applied FBR method produces solar-grade polysilicon through the thermal decomposition of silane ( $\text{SiH}_4$ ) in a fluidized bed of silicon seed particles. In this process, fine silicon granules are suspended in an upward gas flow at moderate temperatures of approximately 600°C–700 °C, where silane decomposes and deposits additional silicon onto the moving particles. The continuous operation enables steady growth of granular polysilicon and generally lower specific energy demand compared to the Siemens process, as no electrically heated polysilicon rods and lower reactor temperatures are required.

The resulting polysilicon is subsequently crushed, melted and crystallised into monocrystalline ingots using the Recharged Czochralski (RCz) process, which is widely applied today. RCz is a semi-continuous variant in which additional polysilicon is periodically recharged into the crucible between growth cycles, increasing throughput and reducing production costs and energy consumption compared with conventional Czochralski (Cz) processing [14].

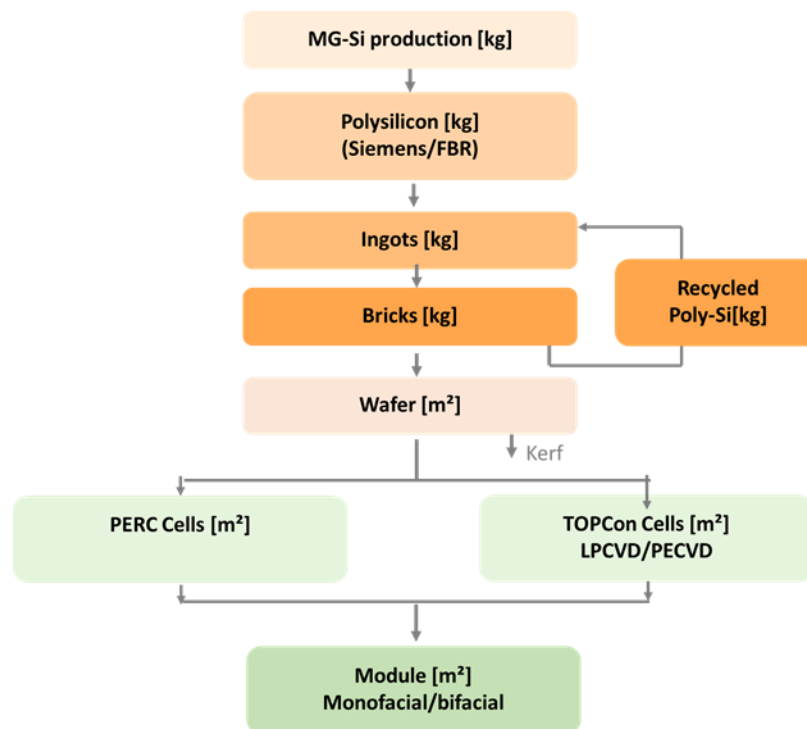
The ingots are then cropped (top and tails cutting), squared, and sliced into bricks., which are sliced into thin wafers for subsequent solar cell manufacturing. The cropping and squaring of silicon ingots into bricks, generate silicon scrap that can be recycled in a closed loop through reintegration into new ingots. Historically, the recycled silicon content was limited because boron gallium doped P type ingots exhibit a highly variable segregation coefficient, leading to significant resistivity variations along the crystal when recycled feedstock containing residual dopants and impurities was added. With the transition toward n-type technologies and the use of more stable dopants such as phosphorus (P) and antimony (Sb), resistivity control has become more consistent, enabling manufacturers to significantly increase the recycled silicon rate while precisely adjusting the final dopant concentration to meet target wafer specifications [18]. The reintegration of recycled silicon from ingot cropping and squaring does not require an energy-intensive recycling process since the silicon has already been purified to solar-grade quality; the material generally undergoes only crushing and light cleaning before being directly reintroduced into the crystal growth process. In parallel, wafer slicing technologies have significantly evolved, with kerf loss continuously decreasing due to ultra-thin diamond wire sawing; according to the ITRPV [14], kerf loss has been around 50  $\mu\text{m}$  in 2024. Current diamond wires are mainly based on traditional high-carbon steel cores coated with nickel and diamond particles, but the industry is increasingly moving toward tungsten-core diamond wires, which offer superior mechanical strength and allow further reductions in wire diameter and silicon losses. On the other hand, kerf loss itself is still only marginally recycled back into the PV silicon value chain because the purity level after sawing is generally not sufficient for direct reintegration into polysilicon or crystal growth processes without additional purification steps [19].

Following wafer production, silicon wafers are processed into solar cells through a sequence of surface chemical cleaning and texturing, dopant diffusion or tunnelling junction formation, passivation, and metallisation steps, resulting in electrically active cells. The specific chemical treatments and process sequence strongly depend on the cell technology adopted (e.g., PERC, TOPCon, HJT or back-contact), as well as on the different industrial process routes implemented within the same technology platform. PERC (Passivated Emitter and Rear Cell) technology, based on rear-side passivation to improve light capture and reduce recombination losses, dominated the PV market for several years due to its relatively low manufacturing cost and compatibility with existing production lines. However, the industry is now rapidly shifting toward TOPCon (Tunnel Oxide Passivated Contact) technology, which



uses an ultra-thin tunnel oxide layer and doped polysilicon passivated contacts to achieve higher conversion efficiencies and better performance, particularly for n-type wafers [14]. Within TOPCon manufacturing, different deposition routes are used for the polysilicon passivated contact layer: LPCVD (Low-Pressure Chemical Vapor Deposition) generally relies on high-temperature silane-based deposition chemistry [20], while PECVD (Plasma-Enhanced Chemical Vapor Deposition) uses plasma-assisted reactions with silane and hydrogen-containing precursor gases at lower temperatures, resulting in different energy consumption, gas usage, and film properties [21].

The finished cells are cut into half-cells, third-cells or shingle cells using infrared or near-infrared laser scribing followed by mechanical cleaving. The cut cells are then electrically interconnected, most commonly using multi-busbar or wire-based interconnection technologies, and assembled into strings. These strings are laid up with encapsulation materials and front and rear cover materials to form a module stack. Module encapsulation typically involves either a glass–foil or glass–glass configuration, with polymer encapsulants and a backsheet or rear glass, respectively. The module stack is subsequently laminated under vacuum and a temperature around 150°C - 200°C to ensure mechanical stability and electrical insulation. Depending on the design, modules may be equipped with a conventional aluminium perimeter frame or manufactured without a continuous frame, relying instead on glass-edge protection and integrated mounting solutions. Final assembly steps include junction box attachment, curing, and electrical and mechanical quality control prior to shipment. Figure 4 provides an overview on the process steps of the crystalline silicon PV supply chain covered in this report.



**Figure 4: Overview of the crystalline PV module production process steps covered in this report**

Crystalline silicon-based PV modules have become increasingly heterogeneous in recent years due to the diversification of wafer formats and cell technologies available on the market. The following specifications are selected in view of a market representative average technology. The most common wafer formats currently in use are M10 (182 mm × 182 mm) and G12 (210 mm × 210 mm). Commercially manufactured modules are typically composed of 108, 120, or 144 half-cut M10 cells, resulting in module areas of approximately 2.0 m<sup>2</sup>, 2.2 m<sup>2</sup>, and 2.6 m<sup>2</sup>, respectively. To account for this variability, life cycle inventory data of the wafer, cell, and module stages, including both framed and frameless modules, are normalised per unit area (m<sup>2</sup>).

The life cycle inventory models presented in this report are based on aggregated data from multiple manufacturers across the PV supply chain participating in the French solar tenders. For mono-c-Si PV modules, the inventory



models include distinct datasets representing selective product lines of TOPCon and PERC cell technologies, framed and frameless module designs, as well as glass–backsheet and glass–glass module configurations. The average conversion efficiencies assumed in this report are 21.7 % for p-type PERC and 23.2 % for n-type TOPCon modules [7], which are representative of year 2024.

TOPCon-specific processes, including polysilicon, ingot, brick, wafer, cell, and module production, were updated based on aggregated and anonymized industry data collected from LCAs in the context of the French PV tendering scheme. PERC-specific key parameters and processes are based on the 2020 LCI report, and were updated based on data from PV industry–specific reports [14; 22] and primary industry data provided by [23]. The inventories of multi-crystalline silicon (multi-c-Si) PV were not updated, as this technology has disappeared from the PV market in recent years.

Key parameters of the LCI of the crystalline silicon module supply chain, covering polysilicon feedstock purification, crystallization, brick cutting, wafering, cell processing, and module assembly, were updated using industry data. These data were originally collected in the context of the French photovoltaic tender process operated by ADEME and cover all relevant supply chain steps of selected PV module production lines. Data control and aggregation were performed by École des Mines de Paris, while expert review, analysing and anonymization were carried out by CEA (Commissariat à l’Energie Atomique et aux Energies Alternatives) and CERTISOLIS. The method of data collection, aggregation, and quality assurance are further detailed in the subsections below; the LCI of monocrystalline silicon LCI is presented in section 3.2 of this report.

## 2.1.2 Life cycle inventory data from French PV tender process

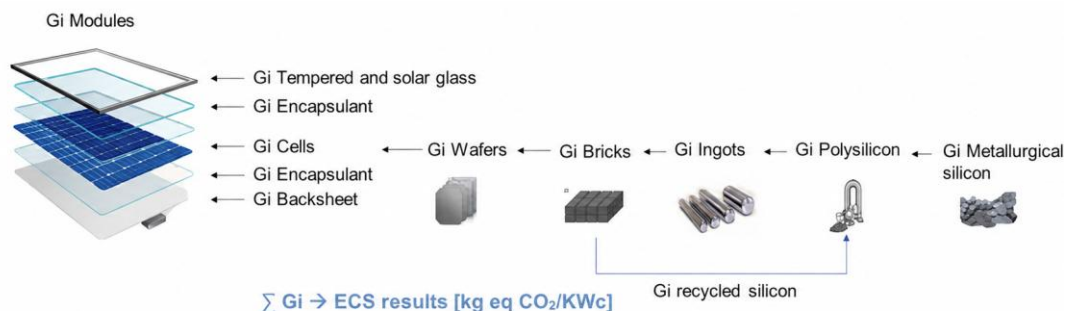
### Simplified carbon footprint methodology for public tenders in France

France introduced its first explicit carbon footprint criterion in photovoltaic tenders through the CRE2 call for tenders launched in March 2013 for PV installations above 250 kWp, including “Évaluation Carbone Simplifiée (ECS)” (Simplified Carbon Evaluation) methodology covering polysilicon, ingots, wafers, cells and module manufacturing [24]. The methodology was subsequently improved and strengthened in the CRE3 and CRE4 tenders, with a more detailed evaluation of the PV supply chain and increasing weighting of the carbon criterion in the final project scoring. A major update was then introduced in 2021 through the PPE2 framework and the “PP2 V2” carbon methodology revision, which refined the calculation rules, updated electricity mix assumptions, and expanded traceability requirements across the PV manufacturing chain. [24; 25]

The calculation relies on two main elements:

- a) The quantities of materials per component, considering module-specific parameters such as wafer thickness, module power, and module size
- b) The carbon footprint of each component, based either on default LCA values provided by CEA and published in the call of tender or on LCA-based company specific value of the component.

By “component,” we refer to the following list of components: polysilicon, ingot, brick, wafer, recycled polysilicon, cell, module, frontsheet, encapsulant, and backsheet (Figure 5). For each component of the PV supply chain, manufacturers can either provide a dedicated (LCA) for the process of the production of the specific component or use the default values defined in the French tender specifications according to the country of production. The different component-level carbon values ( $G_i$ ) are then combined using standardized loss and breakage rates defined in the methodology for each manufacturing step. These calculations also account for the technical characteristics of the module, such as efficiency, wafer format, and power output, to determine the final carbon footprint expressed in kg CO<sub>2</sub>-eq/kWp.



**Figure 5: PV module supply chain components evaluated for the ECS calculation for the French Tender (Note that Gi represents silicon in French)\_(Source: CERTISOLIS, licensed under CC BY-NC-SA 4.0)**

LCA studies are carried out by specialised consultants who collect production data from specific component factories over the preceding 12 months. The data collection period must be sufficiently representative of the plant's actual manufacturing capacity and operating conditions. The life cycle assessments are required to ensure a high level of transparency in the inventory data, including the origin of the datasets, inventory periods, and detailed descriptions of material and energy flows. Assumptions related to flow allocation and distribution must be explicitly documented, and the impact factors and associated processes used in the calculations must be clearly identified. All documents supporting the inventories must be provided. An initial critical review is then conducted to verify compliance with the LCA methodology requirements. The complete dossier is subsequently submitted to CERTISOLIS, which is responsible for technical and administrative verification of all supporting evidence and consistency checks. Once validated by CERTISOLIS, the dossier is transmitted to ADEME for final approval. The resulting ADEME attestation must accompany the application file of any candidate seeking the ECS certification required to participate in French photovoltaic calls for tenders. ADEME generally issues the attestation within approximately one to two months of submission. In addition, on-site audits may be conducted to verify the accuracy and consistency of the procurement flows, manufacturing operations, and supporting documents provided by the manufacturer.

Thanks to the implementation of the LCA framework within the French photovoltaic calls for tenders, ADEME progressively built a large database of LCAs representing different life cycle inventories (LCIs) for the various components of the PV value chain. Based on this extensive dataset, ADEME decided to develop horizontally aggregated inventories for public use for each component of the value chain.

Due to the large volume and complexity of the data, ADEME relied on the expertise of specialists in data processing and photovoltaic technologies, notably from CEA, CERTISOLIS and O.I.E. Mines Paris–PSL. Table 1 and Figure 5 provide an overview of the anonymized assessments of LCA studies and the corresponding PV supply chain components. To ensure market technologies representativeness within the LCI obtained from the French tender, only LCAs covering the 2022–2025 period were analysed. A total of 89 LCAs across the global PV value chain were initially analysed. Each LCA represents the production that took place at a specific factory over a 12-month period. Following consistency checks and the exclusion of several non-coherent or insufficiently representative datasets, the final analysis was based on 83 factory-level LCAs. These covered production at sites manufacturing different PV supply chain components, including 23 module manufacturing plants and 60 factories producing components other than modules. The approach of selection is detailed in the following section. Table 1 provides an overview of the analysed LCA studies and the corresponding PV supply chain components. The detailed screening, selection, and analysis methodology is presented in a later section. The LCAs are always covering the entire factory and its production during a 1-year period. The numbers of factories reported in Table 1 correspond to the number of LCAs conducted for each component. Out of the 83 factories assessed, 82 are located in China.



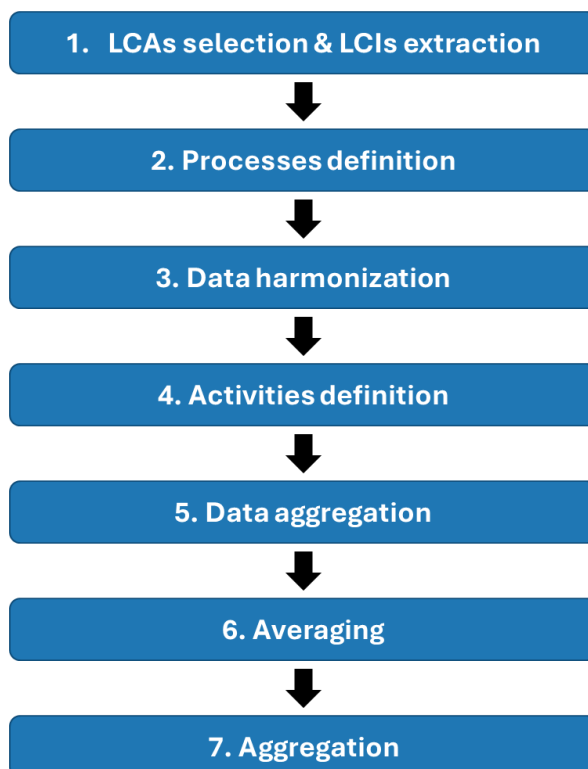
**Table 1: LCA studies conducted by CEA and CERTISOLIS on PV components used for LCI dataset modeling in this report. Column 2 indicates the number of factories analysed per component.**

Components	Factories (**)	Data collection period	Production capacity
Polysilicon Siemens	6	2023-2025	256 GW
Polysilicon FBR	5	2022-2025	236 GW
Ingots Type N	9	2022-2025	200 GW
Recycled polysilicon	10	2023-2025	213 GW
Bricks (N Type)	10	2023-2025	213 GW
Wafers (N Type)	9	2023-2025	218 GW
TOPCON LPCVD cells (*)	6	2024-2025	52 GW
TOPCON PECVD cells (*)	5	2024-2025	45 GW
Glass Glass module	12	2023-2025	82 GW
Mono Glass module	11	2023-2025	42 GW
	<b>83</b>		

(\*) Passivation process type

(\*\*) 82/83 LCAs are Chinese factories

For each component, the following five-step methodology was applied, as illustrated in Figure 6 and described in the subsequent subsections.



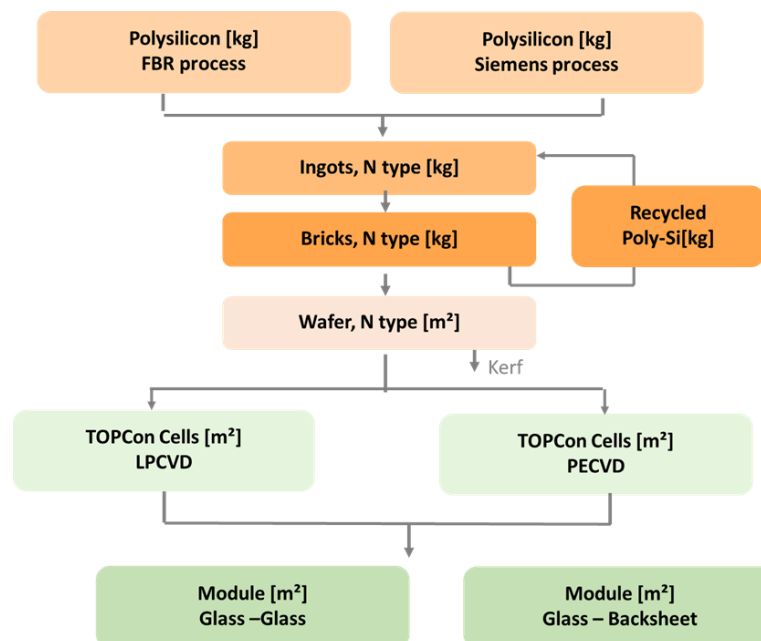
**Figure 6: Workflow for establishment of the aggregated LCI data per component**

### 1. LCAs selection and LCI extraction

This step was carried out by the CERTISOLIS team, with the authorization of ADEME, in an anonymized manner. It involved extracting 89 inventories from validated LCAs of different factories producing different PV supply chain



component and recording material inputs, energy use, packaging, infrastructure, transport, and waste flows, together with the corresponding quantities per manufacturer and per component. A first screening of the database was performed based on temporal representativeness, leading to the selection of datasets covering the 2022–2025 period to reflect recent market trends and industrial practices across the PV value chain. The data from the 89 inventories were imported into a single data structure and subsequently harmonised. Production capacities and selected flows were converted to common units. In addition, certain processes were disaggregated into technological subcategories (e.g. glass-glass versus glass-foil modules, Siemens versus FBR polysilicon) to improve the representation of production lines. A second filtering step was then conducted based on technological representativeness. The decision was to focus on n-type technologies for the ingot, wafer, and cell stages, resulting in the exclusion of datasets related to p-type production routes. Similarly, the analysis focused on TOPCon technology rather than PERC for solar cells. For modules, the selection prioritized the most representative market formats, notably 72-cell and 60-cell configurations, while ensuring consistency with the actual market distribution between monofacial and bifacial modules. Based on these criteria of choices, one important selection criterion was the technological representativeness of the production data. In several factory-level LCAs, the production volumes reported over the 12-month inventory period combined both p-type and n-type wafer production. Since the objective of the study was to focus on current market trends toward n-type technologies, the share of n-type production within each inventory was further analysed. LCAs with insufficient representativeness of n-type (<50%) production were therefore excluded from the final dataset. After this technological screening, the final database was reduced to 83 LCAs. (Figure 7)



**Figure 7: Photovoltaic supply chain process selected from the LCAs ADEME database. Several steps are disaggregated by technology: polysilicon production (Siemens/FBR processes), TOPCon cell production (LPVCD/PECVD deposition methods), and module types (glass-backsheet or bifacial glass-glass).**

## 2. Manufacturing processes definition

The definition of the manufacturing processes was carried out by CEA with experts covering the entire photovoltaic value chain. For each component and each production route, a detailed process mapping was first established to define the corresponding bill of materials (BOM) and the mandatory process steps required for manufacturing. For example, at the cell level, the different stages of chemical and thermal treatment were identified, including wafer texturing and wet chemical cleaning, dopant diffusion or tunnelling junction formation, passivation deposition, annealing, metallisation, and firing processes. For each step, the different possible chemistries, gases, and materials



used industrially were documented. Once this framework had been defined for each component, CEA experts analysed the 83 inventories from CERTISOLIS (Step 1) in a fully anonymized manner in detail by distinguishing between mandatory materials and consumables directly required for the manufacturing process and secondary materials or chemicals mainly associated with equipment cleaning, maintenance, or auxiliary operations. This structured classification was introduced to facilitate inventory completeness checks, improve harmonisation across datasets, and support the subsequent aggregation of LCIs into representative inventories for the different PV value chain components.

### 3. Data harmonisation and completion

This step was carried out through a collaboration between CEA, CERTISOLIS, and O.I.E Mines Paris PSL. Once the 83 inventories had been analysed, CEA experts performed an initial completeness and harmonisation review. Secondary data missing from the inventories were completed using zero values where appropriate, while certain missing mandatory parameters were filled using average values observed across the inventories (e.g., water consumption). After this first harmonisation step, O.I.E Mines Paris PSL team performed a preliminary aggregation and used an internal screening tool to identify unusually high variability for specific materials or flows. CERTISOLIS team then re-examined the original LCAs to verify whether these deviations resulted from inconsistencies, reporting errors, or actual industrial differences between manufacturers. When no inconsistency was identified, the value was retained or replaced by a representative average depending on the aggregation strategy. Mass balance consistency was also reviewed by OIE Mines Paris PSL together with CEA and CERTISOLIS to ensure the robustness of the aggregation process and to better understand specific industrial mechanisms such as closed-loop recycling and variability between input and output flows, for example regarding recycled silicon incorporation rates as discussed in Section 2.1.1. This step ensured the completeness, harmonisation, and overall reliability of the datasets despite the technological and operational variability observed among manufacturers and production routes across the PV industry.

### 4. Activities definition

This step involved identifying corresponding activities in the background database and creating new activities where no suitable datasets were available. The work was carried out in collaboration with CEA, Certisolis, and O.I.E. Mines Paris–PSL. In the context of this report, this step is not relevant, since the LCI data was matched by ZHAW with specific datasets of the BAFU database [11] as documented in Section 3.2.

### 5. Data aggregation

This step, performed by the O.I.E. Mines Paris–PSL team, consisted in producing aggregated life cycle inventories for each manufacturing component by combining inventory data from multiple plants. The aggregation was performed at the level of each individual flow (materials, energy, emissions, transport, etc.) after harmonization of units. This work was conducted using the Python library `lca_algebraic` [26].

### 6. Averaging

First, for each production step (column) and each flow (row), the values were averaged using a production capacity-weighted mean, ensuring that larger manufacturing plants contributed proportionally more to the resulting inventory.

At this stage, we also computed standard deviation of the data and detected outliers, which allowed to spot and fix manually potential issues in the data (units typically).

Hence, the final inventories do not aim to represent a specific manufacturer or an existing industrial configuration, but rather a statistically representative average dataset reflecting the current manufacturing landscape covered by the collected inventories.

### 7. Aggregation

Then, for each step of production, we aggregated the flows of the current step and the upstream steps, applying conversion of units if necessary.

The following assumptions were made:



- The virgin silicon in the "Ingots" step is composed of a mix of 92% Siemens poly silicon and 8% of FBR poly silicon.
- To convert the "wafer" flow in the "cell" step from kilograms to square meters, we assumed a wafer thickness of 130 micrometres.
- The initial inventories provided two cell types (LPVCD and PECVD) and four module types (mono/bin 60/72 cells). We expanded it into eight typologies of aggregated module types.
- Silicon scrap from ingot and brick production is fed back in-house into the ingot production step.

The resulting aggregated inventories were exported in Excel format.

### 2.1.3 Monocrystalline–Si PV – simulated LCI data for PERC and TOPCon

In addition to industry-based life cycle inventory (LCI) data, this report introduces simulated LCI datasets derived from a bottom-up modelling approach developed at Fraunhofer ISE. The simulated data used in this chapter are based on process simulations developed by Brailovsky [12]. This work developed a process-based LCI modelling framework of the polysilicon-to-PV-module value chain that includes an assessment of and optimization for circularity, including vertical integration of manufacturing steps, waste revalorization [27], minimal liquid discharge [28] and other circular production strategies, resulting in updated and internally consistent LCI datasets of crystalline-silicon PV manufacturing.

The simulated crystalline-silicon (c-Si) PV LCI applied in this report covers the complete production chain from polysilicon purification, Czochralski (Cz) ingot pulling to wafering, cell processing, and module assembly, with all unit processes modelled explicitly using mass and energy balances, technology-specific yields, and defined recycling efficiencies. Inventory results are normalised per unit module area (m<sup>2</sup>), consistent with the industry-based datasets presented in section 2.1.1, and reflect an integrated production system characterised by full vertical integration, systematic waste revalorization including recovery and reuse of commercially viable residues, and a minimal liquid discharge manufacturing concept based on closed-loop water management and chemical recovery [28], notably of fluor spar (CaF<sub>2</sub>) and potassium hydroxide.

Within the IEA PVPS Task 12 framework, industry-based LCIs remain the primary reference for representing average and market-relevant PV manufacturing conditions, while simulated LCIs complement them by enabling the analysis of novel technologies, optimised process pathways, circularity strategies and prospective manufacturing systems. The simulated datasets do not aim to represent current market conditions but provide a transparent and internally consistent benchmark for assessing advanced production concepts and potential future pathways. Although the datasets presented here focus on crystalline-silicon PV manufacturing, the underlying methodological rationale is technology-agnostic and applicable to other PV technologies such as thin film.

Additionally, the simulated LCI cover bottom-up modelling of the factory building and facilities [29] including related supply streams as e.g. for water make-up as well as waste stream treatment, that support the main production processes. These are typically not available in the same level of detail for industry data.

The simulated LCI in this chapter are based on industrial process receipts and sequences and on actual market available process and facility equipment supplied to new PV factories in multiple countries. The origin of the considered process equipment includes both Chinese and European equipment manufacturers. Lastly, simulated LCI allow the verification and validation of the completeness of industrial data LCI.

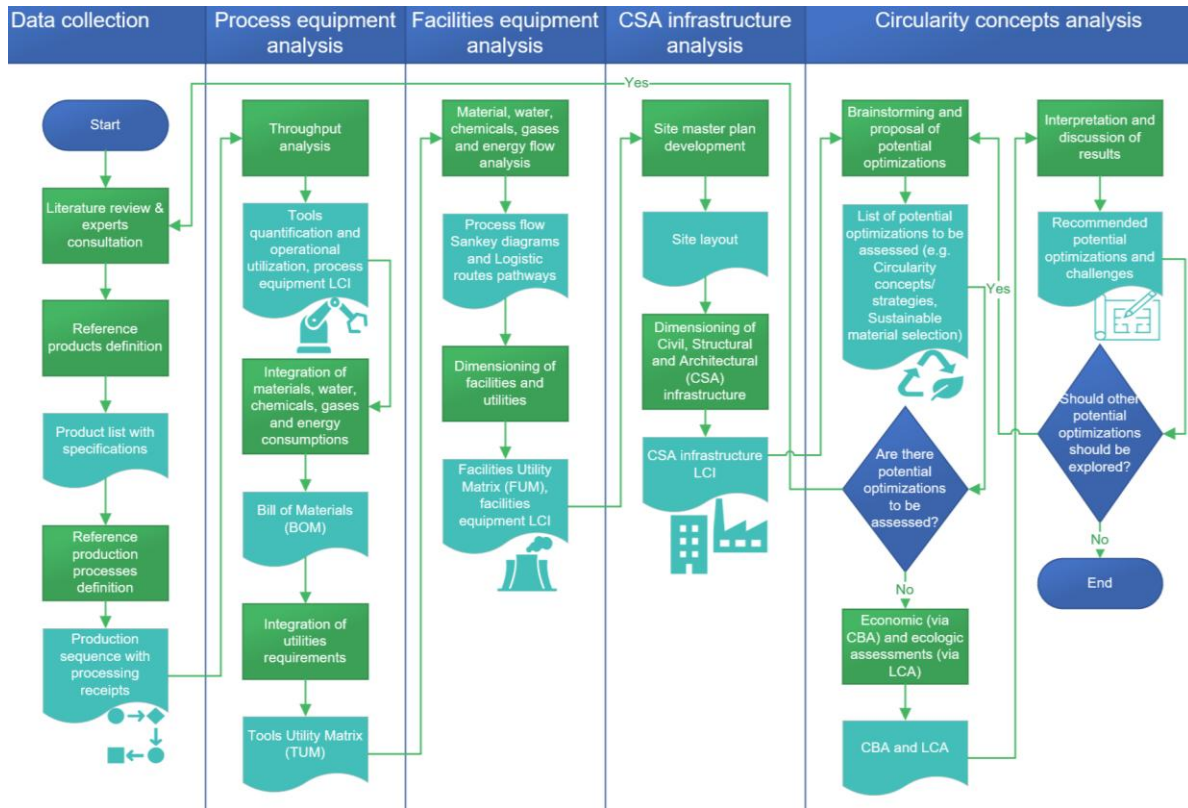
The following section on the methodology for deriving bottom-up process based LCI data has been previously published in the doctoral dissertation of Brailovsky [11] and the doctoral dissertation of Nold [30]. Here, its methodology, main results and conclusions are reproduced with some editions to its original content.

The goal of the modelled LCIs was to identify, assess and reduce potential waste and wastewater. The overall circularity optimization approach is represented in Figure 6, wherein material and energy flows reductions along the production of the value chain of silicon wafer (including the crystallization process)-cell-module are identified in a systematic and sequential manner. Green rectangles represent analysis or applied methods, and the turquoise



boxes represent their corresponding deliverables in form of lists, tables, diagrams, layouts, LCI and recommendations. Blue diamonds represent decision points. The overall circularity assessment is divided into five sections as stated in the Figure 8 headers. The “Data collection” includes the literature research and expert consultations activities for the definition of the reference products and processes sequence and the consolidation of process receipts data. The collected data is implemented in the process sheets of the Fraunhofer ISE model SCost [30], which is a bottom-up PV manufacturing material flow and cost model. In the “Process equipment analysis” step a throughput analysis is performed to generate the required tools for each of the production processes. With the quantified tools and their weight, the **process equipment LCI** for each factory is integrated. Including the energy as well as all process media and materials required to operate the industrial tools for manufacturing the respective product allows the generation of a Bill of Materials (BOM) for each reference product, these represent the core of the **operations LCI**. The utility requirements of all tool types are consolidated in the Tool Utility Matrix (TUM), which is the base element for the dimensioning of the facilities of the industrial site.

The “Facilities equipment analysis” section starts with setting up the resources and energy flows analysis for each factory and within them. The facilities services are dimensioned, and their corresponding consumptions accounted to generate the industrial site Facility Utility Matrix (FUM). The quantified utilities equipment and their weights are used to derive the **facilities equipment LCI**. At this point an understanding of the factory’s processes and requirements is given, where next the Civil, Structural, and Architectural (CSA) infrastructure analysis takes place to account for the areal dimensioning of the industrial site considering safe distance between operations, storages and administration halls, as well as required parking and roads infrastructure and landscaping zones of the industrial site. A **site masterplan layout** is created accordingly. The design of the buildings structure and envelope is performed using the site layout, the processes and facilities equipment inventories and their physical dimensions, floor loads, distribution within the buildings and required environmental conditions. This process results in the generation of a **CSA infrastructure LCI**. The last section of the circularity assessment, “Circularity concepts analysis”, begins. A brainstorming process is done to propose potential improvement to the processes, facilities and buildings flows and inventories, these are then evaluated with Cost Benefit Analysis (CBA) for an economic perspective [30] and by a Life Cycle Assessment (LCA), including a hotspot parameters analysis, for an environmental perspective [3; 31]. The results are interpreted and discussed to generate a set of recommendations. If no more circular concepts or optimizations are proposed the circularity assessment is finished. If there are further potential improvement to be assessed, an iteration to the section “Data collection” takes place.



**Figure 8: Circularity assessment methodology developed by Brailovsky [12]. Green rectangles represent analysis or applied methods, and turquoise boxes represent the corresponding outcomes.**

The applied processes and methods are further described below.

### 1. Literature review and expert consultation

The state-of-the-art of the investigated production system, product and technology was reviewed and documented. Research and industry experts were consulted for gathering in depth feedback towards technological development roadmaps, processes and product specifications.

### 2. Reference products definition

The investigated production system products were defined and described. Technical specifications and parameters were listed to characterize the assessed products [14].

Cz wafers with a p-type doping are considered for the PERC PV modules production, n-type Cz wafers for the TOPCon PV module production. Both with a thickness of 130  $\mu\text{m}$  and M10 format, featuring a wafer edge length of 182 mm with pseudo square shape with an ingot diameter of 247 mm, resulting in a wafer area of 330.15 $\text{cm}^2$ .

The PERC PV modules have an efficiency of 21.5%, 555 Wp at Standard Testing Conditions (STC), 3.2 mm front solar glass and rear backsheet encapsulated with Ethylene-vinyl acetate (EVA). The TOPCon PV modules have an efficiency of 23.0%, 595 Wp STC, 2.0 mm front and rear glass sheets encapsulated with polyolefin elastomers (POE). Both with a length of 2278 mm and a width of 1134 mm, and an arrangement of 6x24=144 half M10 cells.

### 3. Reference production processes definition

The production sequence and process parameters required to produce the reference products were integrated at this stage. Experts' feedback on this definition was an essential element to a solid and plausible outcome [14]. The processes sequence used for the simulated LCI is included and described in Chapter 4 of this report.

### 4. Process equipment throughput analysis

Process equipment, including intralogistics, types, and models capable of executing the reference production sequence for the specified products, were identified. Process equipment datasheets were collected, and equipment



manufacturers were asked to provide net throughputs and uptime capabilities of their equipment. The required tools for each process were backward calculated for the desired factory output, the calculation can be deterministic for a first estimate with the Fraunhofer ISE bottom-up PV manufacturing material flow and cost model SCost [12]. A discrete event simulation of the factory was performed for considering the stochastic behaviour of failure modes and estimating with higher accuracy the required tools and the sizes of work in process storages or buffers.

#### **5. Process equipment integration of space requirements, floor loads, materials, water, chemicals, gases and energy consumption**

After defining the mean incoming piece (wafers, cells, PV modules) throughputs for each tool, the corresponding mean requirements of process consumables were included. Consumables include substrates, materials, chemicals, water, gases and energy. The space requirements are essential for the layout of the factory and the floor loads for the estimation of structural components and environmental impacts. The equipment and process parameters included in the bottom-up LCI model for this report are based on the state-of-the-art equipment and process parameters of international industrial PV equipment manufacturers, which deliver their manufacturing equipment to global PV manufacturers. The process parameters and consumption data received was validated through scientists and technology experts from Fraunhofer ISE, which are working on the development of PV manufacturing processes and are covering the PV manufacturing chain from polysilicon to the finished PV module.

#### **6. Process equipment integration of facilities requirements**

The process equipment in the production area of each factory was supported with external utilities and industrial site facilities with their own consumables and energy requirements. The tools' uptime, which includes productive, standby, and engineering times, is considered for power, adiabatic cooling, water chillers, Compressed Dry Air (CDA) production, nitrogen, ventilation, exhaust, scrubbers, ultrapure water production, wastewater treatment, heating and cooling services needs [27]. All these requirements are documented in a Tool Utility Matrix (TUM).

#### **7. Facilities equipment space requirements, floor loads, material, water, chemicals, gases and energy flow analysis (MFA)**

The facilities, equipment, and consumables were quantified and documented. Transformer rooms and electrical substations are needed for power supply, ultrapure water production units are needed to de-ionized municipal water supplied to the site, compressors and dryers are needed to produce CDA, wastewater treatment facilities are needed to reclaim spent water for the factories and treat the wastewater for discharge to external sewers or local effluent treatment plant, industrial chillers and cooling tower are needed to supply Process Cooled Water (PCW), vacuum generators, filters and scrubbers are needed for the exhaust system, ventilators, filters and chillers are required for the room conditioning, Computer rooms, servers and Uninterruptible Power Supply (UPS) are needed for the facility management and control system, storages for chemicals, water, raw material and finalised products are needed. Other facilities services include reliability laboratories, administrative offices, gates, parking lots, fire protection and landscaping areas [29].

#### **8. Dimensioning of facilities**

After defining external utilities and internal facilities, and the requirements for the facilities, an analysis of equipment vendors was performed. Equipment datasheets are collected, and their capacities are used to quantify the number of tools required. The facilities LCI used for the simulated LCI is described in section 4 of this report. The Appendix A of Brailovsky et al. (2024) lists more details of the considered facilities equipment.

#### **9. Site master plan development**

After defining the requirements of process equipment, facilities equipment, material, and personnel, material flow analysis, a first design of the site master plan was generated. This plan was documented in a 2D plan where all the factory buildings for ingot, wafer, cell and module manufacturing, as well as related facility and service areas are located [17]. The calculated site master plan for the simulated LCI is included in Figure 10 of the Chapter 4 of this report.

#### **10. Dimensioning of Civil, Structural and Architectural (CSA) infrastructure**



With a hypothetical site with certain terrain physical conditions and geometries, and the integrated site master plan, the CSA infrastructure was dimensioned. Civil operations were considered to be performed to level the terrain and assure the desired soil carrying capacity by means of backfilling operations. Structural elements were calculated to support the static and dynamic forces considered for each of the site's buildings and ancillary areas. The architectural finishing considers the required processes, cleanliness standard, fire protection standards, comfort and energy needs [29].

### 11. Assessment of potential optimization and circularity strategies

In the next step, potential optimization and circular strategies were assessed for its technologic and economic feasibility. The ones with a positive assessment result were included to the investigated production system. Improvement to processes, reuse of materials, water, chemicals and energy within the industrial site or even synergies with other industries or communities were identified, described and explored.

In this report the following optimization and circularity strategies were considered in the simulated LCI:

- Revalorized waste scenario (TOPCon & PERC): this strategy implied the establishment of a waste registry to classify solid waste per category (paper and cardboard, glass, plastics, metals, wood and mixed waste). Additionally, recycling, energy recovery, and disposal shares were accounted for each waste type. Also, the use of reusable transportation pallets was considered.
- Vertical integration scenario (TOPCon & PERC): with this strategy wafers and solar cells breakage is reduced, packaging material is avoided, and the footprint and capital expenditure of facilities and ancillary buildings and areas is reduced.
- Minimal liquid discharge scenario (PERC): an advanced water and valuable by-products recycling strategy that saves most of the water in the factory.
- Rinse water recycling scenario (TOPCon): the TOPCon cell production require three wet chemical clusters, with this circular strategy a significant share of Ultra-Pure Water (UPW) can be reclaimed and reused in the process.

### 12. Cost Benefit Analysis (CBA) and LCA

The required infrastructure and operational needs to implement the proposed circular strategies and optimizations were accounted. Prices for consumables and utilities were gathered to estimate operational costs (OPEX). The same is done for investment costs (CAPEX). A Cost Benefit Analysis (CBA) was performed with the differences in OPEX and CAPEX of each proposed circular strategy or optimization. The consumables and infrastructure requirements are also used to integrate variations to the reference production LCI. These differences allow the execution of comparative LCA to assess environmental impacts and benefits.

Existing PV manufacturing datasets from the years 1999 to 2006 were updated in the simulated LCI with process-based material flow analysis and engineering dimensioning of all areas of an industrial site. The update of the ingot, wafers, solar cells and PV modules factories resulted in environmental impact reductions between 11.7% and 94.3% for 14 of the 15 environmental impact categories from the European Environmental Footprint method (EF3.1). This due to the large productivity increments in the factories throughputs that took place in the last decade.

#### 2.1.4 CdTe PV

In First Solar's vertically integrated production process, the CdTe absorber layer is deposited by vapor transport deposition (VTD). In this process, CdTe powder is sublimed and transported by an inert carrier gas towards heated glass substrates, where thin-film deposition occurs at approximately 500–600 °C. Electrical cell definition and monolithic series interconnection are achieved through a sequence of laser scribing steps applied directly to the thin-film stack. Following absorber deposition and scribing, functional layers, including window and back-contact layers, are formed and thermally treated to complete the device structure. The completed thin-film stack is subsequently encapsulated in a glass–glass configuration using polymer encapsulants with edge seals. Final module assembly includes lamination under vacuum and elevated temperature, attachment of junction boxes and mounting hardware, and electrical and mechanical quality control prior to shipment.



Specifications of cadmium telluride (CdTe) thin-film PV modules are comparatively homogeneous, as commercial production is concentrated in a limited number of module platforms. The modelling of CdTe PV modules in this report is based on manufacturer data on the currently produced Series 6 and Series 7 module types from First Solar. Average electricity conversion efficiencies of 18.4 % and 18.7 % are assumed for Series 6 and Series 7 modules, respectively. Both module series employ a glass–glass laminate construction and do not use a conventional aluminium perimeter frame. Series 6 modules incorporate an integrated under-mount support frame with edge protection, whereas Series 7 modules use rear-mounted parallel steel support rails designed for fixed-tilt or tracker mounting. The corresponding module areas are approximately 2.5 m<sup>2</sup> for Series 6 modules and 2.8 m<sup>2</sup> for Series 7 modules, with typical module weights of about 34–35 kg and 39–40 kg, respectively [13].

To ensure consistency with the c-Si PV modules assessment, LCI data of CdTe PV modules are normalised per unit module area (m<sup>2</sup>). This report provides LCI datasets of both Series 6 and Series 7 module types. The underlying foreground production data are based on Series 6 Plus manufacturing data collected in 2022, complemented by Series 7–specific bills of materials introduced in 2023, representing all First Solar factories in all regions producing each Series, and reflecting differences in module dimensions, mounting structures, material use, and electrical ratings between the two platforms. Detailed information on the CdTe PV life cycle inventory is provided in section 3.3 of this report.

### 2.1.5 CIGS PV

Copper indium gallium diselenide (CIGS) PV technology is currently not produced in relevant volumes on the global PV market and is predominantly applied in niche applications, such as lightweight, flexible, or building-integrated PV systems. While limited commercial manufacturing activity persists at a small scale, CIGS does not represent a mainstream PV technology comparable to crystalline silicon or cadmium telluride in terms of global production volumes. Consequently, this report does not provide any updates to the life cycle inventory (LCI) of CIGS PV modules.

LCI data of CIGS PV module manufacturing in Europe (Germany), representing the technological status around 2010–2011, were used in the 2015 version of this report [33]. These data were originally published by Jungbluth et al. [34] and subsequently updated by de Wild-Scholten [35]. The life cycle inventory data of CIGS PV modules were last updated in the 2015 version of this report. These data were not updated for the present study and are provided in the Annex.

### 2.1.6 Perovskite silicon tandem PV

LCI data of perovskite–silicon tandem PV were included in the 2020 version of this report based on the European research project CHEOPS<sup>1</sup> and a screening-level LCA using primary data from an industrial pilot context. These data reflected an early development stage of the technology and did not represent commercial-scale manufacturing. The present report does not provide any updates to the perovskite tandem PV LCI, as robust and representative industrial life cycle inventory data are not yet available to us. The LCI data included in the 2020 report are provided in the Annex of this report. An update of the perovskite tandem PV LCI is expected once the technology reaches commercial market entry and industrial-scale production data become available.

Perovskite–silicon tandem PV is currently not produced at commercial scale but represents one of the most important focus areas in photovoltaic research and development. By combining a wide-bandgap perovskite top cell with a crystalline silicon bottom cell, tandem concepts offer substantially higher efficiency potential than single-junction silicon technologies. According to recent photovoltaic technology roadmaps, perovskite–silicon tandem modules are expected to enter the market as early as 2027, with module efficiencies eventually exceeding those of state-of-the-art single-junction silicon modules [14]. Further efficiency gains are anticipated as the technology matures.

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<sup>1</sup> <https://cheops.accelopment.com/>



## 2.2 Balance of system

In the context of LCI and LCA of PV electricity generation, the balance of system (BOS) comprises all non-module components and infrastructure required to install, operate, and connect a PV system to the electricity grid. This includes mechanical support structures, inverters and other electrical components as well as cables and ancillary equipment, depending on the system configuration. The composition of BOS components differs between rooftop and open-ground PV systems. Rooftop systems typically rely on mounting structures that attach PV modules to existing building elements, whereas open-ground PV systems require dedicated support structures, foundations, and site-specific infrastructure. In LCI and LCA, BOS components are explicitly accounted for in terms of material and energy use, replacement requirements, and end-of-life processes.

The BOS inventories described in this section provide the underlying data used to describe PV system configurations and to parameterise the reference PV systems defined in Section 2.2.1.

### 2.2.1 Reference systems

Within the IEA PVPS Task 12 framework, LCA results for PV electricity have traditionally communicated in the context of a single reference system, namely a small scale 3 kWp residential rooftop PV system in Central Europe [36]. In the present report, the previous 3 kWp reference system is replaced by a 10 kWp residential rooftop PV system to better reflect current size and practice and to be more representative of the residential building sector. As the inverter and several balance-of-system components in residential PV systems do not scale linearly with installed capacity, an excessively low reference capacity would cause these components to be disproportionately represented in both LCI and LCIA.

Over the past decade, average residential PV system sizes have increased substantially across all major markets. In the United States, the median size of newly installed residential systems rose from 5.2 kW in 2011 to 7.4 kW in 2023, with most states exceeding 8 kW [37]. Australia shows the trend most clearly: average system size grew from 2.65 kW in 2012 to 9.7 kW in the first half of 2024 [38; 39]. In Germany, the annual share of building-mounted systems  $\leq 10$  kWp in total installed capacity has declined markedly since 2012, while the 10–20 kWp segment has grown consistently since 2020 [40]. Two factors drive this shift. First, rising module efficiencies allow more installed capacity per unit of roof area: average commercial module efficiency increased from approximately 14 % in 2010 to over 23 % for TOPCon modules in 2025 [14]. Second, the electrification of heating and mobility through heat pumps and electric vehicles has significantly increased household electricity demand, driving the adoption of larger systems to maintain high self-sufficiency rates [41].

In addition to the factors discussed above, the choice of a 10 kWp reference capacity reflects the structural diversity of the residential building stock. In the European Union, 48 % of the population lived in flats in 2024 [42]. In South Korea, more than three-quarters of all occupied dwellings are classified as apartments or other multi-unit residential buildings [43]. In the United States, multi-family units accounted for approximately 29 % of the total housing stock in 2023, and their share in new residential construction has increased consistently since 2008 [44]. This gradual shift toward higher-density residential forms is observed across world regions and is primarily driven by urbanisation, rising housing costs, and growth in single-person households. On average, multi-unit residential buildings have substantially larger rooftop footprints per building than detached single-family houses and therefore offer correspondingly greater usable area for rooftop PV installation per building. A 10 kWp reference system size for residential PV systems accordingly reflects not only the upper range of single-unit residential PV systems but also the lower range of systems on smaller multi-unit residential buildings, where system configurations above 10 kWp are not exceptional.

In addition, reference systems representing commercial-scale and utility-scale PV applications are introduced. These reference systems are used for consistent LCA communication and comparison, while building on both BoS inventories already included in the Task 12 LCI as well as on newly modelled datasets.

To support consistent LCA communication across different PV application segments, this report applies a set of reference PV systems representing residential, commercial, and utility-scale installations. These reference systems



define how the BOS inventories described in this section are combined with PV module inventories and electricity generation parameters for the assessment of PV electricity generation. Reference system datasets are provided for systems with monocrystalline silicon, polycrystalline silicon and cadmium telluride based modules.

The reference PV systems introduced in this report are:

- **10 kWp** DC residential rooftop PV system,
- **250 kWp** DC commercial rooftop PV system,
- **10 MWp** DC utility-scale ground-mounted PV system.

Installed capacities expressed in kWp and MWp refer to DC nameplate power. The selected system sizes do not represent statistical average installation sizes for the respective application segments but are defined as representative reference points to enable consistent system definition and comparability of life cycle inventory and assessment results across different PV application segments. For sufficiently large systems, LCI requirements and environmental impacts per unit of installed capacity and per unit of electricity generated are expected to be largely insensitive to further increases in system size, provided that similar design principles are applied. For the reference systems defined in this report, AC/DC ratios of 0.8 (DC/AC ratio = 1.25) are assumed for residential and commercial PV systems, 0.75 (1.33) for utility-scale reference systems. These ratios reflect commonly applied design choices, whereby inverter capacity is more frequently undersized relative to DC capacity, especially in larger systems [45].

## 2.2.2 Inverter

In addition to the existing 2.5 - 20 kW inverter inventories from the previous IEA PVPS Task 12 LCI report [15], this report includes new LCI for 3 kW, 5.5 kW, 8-10 kW and 100 kW inverters. The BOM of the 3 kW and 5.5 kW inverter models are based on disassembly and laboratory analysis of one inverter type per size, performed at Ricerca Sistema Energetico (RSE) by Andrea Danelli. For 8-10 kW inverters and 100 kW inverters primary material and energy inventories measured in the year 2024 were provided to IEA PVPS Task 12 by leading manufacturers. For anonymization and data enrichment, primary industry data were combined with information derived from Environmental Product Declarations (EPDs) published between the years 2023 and 2025. Three EPDs from distinct inverter manufacturers were used for the aggregation and anonymization of the 8-10 kW inverter dataset [46; 47; 48] and four EPDs for the 100 kW dataset [49; 50; 51; 52]. Inverter EPD documents used for the aggregation and anonymization process were selected based on their suitability in terms of weight and rated power. EPDs with insufficient reporting of component category shares were excluded. Overall, the data covers manufacturing locations in Europe and China and represents an estimated 13 % of global production capacity of the respective inverter size.

For the aggregation, manufacturer-reported material quantities were consolidated into the major component groups typically used in EPDs. Although categorization is not consistent across EPD documents, a set of commonly applied categories can be identified:

- Aluminium & alloys
- Copper & alloys
- Steel
- Electronic components / Printed Circuit Board Assembly (PCBA)
- Plastics

Some EPDs apply alternative aggregation schemes, for example “Metal Parts” as a composite category covering aluminium, copper, and steel, while others use more disaggregated classifications, such as separating electronic components into “PCBA” and “other electronics”. With the LCI anonymization procedure applied here, inverter EPD data were therefore systematically aggregated or disaggregated to align with the component categories defined above. Where disaggregation was required, it was performed based on the relative shares of the respective sub-categories observed in other inverter datasets. If a residual category labelled “Other” was reported, it was assigned to the “Plastics” category.



EPDs, as well as primary inventories provided by manufacturers, differ in the modelling and reporting of relevant components such as inductors. Some data sources include these components as finished components within the category “Electronic components”, whereas others represent them through distinct inputs such as copper, ferrite, and associated manufacturing processes. This leads to significant variations in the reporting of the component categories “Electronic components” and “Copper and alloys”. To address this issue, the category “Copper and alloys” was combined with “Electronic components”.

Table 2 describes how inventory data were matched to the respective EPD component categories.

After aggregation, the average weight shares of the component categories in the primary inventories were combined with the corresponding shares reported in the selected EPD documents, yielding representative average compositions for 8-10 kW and 100 kW inverter models. Subsequently, the component categories of these EPD aggregated inverter datasets were disaggregated into individual LCI inputs based on their relative shares in the primary inventories. Figure 9 provides a schematic overview of the aggregation and disaggregation procedure.

For packaging materials, the same procedure as for inverter components was applied. If an individual packaging component was not included in a given inventory, for example wooden pallets, it was added based on the average weight of the respective component across the other inventories. Subsequently, the average total packaging weight across all inventories was calculated and allocated to the individual packaging components according to the average composition of total packaging. For the 3 kW and 5.5 kW inverters, packaging weight was assumed to be the same percentage of the inverter weight as in the average 8-10 kW inverter. Equally, the distribution of individual packaging components of 3 kW and 5.5 kW inverters is assumed to be identical to the average 8-10 kW inverter.



Table 2: Matching of inverter LCI inputs to EPD component categories

<b>Aluminium</b>	Aluminium, production mix, cast alloy, at plant Aluminium, production mix, wrought alloy, at plant Aluminium hydroxide, at plant
<b>Steel</b>	Steel, low-alloyed, at plant Chromium steel 18/8, at plant Fan, at plant
<b>Plastics</b>	Ethylene vinyl acetate copolymer, at plant Polypropylene, granulate, at plant {RER} S Polyester resin, unsaturated, at plant Polyethylene terephthalate, granulate, amorphous, at plant Polycarbonate, at plant Nylon 66, at plant Glass fibre reinforced plastic, polyamide, injection moulding, at plant Synthetic rubber, at plant Silicone product, at plant
<b>Electronics (incl. Copper &amp; alloys)</b>	Brass, at plant Silver, at regional storage Zinc, primary, at regional storage Copper, at regional storage Power supply unit, at plant Printed wiring board, surface mount, lead-free surface, at plant Connector, clamp connection, at plant Inductor, ring core choke type, at plant Inductor, low value multilayer chip type, LMCI, at plant Integrated circuit, IC, logic type, at plant Integrated circuit, IC, memory type, at plant Transistor, SMD type, surface mounting, at plant Diode, glass-, SMD type, surface mounting, at plant Light emitting diode, LED, at plant Capacitor, film, through-hole mounting, at plant Capacitor, electrolyte type, > 2cm height, at plant Capacitor, electrolyte type, < 2cm height, at plant Capacitor, SMD type, surface-mounting, at plant Resistor, wirewound, through-hole mounting, at plant Resistor, SMD type, surface mounting, at plant Ferrite, at plant  Transformer, low voltage use, at plant Switch, toggle type, at plant Electronic component, passive, unspecified, at plant Epoxy resin, liquid, at plant  Solder, bar, Sn63Pb37, for electronics industry, at plant Solder, paste, Sn63Pb37, for electronics industry, at plant

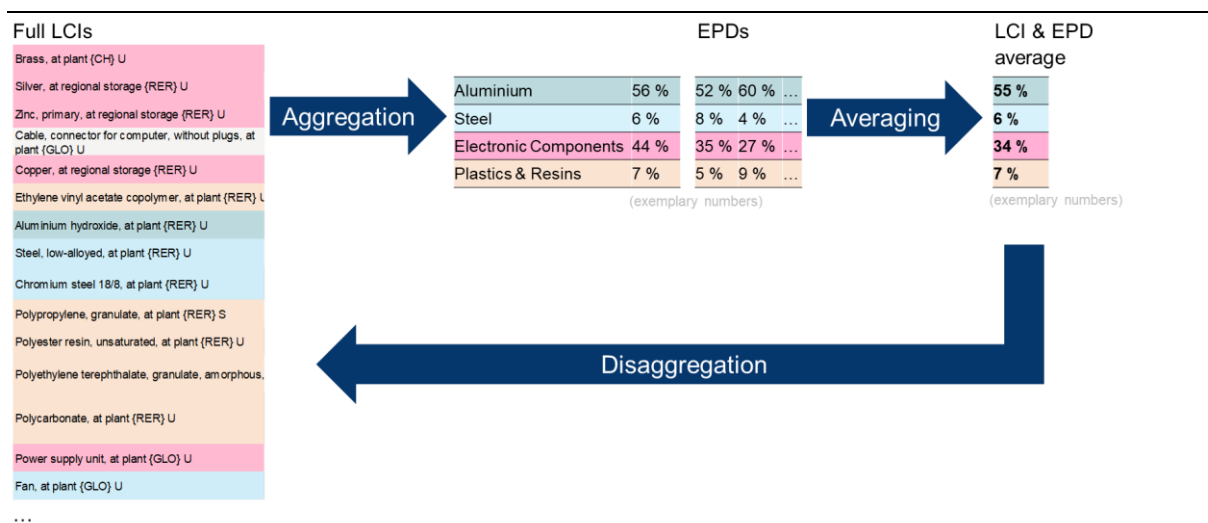


Figure 9: Schematic overview of aggregation and disaggregation of primary and EPD data. Numbers are illustrative examples.

Where data sources reported raw material inputs instead of specific components, material processing efforts were modelled based on the quantities of the respective materials. For aluminium inputs, datasets for cast and wrought aluminium from the background database were applied, representing a production mix that includes both primary and secondary aluminium. The manufacture of cast aluminium parts was modelled using the dataset “Aluminium product manufacturing, average metal working”. For steel, the background dataset similarly represents a production mix of primary and secondary material. The manufacture of steel parts was modelled using the generic dataset “(Chromium) steel product manufacturing, average metal working”. Low alloy steel components were assumed to be zinc coated.

Copper inputs were modelled as being processed into wire and, where applicable, further into inductors, including wire drawing and the application of the dataset “Production efforts, inductors”. Ferrite inputs were modelled as being processed into inductors using the same processing dataset. Plastic components were modelled either as extruded or injection moulded, depending on their application.

The inverter assembly inputs energy, nitrogen and argon use, as well as soldering flux, bars and pastes were reported for one 10 kW and one 100 kW inverter. For all other inverters, these inputs were extrapolated from the 10 kW inverter based on inverter weight. Water consumption and wastewater treatment were extrapolated from the 10 kW inverter model of the previous IEA PVPS Task 12 LCI report [15] based on inverter weight.

The inverter lifetime was assumed to be 15 years. End of life treatment was included in the modelling. Printed circuit board assemblies and metals were assumed to be recycled, whereas plastics as well as cardboard and paper waste from packaging were assumed to be treated in municipal waste incineration plants. Transportation was modelled using standard distances.



### 2.2.3 Mounting structures

Life cycle inventory datasets of photovoltaic mounting systems cover the following types:

- Mounting on façade
- Integrating in façade
- Mounting on flat roof
- Mounting on slanted roof
- Integrating in slanted roof
- Mounting on open ground, fixed tilt
- Mounting on open ground, 1-axis tracker

The inventory data are based on manufacturer information and literature sources. Material quantities for each mounting system type are weighted according to average mass values published by Jungbluth et al. [34]. The inventory data presented in this report are based on the previous LCI report [15]. In the present LCI report, only the inventory for open-ground fixed-tilt mounting was updated, while a 1-axis tracker system was newly introduced.

### 2.2.4 Complete roof-top BoS

Life cycle inventory data of rooftop BoS components representative of the year 2006 were collected within the project “Technologie- en Milieuverkenningen” (ECN project number 7.4750), financed by the Ministry of Economic Affairs of the Netherlands. These data form the basis for describing rooftop BOS configurations and are used as building blocks for the residential and commercial rooftop reference PV systems defined in this report and were not updated for this report edition. Roof-top BoS has been identified as a priority area to be updated in the next report revision.

De Wild-Scholten et al. [53] studied two classes of rooftop mounting systems based on a multi-crystalline silicon PV module (SolarWorld SW220, 220 Wp, 1001 mm × 1675 mm). These configurations include mounting systems that attach PV modules to existing roofing materials using rails, brackets, or comparable fastening elements, as well as in-roof mounting systems in which the modules serve as roof covering. Section 0 and 3.7 of this report details the LCI of rooftop mounting systems, cabling, and inverters.

### 2.2.5 Complete ground mounted BoS

Life cycle inventory data for ground-mounted BoS configurations have been updated and adapted to represent a 10 MW DC fixed-tilt utility-scale PV installation, which constitutes the utility-scale reference system defined in this report. The ground-mount BOS was revised by updating the modelling of the fixed-tilt mounting system based on datasheets, design specifications, and installation guidelines from one of the leading manufacturers of fixed-tilt ground-mount systems. Details on these inventories are provided in Chapter 0.

Fixed-tilt ground-mounted PV systems remain highly relevant, accounting for approximately 45 % of the global utility-scale market in 2024 and representing a substantial share of cumulatively installed ground-mounted capacity. However, single-axis tracking systems have gained increasing market share in recent years, reaching approximately 55 % of newly installed utility-scale ground-mounted capacity in 2024 [14]. For this reason, a single-axis tracker system is introduced in this report alongside the fixed-tilt utility-scale reference system. Its life cycle inventory is based on data from several thousand single-axis tracker installations in Italy, provided by Andrea Danelli (RSE).

The electrical installation, in particular cable lengths and cable modelling, was revised and parameterised to reflect the layout of the 10 MW fixed-tilt system. Inverter and transformer configurations for utility-scale PV systems have also been revised and are described in Chapter 3.7.2..

## 2.3 Advice for use and limitations

The LCI datasets presented in this report are intended to support transparent, consistent and up-to-date LCA of specific PV products lines and generated electricity thereof. They can be used as generic inventory data for certain



PV modules, balance-of-system components and PV electricity generation when specific foreground data from manufacturers, suppliers, installers or plant operators are not available. However, users should carefully select the dataset that best matches the goal and scope of their study, including technology, geography, reference year, system configuration, module design, manufacturing route and application context.

The datasets in this report do not cover all PV technologies, cell architectures, module designs, mounting systems, inverter types or storage configurations currently available on the market. They reflect the best available data at the time of the update and are therefore not a complete representation of the full diversity of global PV manufacturing and deployment. The LCIs are specific to technologies, components or system configurations (e.g. used in the French tender) and may differ in terms of data vintage, technological maturity and market representativeness, depending on the availability and quality of the underlying data sources. Direct comparisons between such datasets should therefore be made only with explicit acknowledgement of potential technological and temporal differences, technological maturity and market development. Where comparative LCA results are reported, users should apply harmonised modelling assumptions as far as possible, including consistent lifetime, yield, degradation, electricity mixes, transport distances, allocation rules, end-of-life assumptions and impact assessment method as described in the Task 12 methodology guidelines [3; 54].

For comparative assessments of specific manufacturers, specific products or procurement options, the use of manufacturer-specific foreground data is strongly recommended. The Task 12 LCI datasets may serve as generic background data or as benchmark, but they should not be used as a substitute for primary foreground data where such data are available or can be obtained with proportionate effort. This is particularly important for comparative assertions involving specific manufacturers, because differences in electricity sourcing, manufacturing location, module efficiency, bill of materials, process yields, recycling rates, quality control, packaging, logistics and plant utilisation can materially affect LCA results.

For both data types, industry and market-based LCI data as well as simulated LCI data, the linking of bill of materials to an flows and processes in LCA background databases [11] required simplifications and in some cases usage of proxy processes, due to the lack of suppliers' data or equivalent datasets available in the database. A further limitation concerns the geographical representativeness of linked background processes. In several cases, foreground bill-of-material data represent global, Chinese, or otherwise non-European supply chains, while the available or selected background processes may represent European conditions. This may lead to inconsistencies between the geographical origin of the foreground material flows and the geographical scope of the associated upstream background processes. Where region-specific datasets were not available, proxy datasets were used.

Proxies were used especially for prefabricated products such as cladding panels and metallization pastes. The use of technical grade datasets for chemicals and process gases is also a limitation, because the solar industry uses highly pure chemicals and gases. LCI background data for industry specific waste treatments and disposal options for the PV industry are not sufficiently available. For water and wastewater treatment analysis, it is important to consider the regional water scarcity. LCI datasets for metal mining and refining activities (i.e. "copper, cathode"), silane ("silicon tetrahydride"), wastewater treatment, waste treatment and disposal, and machinery production (i.e. "metal working machine") should be explored to ensure adequate technological, temporal and geographical representativeness.

The location of factories for heat- and water-intensive production processes has a significant impact on final electricity and water demand. In locations with cold climate, the consumption of HVAC and PCW systems is significantly reduced, resulting in annual electricity demand that is up to 9% lower than that of locations with warm climates [27].

### 2.3.1 Industry and market-based LCI data

The selected market-based LCI datasets in Chapter 3 are the primary reference datasets in this report for representing specific market-relevant PV manufacturing and system components. These datasets are based on empirical information from industrial reporting, validated LCA studies conducted in the context of the French tender process, manufacturer data, environmental product declarations, market statistics and previously published Task 12 LCI



data. They are therefore appropriate for attributional LCA studies that require representative, generic data for PV systems where project- or manufacturer-specific foreground data are not available.

For crystalline silicon PV, the updated industry data are largely based on aggregated and anonymised data derived from the French PV tender process that incentivises low carbon products. These data provide substantially improved insight into recent PV supply chains and cover key manufacturing steps from polysilicon to modules. However, the user should consider several limitations.

First, the underlying data originate from manufacturers participating in a tender framework that includes carbon-footprint criteria. Therefore, the data may be slightly biased towards lower-carbon supply chains. The Simplified Carbon Assessment framework applied in the French tender process is structured such that, for modules with a predominantly Chinese supply chain, applying default values across all process steps is expected to result in a total carbon score exceeding the eligibility threshold of 550 kg CO<sub>2</sub>eq per kWp, creating a strong incentive for manufacturers to provide process-specific LCA data for key steps. Among the plausible mechanisms by which manufacturers could achieve lower carbon scores was the demonstration of site-specific electricity mixes, particularly for polysilicon and ingot production, with a lower carbon intensity than the applicable national grid defaults. This source of potential bias does not manifest in the LCI data included in this report, as the underlying modelling applies country-specific average electricity mixes throughout the supply chain, irrespective of any lower-carbon-intensity mixes or on-site electricity generation reported by individual manufacturers.

Second, the data are horizontally aggregated and anonymised. This protects confidentiality and improves generic usability, and prevents identification of individual manufacturers, specific plant configurations and the full range of process variability.

Third, the datasets represent selected technologies and module designs, with a particular focus on current crystalline silicon technologies such as TOPCon and PERC. In 2024, these accounted for 55 % and 35 % of the c-Si market, respectively. TOPCon is expected to increase to almost 70 % in 2025, while the PERC share is expected to decline below 20 % [14]. Emerging cell technologies such as heterojunction cells or tandem cell configurations are not covered in this report.

Fourth, the LCI datasets modelled based on data from the French tender process predominantly represent production across the PV supply chain in Chinese factories. The factories analysed manufacture either components used in the production of modules destined at least in part for export, or modules that are themselves at least partially intended for export. These datasets are therefore potentially more representative of modules destined for export than of those sold on the domestic Chinese market or of modules representing a global average. A consequent bias towards higher-quality components and modules meeting the low-carbon requirements of the French PV tender process during the reference period 2022 to 2025 (depending on the component) cannot be excluded. Factories investigated by LCA in the context of the French tender process may tend to apply more advanced, energy- and material-efficient manufacturing processes than factories whose components are not sourced by manufacturers supplying modules under the French tender process.

For CdTe PV, the datasets are based on manufacturer-specific data from the dominant global producer. These data are suitable for generic modelling of CdTe PV where the assessed system is consistent with the module series, production regions and market assumptions described in this report. They should not automatically be interpreted as representative of alternative thin-film technologies or potential future CdTe manufacturing routes.

For inverters, mounting systems, electrical components and complete PV installations, users should check the reference year, system type and representativeness of each dataset carefully. Some BOS datasets originate from earlier Task 12 reports and have not or have only partially been updated in the present revision. They remain useful as transparent generic datasets where no better data are available, but they may not fully reflect current design practices, such as larger system sizes, tracker-based utility-scale systems, current electrical system layouts, or reduced material intensities. Where these components are expected to be material to the LCA result, users should perform sensitivity analyses or replace generic datasets with project-specific data.



The industry and market-based datasets can be used for the following applications:

- generic LCA of PV electricity generation;
- national or regional PV electricity mix modelling;
- screening studies and hotspot analysis;
- background modelling for energy-system, building, product or policy LCAs;
- comparison of PV technologies at a generic technology level, provided temporal and methodological differences are transparently addressed;
- and benchmarking manufacturer-specific foreground data against generic industry-average values.

These datasets are not suitable for comparative claims about specific manufacturers, procurement tenders, individual products or environmental product declarations unless supplemented with specific foreground data and harmonised modelling assumptions.

### 2.3.2 Simulated LCI data

The simulated LCI datasets in Chapter 4 represent a different type of inventory data. Rather than being compiled from measured real-life production data, they are built through bottom-up process modelling of the PV manufacturing chain, using process sequences, mass and energy balances, equipment requirements, facility infrastructure and circularity strategies. They include detailed information on production technology, required process equipment including process parameters with energy and media requirements, factory facilities and utilities as well as circular production concepts that are often only partly covered, aggregated or excluded in empirical industry datasets.

These datasets are therefore not intended to replace the industry and market-based LCIs as the primary representation of current average market conditions. Their main purpose is to provide internally consistent, transparent and process-detailed inventories for analysing advanced manufacturing concepts, vertically integrated production, circularity strategies, prospective production systems and improvement potentials. They are especially useful where the research question concerns process optimisation, resource efficiency, water management, waste valorisation, facility design, technology learning or future manufacturing pathways.

The simulated datasets can be used for the following applications:

- plausibility checks and completeness assessment of empirical industry LCI data;
- prospective LCA of advanced PV manufacturing concepts;
- assessment of circularity strategies such as vertical integration, waste revalorisation, minimal liquid discharge or rinse-water recycling;
- analysis of process-level hotspots and improvement potentials;
- sensitivity analysis of manufacturing parameters such as e.g. module efficiency, wafer thickness, kerf loss, metallisation paste use, electricity demand, water use and equipment lifetime;
- and scenario modelling where no representative measured industrial data are available.

The main limitation of the simulated datasets is that they do not represent an observed average of current global manufacturing. They describe modelled production configurations based on industrial process recipes, available production equipment and defined optimisation assumptions. As a result, they may represent high performing, integrated or optimised production systems rather than the full range of existing manufacturing conditions. These data may therefore reflect optimised production practices, including lower material losses, lower water consumption, higher resource recovery or lower environmental impacts than would be expected for less integrated or less optimised factories. The resulting datasets should therefore not be interpreted or used as generic market representations. They reflect specific modelled configurations and should only be applied where the assessed system corresponds to those configurations.

For comparative studies, simulated LCIs should not be compared directly with industry-average LCIs without explaining the difference in data type. A comparison between an industry-average dataset and an optimised simulated dataset is not only a comparison of technologies; it is also a comparison of data sources, modelling approaches



and system assumptions. Such comparisons are valid only when this distinction is explicit and when the interpretation clearly states whether observed differences are caused by technology, geography, temporal scope, process optimisation, data completeness or modelling assumptions.

### 2.3.3 Recommended use in LCA studies

Users should report clearly which type of Task 12 LCI data was applied: industry and market-based LCI data or simulated LCI data. The selected dataset should be justified in relation to the goal and scope of the study. For generic background modelling, the industry and market-based datasets should generally be preferred. For prospective, process-level or circularity-oriented analyses, the simulated datasets may be more appropriate.

Where manufacturer-specific or project-specific data are available, these should be used for foreground processes, especially in comparative LCA. The Task 12 datasets can then be used to fill data gaps, model upstream and downstream background processes, represent generic supply-chain stages or provide benchmark values. In all cases, users should document deviations from the datasets as published, including regionalisation, substitution of electricity mixes, changes in module efficiency, revised transport assumptions, altered end-of-life modelling or updated BOS components.

The following minimum information should be reported when using these datasets:

- dataset name and version;
- technology and module type;
- reference year or time period;
- geographical scope and electricity mix;
- whether the dataset is industry/market-based or simulated;
- system boundary and functional unit;
- lifetime, yield and degradation assumptions for PV electricity modelling;
- modifications made by the user;
- and sensitivity analyses for parameters with high influence on results.

Overall, the LCI datasets in this report provide robust generic data for PV LCA, but they do not remove the need for careful goal-and-scope definition, transparent dataset selection and critical interpretation. Their strongest use is as background data and as a harmonised basis for transparent PV LCA. They should not be used as a proxy for manufacturer-specific performance in comparative claims where specific foreground data should instead be collected and applied.

The limitations identified in this section also indicate priorities for future updates of the Task 12 LCI datasets, as outlined in the following section.

## 2.4 Outlook for future updates

The PV sector is developing rapidly, with continuous changes in cell technologies, module formats, upstream manufacturing processes, supply chains, system designs and end-of-life treatment routes. The LCI datasets presented in this report therefore represent the best available data up to 2025, but they should be considered as part of a continuously evolving Task 12 data framework rather than as static reference values. Future updates could prioritise those areas where technological change, market growth or data uncertainty are expected to have the greatest influence on LCA results, as well as on datasets for components that no longer represent the current state of the art. The priorities below are grouped accordingly: the first three are key priorities that are both environmentally influential and rapidly changing, followed by four further priorities of comparatively lower urgency. The list is not a strict ranking within these groups.

The first priority is the continued revision of crystalline silicon PV manufacturing data, as this remains the most relevant driver of environmental impacts of global PV electricity generation. The current update substantially improves the representation of recent c-Si supply chains as compared to prior Task 12 LCIs, especially for TOPCon



and, to a lesser extent, PERC technologies. However, the market is shifting towards increasingly diversified cell architectures. Future updates could therefore include further differentiation of currently emerging or growing technologies, including silicon heterojunction, back-contact cells and advanced TOPCon variants, as soon as robust and representative industrial data become available. In addition, module-level inventories could be updated to reflect changes in wafer size, wafer thickness, kerf loss, metallisation paste composition, silver use, cell interconnection, glass–glass module designs, frameless modules and bifacial configurations.

The second priority is the integration of commercially relevant emerging PV technologies. Perovskite–silicon tandem PV is currently not yet represented by robust commercial-scale LCI data, but it may become relevant in future PV markets. Once industrial production reaches sufficient scale, future Task 12 updates could revise existing screening-level inventories and replace them with representative manufacturing data. Similar considerations apply to other thin-film or niche PV technologies where present inventories are either outdated or not representative of current manufacturing conditions.

The third priority concerns balance-of-system components. Several BOS datasets used in this report originate from earlier Task 12 reports and do not fully reflect current PV system designs. Future updates could therefore further revise mounting structures, cabling, electrical components, transformers and installation datasets. Particular attention should be given to utility-scale ground-mounted PV systems, where current practice increasingly includes single-axis trackers, larger module formats, higher DC/AC ratios, optimised cabling layouts and system designs that differ from conventional fixed-tilt systems. For rooftop systems, updated data are needed for contemporary residential and commercial installations, including current mounting systems and typical installation sizes.

The fourth priority is the further development of inverter and power electronics inventories. This report includes updated inverter datasets, but the fast development of power electronics, string inverter architectures, central inverter systems, hybrid inverters and inverter replacement strategies requires continued monitoring. Future updates need to further revise the inverter data and, where feasible, extend them for example with additional power classes or module-level inverters.

Battery energy storage systems should remain clearly separated from the core PV system inventory unless they are explicitly part of the assessed system. However, because PV-plus-storage systems are becoming increasingly relevant in several markets, future Task 12 work could consider providing optional, modular LCI datasets for common stationary storage configurations.

A fifth priority is the updating of PV module recycling inventories. Current recycling datasets remain useful for modelling established treatment routes, but they do not fully capture ongoing developments in dedicated PV recycling processes, higher-value material recovery, silicon and silver recovery, improved glass recovery and future treatment needs for new module designs.

A sixth priority is the improvement of regionalisation and market-mix modelling. PV supply chains are geographically concentrated but politically and economically dynamic. Future updates could therefore regularly revise regional production shares, trade flows, electricity mixes, water stress factors and country-specific deployment mixes. Particular attention should be given to changes in manufacturing locations, reshoring policies, supply-chain diversification and the environmental implications of different electricity supply assumptions.

Finally, future updates could further strengthen the documentation of uncertainty, data quality and representativeness. Where possible, future Task 12 datasets could provide parameterised data ranges or sensitivity values for influential parameters such as module efficiency, degradation rate, lifetime, electricity demand, wafer thickness, silver consumption, inverter replacement, transport distances and end-of-life treatment. This would improve the usability of the datasets for both screening studies and more detailed comparative LCAs.

Overall, Task 12 aims to maintain the report as a living reference for PV LCI data. The key priority updates are crystalline silicon manufacturing, emerging cell and tandem technologies, and balance-of-system components, as these are both environmentally influential and rapidly changing: crystalline silicon manufacturing, new cell technol-



ogies, BOS components, utility-scale system designs, power electronics, recycling and regional supply-chain structures. This will ensure that Task 12 continues to provide robust, transparent and practically useful LCI data for PV LCA, while clearly distinguishing between generic background data, manufacturer-specific foreground data and simulated datasets.



## 3 LIFE CYCLE INVENTORY DATA FROM INDUSTRY & MARKETS

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Life cycle inventory (LCI) data may be either collected empirically through measurements, industrial reporting and statistics, or they are estimated by simulations based on existing data and assumptions about physical parameters of the production process. The following chapter describes the LCI data used in this report which were collected empirically. LCI data obtained through the simulation approach are described in chapter 4.

### 3.1 Bill of materials and country specific annual yield

Table shows the bill of materials and panel efficiencies of the monocrystalline silicon and CdTe PV panels modelled in this LCI report. Based on these module efficiencies, the module area required for the installation of PV systems of different sizes can be calculated. The area values reported in the bill of materials represent the module area required for PV systems of 10 kWp, 250 kWp and 10 MWp under STC conditions and do not include additional modules needed to account for rejected or replaced modules. At PV plant level, the LCI models presented in this report include an additional 1 % rejected and 2 % replaced of PV modules as in the previous edition [15].

The country-specific annual electricity yields in Table used in the LCI modelling of country specific photovoltaic mixes are based on average yields for the year 2024 published in the *IEA PVPS Task 1 – Trends in Photovoltaic Applications 2025* [1] with few exceptions (see section 3.9).

The differentiation between rooftop, centralised, and façade PV system yields is based on calculations and estimations as described in [56]. As such, these values provide a suitable basis for modelling country-specific PV electricity mixes for use in life cycle assessments. They are, however, not appropriate for modelling plant- or location-specific electricity generation. Where available, the use of measured or specifically simulated location- and plant-specific yield data is recommended.



Table 3: Bill of materials and panel efficiencies of monocrystalline silicon PV panels

Material		Photovoltaic module (framed / unframed)		
		mono-Si, PERC (glass-foil)	mono-Si, TOPCon (glass-glass)	
Source		IEA PVPS Task 12 2026	IEA PVPS Task 12 2026	
Laminate/unframed	<b>Subtotal wafer / semiconductor</b>		<b>3.27%</b>	<b>2.69%</b>
	Wafer / semiconductor	single-Si wafer, TOPCon / PERC	3.27%	2.69%
	<b>Subtotal metals</b>		<b>1.75%</b>	<b>1.45%</b>
	Metals	aluminium	0.25%	0.09%
		copper	1.32%	1.16%
		lead	0.04%	0.05%
		silver	0.02%	0.02%
		chromium steel	0.00%	0.00%
		tin	0.13%	0.05%
		zinc oxide	0.00%	0.00%
	<b>Subtotal plastics</b>		<b>17.23%</b>	<b>10.84%</b>
	Plastics	ethylvinylacetate	8.50%	9.21%
		polyvinylfluoride film	1.09%	0.00%
		polyethylene terephthalate, PET	3.36%	0.00%
		polyethylene, HDPE	0.23%	0.00%
		polypropylene, granulate	0.00%	0.32%
glass fibre reinforced plastic, polyamide		2.87%	0.00%	
silicone product		1.18%	1.31%	
<b>Subtotal solar glass</b>		<b>77.75%</b>	<b>85.03%</b>	
Solar glass	flat glass	0.00%	0.00%	
	solar glass	77.75%	85.03%	
<b>Subtotal chemicals</b>		<b>0.00%</b>	<b>0.00%</b>	
Chemicals	chemicals, unspecified	0.00%	0.00%	
<b>Subtotal metals panel</b>		<b>14.58%</b>	<b>9.28%</b>	
Panel frame / back rail	Metals	aluminium alloy // steel	14.58%	9.28%
<b>Total weight, framed module [kg/m<sup>2</sup>]</b>		<b>11.8</b>	<b>12.5</b>	
<b>Total weight, unframed module [kg/m<sup>2</sup>]</b>		<b>10.3</b>	<b>11.5</b>	
<b>Rated power [Wp/m<sup>2</sup>]</b>		<b>217</b>	<b>232</b>	
<b>Module efficiency [%]</b>		<b>21.7%</b>	<b>23.2%</b>	
<b>Module area for 10 kWp PV systems [m<sup>2</sup>]</b>		<b>46.0829</b>	<b>43.1</b>	
<b>Module area for 250 kWp PV systems [m<sup>2</sup>]</b>		<b>1152.1</b>	<b>1077.6</b>	
<b>Module area for 10 MW PV systems [m<sup>2</sup>]</b>		<b>46082.9</b>	<b>43103.4</b>	



Table 4: Bill of materials and panel efficiencies of CdTe PV panels based on [57; 58]

Material	CdTe First Solar Series 6	CdTe First Solar Series 7
	EPD NEPD-2993-1671	EPD NEPD-5039-4377
Glass	84.30%	79.00%
Aluminium frame	11.30%	---
Galvanized steel backrail	---	17.50%
Encapsulant	2.70%	2.70%
Frame adhesive	0.83%	0.40%
Thin film CdTe semiconductor	0.15%	0.10%
Junction box	0.13%	0.30%
<b>Total weight [kg/module]</b>	<b>34.50</b>	<b>36.80</b>
<b>Total weight [kg/m<sup>2</sup> module]</b>	<b>13.97</b>	<b>13.14</b>
<b>Module area [m<sup>2</sup>]</b>	<b>2.47</b>	<b>2.80</b>
<b>Rated power [Wp/m<sup>2</sup> module]</b>	<b>184</b>	<b>187</b>
<b>Module efficiency [%]</b>	<b>18.4%</b>	<b>18.7%</b>
<b>Module area for 10 kWp PV systems [m<sup>2</sup>]</b>	<b>54.3</b>	<b>53.5</b>
<b>Module area for 250 kWp PV systems [m<sup>2</sup>]</b>	<b>1358.7</b>	<b>1336.9</b>
<b>Module area for 10 MW PV systems [m<sup>2</sup>]</b>	<b>54347.8</b>	<b>53475.9</b>



Table 5: Country specific annual average yields. Average yields are mainly based on IEA PVPS Trends in PV Applications Report 2025 [1]. Yields of rooftop, façade and centralized are calculated following the approach suggested by Stolz & Frischknecht [56].

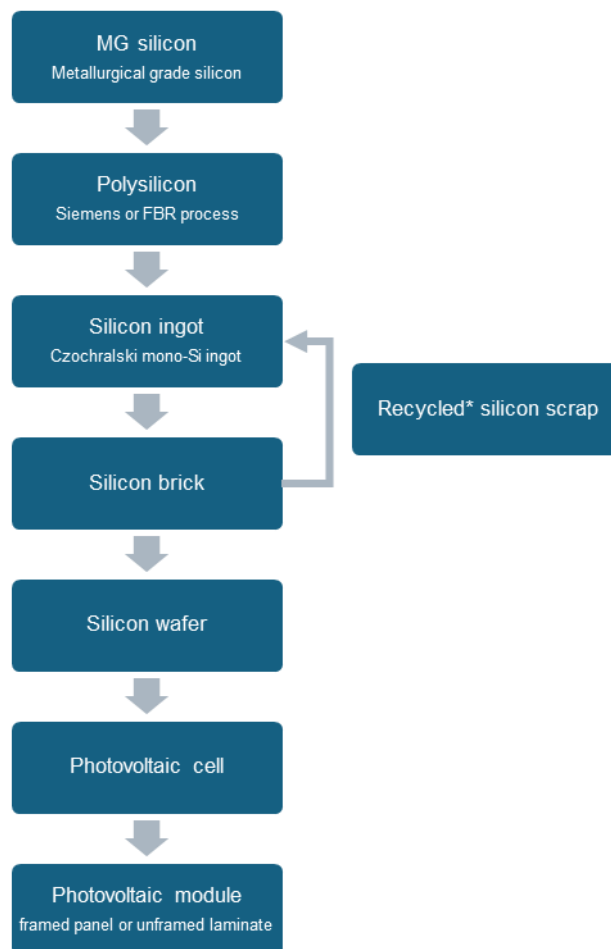
Country	Average yield	Yield rooftop	Yield façade	Yield centralized
	kWh/(kWp·a)	kWh/(kWp·a)	kWh/(kWp·a)	kWh/(kWp·a)
Australia	1400	1444	1011	1461
Austria	1050	1044	731	1111
Belgium	853	857	600	908
Brazil	1506	1474	1032	1572
Canada	1150	1107	775	1173
China	940	907	635	961
Denmark	975	957	670	1014
Finland	850	850	595	902
France	1100	1076	753	1140
Germany	933	922	645	978
Greece	1349	1323	926	1402
Hungary	1112	1090	763	1156
India	1625	1559	1091	1663
Israel	1650	1627	1139	1725
Italy	1066	1051	735	1114
Japan	1100	1078	754	1143
Korea	1261	1200	840	1272
Malaysia	1314	1266	886	1342
Netherlands	875	848	593	899
Norway	760	764	535	810
Portugal	1407	1369	958	1451
South Africa	1733	1706	1194	1808
Spain	1500	1433	1003	1519
Sweden	850	850	595	902
Switzerland	919	924	647	980
Thailand	1522	1464	1025	1552
Turkey	1471	1460	1022	1548
United Kingdom	902	884	619	937
USA	1512	1453	1017	1541
<b>World</b>	<b>1300</b>	<b>1252</b>	<b>876</b>	<b>1335</b>



## 3.2 Single-Crystalline Si PV

### 3.2.1 Description of the supply chain

Figure 6 illustrates the main process steps of the crystalline silicon photovoltaic supply chain, from the extraction of the quartz raw material and the production of metallurgical-grade silicon, through polysilicon production, ingot crystallization, wafer and cell manufacturing, to photovoltaic module assembly. Silicon scrap from ingot and brick production is fed back into the ingot production step. The supply chain is modelled for the world regions Europe (RER), China (CN), Americas, Asia & Pacific (APAC) and Middle East & Africa (MEA).



\* Depending on process details, system boundaries, and definitions such as ISO 14021 [59] / EN 45557 [60], some or all of this stream may or may not qualify as recycled material and may be better described as circulating material.

Figure 10: Supply chain of silicon-based photovoltaic panel and laminate production.

### 3.2.2 Market mixes

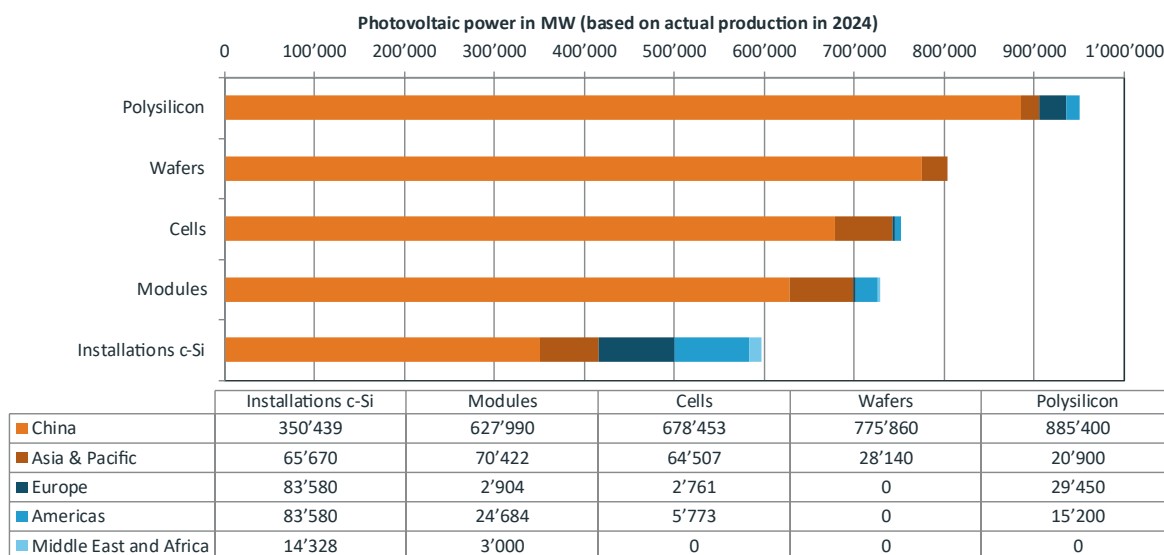
Figure 11 illustrates the market shares of five world regions across different stages of the PV supply chain in 2024. Production volumes are expressed in MW of PV power capacity. Regional market shares are derived from data reported in the 2025 publications of IEA PVPS, SolarPower Europe, and MESIA [1; 61; 62]. Polysilicon production volumes reported in metric tons are converted to MW using an average material intensity of approximately 2 tons of polysilicon per MW of installed PV capacity [1].



China accounts for the dominant share of global crystalline silicon PV production across all supply-chain stages. In 2024, China supplies approximately 93 % of global polysilicon production, 96.5 % of wafer production, 90.3 % of cell production, and 86.1 % of crystalline silicon module production.

Asia and Pacific (APAC) outside China represents the second-largest production region, accounting for about 2.2 % of polysilicon, 3.5 % of wafers, 8.6 % of cells, and 9.7 % of crystalline silicon modules produced globally. The Americas and Europe contribute comparatively small shares to global upstream production, together accounting for less than 5 % of global wafer production, about 1.2 % of cell production, and roughly 4 % of crystalline silicon module production. Module production in the MEA (Middle East and Africa) region remains limited, with a share of about 0.4 %.

In contrast to the highly concentrated production landscape, crystalline silicon PV module deployment is more geographically distributed. In 2024, 58.6 % of global crystalline silicon PV panels were installed in China, while the Americas and Europe each accounted for 14.0 % of installations. The remaining 11.0 % of installations took place in APAC outside China, and 2.4 % in the Middle East and Africa [1; 61; 62].



**Figure 11: PV supply chain market shares of world regions in 2024. Market shares are provided for polysilicon, wafer, c-Si cells and modules production. Additionally, shares in annual installed silicon-based PV panel capacity are provided.**

Table to Table present the regional market shares and resulting import volumes for each PV supply-chain stage. Columns indicate the region of use, while rows indicate the region of production. The values shown are based on a simplified calculation approach and do not necessarily represent observed import and export statistics.

It is assumed that the entire global production volume of an upstream supply-chain stage is used by the subsequent downstream stage. Accordingly, the values reported in the “Total” rows represent total regional demand, and the sum of these totals corresponds to global production. Regional demand is therefore defined by downstream production activity rather than by observed trade flows.

Regions for which zero production or demand volumes are reported at a given supply-chain stage indicate that no relevant volumes are considered for the purpose of this global balancing. This does not imply that no production exists, but rather that such production is negligible at the global scale and therefore not considered in the modelling.

Regional demand for each supply-chain product is derived from downstream production volumes, scaled by the ratio of global production at the respective upstream and downstream stages. For example, wafer demand in the Asia–Pacific region is estimated by multiplying APAC cell production by the ratio of global wafer production to global cell production.



Domestic production is first used to meet regional demand. If production exceeds demand, the surplus is assumed to be exported. If production is insufficient, the remaining demand is met through imports. When multiple regions exhibit excess production at a given supply-chain stage, imports are allocated proportionally to the exporting regions' respective surplus volumes.

Table illustrates the regional supply structure of polysilicon used in wafer production. China relies predominantly on domestic polysilicon production, while a smaller share of its demand is covered by imports originating mainly from Europe and, to a lesser extent, the Americas. In APAC, domestic polysilicon production represents the main supply source. A substantial remainder of polysilicon demand is covered by imports, roughly split between Europe and the Americas, reflecting the limited polysilicon production capacity within the region relative to its wafer manufacturing activity.

**Table 6: Supply volumes (domestic production and imports) and market mixes in 2024 of polysilicon used in wafer production in China, the Americas, Asia & Pacific, Europe and MEA (Middle East & Africa) region.**

<b>Polysilicon Production 2024</b>	<b>China</b>		<b>Asia &amp; Pacific</b>		<b>Americas</b>	<b>Europe</b>	<b>MEA</b>
	<b>MW</b>	<b>%</b>	<b>MW</b>	<b>%</b>	<b>MW</b>	<b>MW</b>	<b>MW</b>
<b>China</b>	885'400	96.5%	0	0.0%	0	0	0
<b>Asia &amp; Pacific</b>	0	0.0%	20'900	62.8%	0	0	0
<b>Americas</b>	10'984	1.2%	4'216	12.7%	0	0	0
<b>Europe</b>	21'282	2.3%	8'168	24.5%	0	0	0
<b>MEA</b>	0	0.0%	0	0.0%	0	0	0
<b>Total</b>	917'667	100.0%	33'283	100.0%	0	0	0

Table summarises the supply structure of wafers used in cell production. China acts as the central supplier of wafers across regions. In APAC, wafer demand is met through a combination of domestic production and imports from China, with imports accounting for a larger share. In contrast, wafer use in the Americas and Europe is supplied almost exclusively by imports from China, reflecting the limited relevance of local wafer production for cell manufacturing in these regions.

**Table 7: Supply volumes (domestic production and imports) and market mixes in 2024 of wafers used in cell production in China, the Americas, Asia & Pacific, Europe and MEA (Middle East & Africa) region.**

<b>Wafer Production 2024</b>	<b>China</b>		<b>Asia &amp; Pacific</b>		<b>Americas</b>		<b>Europe</b>		<b>MEA</b>	
	<b>MW</b>	<b>%</b>	<b>MW</b>	<b>%</b>	<b>MW</b>	<b>%</b>	<b>MW</b>	<b>%</b>	<b>MW</b>	<b>%</b>
<b>China</b>	725'856	100.0%	40'874	59.2%	6'176	100.0%	2'954	100.0%	0	–
<b>Asia &amp; Pacific</b>	0	0.0%	28'140	40.8%	0	0.0%	0	0.0%	0	–
<b>Americas</b>	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	–
<b>Europe</b>	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	–
<b>MEA</b>	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	–
<b>Total</b>	725'856	100.0%	69'014	100.0%	6'176	100.0%	2'954	100.0%	0	–

Table shows the regional supply structure of crystalline silicon cells used in module production. China is the dominant exporter of cells and supplies a significant share of demand in multiple regions. In APAC, most cell demand is covered by domestic production, with a smaller share imported from China. In the Americas, cell supply relies predominantly on imports from China, complemented by a limited contribution from domestic production. Europe shows a contrasting pattern, where domestic cell production covers most of the demand, while imports from China play a secondary role.



**Table 8: Supply volumes (domestic production and imports) and market mixes in 2024 of *cells* produced in China, the Americas, Asia & Pacific, Europe and MEA (Middle East & Africa) region.**

<i>c-Si Cell Production 2024</i>	China		Asia & Pacific		Americas		Europe		MEA	
	MW	%	MW	%	MW	%	MW	%	MW	%
<b>China</b>	647'367	100.0%	8'088	11.1%	19'673	77.3%	233	7.8%	3'093	100.0%
<b>Asia &amp; Pacific</b>	0	0.0%	64'507	88.9%	0	0.0%	0	0.0%	0	0.0%
<b>Americas</b>	0	0.0%	0	0.0%	5'773	22.7%	0	0.0%	0	0.0%
<b>Europe</b>	0	0.0%	0	0.0%	0	0.0%	2'761	92.2%	0	0.0%
<b>MEA</b>	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
<b>Total</b>	647'367	100.0%	72'595	100.0%	25'446	100.0%	2'994	100.0%	3'093	100.0%

Table presents the supply structure of crystalline silicon modules installed across regions. China is the dominant source of module supply globally. In APAC, module installations are largely supplied by domestic production, with imports from China covering a smaller share. In the Americas, Europe, and MEA module installations depend heavily on imports from China, while domestic production contributes only a minor share.

**Table 9: Supply volumes (domestic production and imports) and market mixes in 2024 of *modules* installed in China, the Americas, Asia & Pacific, Europe and MEA (Middle East & Africa) region.**

<i>c-Si Module Production 2024</i>	China		Asia & Pacific		Americas		Europe		MEA	
	MW	%	MW	%	MW	%	MW	%	MW	%
<b>China</b>	427'496	100.0%	9'688	12.1%	77'274	75.8%	99'054	97.2%	14'479	82.8%
<b>Asia &amp; Pacific</b>	0	0.0%	70'422	87.9%	0	0.0%	0	0.0%	0	0.0%
<b>Americas</b>	0	0.0%	0	0.0%	24'684	24.2%	0	0.0%	0	0.0%
<b>Europe</b>	0	0.0%	0	0.0%	0	0.0%	2'904	2.8%	0	0.0%
<b>MEA</b>	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3'000	17.2%
<b>Total</b>	427'496	100.0%	80'110	100.0%	101'958	100.0%	101'958	100.0%	17'479	100.0%

### 3.2.3 General approach

The PV supply chain life cycle inventory published in the previous Task 12 report [8] was updated using the inventory data described in Chapter 2. These data were derived primarily from a data base built by ADEME in the context of the French tender process and refer to selected PV module and component production lines in China for the technologies specified in section 2.1.1. Several adjustments were made to the 83 inventories to meet the objectives of this report update. These adjustments did not modify the core manufacturing processes of the components, but mainly concerned parameters such as the electricity mix selection, regional waste treatment assumptions, and water consumption datasets. The sources and assumptions related to these foreground and background flows are detailed later in the inventory descriptions.

Regionalization of the datasets was therefore implemented mainly through the application of country- or region-specific electricity supply mixes and water use datasets. Electricity consumption at all process stages is modelled using electricity mixes corresponding to the respective world regions. Water use and consumption are modelled using country-specific elementary flows, enabling a regionalized assessment of water scarcity impacts. The structuring of regional supply chains follows the market mixes described in Section 3.2.2. These market mixes determine the regional origin of inputs at each supply chain stage and are used to link the underlying inventory data to the



appropriate regional contexts. All other material and energy inputs, as well as process-related emissions, were kept unchanged across regions due to the lack of robust and representative information on regional differences in production technologies, material efficiencies, and environmental performance. For the share of consumptive water use, it was assumed that 10 % of process water and 5 % of cooling water are evaporated where not stated otherwise in the dataset comments [63].

The silicon mass flow applied in the inventories from metallurgical-grade silicon up to mono-Si wafer manufacturing including closed-loop recycling of scrap from brick cutting is displayed in Figure 12.

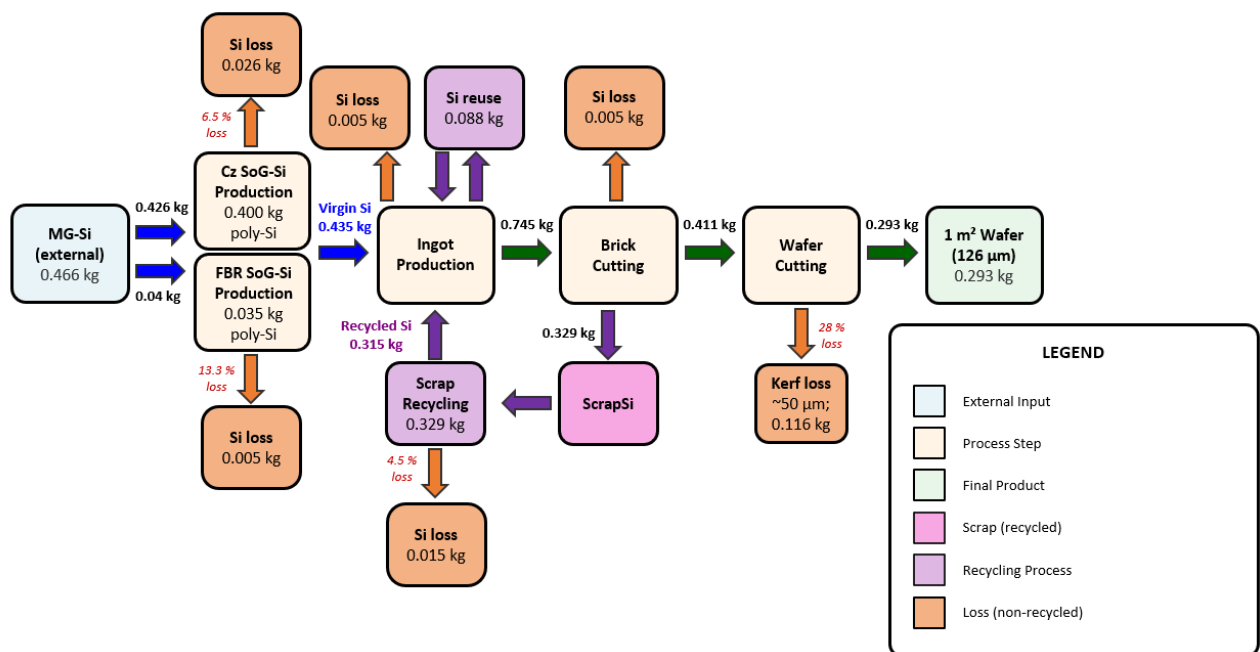


Figure 12: Silicon mass flow from metallurgical-grade silicon up to 1 m<sup>2</sup> mono-Si wafer (130μm thickness, mass = 0.295 kg) including closed-loop recycling of scrap from brick cutting

### 3.2.4 Basic silicon products

#### Basic Silicon Products

The photovoltaic supply chain begins with the extraction of high-grade quartz raw material, which is reduced to metallurgical-grade silicon (MG-Si) by carbothermic reduction. The extraction of the quartz raw material is included in the inventory through background datasets and is represented by a generic silica sand proxy. The quartz raw material extraction is of minor relevance compared to the highly energy-intensive MG-silicon production, which is dominated by furnace electricity and carbon reductants. This simplification is therefore considered acceptable. Table presents the unit process data used to model MG-silicon production for Europe, China, North America, and APAC and was not updated for this report edition. In Europe, MG-silicon production is assumed to take place predominantly in Norway, reflecting the location of the region's major production sites. Accordingly, the Norwegian electricity mix is applied. For the APAC region, the Malaysian electricity mix is used, as Malaysia represents one of the major MG-silicon producing countries in this region [64]. The US electricity mix is used to model electricity consumption in the North American production. Data about material and emissions correspond to the life cycle inventory data of MG-silicon published by Frischknecht et al. [15; 33]. Electricity consumption was updated from 11 kWh in the previous version of this report to an average demand of 12 kWh per kg of MG-silicon based on [65; 66].



Table 10: Unit process LCI data of MG-Silicon production in Europe (NO), China (CN), North America (US) and Asia & Pacific (APAC) – Not updated LCI

Name	Location	Infrastructure	Process	Unit	MG-silicon,	MG-silicon,	MG-silicon,	MG-silicon,	Uncertainty Type	Standard Deviation 95%	General Comment
					at plant {NO}	at plant {CN}	at plant {US}	at plant {APAC}			
					U	U	U	U			
	Location				NO	CN	US	APAC			
	Infrastructure				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	MG-silicon, at plant {NO} U	NO	0	kg	1	0	0	0			
	MG-silicon, at plant {CN} U	CN	0	kg	0	1	0	0			
	MG-silicon, at plant {US} U	US	0	kg	0	0	1	0			
	MG-silicon, at plant {APAC} U	APAC	0	kg	0	0	0	1			
techno-sphere	Electricity, medium voltage, at grid {NO} U	NO	0	kWh	1.20E+1	0	0	0	1	1.22	(2.2,4,1,1,3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection; Saevarsdottir et al. (2021); Takla et al. (2013)
	Electricity, medium voltage, at grid {CN} U	CN	0	kWh	0	1.20E+1	0	0	1	1.22	(2.2,4,1,1,3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection; Saevarsdottir et al. (2021); Takla et al. (2013)
	Electricity, medium voltage, at grid {US} U	US	0	kWh	0	0	1.20E+1	0	1	1.22	(2.2,4,1,1,3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection; Saevarsdottir et al. (2021); Takla et al. (2013)
	Electricity, medium voltage, at grid {MY} U	MY	0	kWh	0	0	0	1.20E+1	1	1.22	(2.2,4,1,1,3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection; Saevarsdottir et al. (2021); Takla et al. (2013)
	Wood chips, production mix, wet, measured as dry mass, at forest road & at sawmill {RER} U	RER	0	kg	3.25E-3	3.25E-3	3.25E-3	3.25E-3	1	1.22	(2.2,4,1,1,3); Literature, 1.35 kg
	Hard coal coke, at plant {RER} U	RER	0	MJ	2.31E+1	2.31E+1	2.31E+1	2.31E+1	1	1.22	(2.2,4,1,1,3); Literature, coal
	Graphite, at plant {RER} U	RER	0	kg	1.00E-1	1.00E-1	1.00E-1	1.00E-1	1	1.22	(2.2,4,1,1,3); Literature, graphite electrodes
	Charcoal, at plant {GLO} U	GLO	0	kg	1.70E-1	1.70E-1	1.70E-1	1.70E-1	1	1.22	(2.2,4,1,1,3); Literature
	Petroleum coke, at refinery {RER} U	RER	0	kg	5.00E-1	5.00E-1	5.00E-1	5.00E-1	1	1.22	(2.2,4,1,1,3); Literature
	Silica sand, at plant {DE} U	DE	0	kg	2.70E+0	2.70E+0	2.70E+0	2.70E+0	1	1.22	(2.2,4,1,1,3); Literature
	Oxygen, liquid, at plant {RER} U	RER	0	kg	2.00E-2	2.00E-2	2.00E-2	2.00E-2	1	1.60	(3,4,5,3,1,5); Literature
	Disposal, slag from MG silicon prod., 0% water, to construction waste landfill {CH} U	CH	0	kg	2.50E-2	2.50E-2	2.50E-2	2.50E-2	1	1.22	(2.2,4,1,1,3); Literature
	Silicone plant {RER} U	RER	1	p	1.00E-11	1.00E-11	1.00E-11	1.00E-11	1	3.09	(1,2,4,1,3,3); Estimation
	Transport, transoceanic freight ship {OCE} U	OCE	0	tkm	2.55E+0	2.55E+0	2.55E+0	2.55E+0	1	2.09	(4,5,na,na,na,na); Charcoal from Asia
	Transport, freight, lorry, fleet average {RER} U	RER	0	tkm	1.56E-1	1.56E-1	1.56E-1	1.56E-1	1	2.09	(4,5,na,na,na,na); Standard distance 50km, 20km for sand
	Transport, freight, rail {RER} U	RER	0	tkm	6.90E-2	6.90E-2	6.90E-2	6.90E-2	1	2.09	(4,5,na,na,na,na); Standard distance 100km
emission air, low population	Heat, waste	-	-	MJ	7.49E+1	7.49E+1	7.49E+1	7.49E+1	1	1.22	(2.2,4,1,1,3); Calculation based on fuel and electricity use minus 25 MJ/kg
	Arsenic	-	-	kg	9.42E-9	9.42E-9	9.42E-9	9.42E-9	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Aluminium	-	-	kg	1.55E-6	1.55E-6	1.55E-6	1.55E-6	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Antimony	-	-	kg	7.85E-9	7.85E-9	7.85E-9	7.85E-9	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Boron	-	-	kg	2.79E-7	2.79E-7	2.79E-7	2.79E-7	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Cadmium	-	-	kg	3.14E-10	3.14E-10	3.14E-10	3.14E-10	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Calcium	-	-	kg	7.75E-7	7.75E-7	7.75E-7	7.75E-7	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Carbon monoxide, biogenic	-	-	kg	6.20E-4	6.20E-4	6.20E-4	6.20E-4	1	5.34	(3,4,5,3,1,5); Literature
	Carbon monoxide, fossil	-	-	kg	1.38E-3	1.38E-3	1.38E-3	1.38E-3	1	5.34	(3,4,5,3,1,5); Literature
	Carbon dioxide, biogenic	-	-	kg	1.61E+0	1.61E+0	1.61E+0	1.61E+0	1	1.22	(2.2,4,1,1,3); Calculation, biogenic fuels
	Carbon dioxide, fossil	-	-	kg	3.58E+0	3.58E+0	3.58E+0	3.58E+0	1	1.22	(2.2,4,1,1,3); Calculation, fossil fuels
	Chromium	-	-	kg	7.85E-9	7.85E-9	7.85E-9	7.85E-9	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Chlorine	-	-	kg	7.85E-8	7.85E-8	7.85E-8	7.85E-8	1	1.85	(3,4,5,3,1,5); Literature
	Cyanide	-	-	kg	6.87E-6	6.87E-6	6.87E-6	6.87E-6	1	1.85	(3,4,5,3,1,5); Estimation
	Fluorine	-	-	kg	3.88E-8	3.88E-8	3.88E-8	3.88E-8	1	1.85	(3,4,5,3,1,5); Literature, in dust
	Hydrogen sulfide	-	-	kg	5.00E-4	5.00E-4	5.00E-4	5.00E-4	1	1.85	(3,4,5,3,1,5); Estimation
	Hydrogen fluoride	-	-	kg	5.00E-4	5.00E-4	5.00E-4	5.00E-4	1	1.85	(3,4,5,3,1,5); Estimation
	Iron	-	-	kg	3.88E-6	3.88E-6	3.88E-6	3.88E-6	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Lead	-	-	kg	3.44E-7	3.44E-7	3.44E-7	3.44E-7	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Mercury	-	-	kg	7.85E-9	7.85E-9	7.85E-9	7.85E-9	1	5.34	(3,4,5,3,1,5); Literature, in dust
	NMOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	9.60E-5	9.60E-5	9.60E-5	9.60E-5	1	1.85	(3,4,5,3,1,5); Literature
	Nitrogen oxides	-	-	kg	9.74E-3	9.74E-3	9.74E-3	9.74E-3	1	1.58	(3,2,4,1,1,3); Calculation based on environmental report
	Particulates, > 10 um	-	-	kg	7.75E-3	7.75E-3	7.75E-3	7.75E-3	1	1.58	(3,2,4,1,1,3); Calculation based on environmental report
	Potassium	-	-	kg	6.20E-5	6.20E-5	6.20E-5	6.20E-5	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Silicon	-	-	kg	7.51E-3	7.51E-3	7.51E-3	7.51E-3	1	5.34	(3,4,5,3,1,5); Literature, SiO2 in dust
	Sodium	-	-	kg	7.75E-7	7.75E-7	7.75E-7	7.75E-7	1	5.34	(3,4,5,3,1,5); Literature, in dust
	Sulfur dioxide	-	-	kg	1.22E-2	1.22E-2	1.22E-2	1.22E-2	1	1.24	(3,2,4,1,1,3); Calculation based on environmental report
	Tin	-	-	kg	7.85E-9	7.85E-9	7.85E-9	7.85E-9	1	5.34	(3,4,5,3,1,5); Literature, in dust



### *Solar grade silicon*

Table 11, Table, and Table present the unit process data of the production of virgin and recycled solar-grade silicon in Europe (RER), China (CN), North America (US), and APAC. Virgin solar-grade silicon production is further differentiated into the modified Siemens process and FBR production. For the APAC region, the Malaysian electricity mix and tap water datasets are applied, as Malaysia accounts for the largest share of solar-grade silicon production within APAC [1]. As no Malaysian dataset is available for deionized water inputs, the corresponding Korean dataset is used instead. Electricity consumption for North American production is modelled using the US electricity mix. Modelling of material and energy inputs, infrastructure, transports, as well as waste disposal processes, is updated based on the data compiled in the context of the French tender process, as described in Section 2.1 and 3.2. Waste heat emissions are calculated based on electricity demand, and emissions of water to air are calculated as the difference between water input and wastewater output. Emissions to water and air that were already included in the previous report were left unchanged where no new data were available. These existing emission data are based on de Wild Scholten [20]. Details on the modelling of the closed-loop silicon recycling are based on manufacturer data and are described in Section 3.2.5 on monocrystalline silicon ingot and brick production.



**Table 11: Unit process LCI data of virgin solar grade silicon production using modified Siemens process in Europe (RER), China (CN), North America (US) and Asia & Pacific (APAC)**

	Location Infrastructure Process Unit	Country	Infrastr.	Unit	process, at plant				Unit Standard		
					plant (RER) U	plant (CN) U	plant (US) U	plant (APAC) U			
					RER kg	CN kg	US kg	APAC kg			
	Silicon, solar grade, modified Siemens process, at plant (RER) U	RER	0	kg	1	0	0	0			
	Silicon, solar grade, modified Siemens process, at plant (CN) U	CN	0	kg	0	1	0	0			
	Silicon, solar grade, modified Siemens process, at plant (US) U	US	0	kg	0	0	1	0			
	Silicon, solar grade, modified Siemens process, at plant (APAC) U	APAC	0	kg	0	0	0	1			
techno- sphere	MG-silicon, at plant (NO) U	NO	0	kg	1.08E+0	0	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), MG-Si & filaments, NO iso RoW
	MG-silicon, at plant (CN) U	CN	0	kg	0	1.08E+0	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), MG-Si & filaments, CN iso RoW
	MG-silicon, at plant (US) U	US	0	kg	0	0	1.08E+0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), MG-Si & filaments, US iso RoW
	MG-silicon, at plant (APAC) U	APAC	0	kg	0	0	0	1.08E+0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), MG-Si & filaments, APAC iso RoW
techno- sphere	Hydrochloric acid, 30% in H2O, at plant (RER) U	RER	0	kg	3.31E-1	3.31E-1	3.31E-1	3.31E-1	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Sodium hydroxide, 50% in H2O, production mix, at plant (RER) U	RER	0	kg	9.60E-2	9.60E-2	9.60E-2	9.60E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Sodium chloride, powder, at plant (RER) U	RER	0	kg	1.82E-1	1.82E-1	1.82E-1	1.82E-1	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Nitrogen, liquid, at plant (RER) U	RER	0	kg	1.40E+0	1.40E+0	1.40E+0	1.40E+0	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Copper oxide, at plant (RER) U	RER	0	kg	1.85E-3	1.85E-3	1.85E-3	1.85E-3	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Graphite, at plant (RER) U	RER	0	kg	2.93E-3	2.93E-3	2.93E-3	2.93E-3	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Ethanol, 99.7% in H2O, from biomass, at distillation (RER) U	RER	0	kg	3.88E-6	3.88E-6	3.88E-6	3.88E-6	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Ethanol, 99.7% in H2O, from biomass, at distillation (CN) U	CN	0	kg	3.88E-6	3.88E-6	3.88E-6	3.88E-6	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Ethanol, 99.7% in H2O, from biomass, at distillation (US) U	US	0	kg	3.88E-6	3.88E-6	3.88E-6	3.88E-6	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
water	Water, deionised, water balance according to MoeK 2013, at plant (RER) U	RER	0	kg	5.96E+1	0	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), RER iso RoW
	Water, deionised, water balance according to MoeK 2013, at plant (CN) U	CN	0	kg	0	5.96E+1	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), CN iso RoW
	Water, deionised, water balance according to MoeK 2013, at plant (US) U	US	0	kg	0	0	5.96E+1	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), US iso RoW
	Water, deionised, water balance according to MoeK 2013, at plant (KR) U	KR	0	kg	0	0	0	5.96E+1	1	1.07	(2.1.1.2.1.1); Industry data (French tender), KR iso RoW
packaging	Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	3.40E-2	3.40E-2	3.40E-2	3.40E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	EUR-flat pallet (RER) U	RER	0	p	7.73E-4	7.73E-4	7.73E-4	7.73E-4	1	1.07	(2.1.1.2.1.1); Industry data (French tender), converted to p (1p = 25kg)
	Packaging, corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	3.09E-2	3.09E-2	3.09E-2	3.09E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Kraft paper, unbleached, at plant (RER) U	RER	0	kg	0	0	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	2.86E+0	2.86E+0	2.86E+0	2.86E+0	1	2.06	(4.5.na.na.na.na); Transport distance MG-Si: 2000 km; Chemicals: 100 km; Disposal:
	Transport, freight, rail (RER) U	RER	0	tkm	1.78E+0	1.78E+0	1.78E+0	1.78E+0	1	2.06	(4.5.na.na.na.na); Transport distance chemicals: 600 km
energy	Electricity, medium voltage, at grid (NO) U	NO	0	kWh	5.27E+1	0	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), NO iso CN
	Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0	kWh	0	0	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), ENTSO iso CN
	Electricity, medium voltage, at grid (CN) U	CN	0	kWh	0	5.27E+1	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Electricity, medium voltage, at grid (US) U	US	0	kWh	0	0	5.27E+1	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender), US iso CN
	Electricity, medium voltage, at grid (MY) U	MY	0	kWh	0	0	0	5.27E+1	1	1.07	(2.1.1.2.1.1); Industry data (French tender), VN iso CN
	District heat, at consumer, natural gas cogen 1MWth, allocation exergy (CH) U	CH	0	MJ	2.14E+1	2.14E+1	2.14E+1	2.14E+1	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
infrastruc- ture	Silicon ingot factory, steel construction, optimized fabrication (DE) U	DE	1	p	3.18E-9	3.18E-9	3.18E-9	3.18E-9	1	3.05	(2.1.1.2.1.1); Industry data (French tender), converted to silicon factory modelled by Brailovsky (2026)
	Metal working machine, unspecified, at plant (RER) U	RER	1	kg	5.62E-3	5.62E-3	5.62E-3	5.62E-3	1	3.05	(2.1.1.2.1.1); Industry data (French tender)
disposal	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	9.53E-2	9.53E-2	9.53E-2	9.53E-2	1	3.05	(2.1.1.2.1.1); Industry data (French tender), incl. PAC
	Disposal, municipal solid waste, 22.9% water, to sanitary landfill (CH) U	CH	0	kg	6.49E-1	6.49E-1	6.49E-1	6.49E-1	1	3.05	(2.1.1.2.1.1); Industry data (French tender)
	Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	8.24E-2	8.24E-2	8.24E-2	8.24E-2	1	3.05	(2.1.1.2.1.1); Industry data (French tender), incl. PAM
	Treatment, sewage, to wastewater treatment, class 2 (CH) U	CH	0	m3	5.36E-2	5.36E-2	5.36E-2	5.36E-2	1	3.05	(2.1.1.2.1.1); Industry data (French tender) or Calculation 90% of water input
emission air, high population density	Heat, waste	-	-	MJ	2.67E+2	2.67E+2	2.67E+2	2.67E+2	1	1.40	(4.4.4.3.1.5); Calculation
	Water, RER	-	-	kg	5.96E+0	0	0	0	1	1.69	(4.4.4.3.1.5); Assumption: 10% evaporation of process water; Frischnecht & Büsser Knöpfel (2013); or calculation Water Input - Waste
	Water, CN	-	-	kg	0	5.96E+0	0	0	1	1.69	(4.4.4.3.1.5); Assumption: 10% evaporation of process water; Frischnecht & Büsser Knöpfel (2013); or calculation Water Input - Waste
	Water, US	-	-	kg	0	0	5.96E+0	0	1	1.69	(4.4.4.3.1.5); Assumption: 10% evaporation of process water; Frischnecht & Büsser Knöpfel (2013); or calculation Water Input - Waste
	Water, MY	-	-	kg	0	0	0	5.96E+0	1	1.69	(4.4.4.3.1.5); Assumption: 10% evaporation of process water; Frischnecht & Büsser Knöpfel (2013); or calculation Water Input - Waste
emission water, river	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	1.26E-5	1.26E-5	1.26E-5	1.26E-5	1	1.66	(4.2.4.1.3.3); Environmental report 2002, average Si product
	BOD5, Biological Oxygen Demand	-	-	kg	2.05E-4	2.05E-4	2.05E-4	2.05E-4	1	1.66	(4.2.4.1.3.3); Environmental report 2002, average Si product
	COD, Chemical Oxygen Demand	-	-	kg	2.02E-3	2.02E-3	2.02E-3	2.02E-3	1	1.66	(4.2.4.1.3.3); Environmental report 2002, average Si product
	Chloride	-	-	kg	3.60E-2	3.60E-2	3.60E-2	3.60E-2	1	3.14	(4.2.4.1.3.3); Environmental report 2002, average Si product
	Copper	-	-	kg	1.02E-7	1.02E-7	1.02E-7	1.02E-7	1	3.14	(4.2.4.1.3.3); Environmental report 2002, average Si product
	Nitrogen	-	-	kg	2.08E-4	2.08E-4	2.08E-4	2.08E-4	1	1.66	(4.2.4.1.3.3); Environmental report 2002, average Si product
	Phosphate	-	-	kg	2.80E-6	2.80E-6	2.80E-6	2.80E-6	1	1.66	(4.2.4.1.3.3); Environmental report 2002, average Si product
	Sodium, ion	-	-	kg	3.38E-2	3.38E-2	3.38E-2	3.38E-2	1	5.16	(4.2.4.1.3.3); Environmental report 2002, average Si product
	Zinc	-	-	kg	1.96E-6	1.96E-6	1.96E-6	1.96E-6	1	5.16	(4.2.4.1.3.3); Environmental report 2002, average Si product
	Iron	-	-	kg	5.61E-6	5.61E-6	5.61E-6	5.61E-6	1	5.16	(4.2.4.1.3.3); Environmental report 2002, average Si product
	DOC, Dissolved Organic Carbon	-	-	kg	9.10E-4	9.10E-4	9.10E-4	9.10E-4	1	1.66	(4.2.4.1.3.3); Environmental report 2002, average Si product
	TOC, Total Organic Carbon	-	-	kg	9.10E-4	9.10E-4	9.10E-4	9.10E-4	1	1.66	(4.2.4.1.3.3); Environmental report 2002, average Si product







### Silicon production mix

Table 14 presents the modelling of solar-grade silicon production mixes for Europe (RER), China (CN), North America (US), and APAC. Regional mixes are modelled using the approach outlined in Section 3.2.2. In 2024, the Siemens process accounts for approximately 90 % of global solar-grade silicon production, while FBR production accounts for the remaining 10 % [14].

**Table 14: Unit process LCI data of the silicon production mixes 2024 of European production (RER), China (CN), North America (US) and Asia & Pacific (APAC)**

Product	Name	Location	Infrastructure	Process	Unit	Silicon, solar grade, production mix, photovoltaics, at regional storage (CN) U	Silicon, solar grade, production mix, photovoltaics, at regional storage (APAC) U	Silicon, solar grade, production mix, photovoltaics, at regional storage (US) U	Silicon, solar grade, production mix, photovoltaics, at regional storage (RER) U	Uncertainty Type	Standard Deviation <sup>5</sup>	General Comment
						CN	APAC	US	RER			
						0	0	0	0			
	Location											
	Infrastructure											
	Unit											
	Silicon, solar grade, production mix, photovoltaics, at regional storage (CN) U	CN	0	kg	1	0	0	0	0			
	Silicon, solar grade, production mix, photovoltaics, at regional storage (APAC) U	APAC	0	kg	0	1	0	0	0			
	Silicon, solar grade, production mix, photovoltaics, at regional storage (US) U	US	0	kg	0	0	1	0	0			
	Silicon, solar grade, production mix, photovoltaics, at regional storage (RER) U	RER	0	kg	0	0	0	0	1			
	Silicon, solar grade, modified Siemens process, at plant (CN) U	CN	0	kg	86.84%	0.00%	0.00%	0.00%	0.00%	1.00	1.11	(3,1,1,1,1,1); Market share Chinese Polysilicon
	Silicon, solar grade, modified Siemens process, at plant (APAC) U	APAC	0	kg	0.00%	56.51%	0.00%	0.00%	0.00%	1.00	1.11	(3,1,1,1,1,1); Market share APAC Polysilicon
	Silicon, solar grade, modified Siemens process, at plant (US) U	US	0	kg	1.08%	11.40%	90.00%	0.00%	0.00%	1.00	1.11	(3,1,1,1,1,1); Market share US Polysilicon
	Silicon, solar grade, modified Siemens process, at plant (RER) U	RER	0	kg	2.09%	22.09%	0.00%	90.00%	0.00%	1.00	1.11	(3,1,1,1,1,1); Market share European Polysilicon
	Silicon, solar grade, FBR, at plant (CN)	CN	0	kg	9.65%	0.00%	0.00%	0.00%	0.00%	1.00	1.11	(3,1,1,1,1,1); Market share Chinese Polysilicon
	Silicon, solar grade, FBR, at plant (APAC)	APAC	0	kg	0.00%	6.28%	0.00%	0.00%	0.00%	1.00	1.11	(3,1,1,1,1,1); Market share APAC Polysilicon
	Silicon, solar grade, FBR, at plant (US)	US	0	kg	0.12%	1.27%	10.00%	0.00%	0.00%	1.00	1.11	(3,1,1,1,1,1); Market share US Polysilicon
	Silicon, solar grade, FBR, at plant (RER)	RER	0	kg	0.23%	2.45%	0.00%	0.00%	10.00%	1.00	1.11	(3,1,1,1,1,1); Market share European Polysilicon
	Transport, transoceanic freight ship (OCE) U	OCE	0	tkm	7.12E-01	6.02E+00	0.00E+00	0.00E+00	0.00E+00	1.00	2.09	(4,5,na,na,na,na); Transport distance CN-EU: 19994 km, CN-US: 20755 km, CN-APAC: 4584 km
	Transport, freight, rail (RER) U	RER	0	tkm	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	1.00	2.09	(4,5,na,na,na,na); Standard distance 200km
	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	1.00	2.09	(4,5,na,na,na,na); Standard distance 50km

### 3.2.5 Monocrystalline silicon ingot & brick

Table 15 presents the unit process data of monocrystalline silicon N type ingot production in Europe (RER), China (CN), North America (US), and APAC region. Table 16 presents the unit process data of monocrystalline silicon brick production in the same regions. For ingot production in APAC, the Malaysian electricity mix and tap water datasets are applied, as Malaysia currently accounts for the largest share of monocrystalline silicon production within the region. For brick production in APAC, a weighted mix of Vietnamese, Thai, and Malaysian electricity mixes and tap water datasets is applied, based on their respective shares in regional wafer production [1]. Electricity consumption for North American production is modelled using the US electricity mix. Modelling of material and energy inputs, infrastructure, transports, as well as waste disposal processes, is updated based on the data compiled in the context of the French tender process, as described in Section 2.1 and 3.2. Waste heat emissions are calculated based on electricity demand, and emissions of water to air are calculated based on water consumption. Emissions to water and air that were already included in the previous report were left unchanged where no new data were available. These existing emission data are based on de Wild Scholten [35].

Silicon recycling is modelled according to a cut-off (recycled-content) approach. Scrap silicon is an output at the monocrystalline silicon brick production stage. Scrap silicon leaves the brick production process burden-free, i.e. without carrying any upstream environmental burdens from ingot or brick manufacturing (Table 16). The scrap silicon is subsequently treated in a dedicated recycled silicon process. This recycling process includes all material and energy inputs, infrastructure, waste flows, and emissions associated with the recycling operation. Details on the recycling process are provided in Table. The recycled silicon is reintroduced into the product system as an input to monocrystalline silicon ingot production (Table 15). All environmental burdens associated with the recycling operation are allocated to the recycled silicon used in ingot production, while no credits nor avoided burdens are assigned to the brick production stage generating the scrap silicon (according to cut off allocation criteria). The analysis shows an increase in the recycled silicon content compared with previous reports. As discussed in Section 2.1.1, this evolution is mainly driven by the transition toward n-type technologies and the associated changes in



dopants, which allow manufacturers to incorporate higher shares of recycled silicon while maintaining stable resistivity and meeting the target electrical specifications of the wafers.

**Table 15: Unit process LCI data of the single-crystalline silicon ingot production<sup>2</sup> in Europe (RER), China (CN), North America (US) and Asia & Pacific (APAC)**

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<sup>2</sup> Note: The share of internally recycled silicon must not be increased independently while keeping production yields and the remaining inventory flows unchanged. Any variation in the recycling rate must be accompanied by a consistent recalculation of virgin silicon input, scrap generation, recycling losses, recycling-process inputs, and saleable product output; otherwise, higher scrap generation could incorrectly appear to reduce environmental impacts.



product	Name	Location	Infrastructure	Process	Unit	CZ single crystalline silicon ingot, photovoltaic, at plant				Uncertainty Type	Standard Deviation 95%	General Comment
						RER	CN	US	APAC			
						kg	kg	kg	kg			
	CZ single crystalline silicon ingot, photovoltaic, at plant (RER)	RER	0	kg	1	0	0	0				
	CZ single crystalline silicon ingot, photovoltaic, at plant (CN)	CN	0	kg	0	1	0	0				
	CZ single crystalline silicon ingot, photovoltaic, at plant (US)	US	0	kg	0	0	1	0				
	CZ single crystalline silicon ingot, photovoltaic, at plant (APAC)	APAC	0	kg	0	0	0	1				
technosphere	Silicon, solar grade, production mix, photovoltaics, at regional storage (CN) U	CN	0	kg	0	5.84E-1	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Silicon, solar grade, production mix, photovoltaics, at regional storage (APAC) U	APAC	0	kg	0	0	0	5.84E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Silicon, solar grade, production mix, photovoltaics, at regional storage (US) U	US	0	kg	0	0	5.84E-1	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Silicon, solar grade, production mix, photovoltaics, at regional storage (RER) U	RER	0	kg	5.84E-1	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Silicon, solar grade, recycled, at plant (RER)	RER	0	kg	5.41E-1	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Silicon, solar grade, recycled, at plant (CN)	CN	0	kg	0	5.41E-1	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Silicon, solar grade, recycled, at plant (US)	US	0	kg	0	0	5.41E-1	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Silicon, solar grade, recycled, at plant (APAC)	APAC	0	kg	0	0	0	5.41E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
materials	Argon, liquid, at plant (RER) U	RER	0	kg	3.24E-1	3.24E-1	3.24E-1	3.24E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Hydrogen fluoride, at plant (GLO) U	GLO	0	kg	4.88E-4	4.88E-4	4.88E-4	4.88E-4	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Nitric acid, 50% in H2O, at plant (RER) U	RER	0	kg	3.95E-3	3.95E-3	3.95E-3	3.95E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Sodium hydroxide, 50% in H2O, production mix, at plant (RER) U	RER	0	kg	2.56E-3	2.56E-3	2.56E-3	2.56E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Ceramic tiles, at regional storage (CH) U	CH	0	kg	4.09E-2	4.09E-2	4.09E-2	4.09E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Graphite, at plant (RER) U	RER	0	kg	3.36E-3	3.36E-3	3.36E-3	3.36E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Ethanol, 99.7% in H2O, from biomass, at distillation (RER) U	RER	0	kg	3.20E-4	3.20E-4	3.20E-4	3.20E-4	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
electricity	Phosphorus, white, liquid, at plant (RER) U	RER	0	kg	1.10E-4	1.10E-4	1.10E-4	1.10E-4	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0	kWh	1.31E+1	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender), ENTSO-E iso CN	
	Electricity, medium voltage, at grid (CN) U	CN	0	kWh	0	1.31E+1	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Electricity, medium voltage, at grid (US) U	US	0	kWh	0	0	1.31E+1	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender), US iso CN	
	Electricity, medium voltage, at grid (MY) U	MY	0	kWh	0	0	0	1.31E+1	1	1.07	(2,1,1,2,1,1); Industry data (French tender), KR iso CN	
resource, in water	Tap water, water balance according to MoeK 2013, at user (RER) U	RER	0	kg	1.87E+1	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender), RER iso RoW	
	Tap water, water balance according to MoeK 2013, at user (CN) U	CN	0	kg	0	1.87E+1	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender), CN iso RoW	
	Tap water, water balance according to MoeK 2013, at user (US) U	US	0	kg	0	0	1.87E+1	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender), CN iso RoW	
	Tap water, water balance according to MoeK 2013, at user (MY) U	MY	0	kg	0	0	0	1.87E+1	1	1.07	(2,1,1,2,1,1); Industry data (French tender), US iso RoW	
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	6.94E-1	6.94E-1	6.94E-1	6.94E-1	1	2.09	(4,5,na,na,na,na); Transport distance: 100km; silicon: 1000km; Disposal: 500km	
	Transport, freight, rail (RER) U	RER	0	tkm	2.29E-1	2.29E-1	2.29E-1	2.29E-1	1	2.09	(4,5,na,na,na,na); Transport distance chemicals: 600 km	
infrastructure	Silicon ingot factory, steel construction, simulated data (DE) U	DE	1	p	5.27E-9	5.27E-9	5.27E-9	5.27E-9	1	3.00	(2,1,1,2,1,1); Industry data (French tender), converted to silicon factory modelled by Bralovsky (2026)	
	Metal working machine, unspecified, at plant (RER) U	RER	1	kg	3.67E-2	3.67E-2	3.67E-2	3.67E-2	1	3.00	(2,1,1,2,1,1); Industry data (French tender)	
disposal	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	6.45E-2	6.45E-2	6.45E-2	6.45E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Disposal, municipal solid waste, 22.9% water, to sanitary landfill (CH) U	CH	0	kg	2.23E-2	2.23E-2	2.23E-2	2.23E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	5.62E-2	5.62E-2	5.62E-2	5.62E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
	Treatment, sewage, to wastewater treatment, class 2 (CH) U	CH	0	m3	1.66E-2	1.66E-2	1.66E-2	1.66E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)	
emission air	Heat, waste	-	-	MJ	4.71E+1	4.71E+1	4.71E+1	4.71E+1	1	1.40	(4,4,4,3,1,5); calculated	
	Water, RER	-	-	kg	2.12E+0	0	0	0	1	1.69	(4,4,4,3,1,5); Calculated: Tap water input - wastewater treated	
	Water, CN	-	-	kg	0	2.12E+0	0	0	1	1.69	(4,4,4,3,1,5); Calculated: Tap water input - wastewater treated	
	Water, US	-	-	kg	0	0	2.12E+0	0	1	1.69	(4,4,4,3,1,5); Calculated: Tap water input - wastewater treated	
	Water, MY	-	-	kg	0	0	0	2.12E+0	1	1.69	(4,4,4,3,1,5); Calculated: Tap water input - wastewater treated	
	Nitrogen oxides	-	-	kg	3.39E-2	3.39E-2	3.39E-2	3.39E-2	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)	
emission water, river	Hydroxide	-	-	kg	4.42E-3	4.42E-3	4.42E-3	4.42E-3	1	3.30	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)	
	BOD5, Biological Oxygen Demand	-	-	kg	1.30E-1	1.30E-1	1.30E-1	1.30E-1	1	3.33	(5,4,4,1,1,5); Extrapolation for sum parameter	
	COD, Chemical Oxygen Demand	-	-	kg	1.30E-1	1.30E-1	1.30E-1	1.30E-1	1	3.33	(5,4,4,1,1,5); Extrapolation for sum parameter	
	DOC, Dissolved Organic Carbon	-	-	kg	4.05E-2	4.05E-2	4.05E-2	4.05E-2	1	3.33	(5,4,4,1,1,5); Extrapolation for sum parameter	
	TOC, Total Organic Carbon	-	-	kg	4.05E-2	4.05E-2	4.05E-2	4.05E-2	1	3.33	(5,4,4,1,1,5); Extrapolation for sum parameter	
	Nitrate	-	-	kg	8.35E-2	8.35E-2	8.35E-2	8.35E-2	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)	
Recycling output	Silicon scrap (used as input for silicon recycling)			kg	1.25E-1	1.25E-1	1.25E-1	1.25E-1			Closed loop recycling into product "Silicon, solar grade, recycled"	



Table 16: Unit process LCI data of the production of single-crystalline silicon brick in Europe (RER), China (CN), North America (US) and Asia & Pacific (APAC)

Name	Location	InfrastructureProcess	Unit	CZ single crystalline silicon brick, photovoltaic, at plant				UncertaintyType	StandardDeviation %	GeneralComment
				RER	CN	US	APAC			
product	Location									
	InfrastructureProcess									
	Unit									
	CZ single crystalline silicon brick, photovoltaic, at plant (RER)	RER	kg	0	0	0	0			
	CZ single crystalline silicon brick, photovoltaic, at plant (CN)	CN	kg	0	1	0	0			
	CZ single crystalline silicon brick, photovoltaic, at plant (US)	US	kg	0	0	1	0			
	CZ single crystalline silicon brick, photovoltaic, at plant (APAC)	APAC	kg	0	0	0	1			
technosphere	CZ single crystalline silicon ingot, photovoltaic, at plant (RER)	RER	kg	1.81E+0	0	0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	CZ single crystalline silicon ingot, photovoltaic, at plant (CN)	CN	kg	0	1.81E+0	0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	CZ single crystalline silicon ingot, photovoltaic, at plant (US)	US	kg	0	0	1.81E+0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	CZ single crystalline silicon ingot, photovoltaic, at plant (APAC)	APAC	kg	0	0	0	1.81E+0	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
Diamond wire	Graphite, at plant (RER) U	RER	kg	2.02E-5	2.02E-5	2.02E-5	2.02E-5	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Nickel, 99.5%, at plant (GLO) U	GLO	kg	1.05E-4	1.05E-4	1.05E-4	1.05E-4	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Steel, converter, low-alloyed, at plant (RER) U	RER	kg	3.08E-4	3.08E-4	3.08E-4	3.08E-4	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Wire drawing, steel (RER) U	RER	kg	3.08E-4	3.08E-4	3.08E-4	3.08E-4	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
materials	Polyurethane, rigid foam, at plant (RER) U	RER	kg	1.72E-4	1.72E-4	1.72E-4	1.72E-4	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Aluminium sulphate, powder, at plant (RER) U	RER	kg	1.76E-4	1.76E-4	1.76E-4	1.76E-4	1	1.07 (2.1,1.2,1.1); Industry data (French tender), proxy for polyaluminium chloride	
	Polyacrylonitrile production (PAN), by polymerisation (RER) U	RER	kg	6.48E-5	6.48E-5	6.48E-5	6.48E-5	1	1.07 (2.1,1.2,1.1); Industry data (French tender), proxy for polyacrylamide	
	Hydrochloric acid, 30% in H2O, at plant (RER) U	RER	kg	1.12E-3	1.12E-3	1.12E-3	1.12E-3	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Sodium hydroxide, 50% in H2O, production mix at plant (RER) U	RER	kg	6.20E-5	6.20E-5	6.20E-5	6.20E-5	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Graphite, at plant (RER) U	RER	kg	0	0	0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Ethanol, 99.7% in H2O, from biomass, at distillation (RER) U	RER	kg	2.64E-4	2.64E-4	2.64E-4	2.64E-4	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Phosphorus, white, liquid, at plant (RER) U	RER	kg	0	0	0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
packaging	Polyethylene, HDPE, granulate, at plant (RER) U	RER	kg	1.86E-2	1.86E-2	1.86E-2	1.86E-2	1	1.07 (2.1,1.2,1.1); Industry data (French tender), pallet + total plastic	
	EUR-flat pallet (RER) U	RER	p	1.38E-4	1.38E-4	1.38E-4	1.38E-4	1	1.07 (2.1,1.2,1.1); Industry data (French tender), converted to p (1p = 25kg)	
	Packaging, corrugated board, mixed fibre, single wall, at plant (RER) U	RER	kg	6.59E-3	6.59E-3	6.59E-3	6.59E-3	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
electricity	Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	kWh	5.66E-1	0	0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender), ENTSO-E iso CN, incl. electricity for diamond wiring	
	Electricity, medium voltage, at grid (CN) U	CN	kWh	0	5.66E-1	0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender), incl. electricity for diamond wiring	
	Electricity, medium voltage, at grid (US) U	US	kWh	0	0	5.66E-1	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender), US iso CN, incl. electricity for diamond wiring	
	Electricity, medium voltage, at grid (MY) U	MY	kWh	0	0	0	8.85E-2	1	1.07 (2.1,1.2,1.1); Industry data (French tender), KR iso CN, incl. electricity for diamond wiring	
	Electricity, medium voltage, at grid (TH) U	TH	kWh	0	0	0	7.08E-2	1	1.07 (2.1,1.2,1.1); Industry data (French tender), TH iso RoW	
	Electricity, medium voltage, at grid (VN) U	VN	kWh	0	0	0	4.07E-1	1	1.07 (2.1,1.2,1.1); Industry data (French tender), MY iso RoW	
resource, in water	Tap water, water balance according to MoeK 2013, at user (RER) U	RER	kg	5.41E+0	0	0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender), RER iso RoW	
	Tap water, water balance according to MoeK 2013, at user (CN) U	CN	kg	0	5.41E+0	0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender), CN iso RoW	
	Tap water, water balance according to MoeK 2013, at user (US) U	US	kg	0	0	5.41E+0	0	1	1.07 (2.1,1.2,1.1); Industry data (French tender), US iso RoW	
	Tap water, water balance according to MoeK 2013, at user (MY) U	MY	kg	0	0	0	8.45E-1	1	1.07 (2.1,1.2,1.1); Industry data (French tender), MY iso RoW	
	Tap water, water balance according to MoeK 2013, at user (TH) U	TH	kg	0	0	0	6.76E-1	1	1.07 (2.1,1.2,1.1); Industry data (French tender), TH iso RoW	
	Tap water, water balance according to MoeK 2013, at user (VN) U	VN	kg	0	0	0	3.89E+0	1	3.00 (4.5,na,na,na,na); Industry data (French tender), VN iso RoW	
transport	Transport, freight, lorry, fleet average (RER) U	RER	tkm	5.37E-2	5.37E-2	5.37E-2	5.37E-2	1	2.09 (4.5,na,na,na,na); Transport distance: 100km; ingots: 0km; Disposal: 500km	
	Transport, freight, rail (RER) U	RER	tkm	2.02E-2	2.02E-2	2.02E-2	2.02E-2	1	2.09 (4.5,na,na,na,na); Transport distance chemicals: 600 km	
infrastructure	Silicon ingot factory, steel construction, simulated data (DE) U	DE	p	6.31E-9	6.31E-9	6.31E-9	6.31E-9	1	3.00 (2.1,1.2,1.1); Industry data (French tender), converted to silicon factory modelled by Brailovsky (2026)	
disposal	Metal working machine, unspecified, at plant (RER) U	RER	kg	2.93E-6	2.93E-6	2.93E-6	2.93E-6	1	3.00 (2.1,1.2,1.1); Industry data (French tender)	
	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	kg	2.78E-2	2.78E-2	2.78E-2	2.78E-2	1	1.07 (2.1,1.2,1.1); Industry data (French tender), incl. PAC	
	Disposal, municipal solid waste, 22.9% water, to sanitary landfill (CH) U	CH	kg	2.21E-2	2.21E-2	2.21E-2	2.21E-2	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Disposal, waste, silicon wafer production, 0% water, to underground deposit (DE) U	DE	kg	5.08E-2	5.08E-2	5.08E-2	5.08E-2	1	1.07 (2.1,1.2,1.1); Industry data (French tender)	
	Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	kg	2.12E-3	2.12E-3	2.12E-3	2.12E-3	1	1.07 (2.1,1.2,1.1); Industry data (French tender), incl. PAM	
emission air	Treatment, sewage, to wastewater treatment, class 2 (CH) U	CH	m3	4.87E-3	4.87E-3	4.87E-3	4.87E-3	1	1.40 (4.4,4.3,1.5); Calculated: 90% of tap water	
	Heat, waste	-	MJ	2.04E+0	2.04E+0	2.04E+0	2.04E+0	1	1.40 (4.4,4.3,1.5); calculated	
	Water, RER	-	kg	5.41E-1	0	0	0	1	1.69 (4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)	
	Water, CN	-	kg	0	5.41E-1	0	0	1	1.69 (4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)	
	Water, US	-	kg	0	0	5.41E-1	0	1	1.69 (4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)	
	Water, MY	-	kg	0	0	0	8.45E-2	1	1.69 (4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)	
	Water, TH	-	kg	0	0	0	6.76E-2	1	1.69 (4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)	
	Water, VN	-	kg	0	0	0	3.89E-1	1	1.69 (4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)	
Recycling output	Silicon scrap (used as input for silicon recycling)		kg	8.00E-1	8.00E-1	8.00E-1	8.00E-1	1	0 Closed loop recycling into product "Silicon, solar grade, recycled"	



### 3.2.6 Silicon wafer production

Table 17 and Table 18 present the unit process data of single-crystalline silicon N-type wafer production in Europe (RER), China (CN), North America (US), and Asia & Pacific (APAC). The datasets represent a typical monocrystalline silicon-based N type wafer produced in the period from 2023 to 2025 collected in the context of the French tender. For wafer production in the APAC region, a weighted mix of Vietnamese, Thai, and Malaysian electricity mixes and tap water datasets is applied, based on their respective shares of single-crystalline silicon wafer production within the region [1]. Electricity consumption and tap water use for North American wafer production are modelled using the US electricity mix and tap water datasets. Data compiled in the context of the French tender process, as described in Section 2.1 and 3.2, include only data on TOPCon solar cell manufacturing. Nevertheless, these data are considered to be sufficiently representative to update the modelling of material and energy inputs, infrastructure, transports, as well as waste disposal processes, for both PERC and TOPCon cell manufacturing. According to ITRPV [14], silicon input tends to be higher in PERC cell production than in TOPCon cell production, and this difference is accounted for accordingly. The manufacturing of the diamond wire for wafer production is modelled with steel, nickel, and graphite input. Waste heat emissions are calculated based on electricity demand, and emissions of water to air are calculated based on water consumption. Emissions to water and air that were already included in the previous report were left unchanged where no new data were available. These existing emission data are based on de Wild Scholten [35].



Table 17: Unit process LCI data of the single-crystalline silicon wafer production in China (CN) and North America (US)

product	Name	Location	Infrastructure	Process	Unit	Single-Si wafer, photovoltaics, PERC, at plant (CN) U	Single-Si wafer, photovoltaics, TOPCon, at plant (CN) U	Single-Si wafer, photovoltaics, PERC, at plant (US) U	Single-Si wafer, photovoltaics, TOPCon, at plant (US) U	Uncertainty Type	Standard Deviation 5%	General Comment
						CN	CN	US	US			
						0	0	0	0			
	Location					CN	CN	US	US			
	InfrastructureProcess					0	0	0	0			
	Unit					m2	m2	m2	m2			
product	Single-Si wafer, photovoltaics, PERC, at plant (CN) U	CN	0	m2	1	0	0	0	0			
	Single-Si wafer, photovoltaics, TOPCon, at plant (CN) U	CN	0	m2	0	1	0	0	0			
	Single-Si wafer, photovoltaics, PERC, at plant (US) U	US	0	m2	0	0	1	0	0			
	Single-Si wafer, photovoltaics, TOPCon, at plant (US) U	US	0	m2	0	0	0	1	1			
	CZ single crystalline silicon brick, photovoltaic, at plant (CN)	CN	0	kg	4.43E-1	4.11E-1	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	CZ single crystalline silicon brick, photovoltaic, at plant (US)	US	0	kg	0	0	4.43E-1	4.11E-1	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
diamond Wire	Graphite, at plant (RER) U	RER	0	kg	4.36E-5	4.36E-5	4.36E-5	4.36E-5	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Diamond Wire
	Nickel, 99.5%, at plant (GLO) U	GLO	0	kg	3.82E-2	3.82E-2	3.82E-2	3.82E-2	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Diamond Wire
	Steel, low-alloyed, at plant (RER) U	RER	0	kg	1.52E-3	1.52E-3	1.52E-3	1.52E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Diamond Wire
	Wire drawing, steel (RER) U	RER	0	kg	1.52E-3	1.52E-3	1.52E-3	1.52E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Diamond Wire
materials	Polyurethane, rigid foam, at plant (RER) U	RER	0	kg	1.53E-4	1.53E-4	1.53E-4	1.53E-4	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Pulley/Wheel for diamond wiring
	Epoxy resin, liquid, at plant (RER) U	RER	0	kg	1.74E-3	1.74E-3	1.74E-3	1.74E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Glue
	Acrylonitrile-butadiene-styrene copolymer, ABS, at plant (RER) U	RER	0	kg	3.71E-2	3.71E-2	3.71E-2	3.71E-2	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Beam Plate for diamond wiring
	Chemicals inorganic, at plant (GLO) U	GLO	0	kg	1.80E-2	1.80E-2	1.80E-2	1.80E-2	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Sodium hydroxide, 50% in H2O, production mix, at plant (RER) U	RER	0	kg	3.45E-3	3.45E-3	3.45E-3	3.45E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Hydrochloric acid, 30% in H2O, at plant (RER) U	RER	0	kg	1.28E-3	1.28E-3	1.28E-3	1.28E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Acetic acid, 98% in H2O, at plant (RER) U	RER	0	kg	6.32E-3	6.32E-3	6.32E-3	6.32E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Proxy for lactic acid
	Hydrogen peroxide, 50% in H2O, at plant (RER) U	RER	0	kg	8.77E-3	8.77E-3	8.77E-3	8.77E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); "in H2O" iso "without water"
	Propylene glycol, liquid, at plant (RER) U	RER	0	kg	1.21E-2	1.21E-2	1.21E-2	1.21E-2	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Cooling liquid for diamond wiring
packaging	Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	1.04E-2	1.04E-2	1.04E-2	1.04E-2	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Pallet - plastic + Other plastic
	EUR-flat pallet (RER) U	RER	0	p	2.34E-4	2.34E-4	2.34E-4	2.34E-4	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Pallet - wood (25kg / unit)
	Packaging, corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	1.23E-2	1.23E-2	1.23E-2	1.23E-2	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Cardboard box
energy	Electricity, medium voltage, at grid (CN) U	CN	0	kWh	3.66E-2	3.66E-2	0	0	0	1	2.00	(2,1,1,2,1,1); Industry data (French tender); Diamond Wiring
	Electricity, medium voltage, at grid (CN) U	CN	0	kWh	2.22E+0	2.22E+0	0	0	0	1	2.00	(2,1,1,2,1,1); Industry data (French tender); Other Electricity
	Electricity, medium voltage, at grid (US) U	US	0	kWh	0	0	3.66E-2	3.66E-2	0	1	2.00	(2,1,1,2,1,1); Industry data (French tender); Diamond Wiring
	Electricity, medium voltage, at grid (US) U	US	0	kWh	0	0	2.22E+0	2.22E+0	0	1	2.00	(2,1,1,2,1,1); Industry data (French tender); Other Electricity
water	Tap water, water balance according to Moek 2013, at user (CN) U	CN	0	kg	1.98E+1	1.98E+1	0	0	0	1	1.06	(1,2,1,2,1,1); Industry data (French tender) CN iso RoW
	Tap water, water balance according to Moek 2013, at user (US) U	US	0	kg	0	0	1.98E+1	1.98E+1	0	1	2.00	(1,2,1,2,1,1); Industry data (French tender) US iso RoW
disposal	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	3.13E-3	3.13E-3	3.13E-3	3.13E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Disposal, municipal solid waste, 22.9% water, to sanitary landfill (CH) U	CH	0	kg	7.51E-2	7.51E-2	7.51E-2	7.51E-2	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	7.12E-3	7.12E-3	7.12E-3	7.12E-3	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Treatment, wafer fabrication effluent, to wastewater treatment, class 2 (CH) U	CH	0	m3	1.57E-2	1.57E-2	1.57E-2	1.57E-2	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	1.48E-1	1.41E-1	1.48E-1	1.41E-1	0	1	2.09	(4,5,na,na,na,na); Transport distance: 100km; silicon: 200km; disposal: 500km, weight EUR-flat pallet 25kg
	Transport, freight, rail (RER) U	RER	0	tkm	3.27E-2	3.27E-2	3.27E-2	3.27E-2	0	1	2.09	(4,5,na,na,na,na); Transport distance: 200km
infrastructure	Ancillary building, wafer factory, steel, simulated data (DE) U	DE	1	p	4.70E-10	4.70E-10	4.70E-10	4.70E-10	0	1	3.00	(2,1,1,2,1,1); Industry data (French tender) converted to ancillary building modelled by Brailovsky (2026); contains metal working machine
	Wafer factory, steel construction, simulated data (DE) U	DE	1	p	9.39E-10	9.39E-10	9.39E-10	9.39E-10	0	1	3.00	(2,1,1,2,1,1); Industry data (French tender) converted to wafer factory modelled by Brailovsky (2026); contains metal working machine
emission air	Heat, waste	-	-	MJ	8.11E+0	8.11E+0	8.11E+0	8.11E+0	0	1	1.40	(4,4,4,3,1,5); All electric energy consumed converted to heat
	Water, CN	-	-	kg	4.15E+0	4.15E+0	0	0	0	1	1.69	(4,4,4,3,1,5); Calculated: Water consumption - wastewater treated
	Water, US	-	-	kg	0	0	4.15E+0	4.15E+0	0	1	1.69	(4,4,4,3,1,5); Calculated: Water consumption - wastewater treated
emission water, river	COD, Chemical Oxygen Demand	-	-	kg	2.95E-2	2.95E-2	2.95E-2	2.95E-2	0	1	1.64	(2,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	BOD5, Biological Oxygen Demand	-	-	kg	2.95E-2	2.95E-2	2.95E-2	2.95E-2	0	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	COD, Chemical Oxygen Demand	-	-	kg	1.11E-2	1.11E-2	1.11E-2	1.11E-2	0	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	TOC, Total Organic Carbon	-	-	kg	1.11E-2	1.11E-2	1.11E-2	1.11E-2	0	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)



Table 18: Unit process LCI data of the single-crystalline silicon wafer production in Asia & Pacific (APAC) and Europe (RER)

Name	Location	Infrastructure	Process	Unit	Single-Si wafer, photovoltaics, PERC, at plant (APAC) U	Single-Si wafer, photovoltaics, TOPCon, at plant (APAC) U	Single-Si wafer, photovoltaics, PERC, at plant (RER) U	Single-Si wafer, photovoltaics, TOPCon, at plant (RER) U	Uncertainty Type	Standard Deviation 5%	General Comment
					APAC	APAC	RER	RER			
Location					APAC	APAC	RER	RER			
Infrastructure Process Unit					0 m2	0 m2	0 m2	0 m2			
Single-Si wafer, photovoltaics, PERC, at plant (APAC) U	APAC	0		m2	1	0	0	0			
Single-Si wafer, photovoltaics, TOPCon, at plant (APAC) U	APAC	0		m2	0	1	0	0			
Single-Si wafer, photovoltaics, PERC, at plant (RER) U	RER	0		m2	0	0	1	0			
Single-Si wafer, photovoltaics, TOPCon, at plant (RER) U	RER	0		m2	0	0	0	1			
CZ single crystalline silicon brick, photovoltaic, at plant (APAC)	APAC	0		kg	4.43E-1	4.11E-1	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
CZ single crystalline silicon brick, photovoltaic, at plant (RER)	RER	0		kg	0	0	4.43E-1	4.11E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
diamond Wire											
Graphite, at plant (RER) U	RER	0		kg	4.36E-5	4.36E-5	4.36E-5	4.36E-5	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Diamond Wire
Nickel, 99.5%, at plant (GLO) U	GLO	0		kg	3.82E-2	3.82E-2	3.82E-2	3.82E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Diamond Wire
Steel, low-alloyed, at plant (RER) U	RER	0		kg	1.52E-3	1.52E-3	1.52E-3	1.52E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Diamond Wire
Wire drawing, steel (RER) U	RER	0		kg	1.52E-3	1.52E-3	1.52E-3	1.52E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Diamond Wire
materials											
Polyurethane, rigid foam, at plant (RER) U	RER	0		kg	1.53E-4	1.53E-4	1.53E-4	1.53E-4	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Pulley/wheel for diamond wiring
Epoxy resin, liquid, at plant (RER) U	RER	0		kg	1.74E-3	1.74E-3	1.74E-3	1.74E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Glue
Acrylonitrile-butadiene-styrene copolymer, ABS, at plant (RER) U	RER	0		kg	3.71E-2	3.71E-2	3.71E-2	3.71E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Beam Plate for diamond wiring
Chemicals inorganic, at plant (GLO) U	GLO	0		kg	1.80E-2	1.80E-2	1.80E-2	1.80E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Sodium hydroxide, 50% in H2O, production mix, at plant (RER) U	RER	0		kg	3.45E-3	3.45E-3	3.45E-3	3.45E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Hydrochloric acid, 30% in H2O, at plant (RER) U	RER	0		kg	1.28E-3	1.28E-3	1.28E-3	1.28E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Acetic acid, 98% in H2O, at plant (RER) U	RER	0		kg	6.32E-3	6.32E-3	6.32E-3	6.32E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Proxy for lactic acid
Hydrogen peroxide, 50% in H2O, at plant (RER) U	RER	0		kg	8.77E-3	8.77E-3	8.77E-3	8.77E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender); "in H2O" iso "without water"
Propylene glycol, liquid, at plant (RER) U	RER	0		kg	1.21E-2	1.21E-2	1.21E-2	1.21E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Cooling liquid for diamond wiring
packaging											
Polyethylene, HDPE, granulate, at plant (RER) U	RER	0		kg	1.04E-2	1.04E-2	1.04E-2	1.04E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Pallet - plastic + Other plastic
EUR-flat pallet (RER) U	RER	0		p	2.34E-4	2.34E-4	2.34E-4	2.34E-4	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Pallet - wood (25kg/unit)
energy											
Packaging, corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0		kg	1.23E-2	1.23E-2	1.23E-2	1.23E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender); Cardboard box
Electricity, medium voltage, at grid (MY) U	MY	0		kWh	5.73E-3	5.73E-3	0	0	2.00	(2,1,1,2,1,1); Industry data (French tender); Diamond Wiring elec	
Electricity, medium voltage, at grid (MY) U	MY	0		kWh	3.46E-1	3.46E-1	0	0	2.00	(2,1,1,2,1,1); Industry data (French tender); Other Electricity	
Electricity, medium voltage, at grid (TH) U	TH	0		kWh	4.58E-3	4.58E-3	0	0	2.00	(2,1,1,2,1,1); Industry data (French tender); Diamond Wiring elec	
Electricity, medium voltage, at grid (TH) U	TH	0		kWh	2.77E-1	2.77E-1	0	0	2.00	(2,1,1,2,1,1); Industry data (French tender); Other Electricity	
Electricity, medium voltage, at grid (VN) U	VN	0		kWh	2.63E-2	2.63E-2	0	0	2.00	(2,1,1,2,1,1); Industry data (French tender); Diamond Wiring elec	
Electricity, medium voltage, at grid (VN) U	VN	0		kWh	1.59E+0	1.59E+0	0	0	2.00	(2,1,1,2,1,1); Industry data (French tender); Other Electricity	
Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0		kWh	0	0	3.66E-2	3.66E-2	1	2.00	(2,1,1,2,1,1); Industry data (French tender); Diamond Wiring elec
Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0		kWh	0	0	2.22E+0	2.22E+0	1	2.00	(2,1,1,2,1,1); Industry data (French tender); Other Electricity
water											
Tap water, water balance according to Moek 2013, at user (MY) U	MY	0		kg	3.10E+0	3.10E+0	0	0	2.00	(1,2,1,2,1,1); Industry data (French tender) MY iso RoW	
Tap water, water balance according to Moek 2013, at user (TH) U	TH	0		kg	2.48E+0	2.48E+0	0	0	2.00	(1,2,1,2,1,1); Industry data (French tender) TH iso RoW	
Tap water, water balance according to Moek 2013, at user (VN) U	VN	0		kg	1.42E+1	1.42E+1	0	0	2.00	(1,2,1,2,1,1); Industry data (French tender) VN iso RoW	
Tap water, water balance according to Moek 2013, at user (RER) U	RER	0		kg	0	0	1.98E+1	1.98E+1	1	1.06	(1,2,1,2,1,1); Industry data (French tender) RER iso RoW
disposal											
Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0		kg	3.13E-3	3.13E-3	3.13E-3	3.13E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Disposal, municipal solid waste, 22.9% water, to sanitary landfill (CH) U	CH	0		kg	7.51E-2	7.51E-2	7.51E-2	7.51E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0		kg	7.12E-3	7.12E-3	7.12E-3	7.12E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Treatment, wafer fabrication effluent, to wastewater treatment, class 2 (CH) U	CH	0		m3	1.57E-2	1.57E-2	1.57E-2	1.57E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
transport											
Transport, freight, lorry, fleet average (RER) U	RER	0		tkm	1.48E-1	1.41E-1	1.48E-1	1.41E-1	1	2.09	(4,5,na,na,na,na); Transport distance: 100km; silicon: 200km; disposal: 500km, weight EUR-flat pallet 25kg
Transport, freight, rail (RER) U	RER	0		tkm	3.27E-2	3.27E-2	3.27E-2	3.27E-2	1	2.09	(4,5,na,na,na,na); Transport distance: 200km
infrastructure											
Ancillary building, wafer factory, steel, simulated data (DE) U	DE	1		p	4.70E-10	4.70E-10	4.70E-10	4.70E-10	1	3.00	(2,1,1,2,1,1); Industry data (French tender) converted to ancillary building modelled by Bralovsky (2026); contains metal working machine
Wafer factory, steel construction, simulated data (DE) U	DE	1		p	9.39E-10	9.39E-10	9.39E-10	9.39E-10	1	3.00	(2,1,1,2,1,1); Industry data (French tender) converted to wafer factory modelled by Bralovsky (2026); contains metal working machine
emission air											
Heat, waste	-	-		MJ	8.11E+0	8.11E+0	8.11E+0	8.11E+0	1	1.40	(4,4,4,3,1,5); All electric energy consumed converted to heat
Water, MY	-	-		kg	6.49E-1	6.49E-1	0	0	1	1.69	(4,4,4,3,1,5); Calculated: Water consumption - wastewater treated
Water, TH	-	-		kg	5.19E-1	5.19E-1	0	0	1	1.69	(4,4,4,3,1,5); Calculated: Water consumption - wastewater treated
Water, VN	-	-		kg	2.99E+0	2.99E+0	0	0	1	1.69	(4,4,4,3,1,5); Calculated: Water consumption - wastewater treated
Water, RER	-	-		kg	0	0	4.15E+0	4.15E+0	1	1.69	(4,4,4,3,1,5); Calculated: Water consumption - wastewater treated
emission water, river											
COD, Chemical Oxygen Demand	-	-		kg	2.95E-2	2.95E-2	2.95E-2	2.95E-2	1	1.64	(2,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
BOD5, Biological Oxygen Demand	-	-		kg	2.95E-2	2.95E-2	2.95E-2	2.95E-2	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
COD, Chemical Oxygen Demand	-	-		kg	1.11E-2	1.11E-2	1.11E-2	1.11E-2	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
TOC, Total Organic Carbon	-	-		kg	1.11E-2	1.11E-2	1.11E-2	1.11E-2	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)



Table 19 presents the unit process data of silicon wafer market mixes in Europe (RER), North America (US), and Asia & Pacific (APAC), based on the market information described in Section 3.2.2. Transport distances by freight ship vary by destination region. Distances of 19'994 km, 20'755 km, and 4'584 km are assumed for transport from China (Shanghai) to Europe (Rotterdam), from China (Shanghai) to North America (New York), and from China (Shanghai) to APAC (Port Klang), respectively. In addition, 50 km of transport by lorry and 200 km of transport by train are assumed, independent of the region.

**Table 19: Unit process LCI data of the silicon wafer market mixes 2024 in Europe (RER), North America (US) and Asia & Pacific (APAC)**

	Name	Location	Infrastructure	Process	Unit	Single-Si wafer, photovoltaics, PERC, at regional storage {RER} U	Single-Si wafer, photovoltaics, TOPCon, at regional storage {RER} U	Single-Si wafer, photovoltaics, PERC, at regional storage {US} U	Single-Si wafer, photovoltaics, TOPCon, at regional storage {US} U	Single-Si wafer, photovoltaics, PERC, at regional storage {APAC} U	Single-Si wafer, photovoltaics, TOPCon, at regional storage {APAC} U	Uncertainty Type	Standard Deviation 95%	General Comment
						RER 0 m2	RER 0 m2	US 0 m2	US 0 m2	APAC 0 m2	APAC 0 m2			
product	Single-Si wafer, photovoltaics, PERC, at regional storage {RER} U	RER	0		m2	1	0	0	0	0	0			
	Single-Si wafer, photovoltaics, TOPCon, at regional storage {RER} U	RER	0		m2	0	1	0	0	0	0			
	Single-Si wafer, photovoltaics, PERC, at regional storage {US} U	US	0		m2	0	0	1	0	0	0			
	Single-Si wafer, photovoltaics, TOPCon, at regional storage {US} U	US	0		m2	0	0	0	1	0	0			
	Single-Si wafer, photovoltaics, PERC, at regional storage {APAC} U	APAC	0		m2	0	0	0	0	1	0			
	Single-Si wafer, photovoltaics, TOPCon, at regional storage {APAC} U	APAC	0		m2	0	0	0	0	0	1			
wafers	Single-Si wafer, photovoltaics, PERC, at plant {RER} U	RER	0	m2		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1	1.56	(5,1,1,1,1,5); Market share European wafers
	Single-Si wafer, photovoltaics, TOPCon, at plant {RER} U	RER	0	m2		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1	1.56	(5,1,1,1,1,5); Market share European wafers
	Single-Si wafer, photovoltaics, PERC, at plant {CN} U	CN	0	m2		100.00%	0.00%	100.00%	0.00%	59.23%	0.00%	1	1.56	(5,1,1,1,1,5); Market share Chinese wafers
	Single-Si wafer, photovoltaics, TOPCon, at plant {CN} U	CN	0	m2		0.00%	100.00%	0.00%	100.00%	0.00%	59.23%	1	1.56	(5,1,1,1,1,5); Market share Chinese wafers
	Single-Si wafer, photovoltaics, PERC, at plant {US} U	US	0	m2		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1	1.56	(5,1,1,1,1,5); Market share US wafers
	Single-Si wafer, photovoltaics, TOPCon, at plant {US} U	US	0	m2		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1	1.56	(5,1,1,1,1,5); Market share US wafers
	Single-Si wafer, photovoltaics, PERC, at plant {APAC} U	APAC	0	m2		0.00%	0.00%	0.00%	0.00%	40.77%	0.00%	1	1.56	(5,1,1,1,1,5); Market share APAC wafers
	Single-Si wafer, photovoltaics, TOPCon, at plant {APAC} U	APAC	0	m2		0.00%	0.00%	0.00%	0.00%	0.00%	40.77%	1	1.56	(5,1,1,1,1,5); Market share APAC wafers
transport	Transport, transoceanic freight ship {OCE} U	OCE	0	tkm		6.06E+0	6.52E+0	6.29E+0	6.77E+0	8.22E-1	8.86E-1	1	2.09	(4,5,na,na,na,na); Transport distance CN-EU: 19994 km, CN-US: 20755 km, CN-APAC: 4584 km
	Transport, freight, rail {RER} U	RER	0	tkm		6.06E-2	6.52E-2	6.06E-2	6.52E-2	6.06E-2	6.52E-2	1	2.09	(4,5,na,na,na,na); Standard distance 200km
	Transport, freight, lorry, fleet average {RER} U	RER	0	tkm		1.51E-2	1.63E-2	1.51E-2	1.63E-2	1.51E-2	1.63E-2	1	2.09	(4,5,na,na,na,na); Standard distance 50km



### 3.2.7 Photovoltaic cell, laminate and panel production

#### *Photovoltaic cells*

For PERC cells, the monocrystalline cell production datasets included in the previous report [15] were updated with respect to material and energy consumption based on data from ITRPV, SmartGreenScans [14; 22; 23]. For TOP-Con cells, the modelling of material and energy inputs, infrastructure, transports, as well as waste disposal processes was updated based on the data compiled from 11 TOPCON cell LCAs validated in the context of the French tender process (Table 1), as described in Section 2.1 and 3.2. Waste heat emissions are calculated based on electricity demand, and emissions of water to air are calculated based on water consumption. Emissions to water and air that were already included in the previous report were left unchanged where no new data were available. These existing emission data are based on de Wild Scholten [35].

Separate datasets are provided for TOPCon cell manufacturing using plasma-enhanced chemical vapor deposition (PECVD) and low-pressure chemical vapor deposition (LPCVD) processes. Chemical vapor deposition (CVD) processes deposit thin films on substrates through gas-phase chemical reactions and are central to silicon PV cell manufacturing. Low-pressure CVD (LPCVD) operates at reduced pressure and elevated temperatures (550–900 °C), yielding highly uniform films used for polycrystalline silicon or silicon nitride layers. Plasma-enhanced CVD (PECVD) substitutes thermal activation with RF-generated plasma, enabling deposition at lower substrate temperatures (150–400 °C) and is the industry-standard process for silicon nitride ( $\text{SiN}_x$ ) anti-reflection and surface passivation layers. Both processes use silane ( $\text{SiH}_4$ ) as the primary precursor gas, with ammonia ( $\text{NH}_3$ ) or nitrogen added depending on the target film composition.

Table 20 and Table present the unit process data of photovoltaic TOPCon cell production in Europe (RER), China (CN), North America (US), and Asia & Pacific (APAC) for PECVD- and LPCVD-based cell manufacturing. Table 22 presents the unit process data of the photovoltaic PERC cell production in Europe (RER), China (CN), North America (US) and Asia & Pacific (APAC).

For cell production in the APAC region, electricity and tap water datasets from Malaysia, Thailand, Vietnam, South Korea, Taiwan, and India are applied and weighted according to their respective shares of monocrystalline cell production within the region [1]. As no dataset of tap water provision in Taiwan is available, the corresponding amount is modelled using the Malaysian tap water dataset. The US electricity mix and tap water are chosen to model North American production.



Table 20: Unit process LCI data of the photovoltaic TOPCon cell production in China (CN) and North America (US)

Name	Location	Infrastructure	Process	Unit	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (CN) U	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (CN) U	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (US) U	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (US) U	Uncertainty Type	Standard Deviation 5%	General Comment
					CN	CN	US	US			
Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (CN) U	CN	0	m2	m2	1	0	0	0			
Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (CN) U	CN	0	m2	m2	0	1	0	0			
Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (US) U	US	0	m2	m2	0	0	1	0			
Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (US) U	US	0	m2	m2	0	0	0	1			
Single-Si wafer, photovoltaics, TOPCon, at plant (CN) U	CN	0	m2	m2	1.08E+0	1.10E+0	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Single-Si wafer, photovoltaics, TOPCon, at regional storage (US) U	US	0	m2	m2	0	0	1.08E+0	1.10E+0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
materials											
Metalization paste, front side, at plant (RER) U	RER	0	kg	kg	1.50E-3	1.87E-3	1.50E-3	1.87E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Metalization paste, back side, at plant (RER) U	RER	0	kg	kg	1.43E-3	1.47E-3	1.43E-3	1.47E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Steel, low-alloyed, at plant (RER) U	RER	0	kg	kg	4.98E-4	4.98E-4	4.98E-4	4.98E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Ethanol, 99.7% in H2O, from biomass, at distillation (RER) U	RER	0	kg	kg	3.79E-5	1.18E-3	3.79E-5	1.18E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
packaging											
Packaging, corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	kg	2.78E-2	1.96E-2	2.78E-2	1.96E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	kg	4.85E-2	1.73E-2	4.85E-2	1.73E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
EUR-flat pallet (RER) U	RER	0	p	p	4.19E-4	4.08E-4	4.19E-4	4.08E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender) 1p pallet = 25kg
chemicals											
Chemicals inorganic, at plant (GLO) U	GLO	0	kg	kg	1.22E-4	2.64E-4	1.22E-4	2.64E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender) TMA
Chemicals inorganic, at plant (GLO) U	GLO	0	kg	kg	3.01E-2	8.09E-2	3.01E-2	8.09E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender) Additive
Trichloroborane, at plant (GLO) U	GLO	0	kg	kg	7.86E-5	6.37E-3	7.86E-5	6.37E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Ammonia, liquid, at regional storehouse (RER) U	RER	0	kg	kg	1.31E-2	1.29E-2	1.31E-2	1.29E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Phosphoryl chloride, at plant (RER) U	RER	0	kg	kg	6.24E-4	0	6.24E-4	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Hydrochloric acid, 30% in H2O, at plant (RER) U	RER	0	kg	kg	3.09E-2	5.61E-2	3.09E-2	5.61E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender) in H2O iso without water
Nitric acid, 50% in H2O, at plant (RER) U	RER	0	kg	kg	0	1.12E-2	0	1.12E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Hydrogen fluoride, at plant (GLO) U	GLO	0	kg	kg	2.43E-1	2.33E-1	2.43E-1	2.33E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender) in H2O iso without water
Sodium hydroxide, 50% in H2O, mercury cell, at plant (RER) U	RER	0	kg	kg	9.47E-2	1.86E-1	9.47E-2	1.86E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Hydrogen peroxide, 50% in H2O, at plant (RER) U	RER	0	kg	kg	3.73E-1	2.98E-1	3.73E-1	2.98E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender) in H2O iso without water
Phosphane, at plant (GLO) U	GLO	0	kg	kg	0	2.24E-4	0	2.24E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Oxygen, liquid, at plant (RER) U	RER	0	kg	kg	3.08E-2	3.73E-2	3.08E-2	3.73E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Argon, liquid, at plant (RER) U	RER	0	kg	kg	1.20E-4	1.67E-3	1.20E-4	1.67E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Helium, at plant (GLO) U	GLO	0	kg	kg	0	1.61E-6	0	1.61E-6	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Nitrogen, liquid, at plant (RER) U	RER	0	kg	kg	7.11E-1	7.77E-1	7.11E-1	7.77E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
silane, at plant (RER) U	RER	0	kg	kg	4.89E-3	7.11E-3	4.89E-3	7.11E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Ammonia, liquid, at regional storehouse (RER) U	RER	0	kg	kg	6.56E-3	9.03E-3	6.56E-3	9.03E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender) proxy for nitrous oxide
water											
Tap water, water balance according to MoeK 2013, at user (CN) U	CN	0	kg	kg	1.21E+2	1.19E+2	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Tap water, water balance according to MoeK 2013, at user (US) U	US	0	kg	kg	0	0	1.21E+2	1.19E+2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
energy											
Electricity, medium voltage, at grid (CN) U	CN	0	kWh	kWh	1.66E+1	1.99E+1	0	0	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
Electricity, medium voltage, at grid (US) U	US	0	kWh	kWh	0	0	1.66E+1	1.99E+1	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
infrastructur											
Ancillary building, water factory, steel, simulated data (DE) U	DE	1	p	p	1.57E-9	7.08E-10	1.57E-9	7.08E-10	1	3.00	(2.1,1.2,1.1); Industry data (French tender) converted to ancillary building modelled by Brailovsky (2026); contains metal working machine
Cell factory, steel construction, simulated data (DE) U	DE	1	p	p	6.30E-9	2.84E-9	6.30E-9	2.84E-9	1	3.00	(2.1,1.2,1.1); Industry data (French tender) converted to cell factory modelled by Brailovsky (2026); contains metal working machine
transport											
Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	tkm	4.37E-1	4.11E-1	4.37E-1	4.11E-1	1	2.09	(4.5,na,na,na,na); Transport distance: 100km; wafer: 200km; disposal: 500km, weight EUR-flat pallet 25kg
Transport, freight, rail (RER) U	RER	0	tkm	tkm	4.34E-1	4.79E-1	4.34E-1	4.79E-1	1	2.09	(4.5,na,na,na,na); Transport distance: 200km
disposal											
Treatment, PV cell production effluent to wastewater treatment, class 3 (CH) U	CH	0	m3	m3	1.09E-1	1.07E-1	1.09E-1	1.07E-1	1	1.34	(3.4,4.3,1.5); Calculation: 90% of tap water
Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	kg	2.17E-1	1.71E-1	2.17E-1	1.71E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Disposal, municipal solid waste, 22.9% water, to sanitary landfill (CH) U	CH	0	kg	kg	4.16E-3	4.24E-4	4.16E-3	4.24E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	kg	7.59E-2	2.60E-2	7.59E-2	2.60E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
emission											
air, high population											
Heat, waste	-	-	MJ	MJ	5.97E+1	7.16E+1	5.97E+1	7.16E+1	1	1.40	(4.4,4.3,1.5); Calculation based on electricity use
Water, CN	-	-	kg	kg	1.21E+1	1.19E+1	0	0	1	1.69	(4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
Water, US	-	-	kg	kg	0	0	1.21E+1	1.19E+1	1	1.69	(4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
Aluminium	-	-	kg	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Hydrogen fluoride	-	-	kg	kg	1.38E-4	1.38E-4	1.38E-4	1.38E-4	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Lead	-	-	kg	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Silicon	-	-	kg	kg	3.17E-8	3.17E-8	3.17E-8	3.17E-8	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Silver	-	-	kg	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Tin	-	-	kg	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Ammonia	-	-	kg	kg	3.73E-5	3.73E-5	3.73E-5	3.73E-5	1	1.38	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Carbon dioxide, fossil	-	-	kg	kg	2.50E-3	3.41E-3	2.50E-3	3.41E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
Chlorine	-	-	kg	kg	4.60E-5	4.60E-5	4.60E-5	4.60E-5	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Hydrogen	-	-	kg	kg	1.10E-2	1.10E-2	1.10E-2	1.10E-2	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
2-Propanol	-	-	kg	kg	1.47E-2	1.47E-2	1.47E-2	1.47E-2	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Acetaldehyde	-	-	kg	kg	6.33E-4	6.33E-4	6.33E-4	6.33E-4	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	kg	3.12E-5	3.12E-5	3.12E-5	3.12E-5	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Silicon	-	-	kg	kg	3.33E-4	3.33E-4	3.33E-4	3.33E-4	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Silicon	-	-	kg	kg	2.63E-3	2.63E-3	2.63E-3	2.63E-3	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
NM/OC, non-methane volatile organic compounds, unspecified origin	-	-	kg	kg	1.26E-2	1.26E-2	1.26E-2	1.26E-2	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Nitrogen oxides	-	-	kg	kg	3.46E-4	5.45E-4	3.46E-4	5.45E-4	1	1.50	(2.1,1.2,1.1); Industry data (French tender)



Table 211: Unit process LCI data of the photovoltaic TOPCon cell production in Europe (RER) and Asia & Pacific (APAC)

	Name	Location	Infrastructure Processes	Unit	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (APAC) U				Uncertainty/Type	Standard Deviation 3%	General Comment
					Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (APAC) U	Photovoltaic cell, single-Si, PECVD, at plant (APAC) U	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (RER) U	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (RER) U			
					APAC	APAC	RER	RER			
	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (APAC) U	APAC	0	m2	0	0	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (APAC) U	APAC	0	m2	0	1	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (RER) U	RER	0	m2	0	0	1	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (RER) U	RER	0	m2	0	0	0	1	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Single-Si wafer, photovoltaics, TOPCon, at regional storage (APAC) U	APAC	0	m2	1.08E+0	1.10E+0	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Single-Si wafer, photovoltaics, TOPCon, at regional storage (RER) U	RER	0	m2	0	0	1.08E+0	1.10E+0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
materials	Metalization paste, front side, at plant (RER) U	RER	0	kg	1.50E-3	1.87E-3	1.50E-3	1.87E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Metalization paste, back side, at plant (RER) U	RER	0	kg	1.43E-3	1.47E-3	1.43E-3	1.47E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Steel, low-alloyed, at plant (RER) U	RER	0	kg	4.98E-4	4.98E-4	4.98E-4	4.98E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Ethanol, 99.7% in H2O, from biomass, at distillation (RER) U	RER	0	kg	3.79E-5	1.18E-3	3.79E-5	1.18E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
packaging	Packaging, corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	2.78E-2	1.96E-2	2.78E-2	1.96E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	4.85E-2	1.73E-2	4.85E-2	1.73E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender) plastic pallet + plastic total
	EUR-flat pallet (RER) U	RER	0	p	4.19E-4	4.08E-4	4.19E-4	4.08E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender) 1p pallet = 25kg
chemicals	Chemicals inorganic, at plant (GLO) U	GLO	0	kg	1.22E-4	2.64E-4	1.22E-4	2.64E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender) TMA
	Chemicals inorganic, at plant (GLO) U	GLO	0	kg	3.01E-2	8.09E-2	3.01E-2	8.09E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender) Additive
	Trichloroborane, at plant (GLO) U	GLO	0	kg	7.89E-5	6.37E-3	7.89E-5	6.37E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Ammonia, liquid, at regional storehouse (RER) U	RER	0	kg	1.31E-2	1.29E-2	1.31E-2	1.29E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Phosphoryl chloride, at plant (RER) U	RER	0	kg	6.24E-4	0	6.24E-4	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Hydrochloric acid, 30% in H2O, at plant (RER) U	RER	0	kg	3.09E-2	5.61E-2	3.09E-2	5.61E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender) in H2O iso without water
	Nitric acid, 50% in H2O, at plant (RER) U	RER	0	kg	0	1.12E-2	0	1.12E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Hydrogen fluoride, at plant (GLO) U	GLO	0	kg	2.43E-1	2.33E-1	2.43E-1	2.33E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender) in H2O iso without water
	Sodium hydroxide, 50% in H2O, mercury cell, at plant (RER) U	RER	0	kg	9.47E-2	1.86E-1	9.47E-2	1.86E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Hydrogen peroxide, 50% in H2O, at plant (RER) U	RER	0	kg	3.73E-1	2.98E-1	3.73E-1	2.98E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender) in H2O iso without water
gases	Phosphane, at plant (GLO) U	GLO	0	kg	0	2.24E-4	0	2.24E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Oxygen, liquid, at plant (RER) U	RER	0	kg	3.08E-2	3.73E-2	3.08E-2	3.73E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Argon, liquid, at plant (RER) U	RER	0	kg	1.20E-4	1.67E-3	1.20E-4	1.67E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Helium, at plant (GLO) U	GLO	0	kg	0	1.61E-6	0	1.61E-6	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Nitrogen, liquid, at plant (RER) U	RER	0	kg	7.11E-1	7.77E-1	7.11E-1	7.77E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	silane, at plant (RER) U	RER	0	kg	4.89E-3	7.11E-3	4.89E-3	7.11E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Ammonia, liquid, at regional storehouse (RER) U	RER	0	kg	6.56E-3	9.03E-3	6.56E-3	9.03E-3	1	1.07	(2.1,1.2,1.1); Industry data (French tender) proxy for nitrous oxide
water	Tap water, water balance according to MoeK 2013, at user (MY) U	MY	0	kg	4.33E+1	4.25E+1	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Tap water, water balance according to MoeK 2013, at user (TH) U	TH	0	kg	2.89E+1	2.83E+1	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Tap water, water balance according to MoeK 2013, at user (VN) U	VN	0	kg	3.03E+1	2.98E+1	0	0	1	3.00	(2.1,1.2,1.1); Industry data (French tender)
	Tap water, water balance according to MoeK 2013, at user (KR) U	KR	0	kg	8.67E+0	8.50E+0	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Tap water, water balance according to MoeK 2013, at user (IN) U	IN	0	kg	1.01E+1	1.19E+2	0	0	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Tap water, water balance according to MoeK 2013, at user (RER) U	RER	0	kg	0	0	1.21E+2	1.19E+2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
energy	Electricity, medium voltage, at grid (MY) U	MY	0	kWh	4.94E+0	5.92E+0	0	0	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019); <Si PV Manufacturing Costs 2018
	Electricity, medium voltage, at grid (TH) U	TH	0	kWh	3.95E+0	4.74E+0	0	0	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019); <Si PV Manufacturing Costs 2018
	Electricity, medium voltage, at grid (VN) U	VN	0	kWh	4.15E+0	4.97E+0	0	0	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019); <Si PV Manufacturing Costs 2018
	Electricity, medium voltage, at grid (KR) U	KR	0	kWh	1.18E+0	1.42E+0	0	0	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019); <Si PV Manufacturing Costs 2018
	Electricity, medium voltage, at grid (TW) U	TW	0	kWh	9.87E-1	1.18E+0	0	0	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019); <Si PV Manufacturing Costs 2018
	Electricity, medium voltage, at grid (IN) U	IN	0	kWh	1.38E+0	1.66E+0	0	0	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019); <Si PV Manufacturing Costs 2018
	Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0	kWh	0	0	1.66E+1	1.99E+1	1	1.07	(2.2,1.1,1.3); Woodhouse et al. (2019); <Si PV Manufacturing Costs 2018
infrastructure	Ancillary building, wafer factory, steel, simulated data (DE) U	DE	1	p	1.57E-9	7.08E-10	1.57E-9	7.08E-10	1	3.00	(2.1,1.2,1.1); Industry data (French tender) converted to ancillary building modelled by Brailovsky (2026); contains metal working machine
	Cell factory, steel construction, simulated data (DE) U	DE	1	p	6.30E-9	2.84E-9	6.30E-9	2.84E-9	1	3.00	(2.1,1.2,1.1); Industry data (French tender) converted to cell factory modelled by Brailovsky (2026); contains metal working machine
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	4.37E-1	4.11E-1	4.37E-1	4.11E-1	1	2.09	(4.5,na,na,na,na); Transport distance: 100km; wafer: 200kg; disposal: 500kg, weight EUR-flat pallet 25kg
	Transport, freight, rail (RER) U	RER	0	tkm	4.34E-1	4.79E-1	4.34E-1	4.79E-1	1	2.09	(4.5,na,na,na,na); Transport distance: 200km
disposal	Treatment, PV cell production effluent, to wastewater treatment, class 3 (CH) U	CH	0	m3	3.90E-2	3.83E-2	1.09E-1	1.07E-1	1	1.34	(3.4,3.4,1.5); Calculation: 90% of tap water
	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	2.17E-1	1.71E-1	2.17E-1	1.71E-1	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Disposal, municipal solid waste, 22.9% water, to sanitary landfill (CH) U	CH	0	kg	4.16E-3	4.24E-4	4.16E-3	4.24E-4	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
	Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	7.59E-2	2.60E-2	7.59E-2	2.60E-2	1	1.07	(2.1,1.2,1.1); Industry data (French tender)
emission air, high	Heat, waste	-	-	MJ	5.97E+1	7.16E+1	5.97E+1	7.16E+1	1	1.40	(4.4,4.3,1.5); Calculation based on electricity use
	Water, MY	-	-	kg	4.33E+0	4.25E+0	0	0	1	1.69	(4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, TH	-	-	kg	2.89E+0	2.83E+0	0	0	1	1.69	(4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, VN	-	-	kg	3.03E+0	2.98E+0	0	0	1	1.69	(4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, KR	-	-	kg	8.67E-1	8.50E-1	0	0	1	1.69	(4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, IN	-	-	kg	1.01E+0	1.19E+1	0	0	1	1.69	(4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RER	-	-	kg	0	0	1.21E+1	1.19E+1	1	1.69	(4.4,4.3,1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Aluminium	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Hydrogen fluoride	-	-	kg	1.38E-4	1.38E-4	1.38E-4	1.38E-4	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Lead	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Silicon	-	-	kg	3.17E-8	3.17E-8	3.17E-8	3.17E-8	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Silver	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Tin	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Ammonia	-	-	kg	3.73E-5	3.73E-5	3.73E-5	3.73E-5	1	1.38	(2.1,1.2,1.1); Industry data (French tender)
	Carbon dioxide, fossil	-	-	kg	2.50E-3	3.41E-3	2.50E-3	3.41E-3	1	1.07	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Chlorine	-	-	kg	4.60E-5	4.60E-5	4.60E-5	4.60E-5	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Hydrogen	-	-	kg	1.10E-2	1.10E-2	1.10E-2	1.10E-2	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	2-Propanol	-	-	kg	1.47E-2	1.47E-2	1.47E-2	1.47E-2	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Acetaldehyde	-	-	kg	6.33E-4	6.33E-4	6.33E-4	6.33E-4	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	3.12E-5	3.12E-5	3.12E-5	3.12E-5	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Silicon	-	-	kg	3.33E-4	3.33E-4	3.33E-4	3.33E-4	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Silicon	-	-	kg	2.63E-3	2.63E-3	2.63E-3	2.63E-3	1	5.11	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	MMOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	1.26E-2	1.26E-2	1.26E-2	1.26E-2	1	1.63	(2.3,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Nitrogen oxides	-	-	kg	3.46E-4	5.45E-4	3.46E-4	5.45E-4	1	1.50	(2.1,1.2,1.1); Industry data (French tender)



Table 22: Unit process LCI data of the photovoltaic PERC cell production in China (CN), North America (US), Asia & Pacific (APAC), and Europe (RER)

product	Name	Location	InfrastructureProcess	Unit	Photovoltaic cell, single-Si, PERC, at plant				Uncertainty Type	Standard Deviation %	General Comment
					CN U	US U	APAC U	RER U			
					CN	US	APAC	RER			
	Photovoltaic cell, single-Si, PERC, at plant (CN) U	CN	0	m2	1	0	0	0			
	Photovoltaic cell, single-Si, PERC, at plant (US) U	US	0	m2	0	1	0	0			
	Photovoltaic cell, single-Si, PERC, at plant (APAC) U	APAC	0	m2	0	0	1	0			
	Photovoltaic cell, single-Si, PERC, at plant (RER) U	RER	0	m2	0	0	0	1			
wafers	Single-Si wafer, photovoltaics, PERC, at plant (CN) U	CN	0	m2	1.09E+0	0	0	0	1	1.10 (2.2.4.1.1.3); Wafer input weight per m2 of cell provided by Gazbour, N. (2026)	
	Single-Si wafer, photovoltaics, PERC, at regional storage (US) U	US	0	m2	0	1.09E+0	0	0	1	1.10 (2.2.4.1.1.3); Wafer input weight per m2 of cell provided by Gazbour, N. (2026)	
	Single-Si wafer, photovoltaics, PERC, at regional storage (APAC) U	APAC	0	m2	0	0	1.09E+0	0	1	1.10 (2.2.4.1.1.3); Wafer input weight per m2 of cell provided by Gazbour, N. (2026)	
	Single-Si wafer, photovoltaics, PERC, at regional storage (RER) U	RER	0	m2	0	0	0	1.09E+0	1	1.10 (2.2.4.1.1.3); Wafer input weight per m2 of cell provided by Gazbour, N. (2026)	
materials	Metallization paste, front side, at plant (RER) U	RER	0	kg	2.59E-3	2.59E-3	2.59E-3	2.59E-3	1	1.09 (2.2.1.1.1.3); ITRPV 2023. Fig. 11	
	Metallization paste, back side, aluminium, at plant (RER) U	RER	0	kg	3.36E-2	3.36E-2	3.36E-2	3.36E-2	1	1.09 (2.2.1.1.1.3); ITRPV 2023. Fig. 13	
chemicals	Ammonia, liquid, at regional storehouse (RER) U	RER	0	kg	2.19E-2	2.19E-2	2.19E-2	2.19E-2	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Phosphoryl chloride, at plant (RER) U	RER	0	kg	1.33E-2	1.33E-2	1.33E-2	1.33E-2	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Isopropanol, at plant (RER) U	RER	0	kg	1.77E-1	1.77E-1	1.77E-1	1.77E-1	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Hydrochloric acid, 30% in H2O, at plant (RER) U	RER	0	kg	6.29E-4	6.29E-4	6.29E-4	6.29E-4	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Hydrogen fluoride, at plant (GLO) U	GLO	0	kg	6.45E-4	6.45E-4	6.45E-4	6.45E-4	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Sodium hydroxide, 50% in H2O, mercury cell, at plant (RER) U	RER	0	kg	6.04E-1	6.04E-1	6.04E-1	6.04E-1	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Lime, hydrated, packed, at plant (CH) U	CH	0	kg	1.51E-2	1.51E-2	1.51E-2	1.51E-2	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
gases	Refrigerant R134a, at plant (RER) U	RER	0	kg	3.12E-5	3.12E-5	3.12E-5	3.12E-5	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Oxygen, liquid, at plant (RER) U	RER	0	kg	0	0	0	0	1	1.05 (1.1.1.1.1.1);	
	Nitrogen, liquid, at plant (RER) U	RER	0	kg	1.15E+0	1.15E+0	1.15E+0	1.15E+0	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	silane, at plant (RER) U	RER	0	kg	2.91E-3	2.91E-3	2.91E-3	2.91E-3	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
water	Tap water, water balance according to MoeK 2013, at user (CN) U	CN	0	kg	1.71E+2	0	0	0	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Tap water, water balance according to MoeK 2013, at user (US) U	US	0	kg	0	1.71E+2	0	0	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Tap water, water balance according to MoeK 2013, at user (MY) U	MY	0	kg	0	0	6.11E+1	0	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Tap water, water balance according to MoeK 2013, at user (TH) U	TH	0	kg	0	0	4.07E+1	0	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Tap water, water balance according to MoeK 2013, at user (VN) U	VN	0	kg	0	0	4.27E+1	0	1	3.05 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Tap water, water balance according to MoeK 2013, at user (KR) U	KR	0	kg	0	0	1.22E+1	0	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Tap water, water balance according to MoeK 2013, at user (IN) U	IN	0	kg	0	0	1.42E+1	0	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Tap water, water balance according to MoeK 2013, at user (RER) U	RER	0	kg	0	0	0	1.71E+2	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
energy	Electricity, medium voltage, at grid (CN) U	CN	0	kWh	9.69E+0	0	0	0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	Electricity, medium voltage, at grid (US) U	US	0	kWh	0	9.69E+0	0	0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	Electricity, medium voltage, at grid (MY) U	MY	0	kWh	0	0	2.88E+0	0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	Electricity, medium voltage, at grid (TH) U	TH	0	kWh	0	0	2.31E+0	0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	Electricity, medium voltage, at grid (VN) U	VN	0	kWh	0	0	2.42E+0	0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	Electricity, medium voltage, at grid (KR) U	KR	0	kWh	0	0	6.92E-1	0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	Electricity, medium voltage, at grid (TW) U	TW	0	kWh	0	0	5.77E-1	0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	Electricity, medium voltage, at grid (IN) U	IN	0	kWh	0	0	8.08E-1	0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0	kWh	0	0	0	9.69E+0	1	1.09 (2.2.1.1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC cell production from 3 manufacturers.	
	District heat, at consumer, natural gas in industrial furnace 1MW (CH) U	CH	0	MJ	6.08E-2	6.08E-2	6.08E-2	6.08E-2	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
infrastructure	Photovoltaic cell factory (DE) U	DE	1	p	4.00E-7	4.00E-7	4.00E-7	4.00E-7	1	3.05 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	km	1.58E+0	1.58E+0	1.58E+0	1.58E+0	1	2.09 (4.5.na.na.na.na); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Transport, freight, rail (RER) U	RER	0	km	5.26E-1	5.26E-1	5.26E-1	5.26E-1	1	2.09 (4.5.na.na.na.na); Transport distance: 200km	
disposal	Treatment, PV cell production effluent, to wastewater treatment, class 3 (CH) U	CH	0	m3	1.54E-1	1.54E-1	1.54E-1	1.54E-1	1	1.22 (2.2.4.1.1.3); Calculation based on water withdrawal and water emissions	
	Disposal, hazardous waste, 0% water, to underground deposit (DE) U	DE	0	kg	0	0	0	0	1	1.05 (1.1.1.1.1.1);	
	Disposal, waste, Si waferprod., inorg. 9.4% water, to residual material landfill (CH) U	CH	0	kg	2.33E+0	2.33E+0	2.33E+0	2.33E+0	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	Disposal, solvents mixture, 16.5% water, to hazardous waste incineration (CH) U	CH	0	kg	1.72E-1	1.72E-1	1.72E-1	1.72E-1	1	1.22 (2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	



Table 22 (continued): Unit process LCI data of the photovoltaic PERC cell production in China (CN), North America (US), Asia & Pacific (APAC), and Europe (RER)

product	Name	Location	InfrastructureProcess	Unit	Photovoltaic cell, single-Si, PERC, at plant				UncertaintyType	StandardDeviation% %	GeneralComment
					CN U	US U	APAC U	RER U			
					0 m2	0 m2	0 m2	0 m2			
	Photovoltaic cell, single-Si, PERC, at plant (CN) U	CN	0	m2	1	0	0	0			
	Photovoltaic cell, single-Si, PERC, at plant (US) U	US	0	m2	0	1	0	0			
	Photovoltaic cell, single-Si, PERC, at plant (APAC) U	APAC	0	m2	0	0	1	0			
	Photovoltaic cell, single-Si, PERC, at plant (RER) U	RER	0	m2	0	0	0	1			
emission air, high population density	Heat, waste	-	-	MJ	5.18E+1	5.18E+1	5.18E+1	5.18E+1	1	1.22	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Water, CN	-	-	kg	1.71E+1	0	0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, US	-	-	kg	0	1.71E+1	0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, MY	-	-	kg	0	0	6.11E+0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, TH	-	-	kg	0	0	4.07E+0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, VN	-	-	kg	0	0	4.27E+0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, KR	-	-	kg	0	0	1.22E+0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, IN	-	-	kg	0	0	1.42E+0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RER	-	-	kg	0	0	0	1.71E+1	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Aluminium	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.06	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Hydrogen fluoride	-	-	kg	1.38E-4	1.38E-4	1.38E-4	1.38E-4	1	1.57	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Lead	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.06	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Silicon	-	-	kg	3.17E-8	3.17E-8	3.17E-8	3.17E-8	1	5.06	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Silver	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.06	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Tin	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.06	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Ammonia	-	-	kg	3.73E-5	3.73E-5	3.73E-5	3.73E-5	1	1.31	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Carbon dioxide, fossil	-	-	kg	1.67E-1	1.67E-1	1.67E-1	1.67E-1	1	1.22	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Chlorine	-	-	kg	4.60E-5	4.60E-5	4.60E-5	4.60E-5	1	1.57	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Hydrogen	-	-	kg	1.10E-2	1.10E-2	1.10E-2	1.10E-2	1	1.57	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	2-Propanol	-	-	kg	1.47E-2	1.47E-2	1.47E-2	1.47E-2	1	1.57	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Acetaldehyde	-	-	kg	6.33E-4	6.33E-4	6.33E-4	6.33E-4	1	1.57	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	3.12E-5	3.12E-5	3.12E-5	3.12E-5	1	1.57	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Silicon	-	-	kg	3.33E-4	3.33E-4	3.33E-4	3.33E-4	1	5.06	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	Silicon	-	-	kg	2.63E-3	2.63E-3	2.63E-3	2.63E-3	1	5.06	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	NMVO, non-methane volatile organic compounds, unspecified origin	-	-	kg	1.26E-2	1.26E-2	1.26E-2	1.26E-2	1	1.57	(2.2.4.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)



Table 23 presents the unit process data of photovoltaic cell market mixes in Europe (RER), North America (US), and Asia & Pacific (APAC), based on the market information described in Section 3.2.2. Cells used in module production in China originate from domestic production, while cell supply in Asia & Pacific (APAC) is mainly domestic and complemented by imports from China. Based on [14], the shares of low-pressure chemical vapor deposition (LPCVD) and plasma-enhanced chemical vapor deposition (PECVD) in 2024 TOPCon cell manufacturing are assumed to be evenly split.

**Table 23: Unit process LCI data of the photovoltaic cell market mix 2024 in Europe (RER), the Americas (US) and Asia & Pacific (APAC)**

product	Name	Location	Unit	Photovoltaic cell, single-Si, PERC, at regional storage						Uncertainty Type	StandardDeviation6S%	GeneralComment
				(RER) U	(RER) U	(US) U	(US) U	(APAC) U	(APAC) U			
	Location InfrastructureProcess Unit			RER	RER	US	US	APAC	APAC			
	Photovoltaic cell, single-Si, PERC, at regional storage (RER) U	RER	0 m2	1	0	0	0	0	0			
	Photovoltaic cell, single-Si, TOPCon, at regional storage (RER) U	RER	0 m2	0	1	0	0	0	0			
	Photovoltaic cell, single-Si, PERC, at regional storage (US) U	US	0 m2	0	0	1	0	0	0			
	Photovoltaic cell, single-Si, TOPCon, at regional storage (US) U	US	0 m2	0	0	0	1	0	0			
	Photovoltaic cell, single-Si, PERC, at regional storage (APAC) U	APAC	0 m2	0	0	0	0	1	0			
	Photovoltaic cell, single-Si, TOPCon, at regional storage (APAC) U	APAC	0 m2	0	0	0	0	0	1			
cells	Photovoltaic cell, single-Si, PERC, at plant (RER) U	RER	0 m2	92.23%	0.00%	0.00%	0.00%	0.00%	0.00%	1	1.30	(4,1,1,1,1,5); Market share European cells
	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (RER) U	RER	0 m2	0.00%	46.11%	0.00%	0.00%	0.00%	0.00%	1	1.30	(4,1,1,1,1,5); Market share European cells
	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (RER) U	RER	0 m2	0.00%	46.11%	0.00%	0.00%	0.00%	0.00%	1	1.30	(4,1,1,1,1,5); Market share European cells
	Photovoltaic cell, single-Si, PERC, at plant (CN) U	CN	0 m2	7.77%	0.00%	77.31%	0.00%	11.14%	0.00%	1	1.30	(4,1,1,1,1,5); Market share Chinese cells
	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (CN) U	CN	0 m2	0.00%	3.89%	0.00%	38.66%	0.00%	5.57%	1	1.30	(4,1,1,1,1,5); Market share Chinese cells
	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (CN) U	CN	0 m2	0.00%	3.89%	0.00%	38.66%	0.00%	5.57%	1	1.30	(4,1,1,1,1,5); Market share Chinese cells
	Photovoltaic cell, single-Si, PERC, at plant (US) U	US	0 m2	0.00%	0.00%	22.69%	0.00%	0.00%	0.00%	1	1.30	(4,1,1,1,1,5); Market share US cells
	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (US) U	US	0 m2	0.00%	0.00%	0.00%	11.34%	0.00%	0.00%	1	1.30	(4,1,1,1,1,5); Market share US cells
	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (US) U	US	0 m2	0.00%	0.00%	0.00%	11.34%	0.00%	0.00%	1	1.30	(4,1,1,1,1,5); Market share US cells
	Photovoltaic cell, single-Si, PERC, at plant (APAC) U	APAC	0 m2	0.00%	0.00%	0.00%	0.00%	88.86%	0.00%	1	1.30	(4,1,1,1,1,5); Market share APAC cells
	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (APAC) U	APAC	0 m2	0.00%	0.00%	0.00%	0.00%	0.00%	44.43%	1	1.30	(4,1,1,1,1,5); Market share APAC cells
	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (APAC) U	APAC	0 m2	0.00%	0.00%	0.00%	0.00%	0.00%	44.43%	1	1.30	(4,1,1,1,1,5); Market share APAC cells
transport	Transport, transoceanic freight ship (OCE) U	OCE	0 tkm	6.08E-1	5.18E-1	6.29E+0	5.35E+0	2.00E-1	1.70E-1	1	2.09	(4,5,na,na,na,na); Transport distance CN-EU: 19994 km, CN-US: 20755 km, APAC-EU: 15026 km, APAC-US: 18411 km
	Transport, freight, rail (RER) U	RER	0 tkm	7.84E-2	6.67E-2	7.84E-2	6.67E-2	7.84E-2	6.67E-2	1	2.09	(4,5,na,na,na,na); Standard distance 200km
	Transport, freight, lorry, fleet average (RER) U	RER	0 tkm	1.96E-2	1.67E-2	1.96E-2	1.67E-2	1.96E-2	1.67E-2	1	2.09	(4,5,na,na,na,na); Standard distance 50km



### *Photovoltaic laminate and panels*

Table 24, Table 25, Table 26, and Table 27 show the unit process data of the TOPCon photovoltaic laminate (glass-glass) and panel production in China (CN), North America (US), Asia & Pacific (APAC) and Europe (RER). The process data is subdivided further into monofacial and bifacial panels, as well as 60 and 72 cell panels (120 and 144 half cells). Modelling of material and energy inputs, infrastructure, transports, as well as waste disposal processes, is updated based on the data compiled in the context of the French tender process, as described in Section 2.1 and 3.2. Waste heat emissions are calculated based on electricity demand, and emissions of water to the air are calculated based on water consumption. Emissions to water and air that were already included in the previous report were left unchanged where no new data were available. These existing emission data are based on de Wild Scholten [35].

The production datasets of monocrystalline modules included in the previous report [15] were updated with respect to PERC-specific material and energy data from ITRPV [14] and SmartGreenScans [23] and IEA report on PERC LCA [67]. Table and Table 29 show the unit process data of PERC laminate and panel production. No differentiation between monofacial and bifacial panels, nor between different cell counts, is made for PERC panels. A full LCA of PERC module technology has been published in a dedicated separate report by Task 12 in 2024 [67].

A weighted mix of Malaysian, Thai, Vietnamese, Korean, Cambodian, and Indian electricity mixes and tap water datasets is applied for the APAC region, based on their respective shares in regional monocrystalline PV module production [1]. Since no datasets of the Cambodian electricity mix and tap water are available, the corresponding shares are modelled using Vietnamese datasets as proxies. North American production is modelled using the US electricity mix and tap water datasets.



Table 24: Unit process LCI data of the photovoltaic TOPCon laminate and panel production in China (CN)

	Name	Location	InfrastructureProcess	Unit	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (CN) U	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (CN) U	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (CN) U	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	UncertaintyType	StandardDeviation95%	GeneralComment
					CN	CN	CN	CN	CN			
product	Location				CN	CN	CN	CN	CN			
	InfrastructureProcess											
	Unit				m2	m2	m2	m2	m2			
	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (CN) U	CN	1	m2	1	0	0	0	0			
	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (CN) U	CN	1	m2	0	1	0	0	0			
materials	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (CN) U	CN	1	m2	0	0	1	0	0			
	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	CN	1	m2	0	0	0	1	0			
	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	CN	1	m2	0	0	0	0	1			
	Photovoltaic cell, single-Si, TOPCon, PECVD, at plant (CN) U	CN	0	m2	4.78E-1	4.69E-1	4.76E-1	4.62E-1	4.62E-1	1	1.07	(2.1.1.2.1.1); Industry data (French tender); Ratio PECVD/LPCVD acc. ITRPV (2025)
	Photovoltaic cell, single-Si, TOPCon, LPCVD, at plant (CN) U	CN	0	m2	4.78E-1	4.69E-1	4.76E-1	4.62E-1	4.62E-1	1	1.07	(2.1.1.2.1.1); Industry data (French tender); Ratio PECVD/LPCVD acc. ITRPV (2025)
	Aluminium alloy, AlMg3, at plant (RER) U	RER	0	kg	1.28E+0	1.17E+0	1.04E+0	1.09E+0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Aluminium frame
	Copper, at regional storage (RER) U	RER	0	kg	1.15E-1	1.10E-1	1.01E-1	1.02E-1	1.02E-1	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Junction Box total + Junction box connector + Interconnection Ribbons + String Ribbons
	Diode, glass-, through-hole mounting, at plant (GLO) U	GLO	0	kg	3.79E-3	3.12E-3	3.62E-3	3.87E-3	3.87E-3	1	1.07	(2.1.1.2.1.1); Industry data (French tender) junction box diode
	Silicone product, at plant (RER) U	RER	0	kg	1.52E-1	1.33E-1	1.59E-1	1.42E-1	1.42E-1	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Solder, bar, Sn63Pb37, for electronics industry, at plant (GLO) U	GLO	0	kg	1.13E-2	9.15E-3	8.32E-3	3.92E-2	3.92E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Interconnection Ribbons + String Ribbons
	Solar glass, low-iron, at regional storage (RER) U	RER	0	kg	8.18E+0	8.02E+0	9.42E+0	1.01E+1	1.01E+1	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Glass
	Polypropylene, granulate, at plant (RER) U	RER	0	kg	6.57E-2	5.18E-2	2.97E-2	4.37E-2	4.37E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Junction box plastic + Junction box connector + Strip
	Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	3.48E-1	3.45E-1	0	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender) PET
	Ethylvinylacetate, foil, at plant (RER) U	RER	0	kg	8.95E-1	1.06E+0	1.15E+0	9.63E-1	9.63E-1	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Encapsulant
	Polyvinylfluoride film, at plant (US) U	US	0	kg	3.43E-2	1.57E-2	0	0	0	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Fluoresin
Treatment	Extrusion, plastic film (RER) U	RER	0	kg	6.53E-2	5.13E-2	2.93E-2	3.86E-2	3.86E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Junction box plastic + Junction box connector
	Wire drawing, copper (RER) U	RER	0	kg	1.15E-1	1.10E-1	1.01E-1	1.02E-1	1.02E-1	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Junction box connector + Interconnection Ribbons + String Ribbons
	Tempering, flat glass (RER) U	RER	0	kg	8.18E+0	8.02E+0	9.42E+0	1.01E+1	1.01E+1	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Calculated to reflect input "tempered glass"
auxiliaries	Tap water, water balance according to MoEK 2013, at user (CN) U	CN	0	kg	8.62E+0	9.00E+0	5.99E+0	6.32E+0	6.32E+0	1	1.07	(2.1.1.2.1.1); Industry data (French tender) water
	Ethanol, 99.7% in H2O, from biomass, at distillation (CN) U	CN	0	kg	8.23E-4	1.33E-5	2.11E-4	2.58E-3	2.58E-3	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Ethanol, from biomass iso ethylene
packaging	Flux, wave soldering, at plant (GLO) U	GLO	0	kg	8.95E-3	9.14E-3	8.94E-3	8.50E-3	8.50E-3	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Soldering flux
	Kraft paper, unbleached, at plant (RER) U	RER	0	kg	9.49E-5	2.10E-2	7.72E-5	2.63E-2	2.63E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Packaging paper
	Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	9.52E-3	6.35E-5	2.14E-2	7.38E-5	7.38E-5	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Packaging plastic
	Corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	1.39E-1	1.20E-1	1.25E-1	7.91E-2	7.91E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
energy	EUR-flat pallet (RER) U	RER	0	p	1.56E-2	1.66E-2	1.81E-2	1.27E-2	1.27E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender) Weight of 1p pallet = 25kg
	Electricity, medium voltage, at grid (CN) U	CN	0	kWh	2.88E+0	3.08E+0	3.32E+0	3.04E+0	3.04E+0	1	1.07	(2.1.1.2.1.1); Industry data (French tender) converted to ancillary building modelled by Brailovsky (2026); contains metal working machine
infrastructure	Ancillary building, wafer factory, steel, simulated data (DE) U	DE	1	p	5.32E-10	5.87E-10	3.55E-10	7.68E-10	0	1	3.00	(2.1.1.2.1.1); Industry data (French tender) converted to panel factory modelled by Brailovsky (2026); contains metal working machine
	Panel factory, steel construction, simulated data (DE) U	DE	1	p	2.13E-9	2.35E-9	1.42E-9	3.08E-9	0	1	3.00	(2.1.1.2.1.1); Industry data (French tender) converted to panel factory modelled by Brailovsky (2026); contains metal working machine
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	1.16E+0	1.15E+0	1.25E+0	1.29E+0	1.33E+0	1	2.09	(4.5.na.na.na.na); Calculation, Transport distances: 100km (materials), 500km (cells), 15km (disposal)
	Transport, freight, rail (RER) U	RER	0	tkm	6.98E+0	6.89E+0	7.52E+0	7.74E+0	7.09E+0	1	2.09	(4.5.na.na.na.na); Calculation, Transport distance: 600km
disposal	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	9.29E-3	9.29E-3	1.21E-2	4.28E-3	4.28E-3	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	2.75E-3	2.38E-3	2.94E-3	1.11E-2	1.11E-2	1	1.07	(2.1.1.2.1.1); Industry data (French tender)
	Treatment, sewage, from residence, to wastewater treatment, class 2 (CH) U	CH	0	m3	7.97E-3	4.46E-3	1.61E-3	5.69E-3	5.69E-3	1	1.07	(2.1.1.2.1.1); Industry data (French tender) wastewater OR 90% of tap water
emissions air	Heat, waste	-	-	MJ	1.04E+1	1.11E+1	1.20E+1	1.10E+1	1.10E+1	1	1.40	(4.4.4.3.1.5); Calculation, electricity use
	NM/OC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.85	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	2.18E-2	2.18E-2	2.18E-2	2.18E-2	1	1.60	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Water, CN	-	-	kg	6.41E-1	4.54E+0	4.38E+0	6.32E-1	6.32E-1	1	1.69	(4.4.4.3.1.5); Calculation; Tap water - wastewater treated OR 10% of tap water



Table 25: Unit process LCI data of the photovoltaic TOPCon laminate and panel production in North America (US)

	Name	Location	InfrastructureProcess	Unit	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (US) U	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (US) U	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (US) U	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (US) U	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (US) U	Uncertainty Type	StandardDeviation5%	GeneralComment
					US	US	US	US	US			
	Location				US	US	US	US	US			
	InfrastructureProcess				1	1	1	1	1			
	Unit				m2	m2	m2	m2	m2			
	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (US) U				1	0	0	0	0			
	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (US) U				0	1	0	0	0			
	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (US) U				0	0	1	0	0			
	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (US) U				0	0	0	1	0			
	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (US) U				0	0	0	0	1			
materials	Photovoltaic cell, single-Si, TOPCon, at regional storage (US) U	US	0	m2	9.55E-1	9.37E-1	9.52E-1	9.25E-1	9.25E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Aluminium alloy, AlMg3, at plant (RER) U	RER	0	kg	1.28E+0	1.17E+0	1.04E+0	1.09E+0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Aluminium frame
	Copper, at regional storage (RER) U	RER	0	kg	1.15E-1	1.10E-1	1.01E-1	1.02E-1	1.02E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Junction Box total + Junction box connector + Interconnection Ribbons + String Ribbons
	Diode, glass-, through-hole mounting, at plant (GLO) U	GLO	0	kg	3.79E-3	3.12E-3	3.62E-3	3.87E-3	3.87E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender) junction box diode
	Silicone product, at plant (RER) U	RER	0	kg	1.52E-1	1.33E-1	1.59E-1	1.42E-1	1.42E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Solder, bar, Sn63Pb37, for electronics industry, at plant (GLO) U	GLO	0	kg	1.13E-2	9.15E-3	8.32E-3	3.92E-2	3.92E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Interconnection Ribbons + String Ribbons
	Solar glass, low-iron, at regional storage (RER) U	RER	0	kg	8.18E+0	8.02E+0	9.42E+0	1.01E+1	1.01E+1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Glass
	Polypropylene, granulate, at plant (RER) U	RER	0	kg	6.57E-2	5.18E-2	2.97E-2	4.37E-2	4.37E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Junction box plastic + Junction box connector + Strip
	Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	3.48E-1	3.45E-1	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender) PET
	Ethylvinylacetate, foil, at plant (RER) U	RER	0	kg	8.95E-1	1.06E+0	1.15E+0	9.63E-1	9.63E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Encapsulant
Treatment	Polyvinylfluoride film, at plant (US) U	US	0	kg	3.43E-2	1.57E-2	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Fluoresin
	Extrusion, plastic film (RER) U	RER	0	kg	6.53E-2	5.13E-2	2.93E-2	3.86E-2	3.86E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Junction box plastic + Junction box connector
	Wire drawing, copper (RER) U	RER	0	kg	1.15E-1	1.10E-1	1.01E-1	1.02E-1	1.02E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Junction box connector + Interconnection Ribbons + String Ribbons
	Tempering, flat glass (RER) U	RER	0	kg	8.18E+0	8.02E+0	9.42E+0	1.01E+1	1.01E+1	1	1.07	(2,1,1,2,1,1); Calculated to reflect input "tempered glass"
	Tap water, water balance according to MoeK 2013, at user (US) U	US	0	kg	8.62E+0	9.00E+0	5.99E+0	6.32E+0	6.32E+0	1	1.07	(2,1,1,2,1,1); Industry data (French tender) water
	Ethanol, 99.7% in H2O, from biomass, at distillation (CN) U	CN	0	kg	8.23E-4	1.33E-5	2.11E-4	2.58E-3	2.58E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Ethanol, from biomass iso ethylene
	Flux, wave soldering, at plant (GLO) U	GLO	0	kg	8.95E-3	9.14E-3	8.94E-3	8.50E-3	8.50E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Soldering flux
	Kraft paper, unbleached, at plant (RER) U	RER	0	kg	9.49E-5	2.10E-2	7.72E-5	2.63E-2	2.63E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Packaging paper
	Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	9.52E-3	6.35E-5	2.14E-2	7.38E-5	7.38E-5	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Packaging plastic
	Corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	1.39E-1	1.20E-1	1.25E-1	7.91E-2	7.91E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
energy	EUR-flat pallet (RER) U	RER	0	p	1.56E-2	1.66E-2	1.81E-2	1.27E-2	1.27E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Weight of 1p pallet = 25kg
	Electricity, medium voltage, at grid	US	0	kWh	2.88E+0	3.08E+0	3.32E+0	3.04E+0	3.04E+0	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
infrastructure	Ancillary building, water factory, steel, simulated data (DE) U	DE	1	p	5.32E-10	5.87E-10	3.55E-10	7.68E-10	0	1	3.00	(2,1,1,2,1,1); Industry data (French tender) converted to ancillary building modelled by Brailovsky (2026); contains metal working machine
	Panel factory, steel construction, simulated data (DE) U	DE	1	p	2.13E-9	2.35E-9	1.42E-9	3.08E-9	0	1	3.00	(2,1,1,2,1,1); Industry data (French tender) converted to panel factory modelled by Brailovsky (2026); contains metal working machine
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	1.16E+0	1.15E+0	1.25E+0	1.29E+0	1.33E+0	1	2.09	(4,5,na,na,na,na); Calculation, Transport distances: 100km (materials), 500km (cells), 15km (disposal)
	Transport, freight, rail (RER) U	RER	0	tkm	6.98E+0	6.89E+0	7.52E+0	7.74E+0	7.09E+0	1	2.09	(4,5,na,na,na,na); Calculation, Transport distance: 600km
disposal	Disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	9.29E-3	9.29E-3	1.21E-2	4.28E-3	4.28E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Disposal, hazardous waste, 25% water, to hazardous waste	CH	0	kg	2.75E-3	2.38E-3	2.94E-3	1.11E-2	1.11E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
	Treatment, sewage, from residence, to wastewater treatment, class 2 (CH)	CH	0	m3	7.97E-3	4.46E-3	1.61E-3	5.69E-3	5.69E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender) wastewater OR 90% of tap water
emissions air	Heat, waste	-	-	MJ	1.04E+1	1.11E+1	1.20E+1	1.10E+1	1.10E+1	1	1.40	(4,4,4,3,1,5); Calculation, electricity use
	NM/OC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	2.18E-2	2.18E-2	2.18E-2	2.18E-2	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Water, US	-	-	kg	6.41E-1	4.54E+0	4.38E+0	6.32E-1	6.32E-1	1	1.69	(4,4,4,3,1,5); Calculation: Tap water - wastewater treated OR 10% of tap water



Table 26: Unit process LCI data of the photovoltaic TOPCon laminate and panel production in Asia & Pacific (APAC)

Name	Location	Infrastructure	Process	Unit	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (APAC) U	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (APAC) U	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (APAC) U	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (APAC) U	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (APAC) U	Uncertainty/Type	Standard/Deviation/5%	General/Comment
					APAC	APAC	APAC	APAC	APAC			
					1 m2	1 m2	1 m2	1 m2	1 m2			
Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (US) U	US	1	m2	0	0	0	0	0				
Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (APAC) U	APAC	1	m2	1	0	0	0	0				
Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (APAC) U	APAC	1	m2	0	1	0	0	0				
Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (APAC) U	APAC	1	m2	0	0	1	0	0				
Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (APAC) U	APAC	1	m2	0	0	0	1	0				
Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (APAC) U	APAC	1	m2	0	0	0	0	1				
Photovoltaic cell, single-Si, TOPCon, at regional storage (APAC) U	APAC	0	m2	9.55E-1	9.37E-1	9.52E-1	9.25E-1	9.25E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Aluminium alloy, AlMg3, at plant (RER) U	RER	0	kg	1.28E+0	1.17E+0	1.04E+0	1.09E+0	0	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Aluminium frame
Copper, at regional storage (RER) U	RER	0	kg	1.15E-1	1.10E-1	1.01E-1	1.02E-1	1.02E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Junction Box total + Junction box connector + Interconnection Ribbons + String Ribbons
Diode, glass-, through-hole mounting, at plant (GLO) U	GLO	0	kg	3.79E-3	3.12E-3	3.62E-3	3.87E-3	3.87E-3	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) junction box diode
Silicone product, at plant (RER) U	RER	0	kg	1.52E-1	1.33E-1	1.59E-1	1.42E-1	1.42E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Solder, bar, Sn63Pb37, for electronics industry, at plant (GLO) U	GLO	0	kg	1.13E-2	9.15E-3	8.32E-3	3.92E-2	3.92E-2	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Interconnection Ribbons + String Ribbons
Solar glass, low-iron, at regional storage (RER) U	RER	0	kg	8.18E+0	8.02E+0	9.42E+0	1.01E+1	1.01E+1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Glass
Polypropylene, granulate, at plant (RER) U	RER	0	kg	6.57E-2	5.18E-2	2.97E-2	4.37E-2	4.37E-2	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Junction box plastic + Junction box connector + Strip
Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	3.48E-1	3.45E-1	0	0	0	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) PET
Ethylvinylacetate, foil, at plant (RER) U	RER	0	kg	8.95E-1	1.06E+0	1.15E+0	9.63E-1	9.63E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Encapsulant
Polyvinylfluoride film, at plant (US) U	US	0	kg	3.43E-2	1.57E-2	0	0	0	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Fluoresin
Extrusion, plastic film (RER) U	RER	0	kg	6.53E-2	5.13E-2	2.93E-2	3.86E-2	3.86E-2	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Junction box plastic + Junction box connector
Wire drawing, copper (RER) U	RER	0	kg	1.15E-1	1.10E-1	1.01E-1	1.02E-1	1.02E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Junction box connector + Interconnection Ribbons + String Ribbons
Tempering, flat glass (RER) U	RER	0	kg	8.18E+0	8.02E+0	9.42E+0	1.01E+1	1.01E+1	1	1.07	(2.1,1.2,1,1);	Calculated to reflect input "tempered glass"
Tap water, water balance according to MoeK 2013, at user (MY) U	MY	0	kg	9.07E-1	9.47E-1	6.31E-1	6.65E-1	6.65E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) water
Tap water, water balance according to MoeK 2013, at user (TH) U	TH	0	kg	1.36E+0	1.42E+0	9.46E-1	9.98E-1	9.98E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) water
Tap water, water balance according to MoeK 2013, at user (VN) U	VN	0	kg	2.90E+0	2.90E+0	2.90E+0	2.90E+0	2.90E+0	1	3.00	(2.1,1.2,1,1);	Industry data (French tender) water
Tap water, water balance according to MoeK 2013, at user (KR) U	KR	0	kg	4.53E-1	4.74E-1	3.15E-1	3.33E-1	3.33E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) water
Tap water, water balance according to MoeK 2013, at user (IN) U	IN	0	kg	2.99E+0	3.13E+0	2.08E+0	2.20E+0	2.20E+0	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) water
Ethanol, 99.7% in H2O, from biomass, at distillation (CN) U	CN	0	kg	8.23E-4	1.33E-5	2.11E-4	2.58E-3	2.58E-3	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Ethanol, from biomass iso ethylene
Flux, wave soldering, at plant (GLO) U	GLO	0	kg	8.95E-3	9.14E-3	8.94E-3	8.50E-3	8.50E-3	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Soldering flux
Kraft paper, unbleached, at plant (RER) U	RER	0	kg	9.49E-5	2.10E-2	7.72E-5	2.63E-2	2.63E-2	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Packaging paper
Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	9.52E-3	6.35E-5	2.14E-2	7.38E-5	7.38E-5	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Packaging plastic
Corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	1.39E-1	1.20E-1	1.25E-1	7.91E-2	7.91E-2	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
EUR-flat pallet (RER) U	RER	0	p	1.56E-2	1.66E-2	1.81E-2	1.27E-2	1.27E-2	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) Weight of 1p pallet = 25kg
Electricity, medium voltage, at grid (US) U	US	0	kWh	0	0	0	0	0	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Electricity, medium voltage, at grid (MY) U	MY	0	kWh	3.03E-1	3.24E-1	3.50E-1	3.20E-1	3.20E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Electricity, medium voltage, at grid (TH) U	TH	0	kWh	4.55E-1	4.86E-1	5.24E-1	4.80E-1	4.80E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Electricity, medium voltage, at grid (VN) U	VN	0	kWh	2.90E+0	2.90E+0	2.90E+0	2.90E+0	2.90E+0	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Electricity, medium voltage, at grid (KR) U	KR	0	kWh	1.52E-1	1.62E-1	1.75E-1	1.60E-1	1.60E-1	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Electricity, medium voltage, at grid (IN) U	IN	0	kWh	1.00E+0	1.07E+0	1.15E+0	1.06E+0	1.06E+0	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Ancillary building, water factory, steel, simulated data (DE) U	DE	1	p	5.32E-10	5.87E-10	3.55E-10	7.68E-10	0	1	3.00	(2.1,1.2,1,1);	Industry data (French tender) converted to ancillary building modelled by Brailovsky (2026); contains metal working machine
Panel factory, steel construction, simulated data (DE) U	DE	1	p	2.13E-9	2.35E-9	1.42E-9	3.08E-9	0	1	3.00	(2.1,1.2,1,1);	Industry data (French tender) converted to panel factory modelled by Brailovsky (2026); contains metal working machine
Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	1.16E+0	1.15E+0	1.25E+0	1.29E+0	1.33E+0	1	2.09	(4.5,na,na,na,na);	Calculation, Transport distances: 100km (materials), 500km (cells), 15km (disposal)
Transport, freight, rail (RER) U	RER	0	tkm	6.98E+0	6.89E+0	7.52E+0	7.74E+0	7.09E+0	1	2.09	(4.5,na,na,na,na);	Calculation, Transport distance: 600km
Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	9.29E-3	9.29E-3	1.21E-2	4.28E-3	4.28E-3	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	2.75E-3	2.38E-3	2.94E-3	1.11E-2	1.11E-2	1	1.07	(2.1,1.2,1,1);	Industry data (French tender)
Treatment, sewage, from residence, to wastewater treatment, class 2 (CH) U	CH	0	m3	7.97E-3	4.46E-3	1.61E-3	5.69E-3	5.69E-3	1	1.07	(2.1,1.2,1,1);	Industry data (French tender) wastewater OR 90% of tap water
Heat, waste	-	-	MJ	1.04E+1	1.11E+1	1.20E+1	1.10E+1	1.77E+1	1	1.40	(4.4,4.3,1,5);	Calculation, electricity use
NM VOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.85	(3.4,5.3,1,5);	de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Carbon dioxide, fossil	-	-	kg	2.18E-2	2.18E-2	2.18E-2	2.18E-2	2.18E-2	1	1.60	(3.4,5.3,1,5);	de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Water, MY	-	-	kg	6.74E-2	4.77E-1	4.62E-1	6.65E-2	6.65E-2	1	1.69	(4.4,4.3,1,5);	Calculation: Tap water - wastewater treated OR 10% of tap water
Water, TH	-	-	kg	1.01E-1	7.16E-1	6.92E-1	9.98E-2	9.98E-2	1	1.69	(4.4,4.3,1,5);	Calculation: Tap water - wastewater treated OR 10% of tap water
Water, VN	-	-	kg	2.90E+0	2.90E+0	2.90E+0	2.90E+0	2.90E+0	1	1.69	(4.4,4.3,1,5);	Calculation: Tap water - wastewater treated OR 10% of tap water
Water, KR	-	-	kg	3.37E-2	2.39E-1	2.31E-1	3.33E-2	3.33E-2	1	1.69	(4.4,4.3,1,5);	Calculation: Tap water - wastewater treated OR 10% of tap water
Water, IN	-	-	kg	2.23E-1	1.58E+0	1.52E+0	2.20E-1	2.20E-1	1	1.69	(4.4,4.3,1,5);	Calculation: Tap water - wastewater treated OR 10% of tap water



Table 27: Unit process LCI data of the photovoltaic TOPCon laminate and panel production in Europe (RER)

Name	Location	Infrastructure	Process	Unit	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (RER) U	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (RER) U	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (RER) U	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (RER) U	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (RER) U	Uncertainty Type	Standard Deviation 95%	General Comment
					RER	RER	RER	RER	RER			
Location												
Infrastructure												
Unit					1	1	1	1	1			
					m2	m2	m2	m2	m2			
Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (RER) U	RER	1		m2	1	0	0	0	0			
Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (RER) U	RER	1		m2	0	1	0	0	0			
Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (RER) U	RER	1		m2	0	0	1	0	0			
Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (RER) U	RER	1		m2	0	0	0	1	0			
Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (RER) U	RER	1		m2	0	0	0	0	1			
Photovoltaic cell, single-Si, TOPCon, at regional storage (RER) U	RER	0		m2	9.55E-1	9.37E-1	9.52E-1	9.25E-1	9.25E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Aluminium alloy, AlMg3, at plant (RER) U	RER	0		kg	1.28E+0	1.17E+0	1.04E+0	1.09E+0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Aluminium frame
Copper, at regional storage (RER) U	RER	0		kg	1.15E-1	1.10E-1	1.01E-1	1.02E-1	1.02E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Junction Box total + Junction box connector + Interconnection Ribbons + String Ribbons
Diode, glass-, through-hole mounting, at plant (GLO) U	GLO	0		kg	3.79E-3	3.12E-3	3.62E-3	3.87E-3	3.87E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender) junction box diode
Silicone product, at plant (RER) U	RER	0		kg	1.52E-1	1.33E-1	1.59E-1	1.42E-1	1.42E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Solder, bar, Sn63Pb37, for electronics industry, at plant (GLO) U	GLO	0		kg	1.13E-2	9.15E-3	8.32E-3	3.92E-2	3.92E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Interconnection Ribbons + String Ribbons
Solar glass, low-iron, at regional storage (RER) U	RER	0		kg	8.18E+0	8.02E+0	9.42E+0	1.01E+1	1.01E+1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Glass
Polypropylene, granulate, at plant (RER) U	RER	0		kg	6.57E-2	5.18E-2	2.97E-2	4.37E-2	4.37E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Junction box plastic + Junction box connector + Strip
Polyethylene, HDPE, granulate, at plant (RER) U	RER	0		kg	3.48E-1	3.45E-1	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender) PET
Ethylvinylacetate, foil, at plant (RER) U	RER	0		kg	8.95E-1	1.06E+0	1.15E+0	9.63E-1	9.63E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Encapsulant
Polyvinylfluoride film, at plant (US) U	US	0		kg	3.43E-2	1.57E-2	0	0	0	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Fluoresin
Extrusion, plastic film (RER) U	RER	0		kg	6.53E-2	5.13E-2	2.93E-2	3.86E-2	3.86E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Junction box plastic + Junction box connector
Wire drawing, copper (RER) U	RER	0		kg	1.15E-1	1.10E-1	1.01E-1	1.02E-1	1.02E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Junction box connector + Interconnection Ribbons + String Ribbons
Tempering, flat glass (RER) U	RER	0		kg	8.18E+0	8.02E+0	9.42E+0	1.01E+1	1.01E+1	1	1.07	(2,1,1,2,1,1); Calculated to reflect input "tempered glass"
Tap water, water balance according to MoeK 2013, at user (RER) U	RER	0		kg	9.07E-1	9.47E-1	6.31E-1	6.65E-1	6.65E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender) water
Ethanol, 99.7% in H2O, from biomass, at distillation (CN) U	CN	0		kg	8.23E-4	1.33E-5	2.11E-4	2.58E-3	2.58E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Ethanol, from biomass iso ethylene
Flux, wave soldering, at plant (GLO) U	GLO	0		kg	8.95E-3	9.14E-3	8.94E-3	8.50E-3	8.50E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Soldering flux
Kraft paper, unbleached, at plant (RER) U	RER	0		kg	9.49E-5	2.10E-2	7.72E-5	2.63E-2	2.63E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Packaging paper
Polyethylene, HDPE, granulate, at plant (RER) U	RER	0		kg	9.52E-3	6.35E-5	2.14E-2	7.38E-5	7.38E-5	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Packaging plastic
Corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0		kg	1.39E-1	1.20E-1	1.25E-1	7.91E-2	7.91E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
EUR-flat pallet (RER) U	RER	0		p	1.56E-2	1.66E-2	1.81E-2	1.27E-2	1.27E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender) Weight of 1p pallet = 25kg
Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0		kWh	3.03E-1	3.24E-1	3.50E-1	3.20E-1	3.20E-1	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Ancillary building, wafer factory, steel, simulated data (DE) U	DE	1		p	5.32E-10	5.87E-10	3.55E-10	7.68E-10	0	1	3.00	(2,1,1,2,1,1); Industry data (French tender) converted to ancillary building modelled by Brailovsky (2026); contains metal working machine
Panel factory, steel construction, simulated data (DE) U	DE	1		p	2.13E-9	2.35E-9	1.42E-9	3.08E-9	0	1	3.00	(2,1,1,2,1,1); Industry data (French tender) converted to panel factory modelled by Brailovsky (2026); contains metal working machine
Transport, freight, lorry, fleet average (RER) U	RER	0		tkm	1.16E+0	1.15E+0	1.25E+0	1.29E+0	1.33E+0	1	2.09	(4,5,na,na,na,na); Calculation, Transport distances: 100km (materials), 500km (cells), 15km (disposal)
Transport, freight, rail (RER) U	RER	0		tkm	6.98E+0	6.89E+0	7.52E+0	7.74E+0	7.07E+0	1	2.09	(4,5,na,na,na,na); Calculation, Transport distance: 600km
Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0		kg	9.29E-3	9.29E-3	1.21E-2	4.28E-3	4.28E-3	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0		kg	2.75E-3	2.38E-3	2.94E-3	1.11E-2	1.11E-2	1	1.07	(2,1,1,2,1,1); Industry data (French tender)
Treatment, sewage, from residence, to wastewater treatment, class 2 (CH) U	CH	0		m3	7.97E-3	4.46E-3	1.61E-3	5.69E-3	5.99E-4	1	1.07	(2,1,1,2,1,1); Industry data (French tender) wastewater OR 90% of tap water
Heat, waste	-	-		MJ	1.04E+1	1.11E+1	1.20E+1	1.10E+1	1.15E+0	1	1.40	(4,4,4,3,1,5); Calculation, electricity use
NM VOC, non-methane volatile organic compounds, unspecified origin	-	-		kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.85	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Carbon dioxide, fossil	-	-		kg	2.18E-2	2.18E-2	2.18E-2	2.18E-2	2.18E-2	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Water, RER	-	-		kg	6.74E-2	4.77E-1	4.62E-1	6.65E-2	6.65E-2	1	1.69	(4,4,4,3,1,5); Calculation: Tap water - wastewater treated OR 10% of tap water



Table 28: Unit process LCI data of the photovoltaic PERC laminate and panel production in China (CN) and North America (US)

Name	Location	Infrastructure	Process	Unit	Photovoltaic panel, single-Si, PERC, at plant				Uncertainty Type	Standard Deviation @ 95%	General Comment
					CN U	CN U	US U	US U			
	Location				CN	CN	US	US			
	Infrastructure				1	1	1	1			
	Process				m2	m2	m2	m2			
product	Photovoltaic panel, single-Si, PERC, at plant (CN) U	CN	1	m2	1	0	0	0			
	Photovoltaic laminate, single-Si, PERC, at plant (CN) U	CN	1	m2	0	1	0	0			
	Photovoltaic panel, single-Si, PERC, at plant (US) U	US	1	m2	0	0	1	0			
	Photovoltaic laminate, single-Si, PERC, at plant (US) U	US	1	m2	0	0	0	1			
materials	Photovoltaic cell, single-Si, PERC, at plant (CN) U	CN	0	m2	9.40E-1	9.40E-1	0	0	1	1.24	(1.4.4.3.1.3); Calculated for a PV module with 108 half-cut cells, M10 format (0.182 m * 0.182 m); cell breakage rate of 2.5 % according to de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Photovoltaic cell, single-Si, PERC, at regional storage (US) U	US	0	m2	0	0	9.40E-1	9.40E-1	1	1.24	(1.4.4.3.1.3); Calculated for a PV module with 108 half-cut cells, M10 format (0.182 m * 0.182 m); cell breakage rate of 2.5 % according to de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Aluminum alloy, AlMg3, at plant (RER) U	RER	0	kg	1.50E+0	0	1.50E+0	0	1	1.24	(1.4.4.3.1.3); Calculation: 0.5 kg/m assumed Aluminium weight for 35 mm x 35 mm frame profile suitable for 3.2 mm glass module
	Copper, at regional storage (RER) U	RER	0	kg	1.03E-1	1.03E-1	1.03E-1	1.03E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Wire drawing, copper (RER) U	RER	0	kg	1.03E-1	1.03E-1	1.03E-1	1.03E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Diode, unspecified, at plant (GLO) U	GLO	0	kg	2.81E-3	2.81E-3	2.81E-3	2.81E-3	1	1.34	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Silicone product, at plant (RER) U	RER	0	kg	1.22E-1	1.22E-1	1.22E-1	1.22E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Tin, at regional storage (RER) U	RER	0	kg	1.29E-2	1.29E-2	1.29E-2	1.29E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Lead, at regional storage (RER) U	RER	0	kg	7.25E-4	7.25E-4	7.25E-4	7.25E-4	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Solar glass, low-iron, at regional storage (RER) U	RER	0	kg	8.00E+0	8.00E+0	8.00E+0	8.00E+0	1	1.33	(1.4.4.3.3.3); 3.2 mm glass thickness; industry standard in 2024.
	Tempering, flat glass (RER) U	RER	0	kg	8.00E+0	8.00E+0	8.00E+0	8.00E+0	1	1.24	(1.4.4.3.1.3); 3.2 mm glass thickness; industry standard in 2024.
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant (RER) U	RER	0	kg	2.95E-1	2.95E-1	2.95E-1	2.95E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Polyethylene terephthalate, granulate, amorphous, at plant (RER) U	RER	0	kg	3.46E-1	3.46E-1	3.46E-1	3.46E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	2.38E-2	2.38E-2	2.38E-2	2.38E-2	1	1.34	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Ethynylacetate, foil, at plant (RER) U	RER	0	kg	8.75E-1	8.75E-1	8.75E-1	8.75E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Polyvinylfluoride film, at plant (US) U	US	0	kg	1.12E-1	1.12E-1	1.12E-1	1.12E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
auxiliaries	Tap water, water balance according to MoeK 2013, at user (CN) U	CN	0	kg	5.03E+0	5.03E+0	0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Tap water, water balance according to MoeK 2013, at user (US) U	US	0	kg	0	0	5.03E+0	5.03E+0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Hydrogen fluoride, at plant (GLO) U	GLO	0	kg	6.24E-2	6.24E-2	6.24E-2	6.24E-2	1	1.34	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	1-propanol, at plant (RER) U	RER	0	kg	1.59E-2	1.59E-2	1.59E-2	1.59E-2	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Adipic acid, at plant (RER) U	RER	0	kg	0	0	0	0	1	1.05	(1.1.1.1.1.1);
	Isopropanol, at plant (RER) U	RER	0	kg	1.47E-4	1.47E-4	1.47E-4	1.47E-4	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Potassium hydroxide, at regional storage (RER) U	RER	0	kg	5.14E-2	5.14E-2	5.14E-2	5.14E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Soap, at plant (RER) U	RER	0	kg	1.16E-2	1.16E-2	1.16E-2	1.16E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Lubricating oil, at plant (RER) U	RER	0	kg	0	0	0	0	1	1.05	(1.1.1.1.1.1);
	Packaging film, LDPE, at plant (RER) U	RER	0	kg	0	0	0	0	1	1.05	(1.1.1.1.1.1);
	Corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	7.63E-1	7.63E-1	7.63E-1	7.63E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	EUR-flat pallet (RER) U	RER	0	p	5.00E-2	5.00E-2	5.00E-2	5.00E-2	1	1.34	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
energy	Electricity, medium voltage, at grid (CN) U	CN	0	kWh	3.60E+0	3.60E+0	0	0	1	1.09	(2.2.1.1.1.3); de Wild-Scholten, M & de Wild, P. (2023). PV industry data collection. Data on PERC module production from 7 manufacturers.
	Electricity, medium voltage, at grid (US) U	US	0	kWh	0	0	3.60E+0	3.60E+0	1	1.09	(2.2.1.1.1.3); de Wild-Scholten, M & de Wild, P. (2023). PV industry data collection. Data on PERC module production from 7 manufacturers.
	Diesel, burned in building machine, average (CH) U	CH	0	MJ	8.75E-3	8.75E-3	8.75E-3	8.75E-3	1	2.12	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
infrastructure	Photovoltaic panel factory (GLO) U	GLO	1	p	4.00E-6	4.00E-6	4.00E-6	4.00E-6	1	3.06	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	2.33E+0	2.18E+0	2.33E+0	2.18E+0	1	2.09	(4.5.na.na.na.na); Standard distance 100km, cells 500km
	Transport, freight, rail (RER) U	RER	0	tkm	1.29E+1	1.20E+1	1.29E+1	1.20E+1	1	2.09	(4.5.na.na.na.na); Standard distance 600km
disposal	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	3.00E-2	3.00E-2	3.00E-2	3.00E-2	1	1.24	(1.4.4.3.1.3); Asema (personal communication) 2007, production waste
	Disposal, polyvinylfluoride, 0.2% water, to municipal incineration (CH) U	CH	0	kg	4.29E-3	4.29E-3	4.29E-3	4.29E-3	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Disposal, plastics, mixture, 15.3% water, to municipal incineration (CH) U	CH	0	kg	2.13E-2	2.13E-2	2.13E-2	2.13E-2	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Disposal, used mineral oil, 10% water, to hazardous waste incineration (CH) U	CH	0	kg	1.61E-3	1.61E-3	1.61E-3	1.61E-3	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Treatment, sewage, from residence, to wastewater treatment, class 2 (CH) U	CH	0	m3	4.53E-3	4.53E-3	4.53E-3	4.53E-3	1	1.24	(1.4.4.3.1.3); Calculation, water use
emissions air	Heat waste	-	-	MJ	1.30E+1	1.30E+1	1.30E+1	1.30E+1	1	1.60	(3.4.5.3.1.5); Calculation, electricity use
	NM VOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.85	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	2.18E-2	2.18E-2	2.18E-2	1	1.60	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Water, CN	-	-	kg	5.03E-1	5.03E-1	0	0	1	1.85	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Water, US	-	-	kg	0	0	5.03E-1	5.03E-1	1	1.85	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)



Table 29: Unit process LCI data of the photovoltaic PERC laminate and panel production in Asia & Pacific (APAC) and Europe (RER)

Name	Location	Infrastructure	Process	Unit	Photovoltaic	Photovoltaic	Photovoltaic	Photovoltaic	Uncertainty Type	Standard Deviation 95%	General Comment
					cell, single-Si, PERC, at plant (APAC) U	c laminate, single-Si, PERC, at plant (APAC) U	c panel, single-Si, PERC, at plant (RER) U	c laminate, single-Si, PERC, at plant (RER) U			
Photovoltaic panel, single-Si, PERC, at plant (APAC) U	APAC	1	m2	1	0	0	0	0			
Photovoltaic laminate, single-Si, PERC, at plant (APAC) U	APAC	1	m2	0	1	0	0	0			
Photovoltaic panel, single-Si, PERC, at plant (RER) U	RER	1	m2	0	0	1	0	0			
Photovoltaic laminate, single-Si, PERC, at plant (RER) U	RER	1	m2	0	0	0	1	0			
Photovoltaic cell, single-Si, PERC, at plant (APAC) U	APAC	0	m2	9.40E-1	9.40E-1	0	0	0	1	1.24	(1.4,4.3,1.3); Calculated for a PV module with 108 half-cut cells, M10 format (0.182 m * 0.182 m); cell breakage rate of 2.5 % according to de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Photovoltaic cell, single-Si, PERC, at regional storage (RER) U	RER	0	m2	0	0	9.40E-1	9.40E-1	0	1	1.24	(1.4,4.3,1.3); Calculated for a PV module with 108 half-cut cells, M10 format (0.182 m * 0.182 m); cell breakage rate of 2.5 % according to de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Aluminum alloy, AlMg3, at plant (RER) U	RER	0	kg	1.50E+0	0	1.50E+0	0	0	1	1.24	(1.4,4.3,1.3); Calculation: 0.5 kg/m assumed Aluminium weight for 35 mm x 35 mm frame profile suitable for 3.2 mm glass module.
Copper, at regional storage (RER) U	RER	0	kg	1.03E-1	1.03E-1	1.03E-1	1.03E-1	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Wire drawing, copper (RER) U	RER	0	kg	1.03E-1	1.03E-1	1.03E-1	1.03E-1	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Diode, unspecified, at plant (GLO) U	GLO	0	kg	2.81E-3	2.81E-3	2.81E-3	2.81E-3	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Silicone product, at plant (RER) U	RER	0	kg	1.22E-1	1.22E-1	1.22E-1	1.22E-1	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Tin, at regional storage (RER) U	RER	0	kg	1.29E-2	1.29E-2	1.29E-2	1.29E-2	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Lead, at regional storage (RER) U	RER	0	kg	7.25E-4	7.25E-4	7.25E-4	7.25E-4	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Solar glass, low-iron, at regional storage (RER) U	RER	0	kg	8.00E+0	8.00E+0	8.00E+0	8.00E+0	0	1	1.33	(1.4,4.3,3.3); 3.2 mm glass thickness; industry standard in 2024.
Tempering, flat glass (RER) U	RER	0	kg	8.00E+0	8.00E+0	8.00E+0	8.00E+0	0	1	1.24	(1.4,4.3,1.3); 3.2 mm glass thickness; industry standard in 2024.
Glass fibre reinforced plastic, polyamide, injection moulding, at plant (RER) U	RER	0	kg	2.95E-1	2.95E-1	2.95E-1	2.95E-1	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Polyethylene terephthalate, granulate, amorphous, at plant (RER) U	RER	0	kg	3.46E-1	3.46E-1	3.46E-1	3.46E-1	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Polyethylene, HDPE, granulate, at plant (RER) U	RER	0	kg	2.38E-2	2.38E-2	2.38E-2	2.38E-2	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Ethylvinylacetate, foil, at plant (RER) U	RER	0	kg	8.75E-1	8.75E-1	8.75E-1	8.75E-1	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Polyvinylfluoride film, at plant (US) U	US	0	kg	1.12E-1	1.12E-1	1.12E-1	1.12E-1	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Tap water, water balance according to MoeK 2013, at user (MY) U	MY	0	kg	5.30E-1	5.30E-1	0	0	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Tap water, water balance according to MoeK 2013, at user (TH) U	TH	0	kg	7.94E-1	7.94E-1	0	0	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Tap water, water balance according to MoeK 2013, at user (VN) U	VN	0	kg	1.69E+0	1.69E+0	0	0	0	1	3.06	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Tap water, water balance according to MoeK 2013, at user (KR) U	KR	0	kg	2.65E-1	2.65E-1	0	0	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Tap water, water balance according to MoeK 2013, at user (IN) U	IN	0	kg	1.75E+0	1.75E+0	0	0	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Tap water, water balance according to MoeK 2013, at user (RER) U	RER	0	kg	0	0	5.03E+0	5.03E+0	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Hydrogen fluoride, at plant (GLO) U	GLO	0	kg	6.24E-2	6.24E-2	6.24E-2	6.24E-2	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
1-propanol, at plant (RER) U	RER	0	kg	1.59E-2	1.59E-2	1.59E-2	1.59E-2	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Adipic acid, at plant (RER) U	RER	0	kg	0	0	0	0	0	1	1.05	(1.1,1.1,1.1);
Isopropanol, at plant (RER) U	RER	0	kg	1.47E-4	1.47E-4	1.47E-4	1.47E-4	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Potassium hydroxide, at regional storage (RER) U	RER	0	kg	5.14E-2	5.14E-2	5.14E-2	5.14E-2	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Soap, at plant (RER) U	RER	0	kg	1.16E-2	1.16E-2	1.16E-2	1.16E-2	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	7.63E-1	7.63E-1	7.63E-1	7.63E-1	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
EUR-18t pallet (RER) U	RER	0	p	5.00E-2	5.00E-2	5.00E-2	5.00E-2	0	1	1.34	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Electricity, medium voltage, at grid (MY) U	MY	0	kWh	3.79E-1	3.79E-1	0	0	0	1	1.09	(2.2,1.1,1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC module production from 7 manufacturers.
Electricity, medium voltage, at grid (TH) U	TH	0	kWh	5.68E-1	5.68E-1	0	0	0	1	1.09	(2.2,1.1,1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC module production from 7 manufacturers.
Electricity, medium voltage, at grid (VN) U	VN	0	kWh	1.21E+0	1.21E+0	0	0	0	1	1.09	(2.2,1.1,1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC module production from 7 manufacturers.
Electricity, medium voltage, at grid (KR) U	KR	0	kWh	1.89E-1	1.89E-1	0	0	0	1	1.09	(2.2,1.1,1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC module production from 7 manufacturers.
Electricity, medium voltage, at grid (IN) U	IN	0	kWh	1.25E+0	1.25E+0	0	0	0	1	1.09	(2.2,1.1,1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC module production from 7 manufacturers.
Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0	kWh	0	0	3.60E+0	3.60E+0	0	1	1.09	(2.2,1.1,1.3); de Wild-Scholten, M. & de Wild, P. (2023). PV industry data collection. Data on PERC module production from 7 manufacturers.
Diesel, burned in building machine, average (CH) U	CH	0	MJ	8.75E-3	8.75E-3	8.75E-3	8.75E-3	0	1	2.12	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Photovoltaic panel factory (GLO) U	GLO	1	p	4.00E-6	4.00E-6	4.00E-6	4.00E-6	0	1	3.06	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
transport											
Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	2.33E+0	2.18E+0	2.33E+0	2.18E+0	0	1	2.09	(4.5,na,na,na,na); Standard distance 100km, cells 500km
Transport, freight, rail (RER) U	RER	0	tkm	1.29E+1	1.20E+1	1.29E+1	1.20E+1	0	1	2.09	(4.5,na,na,na,na); Standard distance 600km
disposal											
Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	3.00E-2	3.00E-2	3.00E-2	3.00E-2	0	1	1.24	(1.4,4.3,1.3); Alsema (personal communication) 2007, production waste
Disposal, polyvinylfluoride, 0.2% water, to municipal incineration (CH) U	CH	0	kg	4.29E-3	4.29E-3	4.29E-3	4.29E-3	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Disposal, plastics, mixture, 15.3% water, to municipal incineration (CH) U	CH	0	kg	2.13E-2	2.13E-2	2.13E-2	2.13E-2	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Disposal, used mineral oil, 10% water, to hazardous waste incineration (CH) U	CH	0	kg	1.61E-3	1.61E-3	1.61E-3	1.61E-3	0	1	1.24	(1.4,4.3,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
Treatment, sewage, from residence, to wastewater treatment, class 2 (CH) U	CH	0	m3	4.53E-3	4.53E-3	4.53E-3	4.53E-3	0	1	1.24	(1.4,4.3,1.3); Calculation, water use
Heat, waste											
NMOC, non-methane volatile organic compounds, unspecified origin											
Carbon dioxide, fossil											
Water, MY											
Water, TH											
Water, VN											
Water, KR											
Water, IN											
Water, DE											
Water, RER											



Tables Table 30, Table 31 and Table 32 present the unit process data of photovoltaic laminate, monofacial panel, and bifacial panel market mixes in Europe (RER), North America (US), and the Asia & Pacific (APAC) region, respectively. Unframed (laminate) and framed (panel) monofacial PV modules are modelled to represent average monofacial PV modules on the market in 2024. The respective shares of TOPCon and PERC panels, amounting to 61 % and 39 %, are calculated based on [14]. In addition, a dataset representing a framed glass-glass PV module with TOPCon cell technology is provided, as this represents the predominant PV module type on the market in 2025. The shares of 120- and 144-cell panels per panel type (monofacial and bifacial) are based on the shares of the respective panel types in the data retrieved in the context of the French tender process.

**Table 30: Unit process LCI data of the photovoltaic laminate, monofacial panel, and bifacial panel market mix 2024 in Europe (RER)**

Name	Location	InfrastructureProcess	Unit	Photovoltaic laminate, single-Si, at regional storage (RER) U	Photovoltaic panel, single-Si, monofacial, at regional storage (RER) U	Photovoltaic panel, single-Si, bifacial, TOPCon, at regional storage (RER) U	UncertaintyType	StandardDeviation95%	GeneralComment
				RER 1 m2	RER 1 m2	RER 1 m2			
Photovoltaic laminate, single-Si, at regional storage (RER) U	RER	1	m2	1	0	0			
Photovoltaic panel, single-Si, monofacial, at regional storage (RER) U	RER	1	m2	0	1	0			
Photovoltaic panel, single-Si, bifacial, TOPCon, at regional storage (RER) U	RER	1	m2	0	0	1			
Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (RER) U	RER	1	m2	0.00%	0.52%	0.00%	1	3.27	(5,1,1,1,1,5); Market share European modules
Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (RER) U	RER	1	m2	0.00%	1.22%	0.00%	1	3.27	(5,1,1,1,1,5); Market share European modules
Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (RER) U	RER	1	m2	0.00%	0.00%	1.01%	1	3.27	(5,1,1,1,1,5); Market share European modules
Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (RER) U	RER	1	m2	0.00%	0.00%	1.84%	1	3.27	(5,1,1,1,1,5); Market share European modules
Photovoltaic panel, single-Si, PERC, at plant (RER) U	RER	1	m2	0.00%	1.11%	0.00%	1	3.27	(5,1,1,1,1,5); Market share European modules
Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (RER) U	RER	1	m2	1.74%	0.00%	0.00%	1	3.27	(5,1,1,1,1,5); Market share European modules
Photovoltaic laminate, single-Si, PERC, at plant (RER) U	RER	1	m2	1.11%	0.00%	0.00%	1	3.27	(5,1,1,1,1,5); Market share European modules
Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (CN) U	CN	1	m2	0.00%	17.59%	0.00%	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (CN) U	CN	1	m2	0.00%	41.78%	0.00%	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (CN) U	CN	1	m2	0.00%	0.00%	34.54%	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	CN	1	m2	0.00%	0.00%	62.61%	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
Photovoltaic panel, single-Si, PERC, at plant (CN) U	CN	1	m2	0.00%	37.78%	0.00%	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	CN	1	m2	59.37%	0.00%	0.00%	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
Photovoltaic laminate, single-Si, PERC, at plant (CN) U	CN	1	m2	37.78%	0.00%	0.00%	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
transport									
Transport, transoceanic freight ship (OCE) U	OCE	0	tkm	2.16E+2	2.19E+2	2.41E+2	1	2.09	(4,5,na,na,na,na); Transport distance CN-EU: 19994 km, APAC-EU: 15026 km
Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	1.05E+1	1.06E+1	1.17E+1	1	2.09	(4,5,na,na,na,na); Transport distance 943 km



**Table 31: Unit process LCI data of the photovoltaic laminate, monofacial panel, and bifacial panel market mix 2024 in North America (US)**

Name	Location	Category	SubCategory	InfrastructureProcess	Unit	Photovoltaic laminate, single-Si, at regional storage (US) U	Photovoltaic panel, single-Si, monofacial, at regional storage (US) U	Photovoltaic panel, single-Si, bifacial, TOPCon, at regional storage (US) U	UncertaintyType	StandardDeviation95%	GeneralComment
						US 1 m2	US 1 m2	US 1 m2			
Location InfrastructureProcess Unit											
product	Photovoltaic laminate, single-Si, at regional storage (US) U	US	-	-	1	m2	1	0	0		
	Photovoltaic panel, single-Si, monofacial, at regional storage (US) U	US	-	-	1	m2	0	1	0		
	Photovoltaic panel, single-Si, bifacial, TOPCon, at regional storage (US) U	US	-	-	1	m2	0	0	1		
	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (US) U	US	-	-	1	m2	0.00%	4.38%	0.00%	1	3.27 (5,1,1,1,1,5); Market share US modules
	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (US) U	US	-	-	1	m2	0.00%	10.41%	0.00%	1	3.27 (5,1,1,1,1,5); Market share US modules
	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (US) U	US	-	-	1	m2	0.00%	0.00%	8.61%	1	3.27 (5,1,1,1,1,5); Market share US modules
	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (US) U	US	-	-	1	m2	0.00%	0.00%	15.60%	1	3.27 (5,1,1,1,1,5); Market share US modules
	Photovoltaic panel, single-Si, PERC, at plant (US) U	US	-	-	1	m2	0.00%	9.41%	0.00%	1	3.27 (5,1,1,1,1,5); Market share US modules
	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (US) U	US	-	-	1	m2	14.79%	0.00%	0.00%	1	3.27 (5,1,1,1,1,5); Market share US modules
	Photovoltaic laminate, single-Si, PERC, at plant (US) U	US	-	-	1	m2	9.41%	0.00%	0.00%	1	3.27 (5,1,1,1,1,5); Market share US modules
	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (CN) U	CN	-	-	1	m2	0.00%	13.72%	0.00%	1	3.27 (5,1,1,1,1,5); Market share Chinese modules
	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (CN) U	CN	-	-	1	m2	0.00%	32.59%	0.00%	1	3.27 (5,1,1,1,1,5); Market share Chinese modules
	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (CN) U	CN	-	-	1	m2	0.00%	0.00%	26.95%	1	3.27 (5,1,1,1,1,5); Market share Chinese modules
	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	CN	-	-	1	m2	0.00%	0.00%	48.84%	1	3.27 (5,1,1,1,1,5); Market share Chinese modules
	Photovoltaic panel, single-Si, PERC, at plant (CN) U	CN	-	-	1	m2	0.00%	29.47%	0.00%	1	3.27 (5,1,1,1,1,5); Market share Chinese modules
	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	CN	-	-	1	m2	46.32%	0.00%	0.00%	1	3.27 (5,1,1,1,1,5); Market share Chinese modules
	Photovoltaic laminate, single-Si, PERC, at plant (CN) U	CN	-	-	1	m2	29.47%	0.00%	0.00%	1	3.27 (5,1,1,1,1,5); Market share Chinese modules
transport	Transport, transoceanic freight ship (OCE) U	OCE	-	-	0	tkm	1.84E+2	1.78E+2	1.95E+2	1	2.09 (4,5,na,na,na,na); Transport distance CN-US: 20755 km, APAC-US: 18411 km
	Transport, freight, rail (RER) U	RER	-	-	0	tkm	2.34E+0	2.26E+0	2.48E+0	1	2.09 (4,5,na,na,na,na); Standard distance 200km
	Transport, freight, lorry, fleet average (RER) U	RER	-	-	0	tkm	5.85E-1	5.65E-1	6.21E-1	1	2.09 (4,5,na,na,na,na); Standard distance 50km

**Table 32: Unit process LCI data of the photovoltaic laminate, monofacial panel, and bifacial panel market mix 2024 in APAC countries**

Name	Location	Category	SubCategory	InfrastructureProcess	Unit	Photovoltaic laminate, single-Si, at regional storage (APAC) U	Photovoltaic panel, single-Si, monofacial, at regional storage (APAC) U	Photovoltaic panel, single-Si, bifacial, TOPCon, at regional storage (APAC) U	UncertaintyType	StandardDeviation95%	GeneralComment
						APAC 1 m2	APAC 1 m2	APAC 1 m2			
Location InfrastructureProcess Unit											
product	Photovoltaic laminate, single-Si, at regional storage (APAC) U	APAC	-	-	1	m2	1	0	0		
	Photovoltaic panel, single-Si, monofacial, at regional storage (APAC) U	APAC	-	-	1	m2	0	1	0		
	Photovoltaic panel, single-Si, bifacial, TOPCon, at regional storage (APAC) U	APAC	-	-	1	m2	0	0	1		
	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (APAC) U	APAC	-	-	1	m2	0.00%	15.92%	0.00%	1	3.09 (4,1,1,1,1,5); Market share APAC modules
	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (APAC) U	APAC	-	-	1	m2	0.00%	37.80%	0.00%	1	3.09 (4,1,1,1,1,5); Market share APAC modules
	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (APAC) U	APAC	-	-	1	m2	0.00%	0.00%	31.26%	1	3.09 (4,1,1,1,1,5); Market share APAC modules
	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (APAC) U	APAC	-	-	1	m2	0.00%	0.00%	56.65%	1	3.09 (4,1,1,1,1,5); Market share APAC modules
	Photovoltaic panel, single-Si, PERC, at plant (APAC) U	APAC	-	-	1	m2	0.00%	34.19%	0.00%	1	3.09 (4,1,1,1,1,5); Market share APAC modules
	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (APAC) U	APAC	-	-	1	m2	53.72%	0.00%	0.00%	1	3.09 (4,1,1,1,1,5); Market share APAC modules
	Photovoltaic laminate, single-Si, PERC, at plant (APAC) U	APAC	-	-	1	m2	34.19%	0.00%	0.00%	1	3.09 (4,1,1,1,1,5); Market share APAC modules
	Photovoltaic panel, single-Si, TOPCon, monofacial, 60 cells, at plant (CN) U	CN	-	-	1	m2	0.00%	2.19%	0.00%	1	3.09 (4,1,1,1,1,5); Market share Chinese modules
	Photovoltaic panel, single-Si, TOPCon, monofacial, 72 cells, at plant (CN) U	CN	-	-	1	m2	0.00%	5.20%	0.00%	1	3.09 (4,1,1,1,1,5); Market share Chinese modules
	Photovoltaic panel, single-Si, TOPCon, bifacial, 60 cells, at plant (CN) U	CN	-	-	1	m2	0.00%	0.00%	4.30%	1	3.09 (4,1,1,1,1,5); Market share Chinese modules
	Photovoltaic panel, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	CN	-	-	1	m2	0.00%	0.00%	7.79%	1	3.09 (4,1,1,1,1,5); Market share Chinese modules
	Photovoltaic panel, single-Si, PERC, at plant (CN) U	CN	-	-	1	m2	0.00%	4.70%	0.00%	1	3.09 (4,1,1,1,1,5); Market share Chinese modules
	Photovoltaic laminate, single-Si, TOPCon, bifacial, 72 cells, at plant (CN) U	CN	-	-	1	m2	7.39%	0.00%	0.00%	1	3.09 (4,1,1,1,1,5); Market share Chinese modules
	Photovoltaic laminate, single-Si, PERC, at plant (CN) U	CN	-	-	1	m2	4.70%	0.00%	0.00%	1	3.09 (4,1,1,1,1,5); Market share Chinese modules
transport	Transport, transoceanic freight ship (OCE) U	OCE	-	-	0	tkm	6.17E+0	6.36E+0	6.98E+0	1	2.09 (4,5,na,na,na,na); Transport distance CN-APAC: 4584 km
	Transport, freight, rail (RER) U	RER	-	-	0	tkm	2.23E+0	2.29E+0	2.52E+0	1	2.09 (4,5,na,na,na,na); Standard distance 200km
	Transport, freight, lorry, fleet average (RER) U	RER	-	-	0	tkm	5.57E-1	5.73E-1	6.29E-1	1	2.09 (4,5,na,na,na,na); Standard distance 50km

### 3.3 CdTe PV

Table 33 and Table 34 present the unit process data of First Solar integrated cadmium telluride (CdTe) absorber layer deposition and Series 6 and Series 7 thin film PV modules production in the U.S., Vietnam, Malaysia, and



India. The modelling of material and energy consumption, waste flows, transport processes, and emissions is based on inventory data provided by First Solar [41].

Table 33: Unit process LCI data of the integrated CdTe photovoltaic cell, laminate, and panel production of First Solar Series 6 in Asia & Pacific (Malaysia, MY), North America (US), and Vietnam (VN) Table 33 and Table 34 present the unit process data of the cadmium telluride (CdTe) laminate panel market mix in Europe (RER) and North America (US), respectively. Transportation from the production sites to the European and North American regional storage is modelled using a combination of freight ship, rail, and road transport.

It is assumed that, in Europe, only Series 6 panels are currently available on the market. Rotterdam is assumed to be the import port for Europe. From Rotterdam, the panels are transported by lorry to regional storage sites. Based on the previous LCI report, Germany, Italy, and Spain are identified as the European countries hosting relevant shares of the cumulative installed CdTe PV capacity. A weighted average transport distance of approximately 943 km from regional storage to these countries is assumed [15].

For North America, it is assumed that the annual installed capacity of 5 GW in 2023 is fully supplied by domestic CdTe production [69]. Annual domestic production of Series 7 panels is assumed to be fully utilised, with the remaining capacity supplied by domestically produced Series 6 panels. For domestic transport, a standard distance of 500 km is assumed.



**Table 33: Unit process LCI data of the integrated CdTe photovoltaic cell, laminate, and panel production or First Solar Series 6 in Asia & Pacific (Malaysia, MY), North America (US), and Vietnam (VN)**

Product	Name	Location	Infrastructure-Process	Unit	Photovoltaic laminate, CdTe, First Solar Series 6, at plant (MY) U	Photovoltaic laminate, CdTe, First Solar Series 6, at plant (US) U	Photovoltaic laminate, CdTe, First Solar Series 6, at plant (VN) U	UncertaintyType	StandardDeviation 95%	GeneralComment
					MY	US	VN			
product	Location									
	InfrastructureProcess									
	Unit									
product	Photovoltaic laminate, CdTe, First Solar Series 6, at plant (MY) U	MY	1	m2	1	0	0			
	Photovoltaic laminate, CdTe, First Solar Series 6, at plant (US) U	US	1	m2	0	1	0			
	Photovoltaic laminate, CdTe, First Solar Series 6, at plant (VN) U	VN	1	m2	0	0	1			
energy	Electricity, medium voltage, at grid (MY) U	MY	0	kWh	2.17E+1	-	-	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	Electricity, medium voltage, at grid (US) U	US	0	kWh	-	2.26E+1	-	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	Electricity, medium voltage, at grid (VN) U	VN	0	kWh	-	-	1.93E+1	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
energy	Natural gas, burned in boiler modulating >100kW (RER) U	RER	0	MJ	0	6.31E+0	0	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	Photovoltaic panel factory CdTe (US) U	US	1	p	4.00E-6	4.00E-6	4.00E-6	1	3.00	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	Aluminium alloy, AlMg3, at plant (RER) U	RER	0	kg	1.60E+0	1.63E+0	1.59E+0	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
materials	Cadmium telluride, semiconductor-grade, at plant (US) U	US	0	kg	2.25E-2	2.32E-2	2.23E-2	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	Chemicals inorganic, at plant (GLO) U	GLO	0	kg	9.21E-3	1.06E-2	9.23E-3	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	Chemicals organic, at plant (GLO) U	GLO	0	kg	2.69E-2	3.37E-2	2.68E-2	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
materials	Copper, at regional storage (RER) U	RER	0	kg	3.23E-3	3.29E-3	3.22E-3	1	1.16	(1,4,3,3,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	Ethylvinylacetate, foil, at plant (RER) U	RER	0	kg	3.79E-1	3.86E-1	3.78E-1	1	1.08	(1,2,2,3,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	EUR-flat pallet (RER) U	RER	0	p	1.45E-2	1.45E-2	1.45E-2	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
materials	Flat glass, uncoated, at plant (RER) U	RER	0	kg	5.40E+0	5.49E+0	5.38E+0	1	1.07	(1,1,1,1,1,3); 2020 data for First Solar in US, Malaysia and Vietnam
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant (RER) U	RER	0	kg	1.08E-1	1.08E-1	1.08E-1	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Silicone product, at plant (RER) U	RER	0	kg	1.19E-1	1.19E-1	1.17E-1	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
auxiliaries	Solar glass, low-iron, at regional storage (RER) U	RER	0	kg	6.76E+0	6.98E+0	6.70E+0	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Chromium steel 18/8, at plant (RER) U	RER	0	kg	1.12E-2	1.14E-2	1.11E-2	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Hydrogen peroxide, 50% in H2O, at plant (RER) U	RER	0	kg	1.67E-2	1.67E-2	1.67E-2	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
auxiliaries	Isopropanol, at plant (RER) U	RER	0	kg	2.08E-3	2.08E-3	2.08E-3	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Nitric acid, 50% in H2O, at plant (RER) U	RER	0	kg	5.72E-2	5.72E-2	5.72E-2	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Nitrogen, liquid, at plant (RER) U	RER	0	kg	7.32E-2	7.32E-2	7.32E-2	1	1.07	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US and Malaysia
auxiliaries	Sodium chloride, powder, at plant (RER) U	RER	0	kg	4.53E-2	4.53E-2	4.53E-2	1	1.16	(1,4,3,3,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US and Malaysia
	Sodium hydroxide, 50% in H2O, production mix, at plant (RER) U	RER	0	kg	4.93E-2	4.93E-2	4.93E-2	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Sulphuric acid, liquid, at plant (RER) U	RER	0	kg	3.93E-2	3.93E-2	3.93E-2	1	1.07	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US and Malaysia
auxiliaries	Tap water, water balance according to MoEK 2013, at user (MY) U	MY	0	kg	1.18E+2			1	1.07	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US and Malaysia
	Tap water, water balance according to MoEK 2013, at user (US) U	US	0	kg	0	6.10E+1		1	1.09	(2,1,1,1,1,3); Assumption
	Tap water, water balance according to MoEK 2013, at user (VN) U	VN	0	kg	0		7.66E+1	1	3.00	(1,1,1,1,1,3); 2010 data for First Solar in Malaysia
transport	Transport, freight, rail (RER) U	RER	0	tkm	1.04E+1	2.15E+1	0	1	2.00	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	9.86E-1	4.74E+0	1.41E+0	1	2.00	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
	Transport, transoceanic freight ship (OCE) U	OCE	0	tkm	6.65E+1	6.50E+1	3.81E+1	1	2.00	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US and Malaysia
disposal	Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	1.01E-1	1.38E-1	1.68E-1	1	1.07	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in Malaysia
	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	2.40E-1	1.12E-1	8.00E-2	1	1.07	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in Malaysia
	Treatment, sewage, unpolluted, to wastewater treatment, class 3 (CH) U	CH	0	m3	0	2.77E-2	4.78E-2	1	1.16	(1,4,3,3,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US and Malaysia
emissions air, high population density	Heat, waste	-	-	MJ	7.81E+1	8.13E+1	6.95E+1	1	1.07	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
	Cadmium	-	-	kg	3.00E-8	1.20E-6	5.16E-7	1	5.09	(3,4,3,3,1,5); Calculation
	Carbon dioxide, fossil	-	-	kg	6.04E-3	1.41E-2	6.02E-3	1	1.29	(3,4,3,3,1,5); 46% evaporation of tap water; Personal communication Parikhit Sinha, FirstSolar
emissions air, high population density	Carbon monoxide, fossil	-	-	kg	-	1.07E-3	5.10E-6	1	5.09	(3,4,3,3,1,5); Difference of tap water supply and wastewater outflow
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	7.87E-6	0	1.21E-5	1	1.50	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
	Methane, trifluoro-, HFC-23	-	-	kg	0	0	2.54E-6	1	1.50	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
emissions water, unspecified	Nitric acid	-	-	kg	1.64E-6	3.35E-4	4.33E-5	1	1.50	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
	Nitrogen oxides	-	-	kg	2.06E-5	3.73E-3	4.54E-4	1	1.50	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
	BOD5, Biological Oxygen Demand	-	-	kg	2.20E-4	1.38E-4	4.23E-4	1	1.50	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
emissions water, unspecified	Cadmium	-	-	kg	8.87E-8	5.55E-7	2.45E-8	1	3.00	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
	COD, Chemical Oxygen Demand	-	-	kg	9.76E-4	1.22E-3	1.06E-3	1	1.50	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
	Copper	-	-	kg	8.87E-7	7.72E-7	8.36E-7	1	3.00	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US
emissions water, unspecified	Suspended solids, unspecified	-	-	kg	4.26E-4	8.84E-5	5.02E-4	1	1.50	(1,1,1,1,1,3); 2015 and 2017-2018 (estimated) data for First Solar in US



**Table 34: Unit process LCI data of the integrated CdTe photovoltaic cell, laminate, and panel production or First Solar Series 7 in North America (US), and India (IN)**

	Name	Location	Infrastructure-Process	Unit	Photovoltaic laminate, CdTe, First Solar Series 7, at plant (US) U	Photovoltaic laminate, CdTe, First Solar Series 7, at plant (IN) U	Uncertainty Type	Standard Deviation 95%	General Comment
					US	IN			
					InfrastructureProcess	Unit			
product	Photovoltaic laminate, CdTe, First Solar Series 7, at plant (US) U	US	1	m2	1	0			
	Photovoltaic laminate, CdTe, First Solar Series 7, at plant (IN) U	IN	1	m2	0	1			
energy	Electricity, medium voltage, at grid (US) U	US	0	kWh	1.81E+1	0	1	1.07	(1,1,1,1,1,3); 2022 data for First Solar in US
	Electricity, medium voltage, at grid (IN) U	IN	0	kWh	0	1.81E+1	1	1.07	(1,1,1,1,1,3); 2022 data for First Solar in US
	Natural gas, burned in boiler modulating >100kW (RER) U	RER	0	MJ	5.23E+0	0	1	1.07	(1,1,1,1,1,3); 2022 data for First Solar in US and estimate for additional 2023 usage; not applicable in India due to warm climate
infrastructure	Photovoltaic panel factory CdTe (US) U	US	1	p	4.00E-6	4.00E-6	1	3.00	(1,1,1,1,1,3); Assumption
materials	Steel, low-alloyed, at plant (RER) U	RER	0	kg	2.49E+0	1.73E+0	1	1.07	(1,1,1,1,1,3); 2023 data for First Solar in US (tracker back-rail), India (fixed-tilt back-rail)
	Cadmium telluride, semiconductor-grade, at plant (US) U	US	0	kg	2.32E-2	2.32E-2	1	1.07	(1,1,1,1,1,3); 2023 data for First Solar in US, India
	Chemicals inorganic, at plant (GLO) U	GLO	0	kg	8.02E-3	8.02E-3	1	1.07	(1,1,1,1,1,3); 2023 data for First Solar in US, India
	Chemicals organic, at plant (GLO) U	GLO	0	kg	2.87E-2	2.87E-2	1	1.07	(1,1,1,1,1,3); 2023 data for First Solar in US, India
	Copper, at regional storage (RER) U	RER	0	kg	3.21E-3	3.21E-3	1	1.16	(1,4,3,3,1,3); 2023 data for First Solar in US, India
	Ethylvinylacetate, foil, at plant (RER) U	RER	0	kg	3.96E-1	3.96E-1	1	1.08	(1,2,2,3,1,3); 2023 data for First Solar in US, India
	EUR-flat pallet (RER) U	RER	0	p	7.76E-3	7.44E-3	1	1.07	(1,1,1,1,1,3); 2023 data for First Solar in US, India
	Flat glass, uncoated, at plant (RER) U	RER	0	kg	5.14E+0	5.14E+0	1	1.07	(1,1,1,1,1,3); 2023 data for First Solar in US, India
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant (RER) U	RER	0	kg	1.08E-1	1.08E-1	1	1.16	(1,4,3,3,1,3); Fthenakis, literature, sum up of several materials
	Silicone product, at plant (RER) U	RER	0	kg	9.20E-2	9.20E-2	1	1.16	(1,4,3,3,1,3); 2023 data for First Solar in US, India
	Solar glass, low-iron, at regional storage (RER) U	RER	0	kg	6.74E+0	6.74E+0	1	1.16	(1,4,3,3,1,3); 2023 data for First Solar in US, India
	Zinc coating, pieces (RER) U	RER	0	m2	1.33E-1	9.29E-2	1	1.07	(1,1,1,1,1,3); 2023 data for First Solar in US, India
auxiliaries	Hydrogen peroxide, 50% in H2O, at plant (RER) U	RER	0	kg	1.67E-2	1.67E-2	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Isopropanol, at plant (RER) U	RER	0	kg	2.08E-3	2.08E-3	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Nitric acid, 50% in H2O, at plant (RER) U	RER	0	kg	5.72E-2	5.72E-2	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Nitrogen, liquid, at plant (RER) U	RER	0	kg	7.32E-2	7.32E-2	1	1.07	(1,1,1,1,1,3); Fthenakis, literature
	Sodium chloride, powder, at plant (RER) U	RER	0	kg	4.53E-2	4.53E-2	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Sodium hydroxide, 50% in H2O, production mix at plant (RER) U	RER	0	kg	4.93E-2	4.93E-2	1	1.16	(1,4,3,3,1,3); Fthenakis, literature
	Sulphuric acid, liquid, at plant (RER) U	RER	0	kg	3.93E-2	3.93E-2	1	1.07	(1,1,1,1,1,3); Fthenakis, literature
	Tap water, water balance according to MoeK 2013, at user (IN) U	IN	0	kg	0	2.20E+1	1	1.07	(1,1,1,1,1,3); 2022 data for First Solar; 60% reuse in India
	Tap water, water balance according to MoeK 2013, at user (US) U	US	0	kg	5.51E+1	0	1	1.09	(2,1,1,1,1,3); 2022 data for First Solar; 60% reuse in India
transport	Transport, freight, rail (RER) U	RER	0	tkm	3.15E+1	3.15E+1	1	2.00	(1,1,1,1,1,3); 2022 data for First Solar in US
	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	4.18E+0	4.18E+0	1	2.00	(1,1,1,1,1,3); 2022 data for First Solar in US; 50% average capacity utilization
	Transport, transoceanic freight ship (OCE) U	OCE	0	tkm	1.19E+2	1.19E+2	1	2.00	(1,1,1,1,1,3); 2022 data for First Solar in US
disposal	Disposal, hazardous waste, 25% water, to hazardous waste incineration (CH) U	CH	0	kg	4.60E-2	4.60E-2	1	1.07	(1,1,1,1,1,3); 2022 data for First Solar in US
	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH) U	CH	0	kg	3.17E-2	3.17E-2	1	1.07	(1,1,1,1,1,3); 2022 data for First Solar in US
	Treatment, sewage, unpolluted, to wastewater treatment, class 3 (CH) U	CH	0	m3	2.61E-2	0	1	1.16	(1,4,3,3,1,3); 2022 data for First Solar in US; zero-liquid discharge in India
emissions air, high population density	Heat, waste	-	-	MJ	6.51E+1	6.51E+1	1	1.07	(1,1,1,1,1,3); Calculation
	Cadmium	-	-	kg	8.69E-7	8.69E-7	1	5.09	(3,4,3,3,1,5); 2020 data for First Solar in US
	Carbon dioxide, fossil	-	-	kg	8.94E-3	8.94E-3	1	1.29	(3,4,3,3,1,5); 2022 data for First Solar in US
	Carbon monoxide, fossil	-	-	kg	4.99E-4	4.99E-4	1	5.09	(3,4,3,3,1,5); 2022 data for First Solar in US
	Nitric acid	-	-	kg	6.90E-5	6.90E-5	1	1.50	(1,1,1,1,1,3); 2022 data for First Solar in US
	Nitrogen oxides	-	-	kg	2.39E-3	2.39E-3	1	1.50	(1,1,1,1,1,3); 2022 data for First Solar in US
emissions water, unspecified	BOD5, Biological Oxygen Demand	-	-	kg	1.38E-4	1.38E-4	1	1.50	(1,1,1,1,1,3); 2020 data for First Solar in US
	Cadmium	-	-	kg	6.97E-7	6.97E-7	1	3.00	(1,1,1,1,1,3); 2022 data for First Solar in US
	COD, Chemical Oxygen Demand	-	-	kg	2.12E-3	2.12E-3	1	1.50	(1,1,1,1,1,3); 2022 data for First Solar in US
	Copper	-	-	kg	1.35E-6	1.35E-6	1	3.00	(1,1,1,1,1,3); 2022 data for First Solar in US
	Suspended solids, unspecified	-	-	kg	2.06E-5	2.06E-5	1	1.50	(1,1,1,1,1,3); 2022 data for First Solar in US



**Table 35: Unit process LCI data of CdTe photovoltaic panels at the European (RER) regional storage**

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	Photovoltaic laminate, CdTe, mix, at regional storage (US) U	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location InfrastructureProcess Unit						RER 1 m2			
product	Photovoltaic laminate, CdTe, mix, at regional storage {US} U	US	-	-	1	m2	1			
materials	Photovoltaic laminate, CdTe, First Solar Series 6, at plant {US} U	US	-	-	1	m2	31.60%	1	3.00	(1,1,1,1,1,3); CdTe Series 6 (domestic production and imports)
	Photovoltaic laminate, CdTe, First Solar Series 7, at plant {US} U	US	-	-	1	m2	68.40%	1	3.00	(1,1,1,1,1,3); CdTe Series 7 (domestic production and imports)
transport	Transport, transoceanic freight ship {OCE} U	OCE	-	-	0	tkm	0	1	2.09	(4,5,na,na,na,na); Assumption: 30 % of Series 6 and Series 7 modules imported from Southeast Asia
	Transport, freight, lorry, fleet average {RER} U	RER	-	-	0	tkm	7.48E+0	1	2.09	(4,5,na,na,na,na); Average transport distance of 500 km assumed

**Table 36: Unit process LCI data of CdTe photovoltaic panels at the North American (US) regional storage**

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	Photovoltaic laminate, CdTe, mix, at regional storage {RER} U	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location InfrastructureProcess Unit						RER 1 m2			
product	Photovoltaic laminate, CdTe, mix, at regional storage {RER} U	RER	-	-	1	m2	1			
materials	Photovoltaic laminate, CdTe, First Solar Series 6, at plant {US} U	US	-	-	1	m2	26.01%	1	3.00	(1,1,1,1,1,3); CdTe module import from US
	Photovoltaic laminate, CdTe, First Solar Series 6, at plant {MY} U	MY	-	-	1	m2	36.00%	1	3.00	(1,1,1,1,1,3); CdTe module import from Malaysia
	Photovoltaic laminate, CdTe, First Solar Series 6, at plant {VN} U	VN	-	-	1	m2	37.98%	1	3.00	(1,1,1,1,1,3); CdTe module import from Vietnam
transport	Transport, transoceanic freight ship {OCE} U	OCE	-	-	0	tkm	2.04E+2	1	2.09	(4,5,na,na,na,na); Import of modules from the US 6469 km, from Malaysia 14783 km, and from Vietnam 18672 km to Rotterdam
	Transport, freight, lorry, fleet average {RER} U	RER	-	-	0	tkm	1.37E+1	1	2.09	(4,5,na,na,na,na); Average transport distance from Rotterdam to Europe is 943 km

### 3.4 PV module recycling

This section has not been updated

Life cycle inventories of current c-Si and CdTe PV module recycling have been compiled [70; 71; 72]. Due to currently limited waste volumes, c-Si PV modules are still predominantly treated in adapted recycling plants originally designed for laminated glass, metals and/or electronic waste. In current industrial practice, recycling often focuses on bulk material recovery (glass, aluminium and copper), while the laminate fraction (cells, encapsulant and back-sheet plastics) is frequently processed via shredding and thermal treatment (e.g., incineration), although dedicated PV recycling lines and routes enabling recovery of additional materials (e.g., Si and Ag) are increasingly being deployed.

CdTe PV modules have been treated in dedicated recycling plants for many years, and life cycle inventories of this process have been published, with the semiconductor being recovered in addition to glass and copper. Regarding the outputs of the recycling processes, yield for glass and nonferrous metal for c-Si PV is 59-75% and 13.5-21.8%, respectively [71]. Yield for glass, semiconductor, and copper in CdTe PV recycling is over 95 % [73]. Under the EU WEEE Directive, recycling of end-of-life PV modules is mandatory in the European Union and the current status of global policy and technology related to PV module recycling has been reviewed by IEA PVPS Task 12 [74; 75].

<b>Name</b>	<b>c-Si and CdTe PV module recycling</b>
<b>Time period</b>	2015-2016 for c-Si PV and 2012 for CdTe PV
<b>Geography</b>	Europe, Western
<b>Technology</b>	Average technology



<b>Representativeness</b>	Data from commercial operations
<b>Approaches</b>	<p><b>cut-off approach:</b> treatment efforts and emissions are allocated based on economic revenue received from selling the treatment service and the materials recovered; to be used in LCA of PV electricity and the assessment of the full life cycle (from cradle to grave) of PV panels.</p> <p><b>end-of-life approach:</b> treatment efforts and emissions are fully attributed to the treatment service; potential environmental benefits are included due to avoiding primary material supply; may be applied in the LCA of different end of life treatment options for PV panels and systems.</p>
<b>Date</b>	10/3/2016
<b>Collection method</b>	Data on c-Si PV collected from four European recycling plants (3 laminated glass recyclers, 1 metal recycler) [22-23]. Data on CdTe PV from publicly available information on first generation CdTe PV recycling in First Solar's PV recycling facility in Germany [70; 72].
<b>Data treatment</b>	Scaled to 1 kg of module

**Table 37: Unit process LCI data of the treatment of used c-Si PV modules in a first-generation recycling process and of the recovered materials according to the cut-off approach**

	Name	Location	InfrastructureProcess	Unit	treatment, c-Si PV module	glass cullets, recovered from c-Si PV module treatment	aluminium scrap, recovered from c-Si PV module treatment	copper scrap, recovered from c-Si PV module treatment	UncertaintyType	StandardDeviation95%	GeneralComment
					RER	RER	RER	RER			
product	treatment, c-Si PV module			kg	1	0	0	0			
	glass cullets, recovered from c-Si PV module treatment			kg	0	1	0	0			
	aluminium scrap, recovered from c-Si PV module treatment			kg	0	0	1	0			
	copper scrap, recovered from c-Si PV module treatment			kg	0	0	0	1			
technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO		kWh	5.56E-2	4.05E-3	1.42E-1	8.09E-1	1	1.25	(2,3,1,1,3,4,BU:1.05); Weighted average of data from recyclers; Economic allocation;
	diesel, burned in building machine, average	CH		MJ	3.24E-2	2.36E-3	8.25E-2	4.71E-1	1	2.07	(2,3,1,1,3,4,BU:2); Weighted average of data from recyclers; Economic allocation;
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH		kg	7.34E-2	5.34E-3	1.87E-1	1.07E+0	1	1.25	(2,3,1,1,3,4,BU:1.05); Weighted average of data from recyclers; Economic allocation;
	disposal, plastics, mixture, 15.3% water, to sanitary landfill	CH		kg	1.28E-2	9.33E-4	3.26E-2	1.87E-1	1	1.25	(2,3,1,1,3,4,BU:1.05); Weighted average of data from recyclers; Economic allocation;
	transport, freight, lorry 3.5-7.5 metric ton, EURO 5	RER		tkm	5.00E-2	3.64E-3	1.27E-1	7.27E-1	1	2.09	(4,5,na,na,na,na,BU:2); Assumed transport distance to collection point: 100 km; Economic allocation; Latunussa et al. 2016
	transport, freight, lorry, fleet average	RER		tkm	2.00E-1	1.45E-2	5.09E-1	2.91E+0	1	2.09	(4,5,na,na,na,na,BU:2); Assumed transport distance to recycling site: 400 km; Economic allocation; Latunussa et al. 2016

**Table 38: Unit process LCI data of the takeback and recycling of used c-Si PV modules in a first-generation recycling process according to the end-of-life approach**

	Name	Location	InfrastructureProcess	Unit	takeback and recycling, c-Si PV module	UncertaintyType	StandardDeviation95%	GeneralComment
					RER			
product	takeback and recycling, c-Si PV module			kg	1			
technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO		kWh	1.11E-1	1	1.25	(2,3,1,1,3,4,BU:1.05); Weighted average of data from recyclers;
	diesel, burned in building machine, average	CH		MJ	6.48E-2	1	2.07	(2,3,1,1,3,4,BU:2); Weighted average of data from recyclers;
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH		kg	1.47E-1	1	1.25	(2,3,1,1,3,4,BU:1.05); Weighted average of data from recyclers;
	disposal, plastics, mixture, 15.3% water, to sanitary landfill	CH		kg	2.57E-2	1	1.25	(2,3,1,1,3,4,BU:1.05); Weighted average of data from recyclers;
	transport, freight, lorry 3.5-7.5 metric ton, EURO 5	RER		tkm	1.00E-1	1	2.09	(4,5,na,na,na,na,BU:2); Assumed transport distance to collection point: 100 km; Latunussa et al. 2016
	transport, freight, lorry, fleet average	RER		tkm	4.00E-1	1	2.09	(4,5,na,na,na,na,BU:2); Assumed transport distance to recycling site: 400 km; Latunussa et al. 2016



**Table 40: Unit process LCI data of the avoided burdens due to materials recovered from used c-Si PV modules in a first-generation recycling process according to the end-of-life approach**

Name	Location	InfrastructureProcess	Unit	avoided burden from recycling, c-Si PV module	UncertaintyType	StandardDeviation95%	GeneralComment	
								Location InfrastructureProcess Unit
product	avoided burden from recycling, c-Si PV module	RER	0	kg				
technosphere	natural gas, burned in industrial furnace >100kW	RER	0	MJ	-8.15E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); Avoided primary glass production materials; Weighted average of data from recyclers; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	-5.28E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); Avoided primary glass production materials; Weighted average of data from recyclers; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	silica sand, at plant	DE	0	kg	-3.44E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); Avoided primary glass production materials; Weighted average of data from recyclers; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	soda, powder, at plant	RER	0	kg	-1.36E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); Avoided primary glass production materials; Weighted average of data from recyclers; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	limestone, milled, packed, at plant	CH	0	kg	-2.38E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); Avoided primary glass production materials; Weighted average of data from recyclers; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	copper, at regional storage	RER	0	kg	-2.48E-2	1	1.14	(2,4,1,1,1,3, BU:1.05); Avoided primary copper production materials from junction box and cables; Recycling content of copper is 44 % according to KBOB-list; Weighted average of data from recyclers; KBOB LCI data DQRv2:2016
	copper, secondary, at refinery	RER	0	kg	2.48E-2	1	1.14	(2,4,1,1,1,3, BU:1.05); Efforts for making secondary copper from scrap;
	aluminium, primary, at plant	RER	0	kg	-5.34E-2	1	1.14	(2,4,1,1,1,3, BU:1.05); Avoided primary aluminium production materials from frame; Recycling content of AlMg3 alloy is 77 % according to KBOB-list; Weighted average of data from recyclers; KBOB LCI data DQRv2:2016
	aluminium, secondary, from old scrap, at plant	RER	0	kg	5.34E-2	1	1.14	(2,4,1,1,1,3, BU:1.05); Efforts for making secondary aluminium from scrap;
emission air, unspecified	Carbon dioxide, fossil	-	-	kg	-1.24E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); Avoided primary glass production materials; Weighted average of data from recyclers; Held and Ilg 2011; KBOB LCI data DQRv2:2016

**Table 39: Unit process LCI data of the treatment of used CdTe PV modules in a first-generation recycling process and of the recovered materials according to the cut-off approach**

Name	Location	InfrastructureProcess	Unit	treatment, CdTe PV module	glass cullets, recovered from CdTe PV module treatment	copper scrap, recovered from CdTe PV module treatment	cadmium sludge, recovered from CdTe PV module treatment	copper telluride cement, recovered from CdTe PV module treatment	UncertaintyType	StandardDeviation95%	GeneralComment		
												Location InfrastructureProcess Unit	
product	treatment, CdTe PV module	DE	0	kg	1	0	0	0					
	glass cullets, recovered from CdTe PV module treatment	DE	0	kg	0	1	0	0					
	copper scrap, recovered from CdTe PV module treatment	DE	0	kg	0	0	1	0					
	cadmium sludge, recovered from CdTe PV module treatment	DE	0	kg	0	0	0	1					
	copper telluride cement, recovered from CdTe PV module treatment	DE	0	kg	0	0	0	0	1				
	electricity, medium voltage, at grid	DE	0	kWh	2.24E-1	1.51E-2	3.02E+0	6.95E-2	5.89E+0	1	1.14	(2,4,1,1,1,3, BU:1.05); ; Sinha et al. 2012	
	water, deionised, at plant	CH	0	kg	2.78E-1	1.87E-2	3.74E+0	8.60E-2	7.29E+0	1	1.14	(2,4,1,1,1,3, BU:1.05); ; Sinha et al. 2012	
technosphere	sulphuric acid, liquid, at plant	RER	0	kg	4.28E-3	2.87E-4	5.75E-2	1.32E-3	1.12E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); ; Sinha et al. 2012	
	hydrogen peroxide, 50% in H2O, at plant	RER	0	kg	2.93E-2	1.97E-3	3.94E-1	9.07E-3	7.68E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); ; Sinha et al. 2012	
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	5.34E-3	3.59E-4	7.18E-2	1.65E-3	1.40E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); ; Sinha et al. 2012	
	transport, freight, lorry 3.5-7.5 metric ton, EURO 5	RER	0	tkm	8.47E-2	5.69E-3	1.14E+0	2.62E-2	2.22E+0	1	2.09	(4,5,na,na,na,na, BU:2); Assumed transport distance to collection point: km; Sinha et al. 2012; Latanussa et al. 2016	
	transport, freight, lorry, fleet average	RER	0	tkm	4.90E-1	3.29E-2	6.59E+0	1.52E-1	1.29E+1	1	2.09	(4,5,na,na,na,na, BU:2); Assumed transport distance to recycling site: km; Sinha et al. 2012; Latanussa et al. 2016	
	treatment, PV cell production effluent, to wastewater treatment, class 3	CH	0	m3	2.46E-4	1.65E-5	3.30E-3	7.61E-5	6.45E-3	1	1.14	(2,4,1,1,1,3, BU:1.05); ; Sinha et al. 2012	
	disposal, plastics, mixture, 15.3% water, to sanitary landfill	CH	0	kg	3.16E-2	2.12E-3	4.25E-1	9.78E-3	8.29E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); ; Sinha et al. 2012	
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	6.59E-3	4.43E-4	8.86E-2	2.04E-3	1.73E-1	1	1.14	(2,4,1,1,1,3, BU:1.05); ; Sinha et al. 2012	
	emission air, unspecified	Cadmium	-	-	kg	3.02E-10	2.03E-11	4.06E-9	9.35E-11	7.93E-9	1	5.02	(2,4,1,1,1,3, BU:5); ; Sinha et al. 2012
		Cadmium	-	-	kg	4.58E-9	3.08E-10	6.15E-8	1.42E-9	1.20E-7	1	3.02	(2,4,1,1,1,3, BU:3); ; Sinha et al. 2012



**Table 41: Unit process LCI data of the takeback and recycling of used CdTe PV modules in a first-generation recycling process according to the end-of-life approach**

	Name	Location	InfrastructureProcess	Unit	takeback and recycling, CdTe PV module	UncertaintyType	StandardDeviation95%	GeneralComment	
					DE 0 kg				
product	takeback and recycling, CdTe PV module	DE	0	kg	1				
technosphere	electricity, medium voltage, at grid	DE	0	kWh	2.65E-1	1	1.14	(2,4,1,1,1,3,BU:1.05);; Sinha et al. 2012	
	water, deionised, at plant	CH	0	kg	3.28E-1	1	1.14	(2,4,1,1,1,3,BU:1.05);; Sinha et al. 2012	
	sulphuric acid, liquid, at plant	RER	0	kg	5.05E-3	1	1.14	(2,4,1,1,1,3,BU:1.05);; Sinha et al. 2012	
	hydrogen peroxide, 50% in H2O, at plant	RER	0	kg	3.46E-2	1	1.14	(2,4,1,1,1,3,BU:1.05);; Sinha et al. 2012	
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	6.31E-3	1	1.14	(2,4,1,1,1,3,BU:1.05);; Sinha et al. 2012	
	transport, freight, lorry 3.5-7.5 metric ton, EURO 5	RER	0	tkm	1.00E-1	1	2.09	(4,5,na,na,na,na,BU:2); Assumed transport distance to collection point: 100 km; Sinha et al. 2012; Latanussa et al. 2016	
	transport, freight, lorry, fleet average	RER	0	tkm	5.78E-1	1	2.09	(4,5,na,na,na,na,BU:2); Assumed transport distance to recycling site: 400 km; Sinha et al. 2012; Latanussa et al. 2016	
	treatment, PV cell production effluent, to wastewater treatment, class 3	CH	0	m3	2.90E-4	1	1.14	(2,4,1,1,1,3,BU:1.05);; Sinha et al. 2012	
	disposal, plastics, mixture, 15.3% water, to sanitary landfill	CH	0	kg	3.73E-2	1	1.14	(2,4,1,1,1,3,BU:1.05);; Sinha et al. 2012	
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	7.78E-3	1	1.14	(2,4,1,1,1,3,BU:1.05);; Sinha et al. 2012	
	emission air, unspecified	Cadmium	-	-	kg	3.57E-10	1	5.02	(2,4,1,1,1,3,BU:5);; Sinha et al. 2012
		Cadmium	-	-	kg	5.40E-9	1	3.02	(2,4,1,1,1,3,BU:3);; Sinha et al. 2012
	emission water, unspecified								



**Table 42: Unit process LCI data of the avoided burdens due to materials recovered from used CdTe PV modules in a first-generation recycling process according to the end-of-life approach**

	Name	Location	InfrastructureProcess	Unit	avoided burden from recycling, CdTe PV module	UncertaintyType	StandardDeviation95%	GeneralComment
					DE 0 kg 1			
product	avoided burden from recycling, CdTe PV module	DE	0	kg				
technosphere	natural gas, burned in industrial furnace >100kW	RER	0	MJ	-1.19E+0	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided primary glass production materials; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	-7.67E-1	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided primary glass production materials; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	silica sand, at plant	DE	0	kg	-5.01E-1	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided primary glass production materials; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	soda, powder, at plant	RER	0	kg	-1.98E-1	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided primary glass production materials; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	limestone, milled, packed, at plant	CH	0	kg	-3.47E-1	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided primary glass production materials; Held and Ilg 2011; KBOB LCI data DQRv2:2016
	copper, at regional storage	RER	0	kg	-2.68E-3	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided primary copper production materials from junction box; Recycling content of copper is 44 % according to KBOB-list; Personal communication Parikhit Sinha, 06.10.2014; KBOB LCI data DQRv2:2016
	copper, secondary, at refinery	RER	0	kg	2.68E-3	1	1.14	(2,4,1,1,1,3,BU:1.05); Efforts for making secondary copper from scrap; Personal communication Parikhit Sinha, 06.10.2014
	cadmium sludge, from zinc electrolysis, at plant	GLO	0	kg	-1.72E-3	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided unrefined semiconductor materials; Sinha et al. 2012
	copper telluride cement, from copper production	GLO	0	kg	-1.95E-3	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided unrefined semiconductor materials; Sinha et al. 2012
emission air, unspecified	Carbon dioxide, fossil	-	-	kg	-1.80E-1	1	1.14	(2,4,1,1,1,3,BU:1.05); Avoided primary glass production materials; Held and Ilg 2011; KBOB LCI data DQRv2:2016



### 3.5 PV mounting structures

Table 43 shows the unit process data of rooftop and façade PV mounting systems in Europe. The data correspond to the life cycle inventory data of mounting systems published by Jungbluth et al. [34] Data includes materials, packaging, and transport of mounting structures and disposal of packaging materials. Rooftop mounting systems were not updated in the context of the 2026 update.

**Table 43: Unit process LCI data of different rooftop and façade PV mounting systems**

	Name	Location	InfrastructureProcesses	Unit	Facade construction, mounted, at building {RER} U	Facade construction, integrated, at building {RER} U	Flat roof construction, on roof {RER} U	Slanted-roof construction, mounted, on roof {RER} U	Slanted-roof construction, integrated, on roof {RER} U	
					RER	RER	RER	RER	RER	
	Location				1	1	1	1	1	
	InfrastructureProcess Unit				m2	m2	m2	m2	m2	
product	Facade construction, mounted, at building {RER} U	RER	1	m2	1	0	0	0	0	
	Facade construction, integrated, at building {RER} U	RER	1	m2	0	1	0	0	0	
	Flat roof construction, on roof {RER} U	RER	1	m2	0	0	1	0	0	
	Slanted-roof construction, mounted, on roof {RER} U	RER	1	m2	0	0	0	1	0	
	Open ground construction, utility scale, on ground {RER} U	RER	1	m2	0	0	0	0	0	
	Open ground construction, 1-axis tracker, utility scale, on ground {IT} U	IT	1	m2	0	0				
	Slanted-roof construction, integrated, on roof {RER} U	RER	1	m2	0	0	0	0	1	
	Open ground construction, on ground {RER} U	RER	1	m2	0	0	0	0	0	
	Slanted-roof construction, mounted, on roof, Stade de Suisse {CH} U	CH	1	m2	0	0	0	0	0	
materials	Aluminium, production mix, wrought alloy, at plant {RER} U	RER	0	kg	2.64E+0	3.27E+0	2.52E+0	2.84E+0	2.25E+0	
	Corrugated board, mixed fibre, single wall, at plant {RER} U	RER	0	kg	4.03E-2	-	1.83E-2	1.33E-1	1.14E-1	
	Polyethylene, HDPE, granulate, at plant {RER} U	RER	0	kg	7.32E-4	-	1.92E+0	1.40E-3	2.82E-2	
	Polystyrene, high impact, HIPS, at plant {RER} U	RER	0	kg	3.66E-3	-	8.30E-3	7.02E-3	6.02E-3	
	Polyurethane, flexible foam, at plant {RER} U	RER	0	kg	-	-	-	-	1.84E-2	
	Synthetic rubber, at plant {RER} U	RER	0	kg	-	-	-	-	1.24E+0	
	Steel, low-alloyed, at plant {RER} U	RER	0	kg	1.80E+0	-	2.67E-1	1.50E+0	2.00E-1	
	Chromium steel 18/8, at plant {RER} U	RER	0	kg	-	-	-	-	-	
	Gravel, unspecified, at mine {CH} U	CH	0	kg	-	-	-	-	-	
	Reinforcing steel, at plant {RER} U	RER	0	kg	-	-	-	-	-	
	Concrete, normal, at plant {CH} U	CH	0	m3	-	-	-	-	-	
	manufacturing	Section bar extrusion, aluminium {RER} U	RER	0	kg	2.64E+0	3.27E+0	2.52E+0	2.84E+0	2.25E+0
		Sheet rolling, steel {RER} U	RER	0	kg	1.10E-1	-	2.67E-1	1.50E+0	0
Section bar rolling, steel {RER} U		RER	0	kg	1.69E+0	-	-	-	2.00E-1	
Wire drawing, steel {RER} U		RER	0	kg	-	-	-	-	-	
Zinc coating, pieces {RER} U		RER	0	m2	-	-	-	-	-	
Zinc coating, coils {RER} U		RER	0	m2	-	-	-	-	-	
transport	Transport, freight, lorry, fleet average {RER} U	RER	0	tkm	2.24E-1	1.64E-1	2.56E-1	2.25E-1	2.07E-1	
	Transport, freight, rail {RER} U	RER	0	tkm	1.61E+0	6.54E-1	1.05E+0	1.50E+0	8.52E-1	
disposal	Transport, freight, light commercial vehicle {RER} U	RER	0	tkm	4.44E-1	3.27E-1	4.72E-1	4.34E-1	3.75E-1	
	Disposal, packaging cardboard, 19.6% water, to municipal incineration {CH} U	CH	0	kg	4.03E-2	-	1.83E-2	1.33E-1	1.14E-1	
	Disposal, building, polyethylene/polypropylene products, to final disposal {CH} U	CH	0	kg	7.32E-4	-	1.92E+0	1.40E-3	1.29E+0	
	Disposal, building, polystyrene isolation, flame-retardant, to final disposal {CH} U	CH	0	kg	3.66E-3	-	8.30E-3	7.02E-3	6.02E-3	



### 3.6 PV mounting structures – utility scale

Table 44 shows the unit process data of a fix-tilt mounting system and a 1-axis tracker mounting system for utility scale PV plants. Life cycle inventories were developed for two utility-scale mounting system configurations: a ground-mounted fixed-tilt racking system and a single-axis horizontal tracker. Both inventories are expressed per 1 m<sup>2</sup> of gross module area.

The fixed-tilt inventory is based on a pile-driven steel table structure at 20° tilt accommodating 27 modules (3×9) with a module area of 53.95 m<sup>2</sup> per table. The total system mass is 524.9 kg (9.73 kg/m<sup>2</sup> module area). The material composition is dominated by coated carbon steel (95 % by mass), supplemented by aluminium clamps (2.9 %) and stainless-steel fasteners (2.1 %). Mass quantities were derived from the manufacturer's technical drawing using nominal cross-section geometry and published coating specifications. The system boundary is cradle-to-gate.

The single-axis tracker inventory is based on primary field data compiled and provided by Andrea Danelli (RSE Italy) from more than 10,000 tracker units installed in the Italian distributed-generation market (2023). Each tracker carries 48 modules arranged in a single-portrait configuration along a horizontal north-south axis, with a total installed capacity of 28.08 kWp and a module area of 134.18 m<sup>2</sup> per tracker. The total material mass is 1,016 kg per tracker (7.57 kg/m<sup>2</sup>), with galvanised low-alloyed structural steel as the dominant fraction. The system boundary is cradle-to-grave and includes manufacturing, transport, on-site installation, tracker self-consumption electricity over a 30-year service life, and end-of-life disassembly.

Land use: Direct land occupation was modelled as an additional inventory flow for the fixed-tilt system based on system-specific geometry (row pitch, ground coverage ratio) and classified into industrial area, vegetation and industrial area, built up. The resulting specific land requirement of approximately 1.0 ha/MW is in good agreement with values reported by [76; 77].



Table 44: Unit process LCI data of fix-tilt and 1-axis tracker ground-mount PV mounting systems

Name	Location	InfrastructureProcess	Unit	Open ground construction, utility scale, on ground {RER} U	Open ground construction, 1-axis tracker, utility scale, on ground {RER} U
Location InfrastructureProcess Unit				RER 1 m2	RER 1 m2
Open ground construction, utility scale, on ground {RER} U	RER	1	m2	1	0
Open ground construction, 1-axis tracker, utility scale, on ground {RER} U	RER	1	m2	0	1
Electricity, medium voltage, production ENTSO-E, at grid {ENTSO-E} U	ENTSO-E	0	kWh	-	3.73E-1
Aluminium, production mix, wrought alloy, at plant {RER} U	RER	0	kg	2.85E-1	-
Polypropylene, granulate, at plant {RER} U	RER	0	kg	5.34E-3	-
Steel, low-alloyed, at plant {RER} U	RER	0	kg	9.24E+0	6.57E+0
Steel, electric, un- and low-alloyed, at plant {RER} U	RER	0	kg	-	8.35E-1
Chromium steel 18/8, at plant {RER} U	RER	0	kg	2.04E-1	-
Electric motor, electric vehicle, at plant {RER} U	RER	0	kg	-	3.19E-2
Corrugated board, mixed fibre, single wall, at plant {RER} U	RER	0	kg	9.26E-2	9.26E-2
Electronics for control units {RER} U	RER	0	kg	-	3.73E-4
Copper, at regional storage {RER} U	RER	0	kg	-	2.15E-2
Ethylene vinyl acetate copolymer, at plant {RER} U	RER	0	kg	-	6.05E-3
Section bar extrusion, aluminium {RER} U	RER	0	kg	0	-
Sheet rolling, aluminium {RER} U	RER	0	kg	2.85E-1	-
Section bar rolling, steel {RER} U	RER	0	kg	9.24E+0	-
Wire drawing, steel {RER} U	RER	0	kg	2.04E-1	-
Wire drawing, copper {RER} U	RER	0	kg	-	2.15E-2
Zinc coating, pieces {RER} U	RER	0	m2	5.14E-1	1.06E-1
Extrusion, plastic pipes {RER} U	RER	0	kg	-	6.05E-3
Transport, freight, lorry, fleet average {RER} U	RER	0	tkm	1.95E+0	4.16E+0
Transport, freight, rail {RER} U	RER	0	tkm	5.84E+0	-
Transport, freight, light commercial vehicle {RER} U	RER	0	tkm	9.73E-1	7.43E-1
Transport, transoceanic container ship {OCE} U	OCE	0	tkm	-	1.27E-2
Disposal, packaging cardboard, 19.6% water, to municipal incineration {CH} U	CH	0	kg	9.26E-2	9.26E-2
Disposal, building, polyethylene/polypropylene products, to final disposal {CH} U	CH	0	kg	5.34E-3	-
Transformation, from pasture and meadow	-	-	m2	2.25E+0	2.25E+0
Transformation, to industrial area, built up	-	-	m2	2.50E-1	2.50E-1
Transformation, to industrial area, vegetation	-	-	m2	2.00E+0	2.00E+0
Occupation, industrial area, built up	-	-	m2a	7.50E+0	7.50E+0
Occupation, industrial area, vegetation	-	-	m2a	6.00E+1	6.00E+1



## 3.7 Electrical components

### 3.7.1 Roof top installations

In this section, only LCI of 3 kW, 5.5 kW, 10 kW, and 100 kW inverters have been amended. All other data specific to the electrical BoS of roof top PV systems have not been updated.

<b>Name</b>	<b>Electrical cabling for module interconnection and AC-interface</b>
<b>Time period</b>	2006
<b>Geography</b>	Europe, Western
<b>Technology</b>	Average technology
<b>Representativeness</b>	Mixed data
<b>Date</b>	11/6/2006
<b>Collection method</b>	For roof top systems: 4 rows of 13 SolarWorld SW220 poly module with 6 x 10 multicrystalline cells of 156 mm x 156 mm.
<b>Data treatment</b>	Scaled to 1 m <sup>2</sup> of module area
<b>Comment</b>	For systems with modules in 150-170 Wp range and dimension of about 1 x 1.3 m <sup>2</sup> , connected to a 4.6 kW inverter.

Table 45: LCI of DC Cable (1)

Type of system		on-roof or in-roof	ground Phoenix Sonnenstrom	ground Springer-ville	
<b>Products</b>	<b>Unit</b>	<b>Amount</b>	<b>Amount</b>	<b>Amount</b>	<b>Comment</b>
DC Cabling	m <sup>2</sup>	1	1	1	per m <sup>2</sup> module area
<b>Materials/fuels</b>					
Copper	kg	0.10	0.62	0.64	2.2 m DC cable and 0.1 m AC cable
TPE = Thermoplastic elastomer	kg	0.06	0.25	0.48	
<b>Electricity</b>					
Electricity, medium voltage	kWh	0.0	0.0	0.0	unknown
<b>Emissions</b>					
<b>Waste to treatment</b>					
					Unknown

Note

1) Typical cable lengths for a roof top system are: 2.2 m DC cable and 0.1 m AC cable per m<sup>2</sup> of module/array area  
Reference: [53]



<b>Date</b>	9/1/2006
<b>Collection method</b>	<a href="http://www.helukabel.de/download.php?lang=en&amp;im=pdf/english/datenblatt/&amp;fid=78990.pdf">http://www.helukabel.de/download.php?lang=en&amp;im=pdf/english/datenblatt/&amp;fid=78990.pdf</a>
<b>Comment</b>	Helukabel Solarflex 101, 4 mm <sup>2</sup> , ROHS compliant. In a typical rooftop system, comprising modules of 1x1.7 m <sup>2</sup> , the DC cable length will be about 2.2 m per m <sup>2</sup> of module area

Table 46: LCI of DC Cable (2)

<b>Products</b>	<b>Unit</b>	<b>Amount</b>	<b>Comment</b>
Cable DC 4 mm <sup>2</sup>	m	1	
<b><u>Materials/fuels</u></b>			
<b>SOLIDS</b>			
Copper	kg	0.038	Cu, Sn coated
TPE = Thermoplastic elastomer	kg	0.030	TPE
<b><u>Electricity</u></b>			
Electricity, medium voltage, total	kWh	0.0	unknown
<b><u>Emissions</u></b>			unknown
<b><u>Waste to treatment</u></b>			unknown

Reference [53]



Table 47: Unit process LCI data of 3 kW, 5.5 kW, 10 kW and 100 kW Inverter (new data)

<b>Name</b>	<b>Inverter 3 kW, 5.5 kW, 10 kW &amp; 100 kW</b>
<b>Time period</b>	2022 - 2025
<b>Geography</b>	Global
<b>Technology</b>	Average technology
<b>Representativeness</b>	3 kW & 5.5 kW: Data representative for one inverter type per size. 10 kW & 100 kW: Data representative for the average of five inverter types per size.
<b>Date</b>	March 2026
<b>Collection method</b>	3 kW & 5.5 kW: Disassembly and weighing of parts. 10 kW & 100 kW: Based on survey of two leading inverter manufacturers and seven EPDs of inverters from six manufacturers worldwide

Name	Location InfrastructureProcess Unit	Location InfrastructureProcess Unit	Units	Inverter, 3 kW, at plant {RER} U	Inverter, 5.5 kW, at plant {RER} U	Inverter, 10 kW, average, at plant {GLO} U	Inverter, 100 kW, average, at plant {GLO} U	Uncertainty Type	Standard Deviation 5%	GeneralComment
				RER	RER	GLO	GLO			
product	Inverter, 3 kW, at plant {RER} U	RER	1 p	1	1	1	1			
	Inverter, 5.5 kW, at plant {RER} U	RER	1 p	0	1	0	0			
	Inverter, 10 kW, average, at plant {GLO} U	GLO	1 p	0	0	1	0			
	Inverter, 100 kW, average, at plant {GLO} U	GLO	1 p	0	0	0	1			
energy use	Electricity, medium voltage, production GLO, at grid {GLO} U	GLO	0 kWh	0	0	1.45E+1	9.32E+1	1	1.05	(2,4,2,3,1,4,BU:1.05); Data from one leading manufacturer;
individual components	Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0 kWh	1.27E+1	1.16E+1	0	0	1	1.33	(1,1,1,1,1,1,BU:1.05); ;
	Aluminium, production mix, cast alloy, at plant {RER} U	RER	0 kg	9.78E+0	0	1.12E+1	4.08E+1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Aluminium, production mix, wrought alloy, at plant {RER} U	RER	0 kg	0	1.25E+0	1.61E-1	5.85E-1	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Aluminium alloy, AlMg3, at plant {RER} U	RER	0 kg	0	2.54E+0	0	0	1	1.36	(1,1,1,1,1,1,BU:1.05); ;
	Brass, at plant {CH} U	CH	0 kg	0	0	1.27E-2	7.77E-2	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Silver, at regional storage {RER} U	RER	0 kg	0	0	2.53E-4	1.96E-3	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Zinc, primary, at regional storage {RER} U	RER	0 kg	0	0	1.49E-4	1.16E-3	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Copper, at regional storage {RER} U	RER	0 kg	2.12E+0	1.54E+0	2.02E-1	1.18E+1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Ethylene vinyl acetate copolymer, at plant {RER} U	RER	0 kg	0	0	2.98E-2	1.21E+0	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Aluminium hydroxide, at plant {RER} U	RER	0 kg	0	0	3.33E-2	1.01E+0	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Steel, low-alloyed, at plant {RER} U	RER	0 kg	1.86E-1	4.02E+0	1.11E+0	8.14E+0	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Chromium steel 18/8, at plant {RER} U	RER	0 kg	0	2.42E-1	9.64E-2	5.13E-1	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Acrylonitrile-butadiene-styrene copolymer, ABS, at plant {RER} U	RER	0 kg	0	1.23E+0	0	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Polypropylene, granulate, at plant {RER} U	RER	0 kg	0	0	3.09E-1	4.52E-1	1	1.61	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Polyester resin, unsaturated, at plant {RER} U	RER	0 kg	0	0	5.30E-1	1.16E+0	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Polyethylene, HDPE, granulate, at plant {RER} U	RER	0 kg	1.82E-1	0	0	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Polyethylene terephthalate, granulate, amorphous, at plant {RER} U	RER	0 kg	0	0	1.07E+0	2.34E+0	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Epoxy resin insulator (Al2O3), at plant {RER} U	RER	0 kg	3.06E+0	0	0	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Polycarbonate, at plant {RER} U	RER	0 kg	0	4.98E-1	9.27E-2	4.75E-1	1	1.36	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Power supply unit, at plant {GLO} U	GLO	0 p	0	0	3.59E-2	1.58E-1	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	LCD screen, at plant {GLO} U	GLO	0 kg	4.02E-2	7.40E-2	0	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Printed wiring board, surface mounted, unspec., Pb free, at plant {GLO} U	GLO	0 kg	5.64E-2	1.42E-1	0	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Fan, at plant {GLO} U	GLO	0 kg	0	3.35E-1	1.13E-2	2.66E+0	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Cable, three-conductor cable, at plant {GLO} U	GLO	0 m	0	1.36E-1	0	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Cable, connector for computer, without plugs, at plant {GLO} U	GLO	0 m	3.21E+0	0	0	0	1	1.36	(1,1,1,1,1,1,BU:1.05); ;



Table 47 (continued): Unit process LCI data of 10 kW and 100 kW Inverter (new data)

product	Name	Location Infrastructure	Process	Unit	Inverter, at plant (GLO) U				Uncertainty Type	Standard Deviation 5%	General Comment
					Inverter, 3 kW, at plant (RER) U	Inverter, 5.5 kW, at plant (RER) U	Inverter, 10 kW, average, at plant (GLO) U	Inverter, 100 kW, average, at plant (GLO) U			
					RER	RER	GLO	GLO			
	Location Infrastructure Process Unit				1	1	1	1			
	Inverter, 3 kW, at plant (RER) U	RER	1	p	1	0	0	0			
	Inverter, 5.5 kW, at plant (RER) U	RER	1	p	0	1	0	0			
	Inverter, 10 kW, average, at plant (GLO) U	GLO	1	p	0	0	1	0			
	Inverter, 100 kW, average, at plant (GLO) U	GLO	1	p	0	0	0	1			
printed board assembly	Printed wiring board, surface mount, lead-free surface, at plant (GLO) U	GLO	0	m2	3.46E-1	1.23E-1	2.33E-1	6.94E-1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Connector, clamp connection, at plant (GLO) U	GLO	0	kg	1.06E-1	0	1.13E-2	4.68E+0	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Inductor, ring core choke type, at plant (GLO) U	GLO	0	kg	2.51E-1	5.12E-1	3.04E+0	3.39E-1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Inductor, low value multilayer chip type, LMCI, at plant (GLO) U	GLO	0	kg	0	0	1.56E-2	1.31E-2	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Integrated circuit, IC, logic type, at plant (GLO) U	GLO	0	kg	2.29E-2	2.40E-2	5.80E-2	4.04E-2	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Integrated circuit, IC, memory type, at plant (GLO) U	GLO	0	kg	0	0	5.86E-4	4.08E-4	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Insulated gate bipolar transistor, electric vehicle application (RER) U	RER	1	kg	4.07E-2	0	0	0	1	3.00	(1,1,1,1,1,1,BU:3); ;
	Transistor, SMD type, surface mounting, at plant (GLO) U	GLO	0	kg	0	0	3.25E-3	2.62E-4	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Diode, glass-, SMD type, surface mounting, at plant (GLO) U	GLO	0	kg	0	0	4.57E-3	2.13E-2	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Light emitting diode, LED, at plant (GLO) U	GLO	0	kg	0	0	1.05E-3	4.89E-3	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Capacitor, film, through-hole mounting, at plant (GLO) U	GLO	0	kg	2.73E-1	1.03E+0	3.19E-1	1.89E+0	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Capacitor, electrolyte type, > 2cm height, at plant (GLO) U	GLO	0	kg	7.96E-1	2.16E-2	1.12E-1	6.63E-1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Capacitor, electrolyte type, < 2cm height, at plant (GLO) U	GLO	0	kg	6.67E-2	4.14E-3	2.92E-3	1.73E-2	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Capacitor, SMD type, surface-mounting, at plant (GLO) U	GLO	0	kg	0	0	1.25E-1	7.42E-1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Resistor, metal film type, through-hole mounting, at plant (GLO) U	GLO	0	kg	4.52E-3	0	0	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Resistor, wirewound, through-hole mounting, at plant (GLO) U	GLO	0	kg	4.28E-2	0	6.62E-2	4.06E-1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Resistor, SMD type, surface mounting, at plant (GLO) U	GLO	0	kg	1.34E-2	0	1.95E-2	1.20E-1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Ferrite, at plant (GLO) U	GLO	0	kg	1.11E+0	4.21E+0	0	1.19E+1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Transformer, low voltage use, at plant (GLO) U	GLO	0	kg	2.09E-1	0	5.07E-1	0	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Switch, toggle type, at plant (GLO) U	GLO	0	kg	0	0	0	3.44E-1	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Plugs, inlet and outlet, for network cable, at plant (GLO) U	GLO	0	p	1.41E+0	0	0	0	1	1.33	(1,1,1,1,1,1,BU:1.05); ;
	Nylon 66, at plant (RER) U	RER	0	kg	2.34E-2	5.27E-2	8.17E-2	1.79E-1	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant (RER) U	RER	0	kg	0	3.09E-1	6.55E-2	8.48E-1	1	1.33	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Cable, ribbon cable, 20-pin, with plugs, at plant (GLO) U	GLO	0	kg	0	7.00E-3	0	0	1	1.33	(1,1,1,1,1,1,BU:1.05); ;
	Electronic component, passive, unspecified, at plant (GLO) U	GLO	0	kg	0	5.04E-1	3.72E-1	4.34E-1	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Epoxy resin, liquid, at plant (RER) U	RER	0	kg	1.05E+0	0	3.26E+0	4.29E+0	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Synthetic rubber, at plant (RER) U	RER	0	kg	8.22E-2	2.00E-3	2.21E-2	4.83E-2	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Silicone product, at plant (RER) U	RER	0	kg	0	0	5.52E-2	1.21E-1	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Solder, bar, Sn63Pb37, for electronics industry, at plant (GLO) U	GLO	0	kg	3.12E-2	2.85E-2	3.57E-2	3.62E-2	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
	Solder, paste, Sn63Pb37, for electronics industry, at plant (GLO) U	GLO	0	kg	1.04E-2	9.51E-3	1.19E-2	1.31E-2	1	1.05	(2,3,2,3,1,4,BU:1.05); BoM data from five manufacturers ; recycled after use;
processing	Sheet rolling, steel (RER) U	RER	0	kg	1.86E-1	4.02E+0	1.11E+0	8.14E+0	1	1.24	(4,3,2,3,1,4,BU:1.05); Assumption based on BoM of five manufacturers;
	Sheet rolling, aluminium (RER) U	RER	0	kg	0	1.25E+0	1.61E-1	5.85E-1	1	1.05	(4,3,2,3,1,4,BU:1.05); Assumption based on BoM of five manufacturers;
	Casting, brass (CH) U	CH	0	kg	0	0	1.27E-2	7.77E-2	1	1.05	(4,3,2,3,1,4,BU:1.05); Assumption based on BoM of five manufacturers;
	Wire drawing, copper (RER) U	RER	0	kg	2.13E+0	1.53E+0	2.02E-1	1.18E+1	1	1.24	(4,3,2,3,1,4,BU:1.05); Assumption based on BoM of five manufacturers;
	Extrusion, plastic pipes (RER) U	RER	0	kg	0	0	2.98E-2	1.21E+0	1	1.05	(4,3,2,3,1,4,BU:1.05); Assumption based on BoM of five manufacturers;
	Injection moulding (RER) U	RER	0	kg	3.26E+0	1.73E+0	1.55E+0	3.45E+0	1	1.05	(4,3,2,3,1,4,BU:1.05); Assumption based on BoM of five manufacturers;
	Production efforts, inductors (GLO) U	GLO	0	kg	3.16E+0	5.74E+0	1.93E-2	2.18E+1	1	1.05	(4,3,2,3,1,4,BU:1.05); Assumption based on BoM of five manufacturers;
	Zinc coating, pieces (RER) U	RER	0	m2	4.64E-2	1.00E+0	2.76E-1	2.04E+0	1	1.05	(4,3,2,3,1,4,BU:1.05); Assumption based on BoM of five manufacturers;
	Thermoforming, with calendaring (RER) U	RER	0	kg	0	2.50E-2	0	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Section bar extrusion, aluminium (RER) U	RER	0	kg	0	2.54E+0	0	0	1	1.24	(1,1,1,1,1,1,BU:1.05); ;





Table 48: Unit process LCI data of 2.5 kW, 5 kW and 20 kW Inverter – Not Updated from 2020 report

<b>Name</b>	<b>Inverter 2.5 kW, 5 kW and 20 kW</b>
<b>Time period</b>	2016
<b>Geography</b>	Europe, Western
<b>Technology</b>	Average technology
<b>Representativeness</b>	Data representative for the average of three specific types of inverters
<b>Date</b>	10/3/2016
<b>Collection method</b>	Based on survey of 3 major European inverter manufacturers [78]

Name	Location	InfrastructureProcess	Unit	Inverter, 2.5 kW, average, at plant (RER) U	Inverter, 5 kW, average, at plant (RER) U	Inverter, 20 kW, average, at plant (RER) U	UncertaintyType	StandardDeviation95%	GeneralComment
				RER	RER	RER			
	Location InfrastructureProcess Unit			P	P	P			
	Inverter, 2.5 kW, average, at plant (RER) U	RER	1 p	1	0	0			
	Inverter, 5 kW, average, at plant (RER) U	RER	1 p	0	1	0			
	Inverter, 20 kW, average, at plant (RER) U	RER	1 p	0	0	1			
energy use	Electricity, medium voltage, production ENTSO-E, at grid (ENTSO-E) U	ENTSO-E	0 kWh	1.06E+1	1.69E+1	4.34E+1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from two European inverter manufacturers;
	Light fuel oil, burned in industrial furnace 1MW, non-modulating (CH) U	CH	0 MJ	2.26E-1	3.61E-1	9.28E-1	1	1.34	(3,4,1,3,3,5,BU:1.05); Data from two European inverter manufacturers;
	Natural gas, burned in power plant (DE) U	DE	0 MJ	3.57E+0	5.72E+0	1.47E+1	1	1.34	(3,4,1,3,3,5,BU:1.05); Data from two European inverter manufacturers;
	Heat, natural gas, at industrial furnace 1MW (CH) U	CH	0 MJ	9.21E+0	1.47E+1	3.79E+1	1	1.34	(3,4,1,3,3,5,BU:1.05); Data from two European inverter manufacturers;
individual components	Aluminium, production mix, cast alloy, at plant (RER) U	RER	0 kg	4.77E+0	7.64E+0	1.96E+1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Aluminium alloy, AlMg3, at plant (RER) U	RER	0 kg	2.12E-1	3.39E-1	8.70E-1	1	1.34	(3,4,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Copper, at regional storage (RER) U	RER	0 kg	1.91E+0	3.06E+0	7.86E+0	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Steel, low-alloyed, at plant (RER) U	RER	0 kg	9.07E-1	1.45E+0	3.73E+0	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use; data on the production of three inverters by two European producers
	Polypropylene, granulate, at plant (RER) U	RER	0 kg	8.82E-1	1.41E+0	3.63E+0	1	1.60	(3,4,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Polycarbonate, at plant (RER) U	RER	0 kg	2.02E-1	3.24E-1	8.32E-1	1	1.34	(3,4,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Cable, connector for computer, without plugs, at plant (GLO) U	GLO	0 m	1.31E-1	2.10E-1	5.40E-1	1	1.34	(3,4,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Inductor, ring core choke type, at plant (GLO) U	GLO	0 kg	8.71E-1	1.40E+0	3.58E+0	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Integrated circuit, IC, logic type, at plant (GLO) U	GLO	0 kg	6.61E-2	1.06E-1	2.72E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Ferrite, at plant (GLO) U	GLO	0 kg	3.49E-2	5.59E-2	1.44E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Plugs, inlet and outlet, for network cable, at plant (GLO) U	GLO	0 p	3.48E+0	5.58E+0	1.43E+1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant (RER) U	RER	0 kg	1.31E-1	2.09E-1	5.37E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
printed board assembly	Printed wiring board, surface mount, lead-free surface, at plant (GLO) U	GLO	0 m2	1.01E-1	1.62E-1	4.16E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Tin, at regional storage (RER) U	RER	0 kg	9.59E-3	1.54E-2	3.94E-2	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Connector, clamp connection, at plant (GLO) U	GLO	0 kg	2.44E-2	3.91E-2	1.00E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Inductor, ring core choke type, at plant (GLO) U	GLO	0 kg	1.31E-1	2.09E-1	5.37E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Inductor, miniature RF chip type, MRFI, at plant (GLO) U	GLO	0 kg	1.10E-3	1.77E-3	4.53E-3	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Integrated circuit, IC, logic type, at plant (GLO) U	GLO	0 kg	1.55E-1	2.49E-1	6.39E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Integrated circuit, IC, memory type, at plant (GLO) U	GLO	0 kg	1.87E-3	3.00E-3	7.70E-3	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Transistor, unspecified, at plant (GLO) U	GLO	0 kg	1.92E-2	3.07E-2	7.89E-2	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Transistor, SMD type, surface mounting, at plant (GLO) U	GLO	0 kg	4.17E-2	6.69E-2	1.72E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Diode, glass-, SMD type, surface mounting, at plant (GLO) U	GLO	0 kg	2.01E-3	3.22E-3	8.25E-3	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Light emitting diode, LED, at plant (GLO) U	GLO	0 kg	1.44E-5	2.31E-5	5.92E-5	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Capacitor, film, through-hole mounting, at plant (GLO) U	GLO	0 kg	1.66E-1	2.67E-1	6.84E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Capacitor, electrolyte type, > 2cm height, at plant (GLO) U	GLO	0 kg	2.57E-1	4.12E-1	1.06E+0	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Capacitor, electrolyte type, < 2cm height, at plant (GLO) U	GLO	0 kg	6.71E-3	1.08E-2	2.76E-2	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Capacitor, SMD type, surface-mounting, at plant (GLO) U	GLO	0 kg	1.33E-3	2.14E-3	5.49E-3	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Resistor, wirewound, through-hole mounting, at plant (GLO) U	GLO	0 kg	1.12E-3	1.79E-3	4.60E-3	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Resistor, SMD type, surface mounting, at plant (GLO) U	GLO	0 kg	4.57E-3	7.33E-3	1.88E-2	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Ferrite, at plant (GLO) U	GLO	0 kg	2.55E-5	4.09E-5	1.05E-4	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Transformer, low voltage use, at plant (GLO) U	GLO	0 kg	4.01E-2	6.43E-2	1.65E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Plugs, inlet and outlet, for network cable, at plant (GLO) U	GLO	0 p	2.79E-1	4.47E-1	1.15E+0	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant (RER) U	RER	0 kg	2.56E-2	4.10E-2	1.05E-1	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;
	Cable, ribbon cable, 20-pin, with plugs, at plant (GLO) U	GLO	0 kg	2.40E-4	3.84E-4	9.86E-4	1	1.31	(2,3,1,3,3,5,BU:1.05); Data from three European inverter manufacturers; recycled after use;



Table 48 (continued): Unit process LCI data of 2.5 kW, 5 kW and 20 kW Inverter

processing	Sheet rolling, steel (RER) U	RER	0	kg	9.07E-1	1.45E+0	3.73E+0	1	1.21	(1,1,1,1,1,5,BU:1.05); Data from three European inverter manufacturers ; recycled after use; Applied as well on the production data of an inverter of an European producer
	Wire drawing, copper (RER) U	RER	0	kg	1.91E+0	3.06E+0	7.86E+0	1	1.21	(1,1,1,1,1,5,BU:1.05); Data from three European inverter manufacturers ; recycled after use; Applied as well on the production data of an inverter of an European producer
	Section bar extrusion, aluminium (RER) U	RER	0	kg	4.77E+0	7.64E+0	1.96E+1	1	1.21	(1,1,1,1,1,5,BU:1.05); Data from three European inverter manufacturers ; recycled after use; Applied as well on the production data of an inverter of an European producer
	Steel product manufacturing, average metal working (RER) U	RER	0	kg	1.92E-2	3.08E-2	7.90E-2	1	1.34	(3,4,1,3,3,5,BU:1.05); data on the production of an inverter by a European producer;
infrastructure	Metal working factory (RER) U	RER	1	p	1.10E-8	1.76E-8	4.51E-8	1	3.05	(1,1,1,1,1,5,BU:3); Calculation, based on annual production of electronic component production plant; taken from theecoinvent v2.2 inverter dataset;
packaging	Corrugated board, mixed fibre, single wall, at plant (RER) U	RER	0	kg	6.60E-1	1.06E+0	2.71E+0	1	1.21	(1,1,1,1,1,5,BU:1.05); data on the production of an inverter by a European producer;
	Folding boxboard, FBB, at plant (RER) U	RER	0	kg	1.16E+0	1.85E+0	4.75E+0	1	1.34	(3,4,1,3,3,5,BU:1.05); data on the production of an inverter by a European producer;
	Packaging film, LDPE, at plant (RER) U	RER	0	kg	1.15E-2	1.84E-2	4.73E-2	1	1.34	(3,4,1,3,3,5,BU:1.05); data on the production of an inverter by a European producer;
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	6.76E-1	1.08E+0	2.78E+0	1	2.09	(4,5,na,na,na,na,BU:2); Standard distance 60km incl. disposal;
	Transport, freight, rail (RER) U	RER	0	tkm	2.25E+0	3.61E+0	9.27E+0	1	2.09	(4,5,na,na,na,na,BU:2); Standard distances 200km;
	Transport, transoceanic freight ship (OCE) U	OCE	0	tkm	2.03E+1	3.25E+1	8.34E+1	1	2.09	(4,5,na,na,na,na,BU:2); Estimation: 18000km;
emission emissions to air, unspecified	Heat, waste	-	-	MJ	3.80E+1	6.09E+1	1.56E+2	1	1.22	(2,3,1,1,1,5,BU:1.05); Calculation;
technosphere resources, in water	Tap water, at user (RER) U	RER	0	kg	1.99E+1	3.18E+1	8.17E+1	1	1.34	(3,4,1,3,3,5,BU:1.05); data on the production of an inverter by a European producer;
	Water, unspecified natural origin, DE	-	-	m3	3.78E-2	6.06E-2	1.56E-1	1	1.34	(3,4,1,3,3,5,BU:1.05); data on the production of an inverter by a European producer;

### 3.7.2 Utility scale installations

This section describes the updated life cycle inventory modelling of the electrical balance-of-system for the 10 MWP utility-scale reference PV plant. The update covers the main electrical infrastructure required between the PV modules and the medium-voltage grid connection, including DC string cabling, AC cabling, string inverters, the medium-voltage step-up transformer, transformer station infrastructure, and auxiliary installation materials. Particular attention was given to layout-dependent cable quantities, transformer material composition, and the modelling of materials for which no dedicated datasets are available in the background database. The inventories are expressed per square metre of installed module area and are intended to represent the electrical balance-of-system at the point of installation for a fixed-tilt open-ground PV system.

The life cycle inventory for the medium-voltage step-up transformer was established based on declared material masses from product documentation and empirical allocation factors from published transformer LCI literature (see Table 49). The functional unit is one oil-immersed distribution transformer with a rated power of 2500 kVA and a voltage ratio of 20/0.4 kV, modelled at the point of manufacture (cradle-to-gate). The total material inventory amounts to approximately 5680 kg per unit. Transformer oil, aluminium winding conductors, and structural steel masses are taken directly from declared product specifications; insulating paper and pressboard masses are estimated from the aluminium winding mass using empirically established ratios, and minor materials (potting resin, copper contacts, stainless fittings, sealing gaskets, and external coating) are drawn from the same literature source.

The magnetic core of an oil-immersed power transformer consists of grain-oriented electrical steel (GOES), a specialised silicon-alloyed steel whose microstructure is aligned through controlled cold-rolling and high-temperature annealing to minimise core losses. With a core mass of approximately 2150 kg, GOES represents the single largest material fraction (38 % by mass) in this inventory. As no dedicated GOES dataset is available in the background database, the core was disaggregated into its constituent production inputs following a published LCI methodology: unalloyed converter-route steel as the base material, metallurgical-grade silicon as the alloying input, hot and cold rolling to the final sheet thickness, and annealing energy for the decarburisation, secondary recrystallisation, and stress-relief stages. The use of converter-route steel as base material feedstock is technically justified, as GOES production imposes strict chemical composition requirements that cannot be met with electric-arc-furnace-derived steel. Annealing energy was estimated from published plant measurement data and carries the highest parametric uncertainty in the inventory, owing to the absence of primary European mill data and the use of a proxy dataset that does not fully represent the large-capacity continuous strip furnaces characteristic of industrial GOES production.



Table 49: LCI of oil-immersed 2.5 MW transformer.

Name	Location	Infrastructure Process	Unit	Transformer, oil-immersed, 2.5 MW, at plant {RER} U	Uncertainty Type Standard Deviations 5%	General Comment
Location Infrastructure Process				RER 1 p		
Unit						
Transformer, oil-immersed, 2.5 MW, at plant {RER} U	RER	1	p	1		
Steel, converter, unalloyed, at plant {RER} U	RER	0	kg	2.09E+3	1 1.33	(2,2,2,1,2,3); GOES (grain-oriented electrical steel) core, Si-alloying step. Factor 0.9712 kg/kg GOES. Source: Clementi 2024 [EC312].
MG-silicon, at plant {NO} U	NO	0	kg	7.32E+1	1 1.34	(2,2,2,2,3,3); GOES core, Si-alloying step. FeSi75 proxy (no FeSi dataset in BAFU 2025). Factor 0.034 kg/kg GOES. ESTIMATED. Source: Clementi 2024 [EC312].
Hot rolling, steel {RER} U	RER	0	kg	2.15E+3	1 1.33	(2,2,2,1,1,3); GOES core, hot rolling. Factor 1.000 kg/kg GOES. Source: Clementi 2024 [EC312].
Sheet rolling, steel {RER} U	RER	0	kg	4.31E+3	1 1.33	(2,2,2,1,2,3); GOES core, cold rolling, 2 passes to 0.23 mm. Factor 2.000 kg/kg GOES. Source: Clementi 2024 [EC312].
Electricity, medium voltage, production ENTSO-E, at grid {ENTSO-E} U	ENTSO-E	0	kWh	2.37E+0	1 1.84	(3,3,4,2,2,4); GOES core, annealing electricity (decarburisation, box annealing, heat flattening). ~1100 kWh/t. ESTIMATED. Source: Vasilyev & Samokish 2013 [VAL13].
Heat, natural gas, at industrial furnace 1MW {CH} U	CH	0	MJ	9.90E+3	1 1.87	(4,3,4,3,3,4); GOES core, heat for all annealing stages (decarburisation anneal, secondary recrystallisation / box
Lubricating oil, at plant {RER} U	RER	0	kg	1.06E+3	1 1.34	(2,2,3,1,3,3); Transformer oil (mineral oil). Proxy: lubricating oil dataset.
Aluminium, production mix, wrought alloy, at plant {RER} U	RER	0	kg	6.18E+2	1 1.34	(2,2,3,1,1,3); Al winding conductors, wrought alloy.
Sheet rolling, aluminium {RER} U	RER	0	kg	6.18E+2	1 1.34	(2,2,3,1,2,3); Al winding, flat conductor rolling step. Source:
Aluminium product manufacturing, average metal working {RER} U	RER	0	kg	6.18E+2	1 1.34	(2,2,3,1,2,3); Al winding, general metalworking step. Source:
Steel, low-alloyed, at plant {RER} U	RER	0	kg	1.73E+3	1 1.33	(2,2,2,1,1,3); Structural steel (tank, frame, brackets). Residual mass. Source: Schneider Electric 2016 [MIN16]; Boutros et al. 2026 [BUT26].
Kraft paper, unbleached, at plant {RER} U	RER	0	kg	3.41E+1	1 1.36	(2,3,2,1,2,3); Conductor insulating paper. Al×0.115×0.48=34.11 kg. Source: Boutros et al. 2026 [BUT26].
Solid bleached board, SBB, at plant {RER} U	RER	0	kg	3.70E+1	1 1.36	(2,3,2,1,3,3); Transformer pressboard. Proxy: hard fibreboard (compressed cellulose; no pressboard dataset in BAFU 2025) ESTIMATED. Al×0.115×0.52=36.96 kg. Source: Boutros et al. 2026 [BUT26].
Epoxy resin, liquid, at plant {RER} U	RER	0	kg	1.50E+1	1 1.33	(2,2,2,1,2,3); Potting compound / adhesives. Source: Boutros et al. 2026 [BUT26].
Copper, at regional storage {RER} U	RER	0	kg	2.10E+0	1 1.33	(2,2,2,1,1,3); Copper (bushings, contacts). Source: Boutros et al. 2026 [BUT26].
Chromium steel 18/8, at plant {RER} U	RER	0	kg	2.50E+0	1 1.33	(2,2,2,1,1,3); Stainless steel fittings. Source: Boutros et al. 2026 [BUT26].
Synthetic rubber, at plant {RER} U	RER	0	kg	2.00E-1	1 1.33	(2,2,2,1,2,3); Sealing gaskets. Source: Boutros et al. 2026 [BUT26].
Alkyd paint, white, 60% in H2O, at plant {RER} U	RER	0	kg	1.36E+1	1 1.33	(2,2,2,1,2,3); External tank coating. Total×0.0024=13.61 kg. Source: Boutros et al. 2026 [BUT26].
Disposal, used mineral oil, 10% water, to hazardous waste incineration {CH} U	CH	0	kg	1.06E+3	1 2.77	(2,2,3,1,2,3); EoL transformer oil → hazardous waste incineration.
Disposal, paper, 11.2% water, to municipal incineration {CH} U	CH	0	kg	7.11E+1	1 2.77	
Disposal, plastics, mixture, 15.3% water, to municipal incineration {CH} U	CH	0	kg	1.50E+1	1 3.00	
Disposal, organic floor covering as construction waste, to municipal waste incineration, synthetic rubber {CH} U	CH	0	kg	2.00E-1	1 3.00	
Disposal, building, paint on metal, to final disposal {CH} U	CH	0	kg	1.36E+1	1 2.77	(2,2,2,1,2,3); EoL tank coating → final disposal.

The life cycle inventory for the electrical balance-of-system was established for a reference plant of 10 MWp DC capacity (22,240 modules at 450 Wp, total module area 44,438 m<sup>2</sup>) and is expressed per square metre of module area installed (see Table 50). The plant comprises 40 table rows, each containing 14 full tables of 39 modules and one partial table of 10 modules. Eighty string inverters of 100 kVA each are distributed across the plant at a rate of two inverters per row, located below table positions 7 and 8 within each row. The electrical building housing the switchgear and medium-voltage transformer is positioned centrally at approximately 20 m from one end of row 19, minimising the average AC cable run across all inverter positions.



DC string cables (6 mm<sup>2</sup> Cu, single-core) connect individual module strings to the row inverters. Route lengths were derived from the horizontal distance between each table and its assigned row inverter; the total installed DC conductor length, counting positive and negative runs separately, amounts to approximately 222,000 m for the plant. Each of the 80 inverters is connected individually to the transformer building via single-core AC cables (95 mm<sup>2</sup> Cu); route lengths were calculated from each inverter position to the central transformer location including a ten-percent safety allowance, resulting in a total AC conductor length of approximately 12,000 m for the plant. The inventory covers the full copper conductor mass, the cable polymer layers, and the associated processing steps. The DC cable insulation and sheath are modelled using a linear low-density polyethylene proxy for the actual cross-linked polyolefin compound; the AC cable uses an EPDM proxy for the ethylene-propylene rubber insulation layer and the same polyethylene proxy for the halogen-free thermoplastic outer sheath, both reflecting the absence of dedicated specialty polymer datasets in the background database.

The medium-voltage step-up transformer consists of four oil-immersed 2500 kVA units housed in the central electrical building, together yielding an installed AC capacity of 10 MVA. Copper in transformer windings and contacts is included in the transformer unit process and therefore excluded from the cable copper inventory. The transformer station buildings are modelled using a generic industrial hall proxy scaled to an assumed floor area of 10 m<sup>2</sup> per station. Cable tie quantities are derived from a layout-based estimate of twenty ties per table position.



**Table 50: LCI of 10 MW utility-scale electrical BoS including 4 units 2.5 MW transformers (per m<sup>2</sup> module area).**

Name	Location	Infrastructure Process	Unit	Electric installation, utility scale, open ground {RER} U	Uncertainty Type	Standard Deviation %	General Comment
Location				RER			
Infrastructure Process				1 m <sup>2</sup>			
Unit				1			
Electric installation, utility scale, open ground {RER} U	RER	1	m <sup>2</sup>	1			
Copper, at regional storage {RER} U	RER	0	kg	5.34E-1	1	1.33	(2,2,2,1,2,3); DC cable Cu (Lapp H1Z2Z2-K 1x6mm <sup>2</sup> ; 222300m; 0.0576 kg/m = 12804.5 kg) AC cable Cu (FG16M16-flex 1x95mm <sup>2</sup> ; 12000m; 0.912 kg/m = 10944.0 kg). Total 23748 kg / 44438 m <sup>2</sup> . Transformer Cu in Z-PV-276.
Polyethylene, LLDPE, granulate, at plant {RER} U	RER	0	kg	1.12E-1	1	1.33	(2,2,2,1,3,3); DC cable insulation+sheath (XLPO; 0.0224 kg/m × 222300 m = 4980 kg / 44438 m <sup>2</sup> = 0.1121 kg/m <sup>2</sup> ); proxy: LLDPE
Synthetic rubber, at plant {RER} U	RER	0	kg	1.67E-2	1	1.33	(2,2,2,1,3,3); AC cable insulation (EPR; FG16M16-flex 1x95mm <sup>2</sup> ; 0.062 kg/m × 12000 m = 744 kg / 44438 m <sup>2</sup> = 0.01674 kg/m <sup>2</sup> ); proxy: EPDM synthetic rubber {RER}. Dataset includes rubber compounding.
Polyethylene, LLDPE, granulate, at plant {RER} U	RER	0	kg	1.97E-2	1	1.33	(2,2,2,1,3,3); AC cable outer sheath (M16, halogen-free TPO per IEC; 0.0728 kg/m × 12000 m = 873.6 kg / 44438 m <sup>2</sup> = 0.01966 kg/m <sup>2</sup> ); proxy: LLDPE
Transformer, oil-immersed, 2.5 MW, at plant {RER} U	RER	1	p	9.00E-5	1	3.11	(2,2,2,1,2,3); Transformer, oil-immersed, 2500 kVA, 20/0.4 kV; 4 units / 44438 m <sup>2</sup> = 9.0013e-05 p/m <sup>2</sup> .
Building, hall, steel construction {CH} U	CH	1	m <sup>2</sup>	9.00E-4	1	3.12	(3,3,2,2,3,3); Trafo station buildings (4 × 10 m <sup>2</sup> = 40 m <sup>2</sup> / 44438 m <sup>2</sup> = 9.0013e-04 m <sup>2</sup> /m <sup>2</sup> ); proxy: building, hall, steel construction {CH}.
Nylon 66, at plant {RER} U	RER	0	kg	7.36E-4	1	1.35	(2,3,2,1,1,3); Cable ties PA66 UV-stabilised (OBO 565 7.6×200; 20 per table × 570 tables = 11400 pcs × 0.00287 kg/pc = 32.7 kg / 44438 m <sup>2</sup> = 7.3586e-04 kg/m <sup>2</sup> ).
Wire drawing, copper {RER} U	RER	0	kg	5.34E-1	1	1.33	(2,2,2,1,2,3); Wire drawing, Cu (same total as R16: 23748 kg / 44438 m <sup>2</sup> = 0.5344 kg/m <sup>2</sup> ).
Extrusion, plastic pipes {RER} U	RER	0	kg	1.49E-1	1	1.33	(2,2,2,1,3,3); Cable extrusion onto conductor: LLDPE/XLPO DC (4980 kg) + EPR AC insulation (744 kg) + LLDPE M16 AC sheath (877 kg) = 6601 kg / 44438 m <sup>2</sup> = 0.1485 kg/m <sup>2</sup> . EPR dataset covers rubber compounding only; this step models the cable extrusion.
Transport, freight, lorry, fleet average {RER} U	RER	0	tkm	8.21E-1	1	2.33	(4,5,na,na,na,na); Standard distance 60km incl. disposal
Transport, freight, rail {RER} U	RER	0	tkm	5.47E-1	1	2.33	(4,5,na,na,na,na); Standard distances 200km (metals 600km)
Disposal, treatment of cables {GLO} U	GLO	0	kg	6.63E-1	1	1.61	(2,3,1,3,1,4);

The inventories for the DC and AC cables were modelled per metre of installed single-core cable, based on product-specific conductor cross-sections and declared cable masses, with material-specific proxies used for polymer insulation and sheath materials where no dedicated datasets were available in the background database.

Table 51: LCI of 6 mm<sup>2</sup> DC cable for string to inverter cabling in PV systems

Products	Unit	Amount	Comment
<b>Cable DC, 1×6 mm<sup>2</sup>, Cu, XLPO</b>	m	1	H1Z2Z2-K 1×6 mm <sup>2</sup> , Based on [79]
<b>Materials/fuels</b>			
<b>SOLIDS</b>			
Copper, at regional storage {RER}	kg	0.0576	Cu conductor, 6 mm <sup>2</sup> stranded
Polyethylene, LLDPE, granulate, at plant {RER}	kg	0.0224	XLPO insulation + outer sheath; LLDPE proxy (no XLPO dataset in BAFU 2025)
<b>Processing</b>			
Wire drawing, copper {RER}	kg	0.0576	Applied to Cu conductor
Extrusion, plastic pipes {RER}	kg	0.0224	Cable application extrusion; plastic pipe proxy
<b>Waste to treatment</b>			
Disposal, plastics, mixture, 15.3% water, to municipal incineration {CH}	kg	0.0224	XLPO insulation + sheath; plastics mixture proxy (Std414742). Consistent with transformer model (Z-PV-276). ESTIMATED.

Table 52: LCI of 95 mm<sup>2</sup> AC cable

Products	Unit	Amount	Comment
<b>Cable AC, 1×95 mm<sup>2</sup>, Cu, EPR/M16</b>	m	1	FG16M16-flex Cca hal-frei 1×95 mm <sup>2</sup> , based on [80]
<b>Materials/fuels</b>			
<b>SOLIDS</b>			
Copper, at regional storage {RER}	kg	0.912	Cu conductor, 95 mm <sup>2</sup> stranded
Synthetic rubber, at plant {RER}	kg	0.062	EPR insulation; EPDM proxy (same ethylene-propylene monomer base)
Polyethylene, LLDPE, granulate, at plant {RER}	kg	0.073	M16 halogen-free TPO outer sheath; LLDPE proxy (no halogen-free TPO in BAFU 2025)
<b>Processing</b>			
Wire drawing, copper {RER}	kg	0.912	Applied to Cu conductor
Extrusion, plastic pipes {RER}	kg	0.135	Cable application extrusion (EPR 0.062 + M16 0.073 kg); plastic pipe proxy
<b>Waste to treatment</b>			
Disposal, organic floor covering as construction waste, to municipal waste incineration, synthetic rubber {CH}	kg	0.062	EPR insulation; synthetic rubber proxy (Std473679). Consistent with transformer model (Z-PV-276). ESTIMATED.
Disposal, plastics, mixture, 15.3% water, to municipal incineration {CH}	kg	0.073	M16 TPO outer sheath; plastics mixture proxy (Std414742). Consistent with transformer model (Z-PV-276). ESTIMATED.



### 3.8 Reference residential, commercial and utility scale PV systems

<b>Name</b>	10 kWp residential, 250 kWp commercial and 10 MWp utility scale PV installations.
<b>Time period</b>	2024
<b>Geography</b>	World
<b>Technology</b>	Mono-Si, mounted on slanted (10 kWp, 250 kWp/200 kVA) and flat roof (250 kWp/200 kVA) and fixed tilt open ground system (10 MWp/7.5 MVA).
<b>Representativeness</b>	Representative for commercial and utility scale PV.
<b>Comment</b>	Photovoltaic installations on buildings are considered with 10 kWp and 250 kWp installations. Centralized installations are considered with 10 MW utility-scale open ground installations.

Table 53: LCI of reference PV systems with 10 kWp, 250 kW and 10 MW installed DC power.

Name	Location	Infrastructure	Process	Unit	10 kWp	250 kWp	250 kWp	250 kWp	10 MW	Uncertainty	Type	StandardDeviation95%	GeneralComment
					slanted-roof installation, single-Si, panel, mounted, on roof {GLO} U	slanted-roof installation, single-Si, panel, mounted, on roof {GLO} U	slanted-roof installation, single-Si, laminate, integrated, on roof {GLO} U	flat-roof installation, single-Si, panel, mounted, on roof {GLO} U	ground-mounted installation, single-Si, panel, on open ground {GLO} U				
					GLO	GLO	GLO	GLO	GLO				
					1	1	1	1	1				
					p	p	p	p	p				
10 kWp slanted-roof installation, single-Si, panel, mounted, on roof {GLO} U	GLO	1	p		1	0	0	0	0				
250 kWp slanted-roof installation, single-Si, panel, mounted, on roof {GLO} U	GLO	1	p		0	1	0	0	0				
250 kWp slanted-roof installation, single-Si, laminate, integrated, on roof {GLO} U	GLO	1	p		0	0	1	0	0				
250 kWp flat-roof installation, single-Si, panel, mounted, on roof {GLO} U	GLO	1	p		0	0	0	1	0				
10 MW ground-mounted installation, single-Si, panel, on open ground {GLO} U	GLO	1	p		0	0	0	0	1				
Electricity, low voltage, at grid {GLO} U	GLO	0	kWh		0	1.92E+1	1.92E+1	1.92E+1	7.67E+2	1	1.28		(3,4,3,1,1,5); Electricity use for installation of PV plant
Electricity, low voltage, at grid {CH} U	CH	0	kWh		7.67E-1	0	0	0	0	1	1.28		(3,4,3,1,1,5); Electricity use for erection of PV plant
Diesel, burned in building machine, with particle filter {GLO} U	GLO	0	MJ		0	0	0	0	4.32E+4	1	1.28		(3,4,3,1,1,5); Diesel use for installation of PV plant
Inverter, 10 kW, average, at plant {GLO} U	GLO	1	p		2.00E+0	0	0	0	0	1	1.24		(2,4,1,1,1,na); 1 replacement during the lifetime of the PV system
Inverter, 100 kW, average, at plant {GLO} U	GLO	1	p		0	4.00E+0	4.00E+0	4.00E+0	1.50E+2	1	1.24		(2,4,1,1,1,na); 1 replacement during the lifetime of the PV system
Electric installation, photovoltaic plant, at plant {CH} U	CH	1	p		2.27E+0	0	0	0	0	1	2.09		(3,4,3,1,1,5); Literature
Electric installation, 280 kWp photovoltaic plant, at plant {CH} U	CH	1	p		0	8.93E-1	8.93E-1	8.93E-1	0	1	2.09		(3,4,3,1,1,5); Literature
Electric installation, utility scale, open ground {RER} U	RER	1	m2		0	0	0	0	4.43E+4	1	3.08		(3,4,3,1,1,5); Literature
Flat roof construction, on roof {RER} U	RER	1	m2		0	0	0	1.11E+3	0	1	1.23		(3,1,1,1,1,na); calculation with m2 panel
Slanted-roof construction, integrated, on roof {RER} U	RER	1	m2		0	0	1.11E+3	0	0	1	1.23		(3,1,1,1,1,na); calculation with m2 panel
Slanted-roof construction, mounted, on roof {RER} U	RER	1	m2		4.43E+1	1.11E+3	0	0	0	1	1.23		(3,1,1,1,1,na); calculation with m2 panel
Open ground construction, utility scale, on ground {RER} U	RER	1	m2		0	0	0	0	4.43E+4	1	1.23		(3,1,1,1,1,na); calculation with m2 panel
Photovoltaic panel, single-Si, monofacial, at regional storage {RER} U	RER	1	m2		1.69E+1	4.22E+2	4.22E+2	4.22E+2	1.69E+4	1	1.36		(3,4,3,1,1,5); Calculation, 2% of modules repaired in the life time, 1% rejects
Photovoltaic panel, single-Si, bifacial, TOPCon, at regional storage {RER} U	RER	1	m2		2.87E+1	7.18E+2	7.18E+2	7.18E+2	2.87E+4	1	1.36		(3,4,3,1,1,5); Calculation, 2% of modules repaired in the life time, 1% rejects
Treatment, c-Si PV module {RER} U	RER	0	kg		5.54E+2	1.39E+4	1.39E+4	1.39E+4	5.54E+5	1	1.28		(3,4,3,1,1,5); recycling of PV modules at the end of life
Transport, freight, lorry 7.5-16 metric ton, fleet average {RER} U	RER	0	tkm		8.74E+1	2.06E+3	1.99E+3	2.09E+3	1.11E+5	1	2.09		(3,4,3,1,1,5); transport of inverter, electric installation, mounting structure and module 100km to construction site
Heat, waste	-	-	MJ		2.76E+0	6.90E+1	6.90E+1	6.90E+1	2.76E+3	1	1.28		(3,4,3,1,1,5); calculated with electricity use



### 3.9 Country specific photovoltaic mixes

The country-specific annual electricity yields used in the LCI modelling of country specific photovoltaic mixes in Table 54 are based on average yields for the year 2024 published in the *IEA PVPS Task 1 – Trends in Photovoltaic Applications 2025* [1]. Exceptions were made for four countries. For Germany, Greece and Hungary, average annual yields were estimated using the population-weighted average irradiation for fixed, optimally tilted PV systems reported by Breyer and Schmid [55]. Performance ratios of 0.80 for utility-scale systems and 0.75 for rooftop systems were applied. For façade-integrated systems, annual yields were assumed to equal 70% of the corresponding rooftop system yield. For Sweden, the average yield of 850 kWh/kWp reported in the *IEA PVPS National Survey Report for Sweden* [81] was adopted. This approach replaces the country's yield sources applied in earlier Task 12 reports. Photovoltaic installations on buildings are considered with 10 kWp and 250 kWp installations. Centralized installations are considered with 10 MW utility-scale open ground installations. More detailed documentation on the approach for modelling country specific photovoltaic mixes can be found in Stolz and Frischknecht [56].



Table 54: Unit process LCI data of country-specific photovoltaic mixes. Note: share refers to relative proportion with shares in each country summing to 1.

Country	Code	Façade				Flat Roof				Slanted Roof Thin-Film	
		10 kWp facade installation, single-Si, laminated, integrated, at building	10 kWp facade installation, single-Si, panel, mounted, at building	10 kWp facade installation, multi-Si, laminated, integrated, at building	10 kWp facade installation, multi-Si, panel, mounted, at building	10 kWp flat roof installation, single-Si, on roof	250 kWp flat-roof installation, single-Si, panel, mounted, on roof	10 kWp flat roof installation, multi-Si, on roof	250 kWp flat-roof installation, multi-Si, panel, mounted, on roof	10 kWp slanted-roof installation, CdTe, laminated, integrated, on roof	10 kWp slanted-roof installation, CdTe, panel, mounted, on roof
		Share	Share	Share	Share	Share	Share	Share	Share	Share	Share
Australia	AU	4.89E-03	4.89E-03	1.75E-03	1.75E-03	8.80E-02	1.32E-01	3.14E-02	4.71E-02	1.88E-03	3.13E-02
Austria	AT	4.54E-03	0.00E+00	1.62E-03	0.00E+00	1.30E-01	1.95E-01	4.63E-02	6.95E-02	1.33E-03	4.37E-02
Belgium	BE	7.19E-03	7.19E-03	2.57E-03	2.57E-03	1.29E-01	1.94E-01	4.62E-02	6.93E-02	2.76E-03	4.60E-02
Canada	CA	2.35E-03	2.35E-03	8.39E-04	8.39E-04	4.23E-02	6.34E-02	1.51E-02	2.27E-02	9.02E-04	1.50E-02
Chile	CL	6.84E-05	6.84E-05	2.44E-05	2.44E-05	1.23E-03	1.85E-03	4.40E-04	6.59E-04	2.63E-05	4.38E-04
China	CN	2.63E-03	2.63E-03	9.39E-04	9.39E-04	4.73E-02	7.10E-02	1.69E-02	2.54E-02	1.01E-03	1.68E-02
Czech Republic	CZ	4.46E-03	4.46E-03	1.59E-03	1.59E-03	8.03E-02	1.20E-01	2.87E-02	4.30E-02	1.71E-03	2.86E-02
Denmark	DK	4.55E-03	4.55E-03	1.63E-03	1.63E-03	8.20E-02	1.23E-01	2.93E-02	4.39E-02	1.75E-03	2.92E-02
Finland	FI	6.74E-03	6.74E-03	2.41E-03	2.41E-03	1.21E-01	1.82E-01	4.33E-02	6.50E-02	2.59E-03	4.31E-02
France	FR	4.18E-03	4.18E-03	1.49E-03	1.49E-03	7.53E-02	1.13E-01	2.69E-02	4.03E-02	1.61E-03	2.68E-02
Germany	DE	5.43E-03	5.43E-03	1.94E-03	1.94E-03	9.77E-02	1.46E-01	3.49E-02	5.23E-02	2.08E-03	3.47E-02
Greece	GR	4.46E-03	4.46E-03	1.59E-03	1.59E-03	8.03E-02	1.20E-01	2.87E-02	4.30E-02	1.71E-03	2.86E-02
Hungary	HU	4.46E-03	4.46E-03	1.59E-03	1.59E-03	8.03E-02	1.20E-01	2.87E-02	4.30E-02	1.71E-03	2.86E-02
Ireland	IE	4.46E-03	4.46E-03	1.59E-03	1.59E-03	8.03E-02	1.20E-01	2.87E-02	4.30E-02	1.71E-03	2.86E-02
Israel	IL	5.12E-03	5.12E-03	1.83E-03	1.83E-03	9.22E-02	1.38E-01	3.29E-02	4.94E-02	1.97E-03	3.28E-02
Italy	IT	5.06E-03	5.06E-03	1.81E-03	1.81E-03	9.12E-02	1.37E-01	3.26E-02	4.88E-02	1.95E-03	3.24E-02
Japan	JP	4.40E-03	4.40E-03	1.57E-03	1.57E-03	7.91E-02	1.19E-01	2.83E-02	4.24E-02	1.69E-03	2.81E-02
Korea	KR	1.04E-03	1.04E-03	3.72E-04	3.72E-04	1.88E-02	2.81E-02	6.70E-03	1.00E-02	4.00E-04	6.67E-03
Luxembourg	LU	4.46E-03	4.46E-03	1.59E-03	1.59E-03	8.03E-02	1.20E-01	2.87E-02	4.30E-02	1.71E-03	2.86E-02
Malaysia	MY	2.46E-03	2.46E-03	8.77E-04	8.77E-04	4.42E-02	6.63E-02	1.58E-02	2.37E-02	9.44E-04	1.57E-02
Mexico	MX	1.03E-03	1.03E-03	3.68E-04	3.68E-04	1.85E-02	2.78E-02	6.62E-03	9.93E-03	3.96E-04	6.59E-03
Netherlands	NL	3.11E-03	3.11E-03	1.11E-03	1.11E-03	5.60E-02	8.40E-02	2.00E-02	3.00E-02	1.19E-03	1.99E-02
New Zealand	NZ	4.89E-03	4.89E-03	1.75E-03	1.75E-03	8.80E-02	1.32E-01	3.14E-02	4.71E-02	1.88E-03	3.13E-02
Norway	NO	7.26E-03	7.26E-03	2.59E-03	2.59E-03	1.31E-01	1.96E-01	4.67E-02	7.00E-02	2.79E-03	4.65E-02
Portugal	PT	3.58E-03	3.58E-03	1.28E-03	1.28E-03	6.45E-02	9.68E-02	2.30E-02	3.46E-02	1.38E-03	2.29E-02
South Africa	ZA	4.91E-03	4.91E-03	1.75E-03	1.75E-03	8.84E-02	1.33E-01	3.16E-02	4.73E-02	1.89E-03	3.14E-02
Spain	ES	1.49E-03	1.49E-03	5.31E-04	5.31E-04	2.68E-02	4.02E-02	9.57E-03	1.43E-02	5.72E-04	9.53E-03
Sweden	SE	6.76E-03	6.76E-03	2.42E-03	2.42E-03	1.22E-01	1.83E-01	4.35E-02	6.52E-02	2.60E-03	4.33E-02
Switzerland	CH	8.19E-04	1.64E-03	2.92E-04	5.85E-04	1.47E-01	2.21E-01	5.26E-02	7.89E-02	1.97E-02	2.98E-02
Thailand	TH	2.26E-03	2.26E-03	8.09E-04	8.09E-04	4.08E-02	6.11E-02	1.46E-02	2.18E-02	8.70E-04	1.45E-02
Turkey	TR	5.86E-03	5.86E-03	2.09E-03	2.09E-03	1.05E-01	1.58E-01	3.77E-02	5.65E-02	2.25E-03	3.75E-02
United Kingdom	GB	4.46E-03	4.46E-03	1.59E-03	1.59E-03	8.03E-02	1.20E-01	2.87E-02	4.30E-02	1.71E-03	2.86E-02
USA	US	2.42E-03	2.42E-03	5.58E-04	5.58E-04	4.31E-02	6.47E-02	9.95E-03	1.49E-02	2.38E-03	5.71E-02



Country	Code	Slanted Roof c-Si >50kWp				Slanted Roof c-Si <50kWp				Centralized		
		250 kWp slanted roof installation, single-Si, laminated, integrated, on roof	250 kWp slanted roof installation, single-Si, panel, mounted, on roof	250 kWp slanted roof installation, multi-Si, laminated, integrated, on roof	250 kWp slanted roof installation, multi-Si, panel, mounted, on roof	10 kWp slanted roof installation, single-Si, laminated, integrated, on roof	10 kWp slanted roof installation, single-Si, panel, mounted, on roof	10 kWp slanted roof installation, multi-Si, laminated, integrated, on roof	10 kWp slanted roof installation, multi-Si, panel, mounted, on roof	10 MW ground-mounted installation, single-Si, on open ground	10 MW ground-mounted installation, multi-Si, on open ground	10 MW ground-mounted installation, multi-Si, on open ground
		Share	Share	Share	Share	Share	Share	Share	Share	Share	Share	Share
Australia	AU	8.80E-03	1.47E-01	3.14E-03	5.24E-02	4.48E-03	7.47E-02	1.60E-03	2.67E-02	2.36E-01	8.41E-02	1.68E-02
Austria	AT	5.91E-03	1.95E-01	2.11E-03	6.95E-02	2.96E-03	9.76E-02	1.06E-03	3.49E-02	6.99E-02	2.50E-02	4.99E-03
Belgium	BE	1.29E-02	2.16E-01	4.62E-03	7.70E-02	6.59E-03	1.10E-01	2.35E-03	3.92E-02	1.71E-02	6.11E-03	1.22E-03
Canada	CA	4.23E-03	7.05E-02	1.51E-03	2.52E-02	2.15E-03	3.59E-02	7.69E-04	1.28E-02	4.77E-01	1.70E-01	3.41E-02
Chile	CL	1.23E-04	2.05E-03	4.40E-05	7.33E-04	6.27E-05	1.04E-03	2.24E-05	3.73E-04	6.94E-01	2.48E-01	4.95E-02
China	CN	4.73E-03	7.89E-02	1.69E-03	2.82E-02	2.41E-03	4.02E-02	8.61E-04	1.44E-02	4.50E-01	1.61E-01	3.22E-02
Czech Republic	CZ	8.03E-03	1.34E-01	2.87E-03	4.78E-02	4.09E-03	6.82E-02	1.46E-03	2.43E-02	2.76E-01	9.87E-02	1.97E-02
Denmark	DK	8.20E-03	1.37E-01	2.93E-03	4.88E-02	4.18E-03	6.96E-02	1.49E-03	2.49E-02	2.67E-01	9.55E-02	1.91E-02
Finland	FI	1.21E-02	2.02E-01	4.33E-03	7.22E-02	6.18E-03	1.03E-01	2.21E-03	3.68E-02	6.00E-02	2.14E-02	4.28E-03
France	FR	7.53E-03	1.25E-01	2.69E-03	4.48E-02	3.84E-03	6.39E-02	1.37E-03	2.28E-02	3.03E-01	1.08E-01	2.16E-02
Germany	DE	9.77E-03	1.63E-01	3.49E-03	5.81E-02	4.97E-03	8.29E-02	1.78E-03	2.96E-02	1.85E-01	6.59E-02	1.32E-02
Greece	GR	8.03E-03	1.34E-01	2.87E-03	4.78E-02	4.09E-03	6.82E-02	1.46E-03	2.43E-02	2.76E-01	9.87E-02	1.97E-02
Hungary	HU	8.03E-03	1.34E-01	2.87E-03	4.78E-02	4.09E-03	6.82E-02	1.46E-03	2.43E-02	2.76E-01	9.87E-02	1.97E-02
Ireland	IE	8.03E-03	1.34E-01	2.87E-03	4.78E-02	4.09E-03	6.82E-02	1.46E-03	2.43E-02	2.76E-01	9.87E-02	1.97E-02
Israel	IL	9.22E-03	1.54E-01	3.29E-03	5.49E-02	4.70E-03	7.83E-02	1.68E-03	2.80E-02	2.13E-01	7.62E-02	1.52E-02
Italy	IT	9.12E-03	1.52E-01	3.26E-03	5.43E-02	4.64E-03	7.74E-02	1.66E-03	2.76E-02	2.19E-01	7.82E-02	1.56E-02
Japan	JP	7.91E-03	1.32E-01	2.83E-03	4.71E-02	4.03E-03	6.72E-02	1.44E-03	2.40E-02	2.82E-01	1.01E-01	2.02E-02
Korea	KR	1.88E-03	3.13E-02	6.70E-04	1.12E-02	9.55E-04	1.59E-02	3.41E-04	5.69E-03	6.01E-01	2.15E-01	4.29E-02
Luxembourg	LU	8.03E-03	1.34E-01	2.87E-03	4.78E-02	4.09E-03	6.82E-02	1.46E-03	2.43E-02	2.76E-01	9.87E-02	1.97E-02
Malaysia	MY	4.42E-03	7.37E-02	1.58E-03	2.63E-02	2.25E-03	3.75E-02	8.05E-04	1.34E-02	4.67E-01	1.67E-01	3.33E-02
Mexico	MX	1.85E-03	3.09E-02	6.62E-04	1.10E-02	9.45E-04	1.57E-02	3.37E-04	5.62E-03	6.02E-01	2.15E-01	4.30E-02
Netherlands	NL	5.60E-03	9.33E-02	2.00E-03	3.33E-02	2.85E-03	4.75E-02	1.02E-03	1.70E-02	4.04E-01	1.44E-01	2.89E-02
New Zealand	NZ	8.80E-03	1.47E-01	3.14E-03	5.24E-02	4.48E-03	7.47E-02	1.60E-03	2.67E-02	2.36E-01	8.41E-02	1.68E-02
Norway	NO	1.31E-02	2.18E-01	4.67E-03	7.78E-02	6.66E-03	1.11E-01	2.38E-03	3.96E-02	1.02E-02	3.65E-03	7.30E-04
Portugal	PT	6.45E-03	1.08E-01	2.30E-03	3.84E-02	3.29E-03	5.48E-02	1.17E-03	1.96E-02	3.60E-01	1.28E-01	2.57E-02
South Africa	ZA	8.84E-03	1.47E-01	3.16E-03	5.26E-02	4.50E-03	7.50E-02	1.61E-03	2.68E-02	2.34E-01	8.34E-02	1.67E-02
Spain	ES	2.68E-03	4.46E-02	9.57E-04	1.59E-02	1.36E-03	2.27E-02	4.87E-04	8.12E-03	5.59E-01	2.00E-01	3.99E-02
Sweden	SE	1.22E-02	2.03E-01	4.35E-03	7.25E-02	6.20E-03	1.03E-01	2.21E-03	3.69E-02	5.75E-02	2.05E-02	4.11E-03
Switzerland	CH	8.60E-02	1.30E-01	3.07E-02	4.64E-02	4.28E-02	6.47E-02	1.53E-02	2.31E-02	5.82E-03	2.08E-03	4.16E-04
Thailand	TH	4.08E-03	6.79E-02	1.46E-03	2.43E-02	2.08E-03	3.46E-02	7.42E-04	1.24E-02	4.85E-01	1.73E-01	3.46E-02
Turkey	TR	1.05E-02	1.76E-01	3.77E-03	6.28E-02	5.37E-03	8.96E-02	1.92E-03	3.20E-02	1.43E-01	5.12E-02	1.02E-02
United Kingdom	GB	8.03E-03	1.34E-01	2.87E-03	4.78E-02	4.09E-03	6.82E-02	1.46E-03	2.43E-02	2.76E-01	9.87E-02	1.97E-02
USA	US	3.10E-03	7.43E-02	7.15E-04	1.71E-02	1.31E-04	3.14E-03	3.02E-05	7.26E-04	4.57E-01	1.05E-01	1.41E-01



## 4 LIFE CYCLE INVENTORY DATA FROM SIMULATION

In contrast to empirically gathered LCI data of PV systems, such inventory data can also be obtained through modelling and simulation. Brailovsky (2026) pursued such an approach by presenting a process-based bottom-up model, which integrates circularity strategies into the PV module value chain [5]. Drawing from existing data of reference products he developed a model for PV module production at a single site that vertically integrates the steps from polysilicon to module production. This is achieved by first defining the operational required process and facilities and then dimensioning the necessary civil, structural, and architectural infrastructure for a production site with 5 GWp/a production capacity. Subsequently the corresponding LCIs are generated. Additionally, Brailovsky evaluated several circularity strategies, of which the following are considered in the LCI reported here:

- Revalorized waste scenario (TOPCon & PERC): this strategy implied the establishment of a waste cadastre to classify solid waste per category (Paper and cardboard, Glass, Plastics, Metals, Wood and Mix Waste). Additionally, factory internal recycling, energy recovery, and disposal shares were accounted for each waste type. Also, the use of reusable transportation pallets was considered.
- Vertical integration scenario (TOPCon & PERC): this strategy includes the localisation of all processing steps from incoming polysilicon to wafer, solar cell, and the finished PV module at one location. The implementation of this scenario omits the transport between manufacturing locations and reduces the breakage of wafers and solar cells breakage, packaging material is avoided, and the footprint and capital expenditure of facilities and ancillary buildings and areas is reduced.
- Minimal liquid discharge scenario (PERC): an advanced water and valuable by-products recycling strategy that saves a significant amount of the water in cell manufacturing.
- Rinse water recycling scenario (TOPCon): the TOPCon cell production requires three wet chemical clusters, with this circular strategy a significant share of Ultra-Pure Water (UPW) can be reclaimed and reused in the process.

Simulated LCI allow the exploration of material, resource and energy flow distributions. This is essential to identify and propose improvements to production processes such as the analysed circularity strategies. Factory or product LCI do not allow this exploration. Additionally, the simulated LCI covered in detail facilities, buildings and services that support the main production processes, these are poorly covered or excluded from available industrial data LCI. The simulated LCI are based on industrial process receipts and sequences and on actual market available process and facilities equipment.

### 4.1 Production infrastructure

Inventories of production infrastructure are updated with data about a conventional steel construction as designed by Brailovsky [12]. While the base model represents a singular, vertically integrated production site with 5GWp/a capacity, the individual structures for Cz silicon ingots, wafer, cell, and module manufacture can be scaled in the respective process inventories to represent individual factories dedicated to each process. Table 55, Table 56, Table 57, Table 58, and Table 59 show the inventories of silicon-ingot factory, industrial site ancillary buildings, wafer factory, cell factory, and panel factory. Each factory inventory includes the required process equipment. The ancillary buildings model includes the facilities equipment. All the inventories were bottom-up calculated, from the products specification, required processes, required process equipment, required facilities equipment and required buildings and areas in an industrial site, the full methodology is described in Brailovsky et al. [29] including pre-cast concrete and structural timber building systems





Table 57: LCI for Wafer factory, steel construction

Table with 10 columns: Name, Location, Unit, Wafer factory steel construction simulated data (DE) U, General Comment, Location Infrastructure/Process, DE Unit, and DE U. Rows include categories like product, microprocess, Backfilling Ceilings, and various components like doors, windows, and earthworks.

Table 58: LCI for Cell factory, steel construction

Table with 10 columns: Name, Location, Unit, Cell factory steel construction simulated data (DE) U, General Comment, Location Infrastructure/Process, DE Unit, and DE U. Rows include categories like product, materials, Backfilling Ceilings, and various components like doors, windows, and earthworks.



Table 59: LCI for Panel factory, steel construction, 5 GWp/a capacity

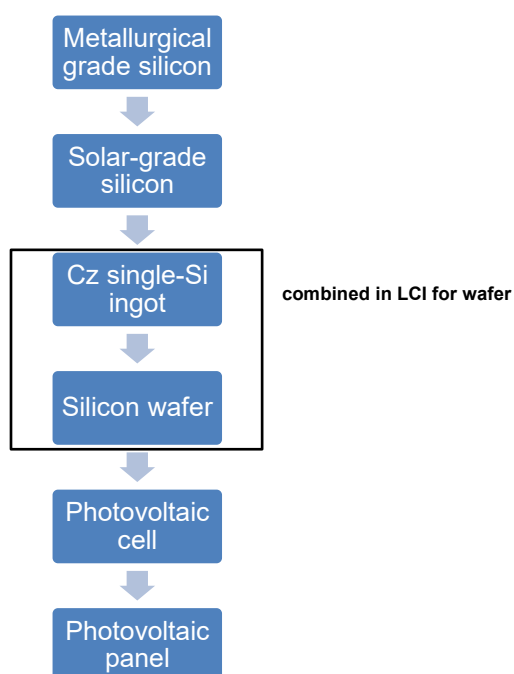
Name	Location	Infrastructure	Process	Unit	Panel factory, steel construction, simulated data (DE) U	Uncertainty type	StandardDeviation%	GeneralComment
product	Photovoltaic panel factory (GLO) U	GLO	1	p	-			
materials	Panel factory steel construction, simulated data (DE) U	DE	1	p	1.00E+0			
Potable water	Building, hall (CH) U	CH	1	m2		1	3.00	(1.1,1.1,1.1);
Backfilling	Metal working machine, unspecified, at plant (RER) U	RER	1	kg	3.01E+6	1	3.29	(2.4,1.3,4.5); Brallosky et al. (2024) from process equipment A1-A3
Ceilings	Water supply network (CH) U	CH	1	km	1.53E+0	1	3.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Gravel, crushed, at mine (CH) U	CH	0	kg	1.90E+7	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Aluminum alloy, AlMg3, at plant (RER) U	RER	0	kg	1.44E+4	1	1.33	(2.4,1.3,3.5); Brallosky et al. (2024) AlMg3 iso ALLI
	Polyurethane, rigid foam, market mix, at regional storage (CH) U	CH	0	kg	8.85E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Powder coating, steel (RER) U	RER	0	m2	6.17E+4	1	1.24	(2.4,1.3,1.5); RER iso GLO, prod iso market
	Sheet rolling, aluminium (RER) U	RER	0	kg	1.44E+4	1	1.24	(2.4,1.3,1.5); RER iso GLO, prod iso market
	Sheet rolling, steel (RER) U	RER	0	kg	4.83E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Steel, converter, low-alloyed, at plant (RER) U	RER	0	kg	4.83E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Zinc coating, pieces (RER) U	RER	0	m2	3.71E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
Civil works AA45	Flooring 2k, epoxy resin, industrial use, at plant (CH) U	CH	0	m2	2.90E+3	1	1.33	(2.4,1.3,3.5); Brallosky et al. (2024); CH iso RER, iso bisphenol A epoxy based vinyl ester resin; Assumption 200g/m <sup>2</sup>
	Diesel, burned in building machine, average (CH) U	CH	0	MJ	2.88E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	1.10E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Excavation, skid-steer loader (RER) U	RER	0	m3	1.02E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	2.89E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, <18.64kW, energy density 45.5MJ/kg
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	8.01E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	1.95E+7	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, >= 74.57 kW, energy density 45.5MJ/kg
	Transport, freight, rail (RER) U	RER	0	km	2.08E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	3.85E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, transoceanic container ship (OCE) U	OCE	0	km	2.32E+2	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Doors & Windows	Door, inner, room, wood, wooden frame, at plant (CH) U	CH	0	m2	3.02E+1	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	8.97E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Glazing, double (2-IV), U<1.1 W/m2K, at plant (RER) U	RER	0	m2	1.30E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Sheet rolling, steel (RER) U	RER	0	kg	3.60E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Steel, converter, low-alloyed, at plant (RER) U	RER	0	kg	3.60E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
Earthworks	Window frame, plastic (PVC), U<1.1 W/m2K, at regional storage (CH) U	CH	0	m2	1.17E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	2.09E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	4.39E+6	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, >= 18.64 kW and < 74.57 kW, energy density 45.5MJ/kg
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	2.38E+7	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, >= 74.57 kW, energy density 45.5MJ/kg
	Transport, freight, rail, diesel, with particle filter (CH) U	CH	0	km	2.30E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	1.14E+6	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Insitu concrete A1-A3	Concrete, normal, at plant (CH) U	CH	0	m3	2.71E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) CH iso RER
	Lean concrete, CEM III B, 100% RC-M, at plant (CH) U	CH	0	m3	1.38E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	1.23E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) DE iso Europe w/o Switzerland
	Glass wool mat, at plant (CH) U	CH	0	kg	8.01E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Gypsum plaster board, at regional storage (CH) U	CH	0	m2	1.23E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) CH iso GLO; Flächengewicht = 10kg/m2
	Heat, natural gas, at boiler condensing modulating 15kW (CH) U	CH	0	MJ	1.11E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) CH iso RER
	Sheet rolling, steel (RER) U	RER	0	kg	8.01E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Steel, converter, low-alloyed, at plant (RER) U	RER	0	kg	8.01E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
Non structural components AA45	Alkyd paint, white, 60% in H2O, at plant (RER) U	RER	0	kg	9.17E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	2.47E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, <18.64kW, energy density 45.5MJ/kg
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	6.10E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, >= 74.57 kW, energy density 45.5MJ/kg
	Transport, freight, rail (RER) U	RER	0	km	1.36E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	2.03E+4	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	2.96E+4	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, transoceanic container ship (OCE) U	OCE	0	km	8.89E+1	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Process equipment AA45	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	2.25E+6	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, >= 74.57 kW, energy density 45.5MJ/kg
	Transport, freight, rail (RER) U	RER	0	km	1.23E+4	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, barge (RER) U	RER	0	km	4.37E+3	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	1.04E+6	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024) RER iso RoW
RebarFab_A1-A3	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	6.14E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
Roads	Reinforcing steel, at regional storage (CH) U	CH	0	kg	2.08E+6	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
Roofing A1-A3	Roads, company, internal (CH) U	CH	1	m2a	4.88E+4	1	3.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	6.21E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) DE iso RER
	Heat, natural gas, at boiler condensing modulating 15kW (CH) U	CH	0	MJ	5.99E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Polyurethane, rigid foam, market mix, at regional storage (CH) U	CH	0	kg	2.98E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Powder coating, steel (RER) U	RER	0	m2	1.86E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Sheet rolling, steel (RER) U	RER	0	kg	6.05E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Steel, converter, low-alloyed, at plant (RER) U	RER	0	kg	6.05E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
Roofing AA45	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	5.80E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, >= 74.57 kW, energy density 45.5MJ/kg
	Transport, freight, rail (RER) U	RER	0	km	2.26E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	4.17E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Services AA45	Diesel, burned in building machine, average (CH) U	CH	0	MJ	1.09E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Excavation, hydraulic digger (proj. 500) (RER) U	RER	0	m3	1.82E+4	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Sewer Grid	Residential sewer grid (CH) U	CH	1	km	1.53E+0	1	3.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Siding A1-A3	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	1.17E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Heat, natural gas, at boiler condensing modulating 15kW (CH) U	CH	0	MJ	1.05E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Polyurethane, rigid foam, market mix, at regional storage (CH) U	CH	0	kg	5.61E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Powder coating, steel (RER) U	RER	0	m2	3.51E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Sheet rolling, steel (RER) U	RER	0	kg	1.14E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Steel, converter, low-alloyed, at plant (RER) U	RER	0	kg	1.14E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
Siding AA45	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	1.09E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, >= 74.57 kW, energy density 45.5MJ/kg
	Transport, freight, rail (RER) U	RER	0	km	4.25E+4	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	7.86E+4	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Steeel A1-A3	Hot rolling, steel (RER) U	RER	0	kg	5.18E+6	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Powder coating, steel (RER) U	RER	0	m2	4.44E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Steel, electric, low-alloyed, at plant (CH) U	CH	0	kg	5.18E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Steel, converter, low-alloyed, at plant (RER) U	RER	0	kg	4.86E+6	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, rail (RER) U	RER	0	km	9.84E+5	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	2.01E+6	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, transoceanic container ship (OCE) U	OCE	0	km	2.28E+6	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Steeel AA45	Welding, arc, steel (RER) U	RER	0	m	4.14E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	1.05E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	2.67E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, <18.64kW, energy density 45.5MJ/kg
	Diesel, burned in building machine, with particle filter (GLO) U	GLO	0	MJ	2.42E+7	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024); From machine operation, diesel, >= 74.57 kW, energy density 45.5MJ/kg
	Transport, freight, rail (RER) U	RER	0	km	2.85E+6	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	5.27E+6	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
	Transport, freight, lorry, fleet average (RER) U	RER	0	km	3.33E+7	1	2.06	(2.4,1.3,1.5); Brallosky et al. (2024)
Transportation EW	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	3.71E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
Wooden floor	Fibreboard, hard, at regional storage (CH) U	CH	0	kg	2.67E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) Density 900 kg/m <sup>3</sup>
	Heat, natural gas, at boiler condensing modulating 15kW (CH) U	CH	0	MJ	3.34E+2	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
disposal	Paper, melamine impregnated, at plant (RER) U	RER	0	kg	1.11E+3	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024)
	Disposal, polyurethane foam, as building waste (CH) U	CH	0	kg	8.85E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) from ceilings
	Disposal, polyurethane foam, as building waste (CH) U	CH	0	kg	2.98E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) from roofing A1-A3
	Disposal, polyurethane foam, as building waste (CH) U	CH	0	kg	5.61E+4	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) from siding A1-A3
	Disposal, building, reinforcement steel, to sorting plant (CH) U	CH	0	kg	4.83E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) from ceilings
	Disposal, building, reinforcement steel, to sorting plant (CH) U	CH	0	kg	6.05E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) from roofing A1-A3
	Disposal, building, reinforcement steel, to sorting plant (CH) U	CH	0	kg	1.14E+5	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) from siding A1-A3
	Disposal, building, reinforcement steel, to sorting plant (CH) U	CH	0	kg	6.66E+6	1	1.24	(2.4,1.3,1.5); Brallosky et al. (2024) from Ststeel A1-A3
	Disposal, concrete, as building waste (CH) U	CH	0	kg	6.81E+6	1	1.24	



## 4.2 LCI Monocrystalline Si PV

### 4.2.1 Description of the production steps

Figure 13 (adapted from Jungbluth et al. [19]) shows the production steps of photovoltaic electricity production in vertically integrated fabrication as modelled in Brailovsky (2026) [5]. In contrast to the LCIs described in section 3.2, here the inventories of the production steps from Sc single-Si to silicon wafer are combined in the wafer production inventory, the so called ingot-brick-wafer production. The processing sequences and their consumables are based on multiple technology transfer projects executed by Fraunhofer ISE for the planning of new factories between the years 2021 and 2024. Aggregated equipment and process parameters of both, Chinese and European process were considered. Solid waste management, wastewater treatment, exhaust treatment requirements were calculated based on European requirements and legislation [82; 83; 84; 85; 86; 87], Chinese legislation was accounted for as far as it was identifiable [88].



**Figure 13: Supply chain of silicon-based photovoltaic panel and laminate production**

The process steps included in the aggregated inventory data up to the module factory gate are displayed in Figure 14. Due to vertical integration, all solid waste treatments are inventoried at the panel stage. Transport of intermediate products between the wafer to cell and cell to panel factories as well as packaging materials are avoided through vertical integration. The vertical integration of the ingot-brick-wafer process allows the efficient recycling of solar grade polysilicon from rods sidewalls slabs, misprocessed workpieces, ingot tails and tops.

The simulated industrial site with an annual production capacity of 5 GWp/a produces 25,902 metric tons of Cz-ingots per year, 24,631,830 m<sup>2</sup>/a of wafers, 23,678,425 m<sup>2</sup>/a of PERC solar cells and 25,500,741 m<sup>2</sup>/a of bifacial glass-backsheet PV modules with an aluminium frame and 21.5% efficiency. In total, from the incoming polysilicon to the finished PV module, 35 processes are accounted for the PERC route leading to a PV module efficiency of 21.5%, and 38 processes for the TOPCon PV module featuring a module efficiency of 23.0%. The ingot-brick-wafer processing is the same for both cell technologies, changing only the doping material for the polysilicon. The module factory processes are also the same for both routes, but the backsheet assumed to be integrated within the PERC PV module is replaced by a second layer of glass and the back side of the TOPCon module. Additionally, the EVA



(Ethylene-vinyl acetate) encapsulant within the PERC module is replaced by POE (Polyolefin elastomers) as encapsulants within the TOPCon PV module. Advanced cross binders and tabbing wires are considered for the TOP-Con module.

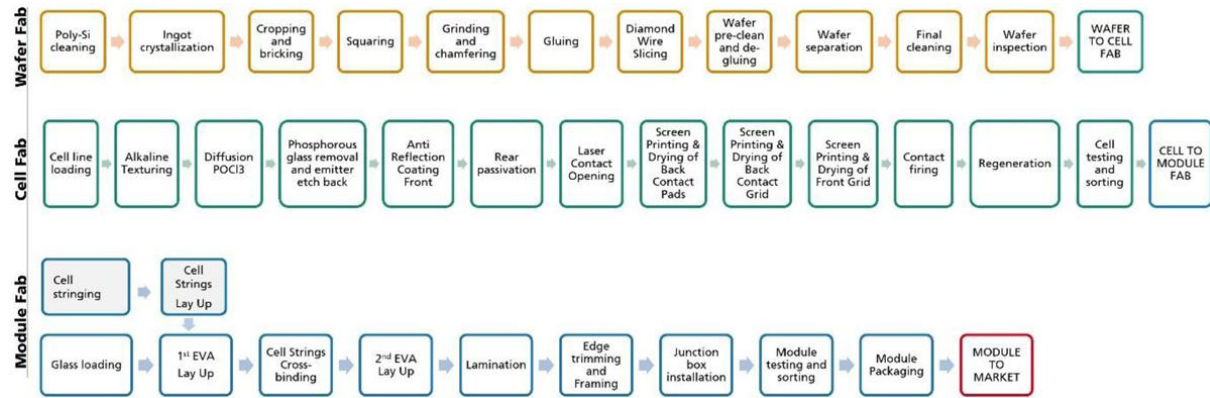


Figure 14: Reference production chain scenario, from polysilicon to PERC glass-backsheet PV modules according to Brailovsky et al. (2023) under creative common licences CC BY [32]

For the TOPCon solar cell fabrication the PECVD processing route listed in Figure 15 was considered. An n-type Cz wafer is firstly inspected, then the saw damage from the diamond wire slicing is removed. The wafer is textured and cleaned. Then, boron is diffused into the wafer to form the p-n junction; the parasitic rear emitter is etched via wet chemical baths. The Tunnel Oxide is deposited as well as an amorphous silicon a-Si(n) layer which is doped with phosphorus. The cells are then annealed to form the polycrystalline layer. The poly-Si layer is etched from the front side. Cells are rear and front passivated with a stack of  $Al_2O_3$  and  $SiN_x$ . Then, the contact fingers and busbars are screen printed on the rear and front. Finally, the cells are fired for sintering the contacts, followed by a contacts enhancement step. The finished cells are then tested and sorted.

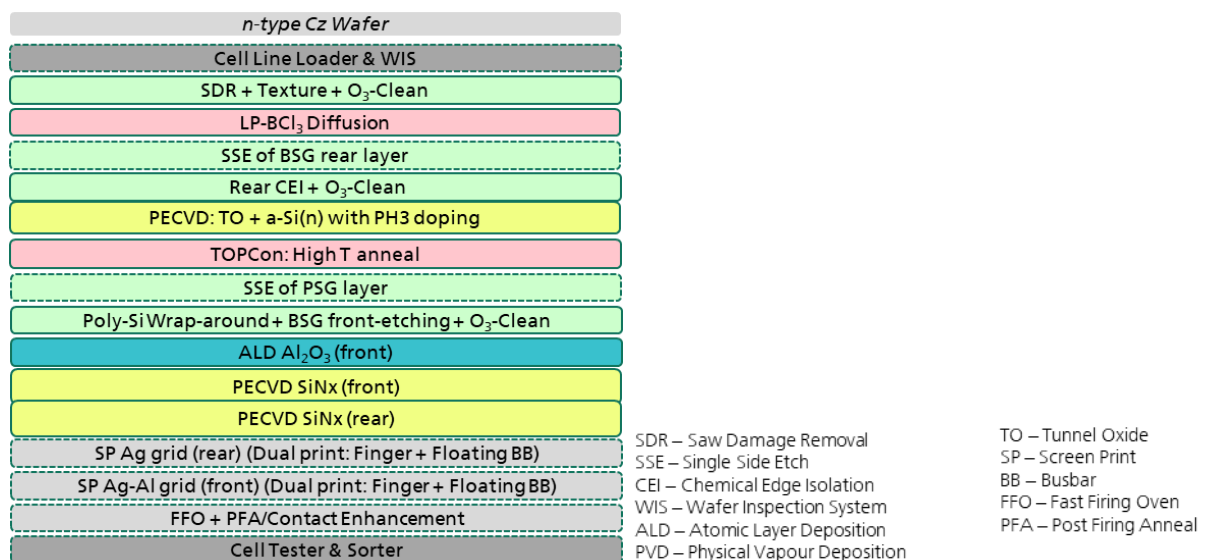


Figure 15: Reference TOPCon solar cell production sequence, PECVD route. Line borders represent bath processes and point borders inline processes.

The industrial site master plan layout shown in Figure 16 has been accounted for the fully integrated 5 GWp/a PV industrial site. Warehouses and storage buildings and areas are considered for chemicals, gases, materials and finished PV modules. Four factory buildings are included, one to produce Cz silicon bricks, then a wafering factory,



a solar cell factory and PV modules factory. Facilities and ancillary buildings include a Central Utilities Building, an Effluent Treatment Plant, electrical substation, as well as maintenance and reliability workshops. The Appendix A of Brailovsky et al. (2024) [29] lists the considered facilities equipment.

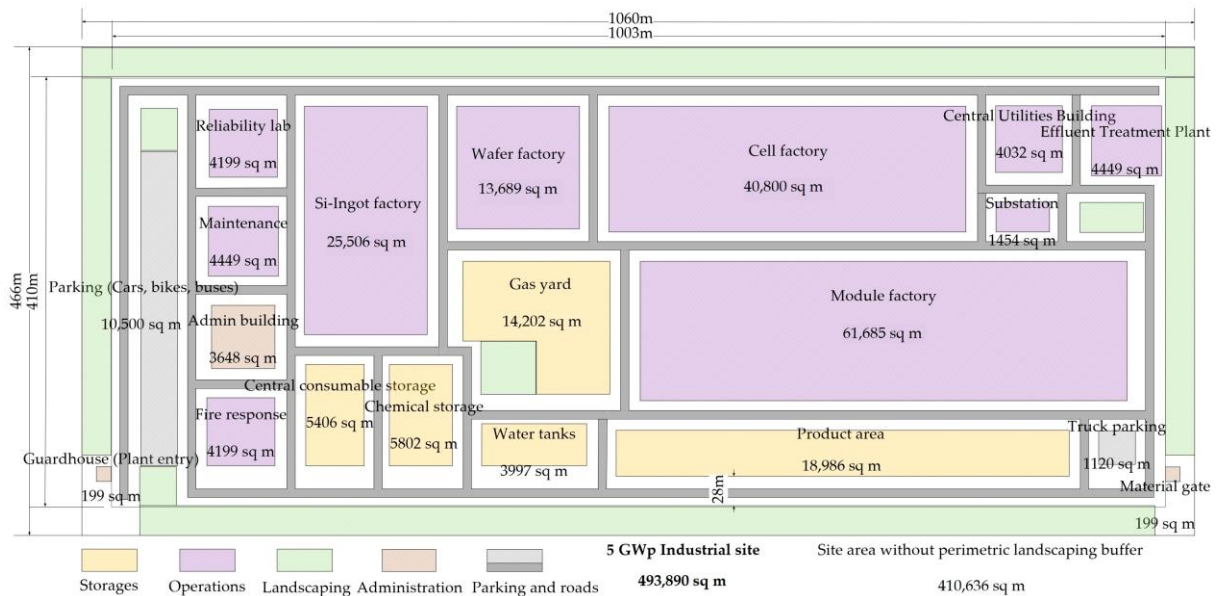


Figure 16: Site master plan layout of the 5 GWp/a fully integrated PV industrial site. Reproduced from Brailovsky et al. (2024) under creative common licence CC BY [29].

## 4.2.2 General approach

Based on simulated data from Brailovsky [12], vertically integrated production of PERC and TOPCon modules using circular strategies in Germany (DE) and China (CN) is modelled. The electricity consumption on all process levels is modelled with specific electricity mixes corresponding to the respective country. Water use and consumption is modelled using country specific elementary flows, which allows for a regionalised assessment of water scarcity. Since the data stems from simulation, there is no real-life market data on this production approach and therefore, no market datasets are modelled.

## 4.2.3 Basic silicon products

### Basic Silicon Products

The inventory of metallurgical grade silicon (MG-silicon) used for the simulated LCI is the same as described in Table in Section 3.2.4 (Norwegian electricity and Chinese electricity respectively).

### Solar grade silicon

Table 60 shows the unit process data of simulated solar grade silicon production in Germany (DE) and China (CN). The emission of waste heat is calculated based on the electricity demand. Transport of raw materials which are not produced on site is calculated based on standard distances. Relevant updates were made to the energy, water and chemical requirements based on material and energy flow analysis and literature sources [89; 90]. The heat requirement is completely covered by waste heat recovery from the Chemical Vapour Deposition (CVD) Siemens reactors. Chloride is calculated from the Silicon Tetrachloride (STC) makeup requirements. Sodium hydroxide is calculated for metal chlorides treatment.



**Table 60: Unit process LCI data of simulated solar grade silicon production in Germany (DE) and China (CN)**

Name	Location	InfrastructureProcess	Unit	Silicon, solar grade, Siemens process, simulated data, at plant (DE) U	Silicon, solar grade, Siemens process, simulated data, at plant (CN) U	Uncertainty Type	StandardDeviation95%	GeneralComment
Location	InfrastructureProcess	Unit		DE	CN			
				kg	kg			
Silicon, solar grade, Siemens process, simulated data, at plant (DE) U	DE	0	kg	1	0			
Silicon, solar grade, Siemens process, simulated data, at plant (CN) U	CN	0	kg	0	1			
MG-silicon, at plant (NO) U	NO	0	kg	1.05E+0	0	1	1.07	(2,4,1,3,1,5); Brailovsky (2026), NO iso Multiple Regions
MG-silicon, at plant (CN) U	CN	0	kg	0	1.05E+0	1	1.07	(2,4,1,3,1,5); Brailovsky (2026), CN iso Multiple Regions
Sodium hydroxide, 50% in H2O, production mix, at plant (RER) U	RER	0	kg	6.20E-2	6.20E-2	1	1.07	(2,4,1,3,1,5); Brailovsky (2026)
Hydrogen production, steam methane reforming of natural gas, 25 bar (CH) U	CH	0	kg	3.20E-2	3.20E-2	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)
Silicon tetrachloride, at plant (DE) U	DE	0	kg	4.50E-2	4.50E-2	1	1.07	(2,4,1,3,1,5); Brailovsky (2026)
Water, completely softened, at plant (RER) U	RER	0	kg	6.00E+1	6.00E+1	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)
Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	2.11E+0	2.11E+0	1	2.09	(4,5,na,na,na,na); Transport distance MG-Si: 2000 km; Chemicals: 100 km
Transport, freight, rail (RER) U	RER	0	tkm	1.21E-1	1.21E-1	1	2.09	(4,5,na,na,na,na); Transport distance chemicals: 600 km
Electricity, medium voltage, at grid (NO) U	NO	0	kWh	5.45E+1	0	1	1.07	(2,4,1,3,1,5); Brailovsky (2026), NO iso RER
Electricity, medium voltage, at grid (CN) U	CN	0	kWh	0	5.45E+1	1	1.07	(2,4,1,3,1,5); Brailovsky (2026), CN iso RER
Silicone plant (RER) U	RER	1	p	1.00E-11	1.00E-11	1	3.05	(2,4,1,3,1,5); Brailovsky (2026)
Heat, waste	-	-	MJ	1.96E+2	1.96E+2	1	1.40	(4,4,4,3,1,5); Calculation
Water, DE	-	-	kg	5.40E-2	0	1	1.50	(2,4,1,3,1,5); Brailovsky (2026)
Water, CN	-	-	kg	0	5.40E-2	1	1.69	(2,4,1,3,1,5); Brailovsky (2026)
AOX, Adsorbable Organic Halogen as Cl	-	-	kg	1.26E-5	1.26E-5	1	1.68	(2,4,1,3,1,5); Brailovsky (2026)
BOD5, Biological Oxygen Demand	-	-	kg	2.05E-4	2.05E-4	1	1.68	(2,4,1,3,1,5); Brailovsky (2026)
COD, Chemical Oxygen Demand	-	-	kg	2.02E-3	2.02E-3	1	1.68	(2,4,1,3,1,5); Brailovsky (2026)
Chloride	-	-	kg	3.79E-2	3.79E-2	1	3.14	(2,4,1,3,1,5); Brailovsky (2026)
Copper	-	-	kg	1.02E-7	1.02E-7	1	3.14	(2,4,1,3,1,5); Brailovsky (2026)
Nitrogen	-	-	kg	2.08E-4	2.08E-4	1	1.68	(2,4,1,3,1,5); Brailovsky (2026)
Phosphate	-	-	kg	2.80E-6	2.80E-6	1	1.68	(2,4,1,3,1,5); Brailovsky (2026)
Sodium, ion	-	-	kg	3.58E-2	3.58E-2	1	5.16	(2,4,1,3,1,5); Brailovsky (2026)
Zinc	-	-	kg	1.96E-6	1.96E-6	1	5.16	(2,4,1,3,1,5); Brailovsky (2026)
Iron	-	-	kg	5.61E-6	5.61E-6	1	5.16	(2,4,1,3,1,5); Brailovsky (2026)
DOC, Dissolved Organic Carbon	-	-	kg	9.10E-4	9.10E-4	1	1.68	(2,4,1,3,1,5); Brailovsky (2026)
TOC, Total Organic Carbon	-	-	kg	9.10E-4	9.10E-4	1	1.68	(2,4,1,3,1,5); Brailovsky (2026)
Hydroxide	-	-	kg	2.65E-2	2.65E-2	1	1.50	(2,4,1,3,1,5); Brailovsky (2026)
Water, DE	-	-	kg	6.00E+0	0	1	1.50	(2,4,1,3,1,5); Brailovsky (2026)
Water, CN	-	-	kg	0	6.00E+0	1	1.50	(2,4,1,3,1,5); Brailovsky (2026)



#### 4.2.4 Silicon wafer production

Table 62 shows the unit process data of the simulated single-crystalline silicon wafer production in Germany (DE) and China (CN) based on Brailovsky [12]. The simulated wafer fabrication process includes fabrication of ingots and bricks from solar grade silicon. The emission of waste heat is calculated based on the electricity demand. Transport of raw materials which are not produced on site is calculated based on standard distances. The technical data of the wafers is shown in Table 61.

**Table 61: Key characteristics of crystalline silicon wafers and key parameters of simulated wafer manufacturing**

	unit	single-Si, simulated
Length	mm	182
Width	mm	182
Area	cm <sup>2</sup>	330.15
Thickness	µm	130
Kerf loss	µm	50
Total silicon demand	g/m <sup>2</sup>	461
Electricity demand	kWh/m <sup>2</sup>	16.21
Diamond wire demand	m/m <sup>2</sup>	45.29 (42 microns diameter for slicing) 0.44 (350 microns diameter for cropping/bricking/squaring)
Diamond wire demand	g/m <sup>2</sup>	0.91
Water demand	litre/m <sup>2</sup>	45.3

Virgin polysilicon requirement per m<sup>2</sup> wafer was significantly reduced with the improvement in diamond wire slicing, compared to slurry-based slicing in the past. Electricity demand was significantly reduced due to Cz furnaces efficiency improvements, larger crucible and ingot diameters, efficient hot zones and multiple silicon recharge cycles. Completely new models and LCI are used for modelling the factory and facilities infrastructure, as previous datasets were substantially outdated.



**Table 62: Unit process LCI data of the simulated single-crystalline silicon wafer production in Germany (DE) and China (CN)**

	Name	Location	Infrastructure Processes	Unit	Single-Si wafer, photovoltaics, PERC/TOPCon, simulated data, at plant {DE} U	Single-Si wafer, photovoltaics, PERC/TOPCon, simulated data, at plant {CN} U	Uncertainty Type	Standard Deviation 5%	General Comment
					DE	CN			
	Location								
	Infrastructure Process				0	0			
	Unit				m2	m2			
	Single-Si wafer, photovoltaics, PERC/TOPCon, simulated data, at plant {DE} U	DE	0	m2	1	0			
	Single-Si wafer, photovoltaics, PERC/TOPCon, simulated data, at plant {CN} U	CN	0	m2	0	1			
diamond wire	Silicon, solar grade, Siemens process, simulated data, at plant {DE} U	DE	0	kg	4.61E-1	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04
	Silicon, solar grade, Siemens process, simulated data, at plant {CN} U	CN	0	kg	0	4.61E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04
	Steel, low-alloyed, at plant {RER} U	RER	0	kg	9.07E-4	9.07E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; Diamond wire for bricking & slicing added up
materials	Wire drawing, steel {RER} U	RER	0	kg	9.07E-4	9.07E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; iso steel, low-alloyed
	Polyurethane, rigid foam, at plant {RER} U	RER	0	kg	1.39E-2	1.39E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; RER iso RoW, at plant iso market
	Acrylic binder, 34% in H2O, at plant {RER} U	RER	0	kg	4.07E-3	4.07E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; 34% iso RoW
	Ceramic tiles, at regional storage {CH} U	CH	0	kg	6.25E-2	6.25E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; CH iso GLO
	Potassium hydroxide, at regional storage {RER} U	RER	0	kg	3.11E-2	3.11E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; RER iso GLO
	Hydrochloric acid, 30% in H2O, at plant {RER} U	RER	0	kg	2.69E-4	2.69E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; in H2O iso without water, RER iso RoW,
	Acetic acid, 98% in H2O, at plant {RER} U	RER	0	kg	2.00E-2	2.00E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; RER iso GLO, at plant iso market; Proxy for lactic acid.
	Nitric acid, 50% in H2O, at plant {RER} U	RER	0	kg	7.96E-3	7.96E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; RER iso GLO, "in H2O" iso "without water", at plant iso market
	Hydrogen fluoride, at plant {GLO} U	GLO	0	kg	3.59E-3	3.59E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; GLO iso RoW, at plant iso market
	Hydrogen peroxide, 50% in H2O, at plant {RER} U	RER	0	kg	1.04E-1	1.04E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; RER iso RoW, "in H2O" iso "without water"
	Alkylbenzene sulfonate, linear, petrochemical, at plant {RER} U	RER	0	kg	6.30E-2	6.30E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; RER iso GLO, at plant iso market
	Argon, liquid, at plant {RER} U	RER	0	kg	9.55E-2	9.55E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; RER iso GLO, at plant iso market
packaging	Polyethylene, HDPE, granulate, at plant {RER} U	RER	0	kg	3.01E-3	3.01E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; RER iso GLO, at plant iso market
	Electricity, medium voltage, at grid {CN} U	CN	0	kWh	0	1.62E+1	1	2.06	(2,4,1,3,1,5); Brailovsky (2026) GM 04
energy	Electricity, medium voltage, at grid {DE} U	DE	0	kWh	1.62E+1	0	1	2.06	(2,4,1,3,1,5); Brailovsky (2026) GM 04
	Tap water, water balance according to MoEK 2013, at user {CN} U	CN	0	kg	0	4.53E+1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; at plant iso market
water	Tap water, water balance according to MoEK 2013, at user {RER} U	RER	0	kg	4.53E+1	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; at plant iso market
	Treatment, wafer fabrication effluent, to wastewater treatment, class 2 {CH} U	CH	0	m3	5.30E-10	5.30E-10	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 04; Conversion from l to m^3
transport	Transport, freight, lorry, fleet average {RER} U	RER	0	tkm	4.18E-2	4.18E-2	1	2.09	(4,5,na,na,na,na); Silicon transport excluded due to vertical integration, disposal transport included in x-module-mono_Si, Transport dist. 100km (Inputs), 500km (Waste)
	Transport, freight, rail {RER} U	RER	0	tkm	8.37E-2	8.37E-2	1	2.09	(4,5,na,na,na,na); Silicon transport excluded due to vertical integration, disposal transport included in x-module-mono_Si, Transport dist. 200km (Inputs)
infrastructure	Ancillary building, wafer factory, steel, simulated data {DE} U	DE	1	p	5.30E-10	5.30E-10	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GM Ancillary Buildings Steel BS
	Silicon ingot factory, steel construction, simulated data {DE} U	DE	1	p	1.01E-9	1.01E-9	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GM Ingot Factory Steel BS iso Timber BS
	Wafer factory, steel construction, simulated data {DE} U	DE	1	p	1.06E-9	1.06E-9	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GM Wafer Factory Steel BS iso Timber BS
emission air	Heat, waste	-	-	MJ	5.83E+1	5.83E+1	1	1.33	(2,4,4,3,1,5); All electric energy consumed converted to heat
	Water, CN	-	-	kg	0	1.06E+1	1	1.58	(2,4,1,3,1,5); Brailovsky (2026) GM 04
	Water, DE	-	-	kg	1.06E+1	0	1	1.58	(2,4,1,3,1,5); Brailovsky (2026) GM 04



## 4.2.5 Photovoltaic cell, laminate and panel production

### Photovoltaic cells

The LCI data on simulated material and energy consumption as well as on emissions are based on LCI data of single-crystalline cells published by Brailovsky [12]. Cell production is differentiated into PERC and TOPCon passivation. Data on “tap water, at user” refers to city water for facility and manufacturing process use. The technical data of the cells are shown in Table.

Table 64 and Table 65 show the unit process data of the simulated photovoltaic cell production in Germany (DE) and China (CN) for PERC and TOPCon passivation respectively.

**Table 63: Key characteristics of crystalline silicon cells and key parameters of simulated cell manufacturing**

		TOPCon	PERC
unit			single-Si, simulated
Wafer area	cm <sup>2</sup>	330.15	330.15
Wafer weight	kg/m <sup>2</sup>	0.303	0.303
Wafer thickness	µm	130	130
Cell weight	kg/m <sup>2</sup>	0.290	0.302
Electricity demand	kWh/m <sup>2</sup>	19.34	8.51
Metallization paste, front	g/m <sup>2</sup>	1.53	3.00
Metallization paste, back	g/m <sup>2</sup>	1.53	1.13
Metallization paste, back, Al	g/m <sup>2</sup>	n/a	11.3
Silver demand	g/m <sup>2</sup>	2.75	2.96

It is important to distinguish the material composition of the metallization pastes used for PERC and TOPCon solar cells. The PERC cells are front metallized with silver, and back metallized with aluminium for the contact grid and silver for the contact pads for the cell interconnection. The modelled TOPCon cells only use silver paste but with a reduced amount due to improvements in fingers and busbars geometry. The electricity demand of newer TOPCon cells production site is smaller, in the order of 11 kWh/m<sup>2</sup>.

Completely new models and LCI are used for modelling the factory and facilities infrastructure [29], as previous datasets were two decades old. For the PERC inventory the Minimal Liquid Discharge circular strategy is considered, which minimizes water usage by implementation of rinsing water recovery through reverse osmosis membrane systems and further water reclaim via evaporators. For the TOPCon inventory only the Rinsing Water Recycling strategy is considered [28].



**Table 64: Unit process LCI data of the simulated photovoltaic TOPCon cell production in Germany (DE) and China (CN)**

Name	Location	InfrastructureProcesses	Unit	Photovoltaic cell, single-Si, TOPCon, simulated data, at plant		UncertaintyType	StandardDeviation95%	GeneralComment
				DE	CN			
Location				DE	CN			
InfrastructureProcess				0	0			
Unit				m2	m2			
Photovoltaic cell, single-Si, TOPCon, simulated data, at plant {DE} U	DE	0	m2	1	0			
Photovoltaic cell, single-Si, TOPCon, simulated data, at plant {CN} U	CN	0	m2	0	1			
Single-Si wafer, photovoltaics, PERC/TOPCon, simulated data, at plant {DE} U	DE	0	m2	1.04E+0	0	1	1.22	(2,2,1,2,1,5); Brailovsky (2026) GP 05
Single-Si wafer, photovoltaics, PERC/TOPCon, simulated data, at plant {CN} U	CN	0	m2	0	1.04E+0	1	1.22	(2,2,1,2,1,5); Brailovsky (2026) GP 05
Metallization paste, front side, at plant {RER} U	RER	0	kg	1.53E-3	1.53E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 iso TOPCon Metallization paste Ag90%
Metallization paste, back side, at plant {RER} U	RER	0	kg	1.53E-3	1.53E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 iso TOPCon Metallization paste Ag90%
Graphite, at plant {RER} U	RER	0	kg	2.24E-3	2.24E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 iso activated carbon
Polyurethane, rigid foam, at plant {RER} U	RER	0	kg	3.31E-5	3.31E-5	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Polyvinylfluoride, at plant {US} U	US	0	kg	3.10E-4	3.10E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Polyethylene, LDPE, granulate, at plant {RER} U	RER	0	kg	3.10E-4	3.10E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Polystyrene foam slab, at plant {RER} U	RER	0	kg	1.04E-2	1.04E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Steel, low-alloyed, at plant {RER} U	RER	0	kg	1.80E-5	1.80E-5	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Paper, recycling, with deinking, at plant {RER} U	RER	0	kg	6.85E-4	6.85E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 proxy for tissue paper
Steel product manufacturing, average metal working {RER} U	RER	0	kg	6.85E-4	6.85E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 iso wire drawing; manufacturing of screen for grid printing
Packaging, corrugated board, mixed fibre, single wall, at plant {RER} U	RER	0	kg	7.08E-3	7.08E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Polyethylene, HDPE, granulate, at plant {RER} U	RER	0	kg	0	0	1	1.05	(na,na,na,na,na,na);
Packaging film, LDPE, at plant {RER} U	RER	0	kg	8.85E-5	8.85E-5	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
EUR-flat pallet {RER} U	RER	0	p	9.84E-4	9.84E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Chemicals organic, at plant {GLO} U	GLO	0	kg	3.47E-4	3.47E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 Proxy for trimethylaluminium
Chemicals inorganic, at plant {GLO} U	GLO	0	kg	5.32E-3	5.32E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b Texturing additive
Chemicals inorganic, at plant {GLO} U	GLO	0	kg	1.08E-2	1.08E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b Polishing additive
Ammonia, liquid, at regional storehouse {RER} U	RER	0	kg	2.21E-2	2.21E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Phosphoryl chloride, at plant {RER} U	RER	0	kg	0	0	1	1.05	(na,na,na,na,na,na);
Phosphorous chloride, at plant {RER} U	RER	0	kg	8.58E-5	8.58E-5	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Hydrochloric acid, 30% in H2O, at plant {RER} U	RER	0	kg	2.45E-2	2.45E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Nitric acid, 50% in H2O, at plant {RER} U	RER	0	kg	0	0	1	1.05	(na,na,na,na,na,na);
Hydrogen fluoride, at plant {GLO} U	GLO	0	kg	8.97E-2	8.97E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Lime, hydrated, loose, at plant {CH} U	CH	0	kg	2.97E-1	2.97E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Sodium hydroxide, 50% in H2O, mercury cell, at plant {RER} U	RER	0	kg	6.63E-3	6.63E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Calcium chloride, CaCl2, at plant {RER} U	RER	0	kg	1.36E-1	1.36E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Potassium hydroxide, at regional storage {RER} U	RER	0	kg	1.06E-1	1.06E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Oxygen, liquid, at plant {RER} U	RER	0	kg	2.51E-1	2.51E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Argon, liquid, at plant {RER} U	RER	0	kg	1.40E-3	1.40E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Methane, 96 vol-%, from biogas, low pressure, at consumer {CH} U	CH	0	MJ	2.97E-2	2.97E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Hydrogen production, steam methane reforming of natural gas, 25 bar {CH} U	CH	0	kg	1.50E-4	1.50E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 H2-5.0 and proxy of PH3/H2 (1% PH3 4.0 in H2 5.0)
Helium, at plant {GLO} U	GLO	0	kg	0	0	1	1.05	(na,na,na,na,na,na);
Nitrogen, liquid, at plant {RER} U	RER	0	kg	2.22E+0	2.22E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
silane, at plant {RER} U	RER	0	kg	1.00E-2	1.00E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Ammonia, liquid, at regional storehouse {RER} U	RER	0	kg	1.74E-3	1.74E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 Proxy for nitrous oxide
Tap water, water balance according to MoeK 2013, at user {CN} U	CN	0	kg	0	2.68E+1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b diluting water, CN iso GLO
Tap water, water balance according to MoeK 2013, at user {DE} U	DE	0	kg	2.68E+1	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b diluting water, DE iso GLO
Electricity, medium voltage, at grid {CN} U	CN	0	kWh	0	1.10E+1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 / GP 06b CN iso DE
Electricity, medium voltage, at grid {DE} U	DE	0	kWh	1.10E+1	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05 / GP 06b
District heat, at consumer, natural gas in industrial furnace 1MW {CH} U	CH	0	MJ	2.51E+0	2.51E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Metal working machine, unspecified, at plant {RER} U	RER	1	kg	8.29E-3	8.29E-3	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Ancillary building, wafer factory, steel, simulated data {DE} U	DE	1	p	3.52E-10	3.52E-10	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Cell factory, steel construction, simulated data {DE} U	DE	1	p	1.41E-9	1.41E-9	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Transport, freight, lorry, fleet average {RER} U	RER	0	tkm	6.56E-1	6.56E-1	1	2.09	(4,5,na,na,na,na,na); Transport distance: 100km; weight EUR-flat pallet 25kg; no transport of wafer due to integrated production
Transport, freight, rail {RER} U	RER	0	tkm	6.06E-1	6.06E-1	1	2.09	(4,5,na,na,na,na,na); Transport distance: 200km
Treatment, sewage, to wastewater treatment, class 3 {CH} U	CH	0	m3	2.58E-2	2.58E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Disposal, hazardous waste, 25% water, to hazardous waste incineration {CH} U	CH	0	kg	7.07E-1	7.07E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Heat waste	-	-	MJ	4.22E+1	4.22E+1	1	1.34	(3,4,4,3,1,5); Calculation based on electricity and heat use
Water, CN	-	-	kg	0	1.51E+0	1	1.63	(2,3,4,3,1,5); Brailovsky (2026) GP 06b CN iso DE
Water, DE	-	-	kg	1.51E+0	0	1	1.58	(2,4,1,3,1,5); Brailovsky (2026) GP 06b
Carbon dioxide, fossil	-	-	kg	1.11E-1	1.11E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 05
NMVO, non-methane volatile organic compounds, unspecified origin	-	-	kg	3.20E-6	3.20E-6	1	1.58	(2,4,1,3,1,5); Brailovsky (2026) GP 05
Nitrogen oxides	-	-	kg	1.33E-4	1.33E-4	1	1.58	(2,4,1,3,1,5); Brailovsky (2026) GP 05



Table 65: Unit process LCI data of the simulated photovoltaic PERC cell production Germany (DE) and China (CN)

	Name	Location	Infrastructure	Process	Unit	Photovoltaic cell, single-Si, PERC, simulated data, at plant		Uncertainty Type	Standard Deviation %	General Comment
						DE U	CN U			
						DE	CN			
	Photovoltaic cell, single-Si, PERC, simulated data, at plant (DE) U	DE	0	m2	1	0				
	Photovoltaic cell, single-Si, PERC, simulated data, at plant (CN) U	CN	0	m2	0	1				
	Single-Si wafer, photovoltaics, PERC/TOPCon, simulated data, at plant (DE) U	DE	0	m2	1.04E+0	0	1	1.05	(2,2,1,2,1,5); Brailovsky (2026)	GM 05
	Single-Si wafer, photovoltaics, PERC/TOPCon, simulated data, at plant (CN) U	CN	0	m2	0	1.04E+0	1	1.05	(2,2,1,2,1,5); Brailovsky (2026)	GM 05
materials	Metallization paste, front side, at plant (RER) U	RER	0	kg	3.00E-3	3.00E-3	1	1.09	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; 90 % Ag, at plant iso market, RER iso RoW
	Metallization paste, back side, at plant (RER) U	RER	0	kg	1.13E-3	1.13E-3	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; 43 % Ag, at plant iso market, RER iso RoW
	Metallization paste, back side, aluminium, at plant (RER) U	RER	0	kg	1.13E-2	1.13E-2	1	1.09	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; 79 % Al, at plant iso market, RER iso RoW
	Graphite, at plant (RER) U	RER	0	kg	2.24E-3	2.24E-3	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; iso activated carbon
	Polyurethane, rigid foam, at plant (RER) U	RER	0	kg	3.31E-5	3.31E-5	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; at plant iso market
	Polyvinylfluoride, at plant (US) U	US	0	kg	3.10E-4	3.10E-4	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; at plant iso market, US iso GLO
	Steel, low-alloyed, at plant (RER) U	RER	0	kg	1.80E-5	1.80E-5	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; RER iso GLO, at plant iso market
treatment	Steel product manufacturing, average metal working (RER) U	RER	0	kg	1.80E-5	1.80E-5	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; Steel product manufacturing iso wire drawing; RER iso GLO
chemicals	Chemicals organic, at plant (GLO) U	GLO	0	kg	2.22E-4	2.22E-4	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; Proxy for Trimethylaluminium solar grade
	Ammonia, liquid, at regional storehouse (RER) U	RER	0	kg	1.54E-2	1.54E-2	1	1.22	(2,4,1,3,1,5); Brailovsky (2026)	GM 05
	Phosphorous chloride, at plant (RER) U	RER	0	kg	2.08E-4	2.08E-4	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05
	Solvents, organic, unspecified, at plant (GLO) U	GLO	0	kg	1.42E-2	1.42E-2	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; at plant iso market
	Hydrochloric acid, 30% in H2O, at plant (RER) U	RER	0	kg	1.70E-2	1.70E-2	1	1.22	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; in H2O iso without water
	Hydrogen fluoride, at plant (GLO) U	GLO	0	kg	8.25E-2	8.25E-2	1	1.22	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; GLO iso RER
	Hydrogen peroxide, 50% in H2O, at plant (RER) U	RER	0	kg	1.08E-1	1.08E-1	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; in H2O iso without water
	Sulphuric acid, liquid, at plant (RER) U	RER	0	kg	1.17E-2	1.17E-2	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; at regional storage iso production
	Potassium hydroxide, at regional storage (RER) U	RER	0	kg	1.74E-1	1.74E-1	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; at regional storage iso production
gases	Lime, hydrated, loose, at plant (CH) U	CH	0	kg	3.26E-1	3.26E-1	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; CH iso RoW, at plant iso market, from MLD scenario
	Oxygen, liquid, at plant (RER) U	RER	0	kg	2.14E-1	2.14E-1	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05
	Nitrogen, liquid, at plant (RER) U	RER	0	kg	9.80E-1	9.80E-1	1	1.22	(2,4,1,3,1,5); Brailovsky (2026)	GM 05
	silane, at plant (RER) U	RER	0	kg	2.86E-3	2.86E-3	1	1.22	(2,4,1,3,1,5); Brailovsky (2026)	GM 05
	Ammonia, liquid, at regional storehouse (RER) U	RER	0	kg	1.87E-3	1.87E-3	1	1.05	(2,4,1,3,3,3); GM 05; According to Brailovsky (2026), nitrous oxide is used as a process input. As there is no corresponding dataset in the UVEK database, the 'ammonia, liquid' dataset is used as a proxy.	
water	Tap water, water balance according to MoeK 2013, at user (CN) U	CN	0	kg	0	1.03E+1	1	1.22	(2,4,1,3,1,5); Brailovsky (2026)	GM 06
	Tap water, water balance according to MoeK 2013, at user (DE) U	DE	0	kg	1.03E+1	0	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 06
energy	Electricity, medium voltage, at grid (CN) U	CN	0	kWh	0	8.51E+0	1	1.09	(2,4,1,3,1,5); Brailovsky (2026)	GM 05 + GM 06; at grid iso market
	Electricity, medium voltage, at grid (DE) U	DE	0	kWh	8.51E+0	0	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 05 + GM 06; at grid iso market
	District heat, at consumer, natural gas in industrial furnace 1MW (CH) U	CH	0	MJ	2.14E+0	2.14E+0	1	1.22	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; iso "Heat, district or industrial, natural gas RER"
	Ancillary building, wafer factory, steel, simulated data (DE) U	DE	1	p	3.52E-10	3.52E-10	1	3.00	(2,4,1,3,1,5); Brailovsky (2026)	Ancillary Buildings Steel BS
	Cell factory, steel construction, simulated data (DE) U	DE	1	p	1.41E-9	1.41E-9	1	3.00	(2,4,1,3,1,5); Brailovsky (2026)	GM Cell Factory Steel BS iso Timber BS
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	2.11E-1	2.11E-1	1	2.09	(4,5,na,na,na,na); Wafer transport avoided through vertical integration, Transport distances: 100km (Inputs), 500km (Waste disposal)	
	Transport, freight, rail (RER) U	RER	0	tkm	4.23E-1	4.23E-1	1	2.09	(4,5,na,na,na,na); Wafer transport avoided through vertical integration, Transport distances: 200km (Inputs)	
disposal	Treatment, PV cell production effluent, to wastewater treatment, class 3 (CH) U	CH	0	m3	7.49E-3	7.49E-3	1	1.22	(2,4,1,3,1,5); Brailovsky (2026)	GM 06
	Disposal, hazardous waste, 0% water, to underground deposit (DE) U	DE	0	kg	1.63E-1	1.63E-1	1	1.05	(2,4,1,3,1,5); Brailovsky (2026)	GM 06
emission air, high population density	Heat, waste	-	-	MJ	3.06E+1	3.06E+1	1	1.22	(3,4,4,3,1,5); All electric energy consumed converted to heat	
	Water, CN	-	-	kg	0	1.02E+0	1	1.63	(2,4,1,3,1,5); Brailovsky (2026)	GM 06
	Water, DE	-	-	kg	1.02E+0	0	1	1.50	(2,4,1,3,1,5); Brailovsky (2026)	GM 06
	NMVO, non-methane volatile organic compounds, unspecified origin	-	-	kg	3.20E-6	3.20E-6	1	1.57	(2,4,1,3,1,5); Brailovsky (2026)	GM 05
	Nitrogen oxides	-	-	kg	1.33E-4	1.33E-4	1	1.50	(2,4,1,3,1,5); Brailovsky (2026)	GM 05; iso DE



### *Photovoltaic panels*

Table 66 and Table 67 show the unit process data of the simulated photovoltaic TOPCon glass-glass and PERC glass-backsheet panel production in Germany (DE) and China (CN). The LCI data on material use, energy consumption and emissions are based on LCI data published by Brailovsky [5]. The aluminium frame modelling considers the alloys, extrusion and surface anodization. The cell interconnectors are modelled in detail copper, tin and lead shares. Completely new models and LCI are used for modelling the factory buildings and infrastructure facilities, as previous datasets were two decades old.



**Table 66: Unit process LCI data of the simulated photovoltaic TOPCon panel production in Germany (DE) and China (CN)**

	Name	Location	InfrastructureProcess	Unit	Photovoltaic panel, single-Si, TOPCon, simulated data, at plant {DE} U		UncertaintyType	StandardDeviation95%	GeneralComment
					Photovoltaic panel, single-Si, TOPCon, simulated data, at plant {DE} U	Photovoltaic panel, single-Si, TOPCon, simulated data, at plant {CN} U			
					DE	CN			
	Location								
	InfrastructureProcess				1	1			
	Unit				m2	m2			
	Photovoltaic panel, single-Si, TOPCon, simulated data, at plant {DE} U	DE	1	m2	1	0			
	Photovoltaic panel, single-Si, TOPCon, simulated data, at plant {CN} U	CN	1	m2	0	1			
materials	Photovoltaic cell, single-Si, TOPCon, simulated data, at plant {DE} U	DE	0	m2	9.29E-1	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Photovoltaic cell, single-Si, TOPCon, simulated data, at plant {CN} U	CN	0	m2	0	9.29E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Aluminium alloy, AlMg3, at plant {RER} U	RER	0	kg	1.35E+0	1.35E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08; iso Aluminium frame
	Copper, at regional storage {RER} U	RER	0	kg	1.00E-1	1.00E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08; iso Copper Cathode
	Diode, glass-, through-hole mounting, at plant {GLO} U	GLO	0	kg	1.88E-4	1.88E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Silicone product, at plant {RER} U	RER	0	kg	7.59E-2	7.59E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Tin, at regional storage {RER} U	RER	0	kg	3.35E-3	3.35E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Lead, at regional storage {RER} U	RER	0	kg	3.47E-3	3.47E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Solar glass, low-iron, at regional storage {RER} U	RER	0	kg	9.09E+0	9.09E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Polypropylene, granulate, at plant {RER} U	RER	0	kg	7.39E-1	7.39E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
Treatment	Extrusion, plastic film {RER} U	RER	0	kg	7.39E-1	7.39E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Wire drawing, copper {RER} U	RER	0	kg	1.00E-1	1.00E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Tempering, flat glass {RER} U	RER	0	kg	9.09E+0	9.09E+0	1	1.24	(2,4,1,3,1,5); Calculated to reflect input "tempered glass"
auxiliaries	Tap water, water balance according to MoeK 2013, at user {CN} U	CN	0	kg	0	7.14E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08 water completely softened; CN iso RoW
	Tap water, water balance according to MoeK 2013, at user {DE} U	DE	0	kg	7.14E-1	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08 water completely softened; DE iso RoW
	1-propanol, at plant {RER} U	RER	0	kg	1.70E-2	1.70E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
Packaging	Adipic acid, at plant {RER} U	RER	0	kg	3.66E-4	3.66E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Lubricating oil, at plant {RER} U	RER	0	kg	1.60E-3	1.60E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Packaging film, LDPE, at plant {RER} U	RER	0	kg	3.58E-2	3.58E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Polyethylene, HDPE, granulate, at plant {RER} U	RER	0	kg	6.97E-2	6.97E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08 Junction box plastic
energy	Corrugated board, mixed fibre, single wall, at plant {RER} U	RER	0	kg	1.10E+0	1.10E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	EUR-flat pallet {RER} U	RER	0	p	4.69E-2	4.69E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Electricity, medium voltage, at grid {CN} U	CN	0	kWh	0	3.65E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08; CN iso DE
infrastructure	Electricity, medium voltage, at grid {DE} U	DE	0	kWh	3.65E+0	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Ancillary building, wafer factory, steel, simulated data {DE} U	DE	1	p	3.27E-10	3.27E-10	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GP 08
transport	Panel factory, steel construction, simulated data {DE} U	DE	1	p	1.31E-9	1.31E-9	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Transport, freight, lorry, fleet average {RER} U	RER	0	tkm	1.36E+0	1.36E+0	1	2.09	(4,5,na,na,na,na);
disposal	Transport, freight, rail {RER} U	RER	0	tkm	8.17E+0	8.17E+0	1	2.09	(4,5,na,na,na,na);
	Disposal, inert waste, 5% water, to construction waste landfill {CH} U	CH	0	kg	5.78E-2	5.78E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; wastes for production chain from SoG Silicon to Panel
	Disposal, plastics, mixture, 15.3% water, to municipal incineration {CH} U	CH	0	kg	2.94E-2	2.94E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; wastes for production chain from SoG Silicon to Panel
	Disposal, plastics, mixture, 15.3% water, to municipal incineration {CH} U	CH	0	kg	5.06E-4	5.06E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; wastes for production chain from SoG Silicon to Panel
	Disposal, glass, 0% water, to construction waste landfill {CH} U	CH	0	kg	4.82E-3	4.82E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; wastes for production chain from SoG Silicon to Panel
	Disposal, used mineral oil, 10% water, to hazardous waste incineration {CH} U	CH	0	kg	1.60E-3	1.60E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GP 08
	Disposal, wood untreated, 20% water, to sanitary landfill {CH} U	CH	0	kg	2.36E-3	2.36E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; wastes for production chain from SoG Silicon to Panel
	Disposal, wood untreated, 20% water, to municipal incineration {CH} U	CH	0	kg	2.29E-2	2.29E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; wastes for production chain from SoG Silicon to Panel
	Disposal, steel, 0% water, to municipal incineration {CH} U	CH	0	kg	5.80E-5	5.80E-5	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; wastes for production chain from SoG Silicon to Panel
	Disposal, aluminium, 0% water, to municipal incineration {CH} U	CH	0	kg	1.51E-3	1.51E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; wastes for production chain from SoG Silicon to Panel
emissions air	Heat, waste	-	-	MJ	1.31E+1	1.31E+1	1	1.40	(4,4,4,3,1,5); Calculation, electricity use
	Water, CN	-	-	kg	0	7.14E-1	1	1.69	(4,4,4,3,1,5); Brailovsky (2026) GP 08
	Water, DE	-	-	kg	7.14E-1	0	1	1.69	(4,4,4,3,1,5); Brailovsky (2026) GP 08



Table 67: Unit process LCI data of the simulated photovoltaic PERC panel production in Germany (DE) and China (CN)

	Name	Location	InfrastructureProcess	Unit	Photovoltaic panel, single-Si, PERC, simulated data, at plant		UncertaintyType	StandardDeviation95%	GeneralComment
					DE U	CN U			
	Location				DE	CN			
	InfrastructureProcess				1	1			
	Unit				m2	m2			
	Photovoltaic panel, single-Si, PERC, simulated data, at plant (DE) U	DE	1	m2	1	0			
	Photovoltaic panel, single-Si, PERC, simulated data, at plant (CN) U	CN	1	m2	0	1			
	Photovoltaic cell, single-Si, PERC, simulated data, at plant (DE) U	DE	0	m2	9.27E-1	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Photovoltaic cell, single-Si, PERC, simulated data, at plant (CN) U	CN	0	m2	0	9.27E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
materials	Aluminium alloy, AlMg3, at plant {RER} U	RER	0	kg	1.35E+0	1.35E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; iso aluminium frame, RER iso GLO, personal information from Brailovsky
	Copper, at regional storage (RER) U	RER	0	kg	1.13E-1	1.13E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; iso copper, cathode
	Wire drawing, copper (RER) U	RER	0	kg	1.13E-1	1.13E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Diode, unspecified, at plant {GLO} U	GLO	0	kg	1.88E-4	1.88E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; at plant iso market
	Silicone product, at plant (RER) U	RER	0	kg	9.10E-2	9.10E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; at plant iso market
	Tin, at regional storage (RER) U	RER	0	kg	4.19E-3	4.19E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Lead, at regional storage (RER) U	RER	0	kg	4.34E-3	4.34E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; RER iso GLO
	Solar glass, low-iron, at regional storage (RER) U	RER	0	kg	8.06E+0	8.06E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; RER iso GLO, tempering added separately
	Tempering, flat glass (RER) U	RER	0	kg	8.06E+0	8.06E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant {RER} U	RER	0	kg	1.87E-1	1.87E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; at plant iso market
	Polyethylene terephthalate, granulate, amorphous, at plant {RER} U	RER	0	kg	2.79E-1	2.79E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Polyethylene, HDPE, granulate, at plant {RER} U	RER	0	kg	6.97E-2	6.97E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Ethylvinylacetate, foil, at plant {RER} U	RER	0	kg	7.98E-1	7.98E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; at plant iso market, RER iso GLO
	Polyvinylfluoride film, at plant {US} U	US	0	kg	4.48E-2	4.48E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; US iso GLO, at plant iso market
auxiliaries	Tap water, water balance according to MoeK 2013, at user (DE) U	DE	0	kg	7.14E-1	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Tap water, water balance according to MoeK 2013, at user (CN) U	CN	0	kg	0	7.14E-1	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	1-propanol, at plant {RER} U	RER	0	kg	1.70E-2	1.70E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; RER iso GLO, at plant iso market
	Adipic acid, at plant {RER} U	RER	0	kg	3.66E-4	3.66E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Lubricating oil, at plant {RER} U	RER	0	kg	1.60E-3	1.60E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; at plant iso market
	Packaging film, LDPE, at plant {RER} U	RER	0	kg	3.58E-2	3.58E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Corrugated board, mixed fibre, single wall, at plant {RER} U	RER	0	kg	1.10E+0	1.10E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	EUR-flat pallet {RER} U	RER	0	p	4.69E-3	4.69E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
energy	Electricity, medium voltage, at grid {CN} U	CN	0	kWh	0	3.60E+0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
	Electricity, medium voltage, at grid {DE} U	DE	0	kWh	3.60E+0	0	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08
infrastructure	Ancillary building, wafer factory, steel, simulated data (DE) U	DE	1	p	3.27E-10	3.27E-10	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GM Ancillary Buildings Steel BS
	Panel factory, steel construction, simulated data (DE) U	DE	1	p	1.31E-9	1.31E-9	1	3.06	(2,4,1,3,1,5); Brailovsky (2026) GM Panel Factory Steel BS iso Timber BS
transport	Transport, freight, lorry, fleet average (RER) U	RER	0	tkm	2.05E+0	2.05E+0	1	2.09	(4,5,na,na,na,na); Cell transport avoided by vertical integration; assumed weight europallet 22kg; Distances: 100km (Inputs), 15km (Waste)
	Transport, freight, rail (RER) U	RER	0	tkm	1.23E+1	1.23E+1	1	2.09	(4,5,na,na,na,na); Cell transport avoided by vertical integration; assumed weight europallet 22kg; Distances: 200km (Inputs)
	Disposal, plastics, mixture, 15.3% water, to municipal incineration (CH) U	CH	0	kg	2.94E-2	2.94E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW, CH iso DE
	Disposal, plastics, mixture, 15.3% water, to sanitary landfill (CH) U	CH	0	kg	5.06E-4	5.06E-4	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; CH iso GLO, cables_andfilling
	Disposal, used mineral oil, 10% water, to hazardous waste incineration (CH) U	CH	0	kg	1.60E-3	1.60E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08; CH iso Europe w/o Switzerland
	Disposal, glass, 0% water, to construction waste landfill (CH) U	CH	0	kg	4.82E-3	4.82E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; CH iso Europe w/o Switzerland
	Disposal, wood untreated, 20% water, to sanitary landfill (CH) U	CH	0	kg	2.36E-3	2.36E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; CH iso RoW
	Disposal, inert waste, 5% water, to construction waste landfill (CH) U	CH	0	kg	5.78E-2	5.78E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; CH iso Europe w/o Switzerland
	Disposal, wood untreated, 20% water, to municipal incineration (CH) U	CH	0	kg	2.29E-2	2.29E-2	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; CH iso RoW
	Disposal, steel, 0% water, to municipal incineration (CH) U	CH	0	kg	5.80E-5	5.80E-5	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; CH iso Europe w/o Switzerland
	Disposal, aluminium, 0% water, to municipal incineration (CH) U	CH	0	kg	1.51E-3	1.51E-3	1	1.24	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW; CH iso Europe w/o Switzerland
emissions air	Heat, waste	-	-	MJ	1.30E+1	1.30E+1	1	1.40	(4,4,4,3,1,5); Calculation
	Water, CN	-	-	kg	0	7.14E-1	1	1.58	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW
	Water, DE	-	-	kg	7.14E-1	0	1	1.58	(2,4,1,3,1,5); Brailovsky (2026) GM 08-RW



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## ANNEX: ADDITIONAL INVENTORIES

### Multi-Crystalline Si PV

LCIs of multi-crystalline PV systems are not updated with this LCI release due to their insignificant market share. An exception is the supply of solar-grade silicon and other upstream processes that are amended with the update for single-crystalline PV systems. All other inventories of multi-Si stem from the previous IEA PVPS Task 12 LCI Report [15] including parameter updates made in the LCI data update 2023 for the LCA factsheet [36] (updated electricity consumption in module manufacturing). The description of the inventories is found below.

#### Description of the supply chain

Figure 17 shows the supply chain of photovoltaic electricity production according to Jungbluth et al. [34]. Additional descriptions of specific manufacturers in the crystalline Si PV supply chain and their manufacturing processes are available in de Wild-Scholten [91].

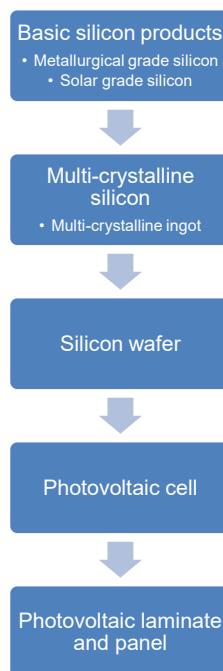
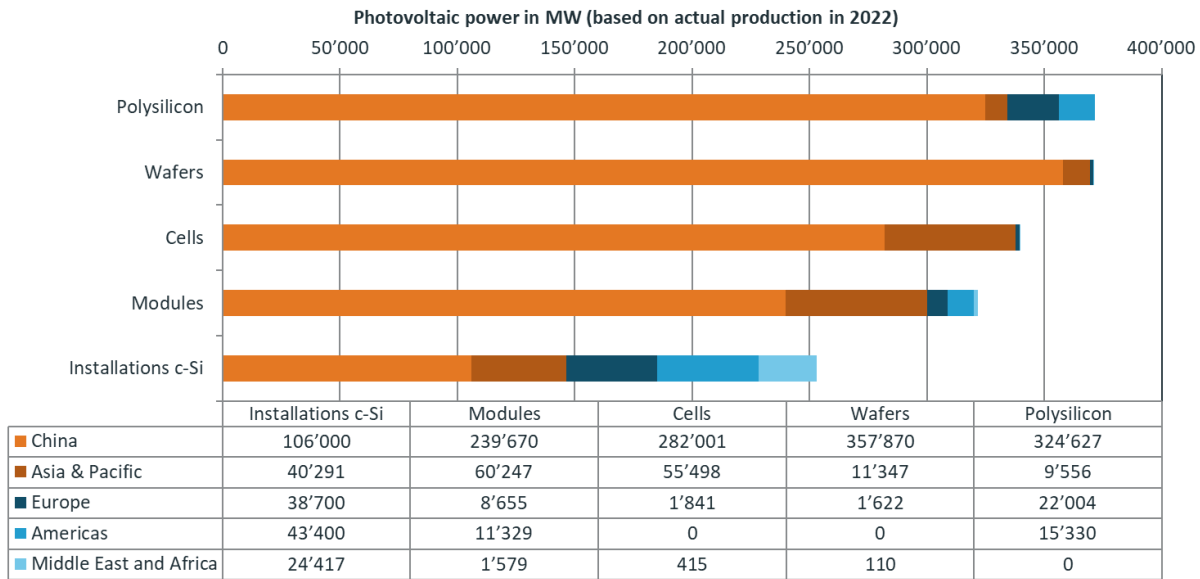


Figure 17: Supply chain of silicon-based photovoltaic electricity production

#### Market mixes in multi-Si PV supply chain LCI

Figure 18 shows the market shares of the four world regions on the different levels of the supply chain in 2022, which are used to model the multi-Si supply chain. The production is given in MW of PV power and based on the Q1 2023 S&P Module Supply Chain Tracker [92] and the IEA PVPS 2023 Trends Report [93]. The amount of silicon in metric tons is converted to MW based on an average consumption of about 2.54 tons of polysilicon per MW of photovoltaic power capacity.



**Figure 18: PV supply chain market shares of world regions in 2022 applied in the multi-Si PV supply chain LCI. Market shares are provided for polysilicon, wafer, c-Si cells and modules production. Additionally, shares in annual installed silicon-based PV panel capacity are provided.**

Table 68, Table 69, Table 70 and Table 71 show the supply volumes and market shares derived from the information shown in Figure 18. Note the column headers indicate the location of use, and the rows show the region of production. Table 68 shows the supply volumes and market mixes of polysilicon used in wafer production in China, the Americas, APAC and Europe. Table 69 shows the supply volumes and market mixes of wafers used in cell production in China, the Americas, APAC, and Europe. Table 70 shows the supply volumes and market mixes of Si cells produced in China, the Americas, APAC and Europe. Table 71 shows the supply volumes and market mixes of panels installed in China, the Americas, APAC and Europe.

**Table 68: Supply volumes (domestic production and imports) and market mixes in 2022 of polysilicon used in wafer production in China, the Americas, Asia and Pacific, Europe and Middle East and Africa region.**

Polysilicon Production 2022	China		Asia & Pacific		Americas	Europe		MEA	
	MW	%	MW	%	MW	MW	%	MW	%
China	324'627	90.6%	0	0.0%	0	0	0.0%	0	0.0%
Asia & Pacific	0	0.0%	9'556	84.1%	0	0	0.0%	0	0.0%
Americas	14'506	4.0%	776	6.8%	0	0	0.0%	0	0.0%
Europe	19'284	5.4%	1'032	9.1%	0	1'624	100.0%	0	0.0%
MEA	0	0.0%	0	0.0%	0	0	0.0%	110	100.0%
<b>Total</b>	<b>358'417</b>	<b>100.0%</b>	<b>11'364</b>	<b>100.0%</b>	<b>0</b>	<b>1'624</b>	<b>100.0%</b>	<b>110</b>	<b>100.0%</b>

**Table 69: Supply volumes (domestic production and imports) and market mixes in 2022 of wafers used in cell production in China, the Americas, Asia and Pacific, Europe and Middle East and Africa region.**

Wafer Production 2022	China		Asia & Pacific		Americas	Europe		MEA	
	MW	%	MW	%	MW	MW	%	MW	%
China	307'891	100.0%	49'247	81.3%	0	388	19.3%	343	75.7%
Asia & Pacific	0	0.0%	11'347	18.7%	0	0	0.0%	0	0.0%
Americas	0	0.0%	0	0.0%	0	0	0.0%	0	0.0%
Europe	0	0.0%	0	0.0%	0	1'622	80.7%	0	0.0%
MEA	0	0.0%	0	0.0%	0	0	0.0%	110	24.3%
<b>Total</b>	<b>307'891</b>	<b>100.0%</b>	<b>60'594</b>	<b>100.0%</b>	<b>0</b>	<b>2'010</b>	<b>100.0%</b>	<b>453</b>	<b>100.0%</b>

**Table 70: Supply volumes (domestic production and imports) and market mixes in 2022 of cells produced in China, the Americas, Asia and Pacific, Europe and Middle East and Africa region.**



<i>c-Si Cell Production 2022</i>	China		Asia & Pacific		Americas		Europe		MEA	
	MW	%	MW	%	MW	%	MW	%	MW	%
China	253'294	100.0%	8'173	12.8%	11'973	100.0%	7'306	79.9%	1'254	75.1%
Asia & Pacific	0	0.0%	55'498	87.2%	0	0.0%	0	0.0%	0	0.0%
Americas	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Europe	0	0.0%	0	0.0%	0	0.0%	1'841	20.1%	0	0.0%
MEA	0	0.0%	0	0.0%	0	0.0%	0	0.0%	415	24.9%
<b>Total</b>	<b>253'294</b>	<b>100.0%</b>	<b>63'672</b>	<b>100.0%</b>	<b>11'973</b>	<b>100.0%</b>	<b>9'147</b>	<b>100.0%</b>	<b>1'669</b>	<b>100.0%</b>

Table 71: Supply volumes (domestic production and imports) and market mixes in 2022 of *modules* installed in China, the Americas, Asia and Pacific, Europe and Middle East and Africa region.

<i>c-Si Module Production 2022</i>	China		Asia & Pacific		Americas		Europe		MEA	
	MW	%	MW	%	MW	%	MW	%	MW	%
China	134'793	100.0%	0	0.0%	40'390	73.2%	37'348	75.9%	27'138	87.4%
Asia & Pacific	0	0.0%	51'236	100.0%	3'470	6.3%	3'209	6.5%	2'332	7.5%
Americas	0	0.0%	0	0.0%	11'329	20.5%	0	0.0%	0	0.0%
Europe	0	0.0%	0	0.0%	0	0.0%	8'655	17.6%	0	0.0%
MEA	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1'579	5.1%
<b>Total</b>	<b>134'793</b>	<b>100.0%</b>	<b>51'236</b>	<b>100.0%</b>	<b>55'189</b>	<b>100.0%</b>	<b>49'212</b>	<b>100.0%</b>	<b>31'050</b>	<b>100.0%</b>

## General approach

The electricity consumption on all process levels is modelled with specific electricity mixes corresponding to the different world regions. The supply chains of the regions are modelled based on the market shares described in the section "Market". Water use and consumption is modelled using country specific elementary flows. This allows for a regionalised assessment of water scarcity. All other inputs and outputs are not changed because of lacking information about the material, energy, and environmental efficiencies of the production in the different world regions.

## Multi-crystalline silicon

Table 72 shows the unit process data of the multi-crystalline silicon production in Europe (RER), China (CN), North America (US) and Asia & Pacific (APAC). The South Korean electricity mix is selected for the APAC region, because at the time, South Korea produced the highest share of multi-crystalline silicon in the APAC region. The US electricity mix is chosen to model electricity consumption in the North American production. The electricity consumption of the casting of multi-Si ingots is estimated at 7 kWh/kg [94]. The emission of waste heat is calculated based on the fuel and electricity demand. The production of 1 kg ingot is assumed to require 1.015 to 1.02 kg of solar grade silicon (1.5 to 2 % material losses according to [4]). These losses are included in the losses accounted for in the wafer manufacturing (see Section "Silicon wafer production").



**Table 72: Unit process LCI data of the multi-crystalline silicon production in Europe (RER), China (CN), North America (US) and Asia & Pacific (APAC)**

	Name	Location	InfrastructureProcess	Unit	silicon, multi-Si, casted, at plant	silicon, multi-Si, casted, at plant	silicon, multi-Si, casted, at plant	silicon, multi-Si, casted, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
					CN	US	APAC	RER			
product	Location				0	0	0	0			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
	silicon, multi-Si, casted, at plant	CN	0	kg	1	0	0	0			
technosphere	silicon, multi-Si, casted, at plant	US	0	kg	0	1	0	0			
	silicon, multi-Si, casted, at plant	APAC	0	kg	0	0	1	0			
	silicon, multi-Si, casted, at plant	RER	0	kg	0	0	0	1			
	silicon, production mix, photovoltaics, at plant	CN	0	kg	1.00E+0	0	0	0	1	1.33	(2,4,4,2,1,5); Estimation
	silicon, production mix, photovoltaics, at plant	US	0	kg	0	1.00E+0	0	0	1	1.33	(2,4,4,2,1,5); Estimation
	silicon, production mix, photovoltaics, at plant	APAC	0	kg	0	0	1.00E+0	0	1	1.33	(2,4,4,2,1,5); Estimation
	silicon, production mix, photovoltaics, at plant	GLO	0	kg	0	0	0	1.00E+0	1	1.33	(2,4,4,2,1,5); Estimation
	argon, liquid, at plant	RER	0	kg	2.52E-1	2.52E-1	2.52E-1	2.52E-1	1	1.22	(1,2,4,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 12)
	helium, at plant	GLO	0	kg	7.76E-5	7.76E-5	7.76E-5	7.76E-5	1	1.22	(1,2,4,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 12)
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	5.00E-3	5.00E-3	5.00E-3	5.00E-3	1	1.58	(3,3,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 12)
	nitrogen, liquid, at plant	RER	0	kg	3.04E-2	3.04E-2	3.04E-2	3.04E-2	1	1.22	(1,2,4,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 12)
	resource, in water	ceramic tiles, at regional storage	CH	0	kg	2.14E-1	2.14E-1	2.14E-1	2.14E-1	1	1.22
electricity, medium voltage, at grid		CN	0	kWh	7.00E+0	0	0	0	1	1.22	(2,2,1,2,1,5); ITRPV 2020, Fig. 6, p.9
electricity, medium voltage, at grid		US	0	kWh	0	7.00E+0	0	0	1	1.22	(2,2,1,2,1,5); ITRPV 2020, Fig. 6, p.9
electricity, medium voltage, at grid		KR	0	kWh	0	0	7.00E+0	0	1	1.22	(2,2,1,2,1,5); ITRPV 2020, Fig. 6, p.9
electricity, medium voltage, production ENTSO, at grid		ENTSO	0	kWh	0	0	0	7.00E+0	1	1.22	(2,2,1,2,1,5); ITRPV 2020, Fig. 6, p.9
Water, cooling, unspecified natural origin, CN		-	-	m3	9.43E-1	0	0	0	1	1.60	(3,4,5,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 12)
Water, cooling, unspecified natural origin, US		-	-	m3	0	9.43E-1	0	0	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 12)
Water, cooling, unspecified natural origin, KR		-	-	m3	0	0	9.43E-1	0	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 12)
Water, cooling, unspecified natural origin, RER		-	-	m3	0	0	0	9.43E-1	1	1.34	(3,4,4,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 12)
transport		transport, freight, lorry, fleet average	RER	0	tkm	1.05E+0	1.05E+0	1.05E+0	1.05E+0	1	2.09
	transport, freight, rail	RER	0	tkm	2.00E-1	2.00E-1	2.00E-1	2.00E-1	1	2.09	(4,5,na,na,na,na); Standard distances 100km
infrastructure	silicone plant	RER	1	unit	1.00E-11	1.00E-11	1.00E-11	1.00E-11	1	3.09	(1,2,4,1,3,3); Estimation
	treatment, sewage, to wastewater treatment, class 2	CH	0	m3	8.96E-1	8.96E-1	8.96E-1	8.96E-1	1	1.63	(4,3,5,3,1,5); Calculation based on water withdrawal and water emissions
emission air	Heat, waste	-	-	MJ	2.52E+1	2.52E+1	2.52E+1	2.52E+1	1	1.58	(3,3,5,3,1,5); Calculation
	Water, CN	-	-	kg	4.72E+1	0	0	0	1	1.88	(4,3,5,3,1,5); Assumption: 5% evaporation of cooling water; Frischknecht & Büsser Knöpfel (2013)
	Water, US	-	-	kg	0	4.72E+1	0	0	1	1.88	(4,3,5,3,1,5); Assumption: 5% evaporation of cooling water; Frischknecht & Büsser Knöpfel (2013)
	Water, KR	-	-	kg	0	0	4.72E+1	0	1	1.88	(4,3,5,3,1,5); Assumption: 5% evaporation of cooling water; Frischknecht & Büsser Knöpfel (2013)
	Water, RER	-	-	kg	0	0	0	4.72E+1	1	1.88	(4,3,5,3,1,5); Assumption: 5% evaporation of cooling water; Frischknecht & Büsser Knöpfel (2013)



## Silicon wafer production

Table 74 shows the unit process data of the multi-crystalline silicon wafer production in Europe (RER), China (CN), North America (US) and Asia & Pacific (APAC). The Korean electricity mix is selected for the APAC region, because at the time Korea produced the highest share of the multi-crystalline wafers in the APAC region [4]. The US electricity mix is chosen to model electricity consumption in the North American production. The data used to model the wafer manufacture life cycle inventory is shown in Table 73.

**Table 73: Key characteristics of crystalline silicon wafers and key parameters of wafer manufacturing**

	unit	multi-Si
Gross silicon demand	g	16
Length	mm	158.75
Width	mm	158.75
Area	cm <sup>2</sup>	252
Thickness	µm	180
Kerf loss	µm	65
Additional losses <sup>1)</sup>	µm	27.5
Silicon content	g/m <sup>2</sup>	419.4
Silicon losses	g/m <sup>2</sup>	215.5
Total silicon demand	g/m <sup>2</sup>	634.9
Electricity demand	kWh/m <sup>2</sup>	5.69
Diamond wire demand <sup>2)</sup>	m/m <sup>2</sup>	52.2
Diamond wire demand <sup>3)</sup>	g/m <sup>2</sup>	1.55
Water demand	litre	56.9

1): this includes losses from pot scrap in the crucibles (see Section “Multi-crystalline silicon”)

2): wire demand (1.1-1.5m per wafer) and wire dimensions (70mm) from [95]

3): approximated with chromium steel (lack of LCI data on industrial diamond manufacture)

silicon density: 2.33 g/cm<sup>3</sup>

gross silicon demand, wafer dimension and wafer thicknesses from [94]



Table 74: Unit process LCI data of the multi-crystalline silicon wafer production in China (CN), North America (US), Asia-Pacific (APAC), and Europe (RER)

product	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	multi-Si wafer, at plant				Uncertainty type	Standard/References	General/Comment
							multi-Si wafer, at plant	multi-Si wafer, at plant	multi-Si wafer, at plant	multi-Si wafer, at plant			
							CN	US	APAC	RER			
	Location												
	InfrastructureProcess												
	Unit												
	single-Si wafer, photovoltaics, at plant	CN	-	-	0	m2	0	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 57 um, additional losses: 3.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	multi-Si wafer, at plant	CN	-	-	0	m2	1	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2020; Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	single-Si wafer, photovoltaics, at plant	US	-	-	0	m2	0	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 160 um, kerf loss: 57 um, additional losses: 3.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	multi-Si wafer, at plant	US	-	-	0	m2	0	1	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2020; Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	single-Si wafer, photovoltaics, at plant	APAC	-	-	0	m2	0	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 160 um, kerf loss: 57 um, additional losses: 3.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	multi-Si wafer, at plant	APAC	-	-	0	m2	0	0	1	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2020; Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	single-Si wafer, photovoltaics, at plant	RER	-	-	0	m2	0	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 160 um, kerf loss: 57 um, additional losses: 3.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	multi-Si wafer, at plant	RER	-	-	0	m2	0	0	0	1	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2020; Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
technosphere	CZ single crystalline silicon, photovoltaics, at plant	CN	-	-	0	kg	0	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	silicon, multi-Si, casted, at plant	CN	-	-	0	kg	6.03E-1	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	CZ single crystalline silicon, photovoltaics, at plant	US	-	-	0	kg	0	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 160 um, kerf loss: 57 um, additional losses: 3.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	silicon, multi-Si, casted, at plant	US	-	-	0	kg	0	6.03E-1	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2020; Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	CZ single crystalline silicon, photovoltaics, at plant	APAC	-	-	0	kg	0	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 160 um, kerf loss: 57 um, additional losses: 3.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	silicon, multi-Si, casted, at plant	APAC	-	-	0	kg	0	0	6.03E-1	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2020; Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	CZ single crystalline silicon, photovoltaics, at plant	RER	-	-	0	kg	0	0	0	0	1	1.22	(2.2,1.2,1.5); Wafer thickness: 160 um, kerf loss: 57 um, additional losses: 3.4 um; silicon density: 2330 kg/m3; ITRPV 2023
	silicon, multi-Si, casted, at plant	RER	-	-	0	kg	0	0	0	6.03E-1	1	1.22	(2.2,1.2,1.5); Wafer thickness: 180 um, kerf loss: 65 um, additional losses: 21.4 um; silicon density: 2330 kg/m3; ITRPV 2020; Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	flat glass, uncoated, at plant	RER	-	-	0	kg	4.08E-2	4.08E-2	4.08E-2	4.08E-2	1	1.26	(3.4,2.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	-	-	0	kg	1.50E-2	1.50E-2	1.50E-2	1.50E-2	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	hydrochloric acid, 30% in H2O, at plant	RER	-	-	0	kg	2.70E-3	2.70E-3	2.70E-3	2.70E-3	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	acetic acid, 98% in H2O, at plant	RER	-	-	0	kg	3.90E-2	3.90E-2	3.90E-2	3.90E-2	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	dipropylene glycol monomethyl ether, at plant	RER	-	-	0	kg	3.00E-1	3.00E-1	3.00E-1	3.00E-1	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	alkylbenzene sulfonate, linear, petrochemical, at plant	RER	-	-	0	kg	2.40E-1	2.40E-1	2.40E-1	2.40E-1	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	acrylic binder, 34% in H2O, at plant	RER	-	-	0	kg	3.85E-3	3.85E-3	3.85E-3	3.85E-3	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	brass, at plant	CH	-	-	0	kg	7.44E-3	7.44E-3	7.44E-3	7.44E-3	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	chromium steel 18/8, at plant	RER	-	-	0	kg	1.51E-3	1.51E-3	1.51E-3	1.51E-3	1	1.32	(3.2,1.1,3.5); Proxy for diamond wire; Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	wire drawing, steel	RER	-	-	0	kg	8.95E-3	8.95E-3	8.95E-3	8.95E-3	1	1.32	(3.2,1.1,3.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	electricity, medium voltage, at grid	CN	-	-	0	kWh	5.56E+0	0	0	0	1	2.05	(2.2,1.2,1.5); Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	electricity, medium voltage, at grid	US	-	-	0	kWh	0	5.56E+0	0	0	1	2.05	(2.2,1.2,1.5); Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	electricity, medium voltage, at grid	KR	-	-	0	kWh	0	0	5.56E+0	0	1	2.05	(2.2,1.2,1.5); Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
	electricity, medium voltage, production ENTSO, at grid	ENTSO	-	-	0	kWh	0	0	0	5.56E+0	1	2.05	(2.2,1.2,1.5); Woodhouse et al. (2019); c-Si PV Manufacturing Costs 2018
water	natural gas, burned in industrial furnace 1MW	CH	-	-	0	MJ	4.00E+0	4.00E+0	4.00E+0	4.00E+0	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	water, deionised, water balance according to Moek 2013, at plant	CN	-	-	0	kg	5.56E+1	0	0	0	1	1.26	(3.4,2.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	water, deionised, water balance according to Moek 2013, at plant	US	-	-	0	kg	0	5.56E+1	0	0	1	1.26	(3.4,2.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	water, deionised, water balance according to Moek 2013, at plant	KR	-	-	0	kg	0	0	5.56E+1	0	1	1.26	(3.4,2.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	water, deionised, water balance according to Moek 2013, at plant	RER	-	-	0	kg	0	0	0	5.56E+1	1	1.26	(3.4,2.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
disposal	disposal, waste, silicon wafer production, 0% water, to underground deposit	DE	-	-	0	kg	1.70E-1	1.70E-1	1.70E-1	1.70E-1	1	1.22	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	treatment, sewage, to wastewater treatment, class 2	CH	-	-	0	m3	5.00E-2	5.00E-2	5.00E-2	5.00E-2	1	1.26	(3.4,2.3,1.5); Calculation based on water withdrawal and water emissions
transport	transport, freight, lorry, fleet average	RER	-	-	0	km	2.71E-1	2.71E-1	2.71E-1	2.71E-1	1	2.09	(4.5,n/a,n/a,n/a); Transport distance: 100km; silicon: 200km
	transport, freight, rail	RER	-	-	0	km	1.27E+0	1.27E+0	1.27E+0	1.27E+0	1	2.09	(4.5,n/a,n/a,n/a); Transport distance: 100-600km
infrastructure	wafer factory	DE	-	-	1	unit	4.00E-6	4.00E-6	4.00E-6	4.00E-6	1	3.05	(1.2,4.1,1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
emission air	Heat, waste	-	air	high population density	-	MJ	2.00E+1	2.00E+1	2.00E+1	2.00E+1	1	1.84	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	Water, CN	-	air	unspecified	-	kg	5.56E+0	0	0	0	1	1.65	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	Water, US	-	air	unspecified	-	kg	0	5.56E+0	0	0	1	1.65	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	Water, KR	-	air	unspecified	-	kg	0	0	5.56E+0	0	1	1.65	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	Water, RER	-	air	unspecified	-	kg	0	0	0	5.56E+0	1	1.65	(3.4,4.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
emission water, river	COD, Chemical Oxygen Demand	-	water	river	-	kg	2.95E-2	2.95E-2	2.95E-2	2.95E-2	1	1.85	(3.4,5.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	BOD5, Biological Oxygen Demand	-	water	river	-	kg	2.95E-2	2.95E-2	2.95E-2	2.95E-2	1	1.85	(3.4,5.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	COD, Chemical Oxygen Demand	-	water	river	-	kg	1.11E-2	1.11E-2	1.11E-2	1.11E-2	1	1.85	(3.4,5.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)
	TOC, Total Organic Carbon	-	water	river	-	kg	1.11E-2	1.11E-2	1.11E-2	1.11E-2	1	1.85	(3.4,5.3,1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19.25)



Table 75 shows the unit process data of the multi-crystalline silicon wafer market mixes in Europe (RER), North America (US) and Asia & Pacific (APAC). The values correspond to the shares given in Table 69. The transport distances with freight ships depend on the world region. Distances of 19'994 km, 20'755 km and 4584 km are assumed for the transport from China (Shanghai) to Europe (Rotterdam), from China (Shanghai) to North America (New York) and from China (Shanghai) to APAC (Port Klang), respectively. Furthermore, 50 km transport by lorry and 200 km transport by train are assumed independent of the region.

**Table 75: Unit process LCI data of the multi-crystalline silicon wafer market mixes 2022 in Europe (RER), North America (US) and Asia & Pacific (APAC)**

product	Name	Location	Infrastructure	Process	Unit	multi-Si wafer, at regional storage			Uncertainty Type	StandardDeviation95%	GeneralComment
						RER	US	APAC			
						0	0	0			
	multi-Si wafer, at regional storage	RER	0	m2	1	0	0				
	single-Si wafer, photovoltaics, at regional storage	RER	0	m2	0	0	0				
	multi-Si wafer, at regional storage	US	0	m2	0	1	0				
	single-Si wafer, photovoltaics, at regional storage	US	0	m2	0	0	0				
	multi-Si wafer, at regional storage	APAC	0	m2	0	0	1				
	single-Si wafer, photovoltaics, at regional storage	APAC	0	m2	0	0	0				
wafers	multi-Si wafer, at plant	RER	0	m2	81%	0.00E+00	0.00E+00	1	1.564	(5,1,1,1,1,5); Market share European wafers	
	single-Si wafer, photovoltaics, at plant	RER	0	m2	0%	0.00E+00	0.00E+00	1	1.564	(5,1,1,1,1,5); Market share European wafers	
	multi-Si wafer, at plant	CN	0	m2	19%	0.00E+00	8.13E-01	1	1.564	(5,1,1,1,1,5); Market share Chinese wafers	
	single-Si wafer, photovoltaics, at plant	CN	0	m2	0%	0.00E+00	0.00E+00	1	1.564	(5,1,1,1,1,5); Market share Chinese wafers	
	multi-Si wafer, at plant	US	0	m2	0%	0.00E+00	0.00E+00	1	1.564	(5,1,1,1,1,5); Market share US wafers	
	single-Si wafer, photovoltaics, at plant	US	0	m2	0%	0.00E+00	0.00E+00	1	1.564	(5,1,1,1,1,5); Market share US wafers	
	multi-Si wafer, at plant	APAC	0	m2	0%	0.00E+00	1.87E-01	1	1.564	(5,1,1,1,1,5); Market share APAC wafers	
	single-Si wafer, photovoltaics, at plant	APAC	0	m2	0%	0.00E+00	0.00E+00	1	1.564	(5,1,1,1,1,5); Market share APAC wafers	
transport	transport, transoceanic freight ship	OCE	0	tkm	1.55E+0	0	1.50E+0	1	2.09	(4,5,na,na,na,na); Transport distance CN-EU: 19994 km, CN-US: 20755 km, CN-APAC: 4584 km	
	transport, freight, rail	RER	0	tkm	8.04E-2	8.04E-2	8.04E-2	1	2.09	(4,5,na,na,na,na); Standard distance 200km	
	transport, freight, lorry, fleet average	RER	0	tkm	2.01E-2	2.01E-2	2.01E-2	1	2.09	(4,5,na,na,na,na); Standard distance 50km	

## Photovoltaic cell, laminate and panel production

### Photovoltaic cells

The LCI data on material and energy consumption as well as about emissions are based on LCI data of multi-crystalline cells published by de Wild-Scholten [35]. Data on “tap water, at user” refers to city water for facility and manufacturing process use.

Table 77 shows the unit process data of the multi-crystalline photovoltaic cell production in Europe (RER), China (CN), North America (US) and Asia & Pacific (APAC). The Korean electricity mix is selected for the APAC region, because at the time Korea produced the highest share multi-crystalline cells in the APAC region. The US electricity mix is chosen to model electricity consumption in the North American production. The data used to update the cell manufacture life cycle inventory is shown in Table 76.

**Table 76: Key characteristics of multi-crystalline silicon cells and key parameters of cell manufacturing (silicon density: 2.33 g/cm<sup>3</sup>)**

	unit	multi-Si
Wafer area	cm <sup>2</sup>	252
Wafer weight	kg/m <sup>2</sup>	0.419
Wafer thickness	µm	180
Cell weight	kg/m <sup>2</sup>	0.498
Electricity demand	kWh/m <sup>2</sup>	17.7
Metallization paste, front	g/m <sup>2</sup>	3.37
Metallization paste, back	g/m <sup>2</sup>	1.11
Metallization paste, back, Al	g/m <sup>2</sup>	56.8
Silver demand	g/m <sup>2</sup>	3.67
Aluminium demand	g/m <sup>2</sup>	45.9



Table 77: Unit process data of the multi crystalline photovoltaic cell production in China (CN), North America (US), Asia & Pacific (APAC) and Europe (RER)

Name	Location	Infrastructure/Process	Unit	photovoltaic cell, multi-Si, at plant				Unitarity type	Standards/revisions	General comment	
				CN	US	APAC	RER				
product	Location										
	Infrastructure/Process										
	Unit										
	photovoltaic cell, single-Si, at plant	CN	0	0	0	0					
wafers	photovoltaic cell, multi-Si, at plant	CN	0	0	0	0					
	photovoltaic cell, single-Si, at plant	US	0	0	0	0					
	photovoltaic cell, multi-Si, at plant	US	0	0	0	0					
	photovoltaic cell, single-Si, at plant	US	0	0	0	0					
	photovoltaic cell, multi-Si, at plant	APAC	0	0	0	0					
	photovoltaic cell, single-Si, at plant	APAC	0	0	0	0					
	photovoltaic cell, multi-Si, at plant	RER	0	0	0	0					
	photovoltaic cell, single-Si, at plant	RER	0	0	0	0					
	single-Si wafer, photovoltaics, at plant	CH	0	0	0	0	1	1.10	(2.2.2.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)		
	multi-Si wafer, at plant	CN	0	1.04E+0	0	0	0	1	1.10	(2.2.2.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	single-Si wafer, photovoltaics, at regional storage	US	0	0	0	0	0	1	3.01	(2.2.2.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	multi-Si wafer, at regional storage	US	0	0	1.04E+0	0	0	1	3.01	(2.2.2.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	single-Si wafer, photovoltaics, at regional storage	APAC	0	0	0	0	0	1	3.01	(2.2.2.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	multi-Si wafer, at regional storage	APAC	0	0	0	1.04E+0	0	1	3.01	(2.2.2.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	single-Si wafer, photovoltaics, at regional storage	RER	0	0	0	0	0	1	3.01	(2.2.2.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	multi-Si wafer, at regional storage	RER	0	0	0	0	1.04E+0	1	3.01	(2.2.2.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
materials	metallization paste, front side, at plant	RER	0	2.98E-3	2.98E-3	2.98E-3	2.98E-3	1	1.09	(2.2.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018	
	metallization paste, back side, at plant	RER	0	1.19E-3	1.19E-3	1.19E-3	1.19E-3	1	1.09	(2.2.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018	
	metallization paste, back side, aluminium, at plant	RER	0	3.57E-2	3.57E-2	3.57E-2	3.57E-2	1	1.09	(2.2.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018	
	ammonia, liquid, at regional storehouse	RER	0	8.92E-3	8.92E-3	8.92E-3	8.92E-3	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
chemicals	phosphoric acid, fertiliser grade, 70% in H2O, at plant	GLO	0	8.63E-3	8.63E-3	8.63E-3	8.63E-3	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	phosphoryl chloride, at plant	RER	0	2.74E-2	2.74E-2	2.74E-2	2.74E-2	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	isopropanol, at plant	RER	0	8.10E-4	8.10E-4	8.10E-4	8.10E-4	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	solvents, organic, unspecified, at plant	GLO	0	1.13E-2	1.13E-2	1.13E-2	1.13E-2	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	calcium chloride, CaCl2, at regional storage	CH	0	3.15E-2	3.15E-2	3.15E-2	3.15E-2	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	hydrochloric acid, 30% in H2O, at plant	RER	0	8.59E-3	8.59E-3	8.59E-3	8.59E-3	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	hydrogen fluoride, at plant	GLO	0	4.03E-1	4.03E-1	4.03E-1	4.03E-1	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	nitric acid, 50% in H2O, at plant	RER	0	2.93E-1	2.93E-1	2.93E-1	2.93E-1	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	7.07E-2	7.07E-2	7.07E-2	7.07E-2	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	lime, hydrated, packed, at plant	CH	0	2.18E-1	2.18E-1	2.18E-1	2.18E-1	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	hydrogen peroxide, 50% in H2O, at plant	RER	0	4.52E-4	4.52E-4	4.52E-4	4.52E-4	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	sulphuric acid, liquid, at plant	RER	0	1.01E-1	1.01E-1	1.01E-1	1.01E-1	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	refrigerant R134a, at plant	RER	0	2.73E-5	2.73E-5	2.73E-5	2.73E-5	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	potassium hydroxide, at regional storage	RER	0	3.00E-2	3.00E-2	3.00E-2	3.00E-2	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	ammonium sulphate, as N, at regional storehouse	RER	0	2.10E-2	2.10E-2	2.10E-2	2.10E-2	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	gases	oxygen, liquid, at plant	RER	0	8.22E-3	8.22E-3	8.22E-3	8.22E-3	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
nitrogen, liquid, at plant		RER	0	1.35E+0	1.35E+0	1.35E+0	1.35E+0	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
silane, at plant		RER	0	2.61E-3	2.61E-3	2.61E-3	2.61E-3	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
tap water, water balance according to Mwek 2013, at user		CH	0	2.51E+2	0	0	0	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
energy	tap water, water balance according to Mwek 2013, at user	US	0	0	2.51E+2	0	0	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	tap water, water balance according to Mwek 2013, at user	KR	0	0	0	2.51E+2	0	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	tap water, water balance according to Mwek 2013, at user	RER	0	0	0	0	2.51E+2	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	electricity, medium voltage, at grid	CN	0	1.77E+1	0	0	0	1	1.09	(2.2.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018	
	electricity, medium voltage, at grid	US	0	0	1.77E+1	0	0	1	1.09	(2.2.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018	
	electricity, medium voltage, at grid	KR	0	0	0	1.77E+1	0	1	1.09	(2.2.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018	
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	0	0	0	1.77E+1	1	1.09	(2.2.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018	
	natural gas, burned in industrial furnace 1MW	CH	0	2.47E-1	2.47E-1	2.47E-1	2.47E-1	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	2.70E-3	2.70E-3	2.70E-3	2.70E-3	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
	infrastructure	photovoltaic cell factory	DE	1	4.00E-7	4.00E-7	4.00E-7	4.00E-7	1	3.05	(4.5.m.n.a.n.a.); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
		transport, freight, lorry, fleet average	RER	0	5.22E-1	5.22E-1	5.22E-1	5.22E-1	1	2.09	(4.5.m.n.a.n.a.); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	transport	transport, freight, rail	RER	0	3.94E-1	3.94E-1	3.94E-1	3.94E-1	1	2.09	(4.5.m.n.a.n.a.); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
		treatment, PV cell production effluent, to wastewater treatment, class 3	CH	0	2.26E-1	2.26E-1	2.26E-1	2.26E-1	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	disposal	disposal, waste, Si waferprod., inorg. 9.4% water, to residual material landfill	CH	0	2.74E+0	2.74E+0	2.74E+0	2.74E+0	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
		disposal, solvents mixture, 16.5% water, to hazardous waste incineration	CH	0	1.08E-2	1.08E-2	1.08E-2	1.08E-2	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
	emission air, high population density	Heat, waste	-	-	MJ	5.18E+1	5.18E+1	5.18E+1	5.18E+1	1	1.22
Water, CN		-	-	kg	2.51E+1	0	0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knopfel (2013)
Water, US		-	-	kg	0	2.51E+1	0	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knopfel (2013)
Water, KR		-	-	kg	0	0	2.51E+1	0	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knopfel (2013)
Water, RER		-	-	kg	0	0	0	2.51E+1	1	1.63	(2.3.4.3.1.5); Assumption: 10% evaporation of process water; Frischknecht & Büsser Knopfel (2013)
Aluminium		-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.06	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Hydrogen fluoride		-	-	kg	6.90E-4	6.90E-4	6.90E-4	6.90E-4	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Lead		-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.06	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Silicon		-	-	kg	3.17E-8	3.17E-8	3.17E-8	3.17E-8	1	5.06	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Silver		-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.06	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Tin		-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.06	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Ammonia		-	-	kg	5.22E-4	5.22E-4	5.22E-4	5.22E-4	1	1.31	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Carbon dioxide, fossil		-	-	kg	6.82E-1	6.82E-1	6.82E-1	6.82E-1	1	1.22	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Chlorine		-	-	kg	0	0	0	0	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Hydrogen		-	-	kg	4.44E-4	4.44E-4	4.44E-4	4.44E-4	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
2-Propanol		-	-	kg	0	0	0	0	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)
Acetaldehyde	-	-	kg	0	0	0	0	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	2.73E-5	2.73E-5	2.73E-5	2.73E-5	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
Silicon	-	-	kg	1.47E-4	1.47E-4	1.47E-4	1.47E-4	1	5.06	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
Silicon	-	-	kg	6.00E-6	6.00E-6	6.00E-6	6.00E-6	1	5.06	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
NMOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	3.53E-4	3.53E-4	3.53E-4	3.53E-4	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
Nitric acid	-	-	kg	1.19E-4	1.19E-4	1.19E-4	1.19E-4	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
Nitrogen oxides	-	-	kg	1.24E-2	1.24E-2	1.24E-2	1.24E-2	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	
Nitrogen oxides	-	-	kg	3.64E-3	3.64E-3	3.64E-3	3.64E-3	1	1.57	(2.2.4.1.13); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30.31)	

The cells used in panel production in China were produced domestically. Panel manufacturers in Europe and the Americas imported a large share of the cells from Asia & Pacific and from China. Table 78 shows the LCI datasets representing the multi-crystalline cell market mixes in Europe and the Americas.



**Table 78: Unit process LCI data of the multi-crystalline photovoltaic cell market mix 2022 in Europe (RER) and the Americas (US)**

	Name	Location	InfrastructureProcess	Unit	photovoltaic cell, multi-Si, at regional storage	photovoltaic cell, multi-Si, at regional storage	UncertaintyType	StandardDeviation95%	GeneralComment
					RER	US			
	Location								
	InfrastructureProcess								
	Unit								
product	photovoltaic cell, multi-Si, at regional storage	RER	0	m2	1	0			
	photovoltaic cell, single-Si, at regional storage	RER	0	m2	0	0			
	photovoltaic cell, multi-Si, at regional storage	US	0	m2	0	1			
	photovoltaic cell, single-Si, at regional storage	US	0	m2	0	0			
cells	photovoltaic cell, multi-Si, at plant	RER	0	m2	2.01E-1	0	1	1.56	(5,1,1,1,1,5); Market share European cells
	photovoltaic cell, single-Si, at plant	RER	0	m2	0	0	1	1.56	(5,1,1,1,1,5); Market share European cells
	photovoltaic cell, multi-Si, at plant	CN	0	m2	7.99E-1	1.00E+0	1	1.56	(5,1,1,1,1,5); Market share Chinese cells
	photovoltaic cell, single-Si, at plant	CN	0	m2	0	0	1	1.56	(5,1,1,1,1,5); Market share Chinese cells
	photovoltaic cell, multi-Si, at plant	US	0	m2	0	0	1	1.56	(5,1,1,1,1,5); Market share US cells
	photovoltaic cell, single-Si, at plant	US	0	m2	0	0	1	1.56	(5,1,1,1,1,5); Market share US cells
	photovoltaic cell, multi-Si, at plant	APAC	0	m2	0	0	1	1.56	(5,1,1,1,1,5); Market share APAC cells
	photovoltaic cell, single-Si, at plant	APAC	0	m2	0	0	1	1.56	(5,1,1,1,1,5); Market share APAC cells
transport	transport, transoceanic freight ship	OCE	0	tkm	7.31E+0	9.50E+0	1	2.09	(4,5,na,na,na,na); Transport distance CN-EU: 19994 km, CN-US: 20755 km, APAC-EU: 15026 km, APAC-US: 18411 km
	transport, freight, rail	RER	0	tkm	9.16E-2	9.16E-2	1	2.09	(4,5,na,na,na,na); Standard distance 200km
	transport, freight, lorry, fleet average	RER	0	tkm	2.29E-2	2.29E-2	1	2.09	(4,5,na,na,na,na); Standard distance 50km

*Photovoltaic laminate and panels*

Table 79 and Table 80 show the unit process data of the multi-crystalline photovoltaic laminate and panel production in China (CN), North America (US), Asia & Pacific (APAC) and Europe (RER).

The Japanese electricity mix was selected for the APAC region, because at the time Japan produced the highest share of multi-crystalline laminate and panel in the APAC region. The US electricity mix is chosen to model electricity consumption in the North American production.

The LCI data on material and energy consumption as well as about emissions are based on LCI data of multi-crystalline modules published by de Wild-Scholten [35].



Table 79: Unit process LCI data of the multi-crystalline photovoltaic laminate and panel production in China (CN) and the Americas (US)

product	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, multi-Si, at plant				Uncertainty Type	Standard deviation 95%	General Comment
					CN	CN	US	US			
					1	1	1	1			
	Location				CN	CN	US	US			
	InfrastructureProcess				1	1	1	1			
	Unit				m2	m2	m2	m2			
product	photovoltaic panel, single-Si, at plant	CN	1	m2	0	0	0	0			
	photovoltaic panel, multi-Si, at plant	CN	1	m2	0	0	0	0			
	photovoltaic laminate, single-Si, at plant	CN	1	m2	0	0	0	0			
	photovoltaic laminate, multi-Si, at plant	CN	1	m2	0	1	0	0			
	photovoltaic panel, single-Si, at plant	US	1	m2	0	0	0	0			
	photovoltaic panel, multi-Si, at plant	US	1	m2	0	0	1	0			
	photovoltaic laminate, single-Si, at plant	US	1	m2	0	0	0	0			
	photovoltaic laminate, multi-Si, at plant	US	1	m2	0	0	0	1			
	photovoltaic panel, single-Si, at plant	APAC	1	m2	0	0	0	0			
	photovoltaic panel, multi-Si, at plant	APAC	1	m2	0	0	0	0			
	photovoltaic laminate, single-Si, at plant	APAC	1	m2	0	0	0	0			
	photovoltaic laminate, multi-Si, at plant	APAC	1	m2	0	0	0	0			
	photovoltaic panel, single-Si, at plant	RER	1	m2	0	0	0	0			
	photovoltaic panel, multi-Si, at plant	RER	1	m2	0	0	0	0			
	photovoltaic laminate, single-Si, at plant	RER	1	m2	0	0	0	0			
	photovoltaic laminate, multi-Si, at plant	RER	1	m2	0	0	0	0			
materials	photovoltaic cell, single-Si, at plant	CN	0	m2	0	0	0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, multi-Si, at plant	CN	0	m2	9.35E-1	9.35E-1	0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, single-Si, at regional storage	US	0	m2	0	0	0	0	1	3.06	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, multi-Si, at regional storage	US	0	m2	0	0	9.35E-1	9.35E-1	1	3.06	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, single-Si, at plant	APAC	0	m2	0	0	0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, multi-Si, at plant	APAC	0	m2	0	0	0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, single-Si, at regional storage	RER	0	m2	0	0	0	0	1	3.06	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, multi-Si, at regional storage	RER	0	m2	0	0	0	0	1	3.06	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	aluminium alloy, AlMg3, at plant	RER	0	kg	2.13E+0	0	2.13E+0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	copper, at regional storage	RER	0	kg	1.03E-1	1.03E-1	1.03E-1	1.03E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	wire drawing, copper	RER	0	kg	1.03E-1	1.03E-1	1.03E-1	1.03E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	2.81E-3	2.81E-3	2.81E-3	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	silicone product, at plant	RER	0	kg	1.22E-1	1.22E-1	1.22E-1	1.22E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tin, at regional storage	RER	0	kg	1.29E-2	1.29E-2	1.29E-2	1.29E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	lead, at regional storage	RER	0	kg	7.25E-4	7.25E-4	7.25E-4	7.25E-4	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	solar glass, low-iron, at regional storage	RER	0	kg	8.81E+0	8.81E+0	8.81E+0	8.81E+0	1	1.33	(1.4.4.3.3.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tempering, flat glass	RER	0	kg	8.81E+0	8.81E+0	8.81E+0	8.81E+0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	2.95E-1	2.95E-1	2.95E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	3.46E-1	3.46E-1	3.46E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	2.38E-2	2.38E-2	2.38E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	styhvinylacetate, foil, at plant	RER	0	kg	8.75E-1	8.75E-1	8.75E-1	8.75E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	polyvinylfluoride film, at plant	US	0	kg	1.12E-1	1.12E-1	1.12E-1	1.12E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
auxiliaries	tap water, water balance according to MoeK 2013, at user	CN	0	kg	5.03E+0	5.03E+0	0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tap water, water balance according to MoeK 2013, at user	US	0	kg	0	0	5.03E+0	5.03E+0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tap water, water balance according to MoeK 2013, at user	KR	0	kg	0	0	0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	tap water, water balance according to MoeK 2013, at user	RER	0	kg	0	0	0	0	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	6.24E-2	6.24E-2	6.24E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	1-propanol, at plant	RER	0	kg	1.59E-2	1.59E-2	1.59E-2	1.59E-2	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	isopropanol, at plant	RER	0	kg	1.47E-4	1.47E-4	1.47E-4	1.47E-4	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	5.14E-2	5.14E-2	5.14E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	soap, at plant	RER	0	kg	1.16E-2	1.16E-2	1.16E-2	1.16E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	7.63E-1	7.63E-1	7.63E-1	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	EUR-flat pallet	RER	0	unit	5.00E-2	5.00E-2	5.00E-2	5.00E-2	1	1.34	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
energy	electricity, medium voltage, at grid	CN	0	kWh	7.61E+0	7.61E+0	0	0	1	1.09	(2.2.1.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	electricity, medium voltage, at grid	US	0	kWh	0	0	7.61E+0	7.61E+0	1	1.09	(2.2.1.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	electricity, medium voltage, at grid	KR	0	kWh	0	0	0	0	1	1.09	(2.2.1.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	0	0	0	0	1	1.09	(2.2.1.1.1.3); Woodhouse et al. (2019): c-Si PV Manufacturing Costs 2018
	diesel, burned in building machine, average	CH	0	MJ	8.75E-3	8.75E-3	8.75E-3	8.75E-3	1	2.12	(3.4.4.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
infrastructure	photovoltaic panel factory	GLO	1	unit	4.00E-6	4.00E-6	4.00E-6	4.00E-6	1	3.06	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
transport	transport, freight, lorry, fleet average	RER	0	tkm	2.99E+0	2.78E+0	2.99E+0	2.78E+0	1	2.09	(4.5.na.na.na.na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	1.66E+1	1.54E+1	1.66E+1	1.54E+1	1	2.09	(4.5.na.na.na.na); Standard distance 600km
disposal	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	3.00E-2	3.00E-2	3.00E-2	1	1.24	(1.4.4.3.1.3); Atsema (personal communication) 2007; production waste
	disposal, polyvinylfluoride, 0.2% water, to municipal incineration	CH	0	kg	4.29E-3	4.29E-3	4.29E-3	4.29E-3	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	2.81E-2	2.81E-2	2.81E-2	2.81E-2	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1.61E-3	1.61E-3	1.61E-3	1	1.24	(1.4.4.3.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.53E-3	4.53E-3	4.53E-3	4.53E-3	1	1.24	(1.4.4.3.1.3); Calculation, water use
emissions air	Heat waste	-	-	MJ	2.74E+1	2.74E+1	2.74E+1	2.74E+1	1	1.60	(3.4.5.3.1.5); Calculation, electricity use
	NMVO, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.85	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Carbon dioxide, fossil	-	-	kg	2.18E-2	2.18E-2	2.18E-2	2.18E-2	1	1.60	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Water, CN	-	-	kg	5.03E-1	5.03E-1	0	0	1	1.85	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	Water, US	-	-	kg	0	0	5.03E-1	5.03E-1	1	1.85	(3.4.5.3.1.5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)



Table 80: Unit process LCI data of the multi-crystalline photovoltaic laminate and panel production in Asia & Pacific (APAC) and Europe (RER)

Name	Location	Infrastructure/Process	Unit	photovoltaic panel, multi-Si, at plant				Uncertainty Type	Standard deviation 95%	General Comment
				APAC	APAC	RER	RER			
				1	1	1	1			
product	Location	Infrastructure/Process	Unit	APAC	APAC	RER	RER			
				1	1	1	1			
				m2	m2	m2	m2			
photovoltaic panel, single-Si, at plant	CN	1	m2	0	0	0	0			
photovoltaic panel, multi-Si, at plant	CN	1	m2	0	0	0	0			
photovoltaic laminate, single-Si, at plant	CN	1	m2	0	0	0	0			
photovoltaic laminate, multi-Si, at plant	CN	1	m2	0	0	0	0			
photovoltaic panel, single-Si, at plant	US	1	m2	0	0	0	0			
photovoltaic panel, multi-Si, at plant	US	1	m2	0	0	0	0			
photovoltaic laminate, single-Si, at plant	US	1	m2	0	0	0	0			
photovoltaic laminate, multi-Si, at plant	US	1	m2	0	0	0	0			
photovoltaic panel, single-Si, at plant	APAC	1	m2	0	0	0	0			
photovoltaic panel, multi-Si, at plant	APAC	1	m2	1	0	0	0			
photovoltaic laminate, single-Si, at plant	APAC	1	m2	0	0	0	0			
photovoltaic laminate, multi-Si, at plant	APAC	1	m2	0	1	0	0			
photovoltaic panel, single-Si, at plant	RER	1	m2	0	0	0	0			
photovoltaic panel, multi-Si, at plant	RER	1	m2	0	0	1	0			
photovoltaic laminate, single-Si, at plant	RER	1	m2	0	0	0	0			
photovoltaic laminate, multi-Si, at plant	RER	1	m2	0	0	0	1			
materials										
photovoltaic cell, single-Si, at plant	CN	0	m2	0	0	0	0	1	1.24	
photovoltaic cell, multi-Si, at plant	CN	0	m2	0	0	0	0	1	1.24	
photovoltaic cell, single-Si, at regional storage	US	0	m2	0	0	0	0	1	3.06	
photovoltaic cell, multi-Si, at regional storage	US	0	m2	0	0	0	0	1	3.06	
photovoltaic cell, single-Si, at plant	APAC	0	m2	0	0	0	0	1	1.24	
photovoltaic cell, multi-Si, at plant	APAC	0	m2	9.35E-1	9.35E-1	0	0	1	1.24	
photovoltaic cell, single-Si, at regional storage	RER	0	m2	0	0	0	0	1	3.06	
photovoltaic cell, multi-Si, at regional storage	RER	0	m2	0	0	9.35E-1	9.35E-1	1	3.06	
aluminium alloy, AlMg3, at plant	RER	0	kg	2.13E+0	0	2.13E+0	0	1	1.24	
copper, at regional storage	RER	0	kg	1.03E-1	1.03E-1	1.03E-1	1.03E-1	1	1.24	
wire drawing, copper	RER	0	kg	1.03E-1	1.03E-1	1.03E-1	1.03E-1	1	1.24	
diode, unspecified, at plant	GLO	0	kg	2.81E-3	2.81E-3	2.81E-3	2.81E-3	1	1.34	
silicone product, at plant	RER	0	kg	1.22E-1	1.22E-1	1.22E-1	1.22E-1	1	1.24	
tin, at regional storage	RER	0	kg	1.29E-2	1.29E-2	1.29E-2	1.29E-2	1	1.34	
lead, at regional storage	RER	0	kg	7.25E-4	7.25E-4	7.25E-4	7.25E-4	1	1.34	
solar glass, low-iron, at regional storage	RER	0	kg	8.81E+0	8.81E+0	8.81E+0	8.81E+0	1	1.33	
tempering, flat glass	RER	0	kg	8.81E+0	8.81E+0	8.81E+0	8.81E+0	1	1.24	
glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	2.95E-1	2.95E-1	2.95E-1	1	1.24	
polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	3.46E-1	3.46E-1	3.46E-1	3.46E-1	1	1.24	
polyethylene, HDPE, granulate, at plant	RER	0	kg	2.38E-2	2.38E-2	2.38E-2	2.38E-2	1	1.34	
styhlylacetate, foil, at plant	RER	0	kg	8.75E-1	8.75E-1	8.75E-1	8.75E-1	1	1.24	
polyvinylfluoride film, at plant	US	0	kg	1.12E-1	1.12E-1	1.12E-1	1.12E-1	1	1.24	
tap water, water balance according to MoeK 2013, at user	CN	0	kg	0	0	0	0	1	1.24	
tap water, water balance according to MoeK 2013, at user	US	0	kg	0	0	0	0	1	1.24	
tap water, water balance according to MoeK 2013, at user	KR	0	kg	5.03E+0	5.03E+0	0	0	1	1.24	
tap water, water balance according to MoeK 2013, at user	RER	0	kg	0	0	5.03E+0	5.03E+0	1	1.24	
hydrogen fluoride, at plant	GLO	0	kg	6.24E-2	6.24E-2	6.24E-2	6.24E-2	1	1.34	
1-propanol, at plant	RER	0	kg	1.59E-2	1.59E-2	1.59E-2	1.59E-2	1	1.24	
isopropanol, at plant	RER	0	kg	1.47E-4	1.47E-4	1.47E-4	1.47E-4	1	1.34	
potassium hydroxide, at regional storage	RER	0	kg	5.14E-2	5.14E-2	5.14E-2	5.14E-2	1	1.34	
soap, at plant	RER	0	kg	1.16E-2	1.16E-2	1.16E-2	1.16E-2	#####	1.34	
corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	7.63E-1	7.63E-1	7.63E-1	1	1.24	
EUR-flat pallet	RER	0	unit	5.00E-2	5.00E-2	5.00E-2	5.00E-2	1	1.34	
energy										
electricity, medium voltage, at grid	CN	0	kWh	0	0	0	0	1	1.09	
electricity, medium voltage, at grid	US	0	kWh	0	0	0	0	1	1.09	
electricity, medium voltage, at grid	KR	0	kWh	7.61E+0	7.61E+0	0	0	1	1.09	
electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	0	0	7.61E+0	7.61E+0	1	1.09	
diesel, burned in building machine, average	CH	0	MJ	8.75E-3	8.75E-3	8.75E-3	8.75E-3	1	2.12	
infrastructure										
photovoltaic panel factory	GLO	1	unit	4.00E-6	4.00E-6	4.00E-6	4.00E-6	1	3.06	
transport, freight, lorry, fleet average	RER	0	tkm	2.99E+0	2.78E+0	2.77E+0	2.56E+0	1	2.09	
transport, freight, rail	RER	0	tkm	1.66E+1	1.54E+1	1.66E+1	1.54E+1	1	2.09	
disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	3.00E-2	3.00E-2	3.00E-2	1	1.24	
disposal, polyvinylfluoride, 0.2% water, to municipal incineration	CH	0	kg	4.29E-3	4.29E-3	4.29E-3	4.29E-3	1	1.24	
disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	2.81E-2	2.81E-2	2.81E-2	2.81E-2	1	1.24	
disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.61E-3	1.61E-3	1.61E-3	1.61E-3	1	1.24	
treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.53E-3	4.53E-3	4.53E-3	4.53E-3	1	1.24	
Heat waste	-	-	MJ	2.74E+1	2.74E+1	2.74E+1	2.74E+1	1	1.60	
NMVO, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.85	
Carbon dioxide, fossil	-	-	kg	2.18E-2	2.18E-2	2.18E-2	2.18E-2	1	1.60	
Water, CN	-	-	kg	0	0	0	0	1	1.85	
Water, US	-	-	kg	0	0	0	0	1	1.85	
Water, KR	-	-	kg	5.03E-1	5.03E-1	0	0	1	1.85	
Water, RER	-	-	kg	0	0	5.03E-1	5.03E-1	1	1.85	



Table 81, Table 82, and Table 83 show the unit process data of the multi-crystalline photovoltaic laminate and panel market mix in Europe (RER), North America (US), and APAC countries, respectively. The market shares for laminate and panels in the different regions of the world are shown in Table 70 and Table 71.

**Table 81: Unit process LCI data of the photovoltaic laminate and panel market mix 2022 in Europe (RER)**

Name	Location	InfrastructureProcess	Unit	photovoltaic laminate, multi-Si, at regional storage		photovoltaic panel, multi-Si, at regional storage		UncertaintyType	StandardDeviation95%	GeneralComment
				RER	m2	RER	m2			
product	Location InfrastructureProcess Unit			1	1	1	1			
photovoltaic laminate, multi-Si, at regional storage	RER	1	m2	1	0	0	0			
photovoltaic laminate, single-Si, at regional storage	RER	1	m2	0	0	0	0			
photovoltaic panel, multi-Si, at regional storage	RER	1	m2	0	0	1	1			
photovoltaic panel, single-Si, at regional storage	RER	1	m2	0	0	0	0			
modules										
photovoltaic panel, multi-Si, at plant	RER	1	m2	0.00E+00	1.76E-01	1	3.27	(5,1,1,1,1,5);	Market share European modules	
photovoltaic panel, single-Si, at plant	RER	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share European modules	
photovoltaic laminate, multi-Si, at plant	RER	1	m2	1.76E-01	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share European modules	
photovoltaic laminate, single-Si, at plant	RER	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share European modules	
photovoltaic panel, multi-Si, at plant	US	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share US modules	
photovoltaic panel, single-Si, at plant	US	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share US modules	
photovoltaic laminate, multi-Si, at plant	US	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share US modules	
photovoltaic laminate, single-Si, at plant	US	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share US modules	
photovoltaic panel, multi-Si, at plant	CN	1	m2	0.00E+00	7.59E-01	1	3.27	(5,1,1,1,1,5);	Market share Chinese modules	
photovoltaic panel, single-Si, at plant	CN	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share Chinese modules	
photovoltaic laminate, multi-Si, at plant	CN	1	m2	7.59E-01	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share Chinese modules	
photovoltaic laminate, single-Si, at plant	CN	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share Chinese modules	
photovoltaic panel, multi-Si, at plant	APAC	1	m2	0.00E+00	6.52E-02	1	3.27	(5,1,1,1,1,5);	Market share APAC modules	
photovoltaic panel, single-Si, at plant	APAC	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share APAC modules	
photovoltaic laminate, multi-Si, at plant	APAC	1	m2	6.52E-02	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share APAC modules	
photovoltaic laminate, single-Si, at plant	APAC	1	m2	0.00E+00	0.00E+00	1	3.27	(5,1,1,1,1,5);	Market share APAC modules	
transport										
transport, transoceanic freight ship	OCE	0	tkm	1.80E+2	2.14E+2	1	2.09	(4,5,na,na,na,na);	Transport distance CN-EU: 19994 km, APAC-EU: 15026 km	
transport, freight, lorry, fleet average	RER	0	tkm	1.05E+1	1.25E+1	1	2.09	(4,5,na,na,na,na);	Transport distance 943 km	

**Table 82: Unit process LCI data of the photovoltaic laminate and panel market mix 2022 in North America (US)**

Name	Location	InfrastructureProcess	Unit	photovoltaic laminate, multi-Si, at regional storage		photovoltaic panel, multi-Si, at regional storage		UncertaintyType	StandardDeviation95%	GeneralComment
				US	m2	US	m2			
product	Location InfrastructureProcess Unit			1	1	1	1			
photovoltaic laminate, multi-Si, at regional storage	US	1	m2	1	0	0	0			
photovoltaic laminate, single-Si, at regional storage	US	1	m2	0	0	0	0			
photovoltaic panel, multi-Si, at regional storage	US	1	m2	0	0	1	1			
photovoltaic panel, single-Si, at regional storage	US	1	m2	0	0	0	0			
modules										
photovoltaic panel, multi-Si, at plant	RER	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share European modules	
photovoltaic panel, single-Si, at plant	RER	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share European modules	
photovoltaic laminate, multi-Si, at plant	RER	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share European modules	
photovoltaic laminate, single-Si, at plant	RER	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share European modules	
photovoltaic panel, multi-Si, at plant	US	1	m2	0	2.05E-1	1	3.27	(5,1,1,1,1,5);	Market share US modules	
photovoltaic panel, single-Si, at plant	US	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share US modules	
photovoltaic laminate, multi-Si, at plant	US	1	m2	2.05E-1	0	1	3.27	(5,1,1,1,1,5);	Market share US modules	
photovoltaic laminate, single-Si, at plant	US	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share US modules	
photovoltaic panel, multi-Si, at plant	CN	1	m2	0	7.32E-1	1	3.27	(5,1,1,1,1,5);	Market share Chinese modules	
photovoltaic panel, single-Si, at plant	CN	1	m2	0	0	0	0.00	-		
photovoltaic laminate, multi-Si, at plant	CN	1	m2	7.32E-1	0	1	3.27	(5,1,1,1,1,5);	Market share Chinese modules	
photovoltaic laminate, single-Si, at plant	CN	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share Chinese modules	
photovoltaic panel, multi-Si, at plant	APAC	1	m2	0	6.29E-2	1	3.27	(5,1,1,1,1,5);	Market share APAC modules	
photovoltaic panel, single-Si, at plant	APAC	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share APAC modules	
photovoltaic laminate, multi-Si, at plant	APAC	1	m2	6.29E-2	0	1	3.27	(5,1,1,1,1,5);	Market share APAC modules	
photovoltaic laminate, single-Si, at plant	APAC	1	m2	0	0	1	3.27	(5,1,1,1,1,5);	Market share APAC modules	
transport										
transport, transoceanic freight ship	OCE	0	tkm	1.82E+2	2.17E+2	1	2.09	(4,5,na,na,na,na);	Transport distance CN-US: 20755 km, APAC-US: 18411 km	
transport, freight, rail	RER	0	tkm	2.23E+0	2.65E+0	1	2.09	(4,5,na,na,na,na);	Standard distance 200km	
transport, freight, lorry, fleet average	RER	0	tkm	5.57E-1	6.63E-1	1	2.09	(4,5,na,na,na,na);	Standard distance 50km	



Table 83: Unit process LCI data of the photovoltaic laminate and panel market mix 2022 in APAC countries

	Name	Location	InfrastructureProcess	Unit	photovoltaic laminate, multi-Si, at regional storage	photovoltaic panel, multi-Si, at regional storage	UncertaintyType	StandardDeviation95%	GeneralComment
					APAC	APAC			
	Location				1	1			
	InfrastructureProcess				m2	m2			
	Unit				1	0			
product	photovoltaic laminate, multi-Si, at regional storage	APAC	1	m2	1	0			
	photovoltaic laminate, single-Si, at regional storage	APAC	1	m2	0	0			
	photovoltaic panel, multi-Si, at regional storage	APAC	1	m2	0	1			
	photovoltaic panel, single-Si, at regional storage	APAC	1	m2	0	0			
modules	photovoltaic panel, multi-Si, at plant	RER	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share European modules
	photovoltaic panel, single-Si, at plant	RER	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share European modules
	photovoltaic laminate, multi-Si, at plant	RER	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share European modules
	photovoltaic laminate, single-Si, at plant	RER	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share European modules
	photovoltaic panel, multi-Si, at plant	US	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share US modules
	photovoltaic panel, single-Si, at plant	US	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share US modules
	photovoltaic laminate, multi-Si, at plant	US	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share US modules
	photovoltaic laminate, single-Si, at plant	US	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share US modules
	photovoltaic panel, multi-Si, at plant	CN	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
	photovoltaic panel, single-Si, at plant	CN	1	m2	0	0	0	0.00	-
	photovoltaic laminate, multi-Si, at plant	CN	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
	photovoltaic laminate, single-Si, at plant	CN	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share Chinese modules
	photovoltaic panel, multi-Si, at plant	APAC	1	m2	0	1.00E+0	1	3.27	(5,1,1,1,1,5); Market share APAC modules
	photovoltaic panel, single-Si, at plant	APAC	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share APAC modules
	photovoltaic laminate, multi-Si, at plant	APAC	1	m2	1.00E+0	0	1	3.27	(5,1,1,1,1,5); Market share APAC modules
	photovoltaic laminate, single-Si, at plant	APAC	1	m2	0	0	1	3.27	(5,1,1,1,1,5); Market share APAC modules
transport	transport, transoceanic freight ship	OCE	0	tkm	0	0	1	2.09	(4,5,na,na,na,na); Transport distance CN-APAC: 4500 km
	transport, freight, rail	RER	0	tkm	2.23E+0	2.65E+0	1	2.09	(4,5,na,na,na,na); Standard distance 200km
	transport, freight, lorry, fleet average	RER	0	tkm	5.57E-1	6.63E-1	1	2.09	(4,5,na,na,na,na); Standard distance 50km



## CI(G)S modules

Table 84 shows the unit process data of the CI(G)S photovoltaic laminate and cell production in Europe (Germany, DE). The data on material, energy consumption and emissions correspond to the life cycle inventory data of CI(G)S laminate and panels published by Jungbluth et al. [34] updated with information published by de Wild-Scholten [35].



Table 84: Unit process LCI data of the CI(G)S photovoltaic laminate and cell production in Europe (Germany, DE)

product	Name	Location	Infrastructure	Process	Unit	photovoltaic laminate, CIS, at plant		photovoltaic panel, CIS, at plant		Uncertainty/Type	Standard/Deviation/95%	GeneralComment
						DE	1	DE	1			
						m2	m2	m2	m2			
product	photovoltaic laminate, CIS, at plant	DE	1	m2		1	0					
energy	photovoltaic panel, CIS, at plant	DE	1	m2		0	1					
	electricity, medium voltage, at grid	DE	0	kWh		45	0			1	1.07	(1.1.1.1.1.3); company information, coating, air-conditioning, water purification, etc.
	natural gas, burned in boiler condensing modulating >100kW	RER	0	MJ		0	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ		0	1.55E+1			1	1.07	(1.1.1.1.1.3); Raugel, literature
infrastructure	photovoltaic panel factory	GLO	1	unit		4.00E-6	0			1	3.02	(1.4.1.3.1.3); Assumption
materials	photovoltaic laminate, CIS, at plant	DE	1	m2		0	1.00E+0			1	3.00	(1.1.1.1.1.3); Assumption
	aluminium alloy, AlMg3, at plant	RER	0	kg		0	2.20E+0			1	1.07	(1.1.1.1.1.3); company information
	copper, at regional storage	RER	0	kg		9.77E-3	0			1	1.07	(1.1.1.1.1.3); company information
	wire drawing, copper	RER	0	kg		9.77E-3	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	aluminium, production mix, at plant	RER	0	kg		4.44E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	flat glass, uncoated, at plant	RER	0	kg		5.27E+0	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	diode, unspecified, at plant	GLO	0	kg		1.44E-3	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	silicone product, at plant	RER	0	kg		4.04E-1	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
coating	molybdenum, at regional storage	RER	0	kg		6.06E-3	0			1	1.13	(3.2.2.1.1.3); company information and assumption for share of metals
	indium, at regional storage	RER	0	kg		2.82E-3	0			1	1.13	(3.2.2.1.1.3); company information and assumption for share of metals
	cadmium sulphide, semiconductor-grade, at plant	US	0	kg		2.69E-4	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	cadmium sulphide, semiconductor-grade, at plant	US	0	kg		0	0			1	1.13	(3.2.2.1.1.3); company information and assumption for share of metals
	gallium, semiconductor-grade, at regional storage	RER	0	kg		8.99E-4	0			1	1.13	(3.2.2.1.1.3); company information and assumption for share of metals
	selenium, at plant	RER	0	kg		5.60E-3	0			1	1.13	(3.2.2.1.1.3); company information and assumption for share of metals
	zinc, primary, at regional storage	RER	0	kg		0	0			1	1.13	(3.2.2.1.1.3); company information and assumption for share of metals
	tin, at regional storage	RER	0	kg		1.23E-2	0			1	1.13	(3.2.2.1.1.3); company information and assumption for share of metals
	solar glass, low-iron, at regional storage	RER	0	kg		7.70E+0	0			1	1.07	(1.1.1.1.1.3); company information
	tempering, flat glass	RER	0	kg		7.70E+0	0			1	1.07	(1.1.1.1.1.3); Assumption
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg		0	4.00E-2			1	1.07	(1.1.1.1.1.3); Raugel, literature
	ethyleneacetate, foil, at plant	RER	0	kg		7.51E-1	0			1	1.07	(1.1.1.1.1.3); company information
	flux, wave soldering, at plant	GLO	0	kg		1.23E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	zinc oxide, at plant	RER	0	kg		9.09E-3	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg		3.36E-1	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyethylene, HDPE, granulate, at plant	RER	0	kg		4.84E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyvinylbutyral foil, at plant	RER	0	kg		1.89E-1	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	polyphenylene sulfide, at plant	GLO	0	kg		8.59E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
auxiliaries	tap water, at user	RER	0	kg		1.31E+2	0			1	1.07	(1.1.1.1.1.3); company information
	acetone, liquid, at plant	RER	0	kg		0	0			1	1.16	(3.1.3.1.1.3); Cleaning agent, Ampenberg 1998
	argon, liquid, at plant	RER	0	kg		1.90E-2	0			1	1.07	(1.1.1.1.1.3); protection gas, company information
	butyl acrylate, at plant	RER	0	kg		1.01E-1	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	diborane, at plant	GLO	0	kg		2.01E-4	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	sulphuric acid, liquid, at plant	RER	0	kg		3.31E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrogen sulphide, H2S, at plant	RER	0	kg		1.91E-1	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg		3.34E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrogen peroxide, 50% in H2O, at plant	RER	0	kg		2.31E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg		9.94E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	nitrogen, liquid, at plant	RER	0	kg		1.57E+1	0			1	1.07	(1.1.1.1.1.3); protection gas, company information
	ammonia, liquid, at regional storehouse	RER	0	kg		9.29E-2	0			1	1.07	(1.1.1.1.1.3); dip coating for CdS, company information
	urea, as N, at regional storehouse	RER	0	kg		1.15E-3	0			1	1.16	(3.1.3.1.1.3); dip coating for CdS, Ampenberg 1998
	EUR-flat pallet	RER	0	unit		5.00E-2	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
transport	transport, freight, lorry, fleet average	RER	0	tkm		1.70E+1	2.24E-1			1	2.09	(4.5.na.na.na.na); Standard distance 100km
	transport, freight, rail	RER	0	tkm		1.02E+2	1.34E+0			1	2.09	(4.5.na.na.na.na); Standard distance 600km
disposal	disposal, waste, Si waferprod., inorg. 9.4% water, to residual material landfill	CH	0	kg		2.02E-2	0			1	1.24	(3.1.1.1.3.3); company information, amount of deposited waste, own estimation for type
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg		6.50E-1	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	disposal, glass, 0% water, to municipal incineration	CH	0	kg		3.44E+0	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
	treatment, glass production effluent, to wastewater treatment, class 2	CH	0	m3		0	0			1	1.07	(1.1.1.1.1.3); company information
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3		1.31E-1	0			1	1.07	(1.1.1.1.1.3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 46)
emissions air	Heat, waste	-	-	MJ		1.61E+2	0			1	1.07	(1.1.1.1.1.3); Calculation
	Cadmium	-	-	kg		2.10E-8	0			1	5.09	(3.4.3.3.1.5); Rough estimation



## Perovskite silicon tandem PV

This section has not been updated. This LCI is not necessarily representative of what is on the market.



Table 85 shows the unit process data of a perovskite silicon tandem PV panel produced in Germany. The data on material, energy consumption and emissions are from the life cycle inventory data in de Wild-Scholten [91] with adaptations by Ramseier et al [96]. Note: theoretical prospective life cycle inventory (not yet commercialized and not representative of what is on the market).



Table 85: Unit process LCI data of perovskite silicon tandem PV panel production in Germany

product	Name	Location	Infrastructure Process	Unit	photovoltaic panel, perovskite-Si-tandem, at plant	Uncertainty Type	Standard Deviation 95%	General Comment
	Location Infrastructure Process Unit				DE 1 m2			
resource, in water	photovoltaic panel, perovskite-Si-tandem, at plant	DE	1	m2	1			
	Water, cooling, unspecified natural origin, DE	-	-	m3	7.31E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); cooling water, from natural origin; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
technosphere	photovoltaic cell, single-Si, at plant	CN	0	m2	9.35E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); Monocrystalline silicone solar cell without the grid, 156mm x 156mm; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	photovoltaic panel factory	GLO	1	unit	4.00E-6	1	3.05	(2,3,1,1,1,5,BU:3); Factory; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	electricity, medium voltage, at grid	DE	0	kWh	2.34E+1	1	1.22	(2,3,1,1,1,5,BU:1.05); electricity from external supply; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	lead, at regional storage	RER	0	kg	1.62E-3	1	1.22	(2,3,1,1,1,5,BU:1.05); Lead iodide; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	methyl iodide	RER	0	kg	3.94E-4	1	1.22	(2,3,1,1,1,5,BU:1.05); Methyl iodide; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	ethylene bromide, at plant	RER	0	kg	3.94E-4	1	1.22	(2,3,1,1,1,5,BU:1.05); Ethylene bromide; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	chemicals organic, at plant	GLO	0	kg	8.13E-5	1	1.22	(2,3,1,1,1,5,BU:1.05); C60 fullerene; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	chemicals organic, at plant	GLO	0	kg	3.82E-5	1	1.22	(2,3,1,1,1,5,BU:1.05); Spiro-OMETAD: 2,2',7,7'-Tetrakis-(N,N-di-4-methoxyphenylamino)-9,9'-spirobifluorene; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	solvents, organic, unspecified, at plant	GLO	0	kg	4.24E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); Solvent 1, organic, no halogen containing; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	solvents, organic, unspecified, at plant	GLO	0	kg	3.94E-2	1	1.22	(2,3,1,1,1,5,BU:1.05); Solvent 2, organic, halogen containing; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	indium, at regional storage	RER	0	kg	7.50E-3	1	1.22	(2,3,1,1,1,5,BU:1.05); Indium Tin Oxide; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	tin, at regional storage	RER	0	kg	7.50E-3	1	1.22	(2,3,1,1,1,5,BU:1.05); Indium Tin Oxide; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	silver, at regional storage	RER	0	kg	3.52E-3	1	1.22	(2,3,1,1,1,5,BU:1.05); Conductive Adhesive: NAMICS H9455: 85-95% Ag, <5% resins (phenolic/epoxy), <5% additives, 5-10% ethylene glycol monophenyl ether (MSDS H9455-21); de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	phenolic resin, at plant	RER	0	kg	9.27E-5	1	1.22	(2,3,1,1,1,5,BU:1.05); Conductive Adhesive: NAMICS H9455: 85-95% Ag, <5% resins (phenolic/epoxy), <5% additives, 5-10% ethylene glycol monophenyl ether (MSDS H9455-21); de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	epoxy resin, liquid, at plant	RER	0	kg	9.27E-5	1	1.22	(2,3,1,1,1,5,BU:1.05); Conductive Adhesive: NAMICS H9455: 85-95% Ag, <5% resins (phenolic/epoxy), <5% additives, 5-10% ethylene glycol monophenyl ether (MSDS H9455-21); de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	diphenylether-compounds, at regional storehouse	RER	0	kg	3.71E-4	1	1.22	(2,3,1,1,1,5,BU:1.05); Conductive Adhesive: NAMICS H9455: 85-95% Ag, <5% resins (phenolic/epoxy), <5% additives, 5-10% ethylene glycol monophenyl ether (MSDS H9455-21); de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	metallization paste, front side, at plant	RER	0	kg	9.38E-3	1	1.22	(2,3,1,1,1,5,BU:1.05); Silver paste; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	solar glass, low-iron, at regional storage	RER	0	kg	8.13E+0	1	1.22	(2,3,1,1,1,5,BU:1.05); Front glass; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	tempering, flat glass	RER	0	kg	8.00E+0	1	1.22	(2,3,1,1,1,5,BU:1.05); Tempering, flat glass; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	flat glass, uncoated, at plant	RER	0	kg	5.08E+0	1	1.22	(2,3,1,1,1,5,BU:1.05); Backside glass; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	ethylvinylacetate, foil, at plant	RER	0	kg	9.75E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); Ethylvinylacetate foil; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	copper, at regional storage	RER	0	kg	1.03E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); String copper; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	wire drawing, copper	RER	0	kg	1.03E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); String copper; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	tin, at regional storage	RER	0	kg	1.29E-2	1	1.22	(2,3,1,1,1,5,BU:1.05); String tin; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	lead, at regional storage	RER	0	kg	7.25E-4	1	1.22	(2,3,1,1,1,5,BU:1.05); String lead; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	1-propanol, at plant	RER	0	kg	1.59E-2	1	1.22	(2,3,1,1,1,5,BU:1.05); Soldering flux: propanol; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	2.95E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); Junction box; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	diode, unspecified, at plant	GLO	0	kg	2.81E-3	1	1.22	(2,3,1,1,1,5,BU:1.05); Bypass diode; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	silicone product, at plant	RER	0	kg	1.22E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); Silicone; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	aluminium alloy, AlMg3, at plant	RER	0	kg	2.13E+0	1	1.22	(2,3,1,1,1,5,BU:1.05); Module frame: aluminium; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	7.63E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); Cardboard for packaging; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	EUR-flat pallet	RER	0	unit	3.13E-2	1	1.22	(2,3,1,1,1,5,BU:1.05); wooden pallet; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	transport, freight, lorry, fleet average	RER	0	tkm	4.61E+0	1	2.05	(2,3,1,1,1,5,BU:2); Transport lorry; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	transport, transoceanic freight ship	OCE	0	tkm	6.14E+1	1	2.05	(2,3,1,1,1,5,BU:2); Transport ship; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	3.02E-2	1	1.22	(2,3,1,1,1,5,BU:1.05); EVA cutting loss; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
	disposal, solvents mixture, 16.5% water, to hazardous waste incineration	CH	0	kg	8.86E-1	1	1.22	(2,3,1,1,1,5,BU:1.05); organic solvent (halogen free), halogen containing solvent, PB + halogen containing solvent; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
emission air, high population density	Lead	-	-	kg	1.16E-5	1	5.06	(2,3,1,1,1,5,BU:5); Lead to air; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
emission water, unspecified	Lead	-	-	kg	1.16E-5	1	5.06	(2,3,1,1,1,5,BU:5); Lead to water; de Wild-Scholten, M. 2017. Deliverable 3.1 Life Cycle Analysis of CHEOPS technologies and benchmarking; Screening. Available online.
emission air, high population density	Water	-	-	kg	3.66E+1	1	1.58	(3,3,1,1,1,5,BU:1.5); Cooling water emissions (5% of used cooling water); Estimated based Frischknecht and Busser (2013)



## Li-ion battery storage

This section has not been updated.

<b>Name</b>	<b>Li-ion battery storage system</b>
<b>Time period</b>	2014
<b>Geography</b>	Europe, Western
<b>Technology</b>	Average technology
<b>Representativeness</b>	Data from a specific component
<b>Date</b>	12/6/2016
<b>Data treatment</b>	Data scaled to 1 MW DC
<b>Comment</b>	Life cycle inventory of nickel-cobalt-manganese (NCM) Li-ion battery pack including single cell, battery management system, battery cooling system, and battery packing. The assembly process takes place in Norway (NO), but the battery cells are produced in East Asia (RAS). These data correspond to the data published by Ager-Wick Ellingsen et al. [97]. Further documentation: see Appendix A of Stolz et al. [98].

**Table 86: Life cycle inventory of 1 kg NCM Li-ion battery pack**

	Name	Location	InfrastructureProcess	Unit	battery, rechargeable, prismatic, LINCM, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				NO			
	InfrastructureProcess				0			
	Unit				kg			
product	battery, rechargeable, prismatic, LINCM, at plant	NO		0	kg	1		
technosphere	single cell, lithium-ion battery, NCM, at plant	RAS		0	kg	6.00E-1	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	battery-management-system, at plant	RAS		0	kg	3.70E-2	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	battery-cooling-system, passive, at plant	RAS		0	kg	4.10E-2	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	electricity, medium voltage, at grid	NO		0	kWh	4.00E-4	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	steel, low-alloyed, at plant	RER		0	kg	1.15E-1	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	nylon 6, at plant	RER		0	kg	7.79E-4	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	nylon 66, at plant	RER		0	kg	5.36E-2	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	steel product manufacturing, average metal working	RER		0	kg	8.22E-2	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	injection moulding	RER		0	kg	1.14E-1	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	aluminium, production mix, at plant	RER		0	kg	4.98E-3	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	anodising, aluminium sheet	RER		0	m2	1.13E-1	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	sheet rolling, aluminium	RER		0	kg	3.90E-3	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	copper, primary, at refinery	CLO		0	kg	6.91E-4	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	copper, secondary, at refinery	RER		0	kg	6.43E-3	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	RER		0	kg	4.56E-3	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	copper product manufacturing, average metal working	RER		0	kg	1.88E-3	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	aluminium product manufacturing, average metal working	RER		0	kg	3.52E-3	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	synthetic rubber, at plant	RER		0	kg	2.13E-2	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	polypropylene, granulate, at plant	RER		0	kg	3.94E-5	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
	butyl acrylate, at plant	RER		0	kg	1.27E-1	2.12	(1,4,1,5,3,3,5, BU:2); ; Ellingsen, 2014 supporting information
	transport, freight, rail	RER		0	tkm	2.24E-1	2.12	(1,4,1,5,3,3,5, BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >32t, EURO3	RER		0	tkm	4.80E-2	2.12	(1,4,1,5,3,3,5, BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >16t, fleet average	RER		0	tkm	6.44E+0	2.12	(1,4,1,5,3,3,5, BU:2); ; Ellingsen, 2014 supporting information
	transport, transoceanic freight ship	COE		0	tkm	2.26E-8	3.12	(1,4,1,5,3,3,5, BU:3); ; Ellingsen, 2014 supporting information
	facilities precious metal refinery	SE		1	unit	1.76E-11	3.12	(1,4,1,5,3,3,5, BU:3); ; Ellingsen, 2014 supporting information
	aluminium casting, plant	RER		1	unit	5.99E-11	3.12	(1,4,1,5,3,3,5, BU:3); ; Ellingsen, 2014 supporting information
	plastics processing factory	RER		1	unit	6.12E-11	3.12	(1,4,1,5,3,3,5, BU:3); ; Ellingsen, 2014 supporting information
	metal working factory	RER		1	unit	1.40E-3	1.34	(1,4,1,5,3,3,5, BU:1.05); ; Ellingsen, 2014 supporting information
emission air, high population density	Heat, waste	-		-	MJ			



Table 87: Life cycle inventory of the manufacture of single cells

	Name	Location	InfrastructureProcess	Unit	single cell, lithium-ion battery, NCM, at plant	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				RAS			
	InfrastructureProcess				0			
	Unit				kg			
product	single cell, lithium-ion battery, NCM, at plant	RAS	0	kg	1			
technosphere	anode, lithium-ion battery, graphite, at plant	RAS	0	kg	3.90E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	electrolyte, LiPF6, at plant	RAS	0	kg	1.60E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	cathode, lithium-ion battery, NCM, at plant	RAS	0	kg	4.30E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	separator, lithium-ion battery, at plant	RAS	0	kg	2.20E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	electricity, medium voltage, production Eastern Asia, at grid	RAS	0	kWh	2.27E+1	1	1.34	(1,4,1,5,3,5,BU:1.05); Due energy efficiency and the development of the battery manufacture electricity consumption was reduced by 20%; Ellingsen, 2014 supporting information
	water, decarbonised, at plant	RER	0	kg	3.80E+2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	transport, freight, rail	RER	0	tkm	2.62E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >32t, EURO3	RER	0	tkm	1.01E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	facilities precious metal refinery	SE	1	unit	1.90E-8	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	sheet rolling, aluminium	RER	0	kg	2.81E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	aluminium casting, plant	RER	1	unit	4.27E-13	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	copper, primary, at refinery	GLO	0	kg	2.16E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	copper, secondary, at refinery	RER	0	kg	3.82E-4	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	sheet rolling, copper	RER	0	kg	2.55E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	metal working factory	RER	1	unit	1.17E-12	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	2.09E-4	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	nylon 6, at plant	RER	0	kg	2.14E-4	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	polypropylene, granulate, at plant	RER	0	kg	8.58E-4	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	polyethylene, LDPE, granulate, at plant	RER	0	kg	6.70E-5	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	injection moulding	RER	0	kg	1.26E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
plastics processing factory	RER	1	unit	9.38E-13	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information	
emission air, high population density	Heat, waste	-	-	MJ	1.00E+2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information



**Table 88: Life cycle inventory of the electricity mix of Eastern Asia (RAS) specific for single cell manufacture**

	Name	Location	InfrastructureProcess	Unit	electricity, production mix Eastern Asia			GeneralComment
	Location				UncertaintyType	StandardDeviation95%		
	InfrastructureProcess						RAS	
	Unit						0 kWh	
product	electricity, production mix Eastern Asia	RAS	0	kWh	1.00E+0			
technosphere	electricity, peat, at power plant	NORDEL	0	kWh	0.000380490	1	1.05	(1,1,1,3,1,1); according to paper of L. Ager-Wick Ellingsen, 2014
	electricity, hard coal, at power plant	UCTE	0	kWh	0.459748349	1	1.05	(1,1,1,3,1,1); according to paper of L. Ager-Wick Ellingsen, 2014
	electricity, oil, at power plant	UCTE	0	kWh	0.043571590	1	1.05	(1,1,1,3,1,1); according to paper of L. Ager-Wick Ellingsen, 2014
	electricity, natural gas, at power plant	UCTE	0	kWh	0.154566868	1	1.05	(1,1,1,2,1,1); according to paper of L. Ager-Wick Ellingsen, 2014
	electricity from waste, at municipal waste incineration plant	CH	0	kWh	0.000439873	1	1.05	(1,1,1,3,1,1); according to paper of L. Ager-Wick Ellingsen, 2014
	electricity, nuclear, at power plant	UCTE	0	kWh	0.325002144	1	1.05	(1,1,1,3,1,1); according to paper of L. Ager-Wick Ellingsen, 2014
	electricity, hydropower, at power plant	CH	0	kWh	0.013539282	1	1.05	(1,1,1,1,1,1); according to paper of L. Ager-Wick Ellingsen, 2014
	electricity, production mix photovoltaic, at plant	US	0	kWh	0.001244840	1	1.05	(1,1,1,2,1,1); according to paper of L. Ager-Wick Ellingsen, 2014
	electricity, at wind power plant	RER	0	kWh	0.001506564	1	1.05	(1,1,1,2,1,1); according to paper of L. Ager-Wick Ellingsen, 2014



Table 89: Life cycle inventory of the anode

product	Name	Location	InfrastructureProcess	Unit	anode, lithium-ion battery, graphite, at plant	Uncertainty Type	StandardDeviation95%	GeneralComment
	Location				RAS			
	InfrastructureProcess				0			
	Unit				kg			
	anode, lithium-ion battery, graphite, at plant	RAS	0	kg	1			
technosphere	transport, freight, rail	RER	0	tkm	9.87E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >32t, EURO3	RER	0	tkm	2.40E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	copper, primary, at refinery	GLO	0	kg	4.88E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	copper, secondary, at refinery	RER	0	kg	8.60E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	sheet rolling, copper	RER	0	kg	5.74E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	metal working factory	RER	1	unit	2.63E-10	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	graphite, battery grade, at plant	CN	0	kg	4.09E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	carboxymethyl cellulose, powder, at plant	RER	0	kg	1.09E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	acrylic acid, at plant	RER	0	kg	1.09E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	N-methyl-2-pyrrolidone, at plant	RER	0	kg	4.05E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	chemical plant, organics	RER	1	unit	1.71E-10	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information



Table 90: Life cycle inventory of the cathode

	Name	Location	InfrastructureProcess	Unit	cathode, lithium-ion battery, NCM, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RAS			
	InfrastructureProcess				0			
	Unit				kg			
product	cathode, lithium-ion battery, NCM, at plant	RAS	0	kg	1			
technosphere	transport, freight, rail	RER	0	tkm	2.97E+0	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >32t EURO3	RER	0	tkm	2.42E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry > 16t, fleet average	RER	0	tkm	1.06E+0	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	aluminium, production mix, at plant	RER	0	kg	1.14E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	sheet rolling, aluminium	RER	0	kg	1.14E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	aluminium casting, plant	RER	1	unit	1.76E-11	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	polyvinylfluoride, at plant	US	0	kg	3.54E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	carbon black, at plant	GLO	0	kg	1.77E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	N-methyl-2-pyrrolidone, at plant	RER	0	kg	4.18E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	chemical plant, organics	RER	1	unit	1.00E-9	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	lithium hydroxide, at plant	GLO	0	kg	2.07E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	heat, unspecified, in chemical plant	RER	0	MJ	4.58E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	soda, powder, at plant	RER	0	kg	6.92E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	ammonia, liquid, at regional storehouse	RER	0	kg	1.42E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	chemicals organic, at plant	GLO	0	kg	7.30E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	chemicals inorganic, at plant	GLO	0	kg	2.49E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	carbon monoxide, CO, at plant	RER	0	kg	4.96E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	hydrogen cyanide, at plant	RER	0	kg	1.14E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	hydrogen, liquid, at plant	RER	0	kg	4.31E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	limestone, milled, loose, at plant	CH	0	kg	3.35E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	portland calcareous cement, at plant	CH	0	kg	1.06E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	sand, at mine	CH	0	kg	1.34E+1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	silica sand, at plant	DE	0	kg	3.20E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	blasting	RER	0	kg	4.86E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	diesel, burned in building machine	GLO	0	MJ	3.43E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	electricity, high voltage, production ENTSO, at grid	ENTSO	0	kWh	4.48E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	6.71E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	1.02E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	heat, at hard coal industrial furnace 1-10MW	RER	0	MJ	3.16E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	2.05E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	1.24E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	aluminium hydroxide, at plant	RER	0	kg	3.73E-10	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
conveyor belt, at plant	RER	1	m	1.23E-6	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information	
non-ferrous metal mine, underground	GLO	1	unit	1.61E-9	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information	
non-ferrous metal smelter	GLO	1	unit	5.67E-12	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information	
disposal, nickel smelter slag, 0% water, to residual material landfill	CH	0	kg	1.62E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	
disposal, sulfidic tailings, off-site	GLO	0	kg	1.23E+1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	
disposal, non-sulfidic tailings, off-site	GLO	0	kg	1.14E+1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	
disposal, non-sulfidic overburden, off-site	GLO	0	kg	5.93E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	
manganese concentrate, at beneficiation	GLO	0	kg	4.66E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	
sulphuric acid, liquid, at plant	RER	0	kg	2.83E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	
natural gas, high pressure, at consumer	CH	0	MJ	1.58E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	
hard coal coke, at plant	RER	0	MJ	6.23E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	



Table 90: Life cycle inventory of the cathode (continued)

	Name	Location	InfrastructureProcess	Unit	cathode, lithium-ion battery, NCM, at plant	UncertaintyType	StandardDeviation5%	GeneralComment
					0 kg			
product	cathode, lithium-ion battery, NCM, at plant	RAS		0 kg	1			
resource, in ground	Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	-	-	kg	2.13E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	Cobalt, in ground	-	-	kg	2.24E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
resource, in water	Water, river	-	-	m3	1.12E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	Water, well, in ground	-	-	m3	6.44E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
emission air, unspecified	Aluminium	-	-	kg	2.48E-4	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Arsenic	-	-	kg	9.01E-7	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Calcium	-	-	kg	1.74E-4	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Carbon dioxide, fossil	-	-	kg	1.44E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	Carbon disulfide	-	-	kg	3.22E-3	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Cobalt	-	-	kg	1.88E-4	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Copper	-	-	kg	5.59E-5	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	kg	1.54E-12	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	Heat, waste	-	-	MJ	1.18E+1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	Lead	-	-	kg	5.31E-6	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Magnesium	-	-	kg	1.49E-4	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Nickel	-	-	kg	6.60E-5	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	NM/VO, non-methane volatile organic compounds, unspecified origin	-	-	kg	3.09E-5	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Particulates, < 2.5 um	-	-	kg	2.87E-3	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	Particulates, > 10 um	-	-	kg	3.71E-3	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Particulates, > 2.5 um, and < 10um	-	-	kg	5.26E-3	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	Silver	-	-	kg	2.14E-8	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Sulfur dioxide	-	-	kg	2.30E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	Tin	-	-	kg	1.01E-6	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Zinc	-	-	kg	1.56E-5	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
emission water, unspecified	Aluminium	-	-	kg	5.56E-6	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Arsenic, ion	-	-	kg	2.27E-7	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	BOD5, Biological Oxygen Demand	-	-	kg	2.83E-4	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Cadmium, ion	-	-	kg	2.57E-8	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	Calcium, ion	-	-	kg	3.14E-2	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	Calcium, ion	-	-	kg	1.28E-2	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	Chromium, ion	-	-	kg	9.12E-8	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	Cobalt	-	-	kg	5.04E-8	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	COD, Chemical Oxygen Demand	-	-	kg	6.74E-4	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Copper, ion	-	-	kg	6.15E-7	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	Cyanide	-	-	kg	1.21E-4	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	DOC, Dissolved Organic Carbon	-	-	kg	1.10E-4	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Iron, ion	-	-	kg	1.87E-5	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Lead	-	-	kg	2.12E-7	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
emission water, fossil-	Manganese	-	-	kg	1.59E-6	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
emission water, unspecified	Mercury	-	-	kg	2.99E-9	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Nickel, ion	-	-	kg	1.61E-6	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	Nitrogen, organic bound	-	-	kg	6.16E-4	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Nitrogen	-	-	kg	8.53E-4	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Suspended solids, unspecified	-	-	kg	3.34E-4	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Sulfate	-	-	kg	1.52E-1	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Tin, ion	-	-	kg	5.58E-8	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
	TOC, Total Organic Carbon	-	-	kg	1.10E-4	1	1.65	(1,4,1,5,3,5,BU:1.5); ; Ellingsen, 2014 supporting information
	Zinc, ion	-	-	kg	5.08E-6	1	5.13	(1,4,1,5,3,5,BU:5); ; Ellingsen, 2014 supporting information
emission air, high population density	Heat, waste	-	-	MJ	1.11E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ;



Table 91: Life cycle inventory of the electrolyte

	Name	Location	InfrastructureProcess	Unit	electrolyte, LiPF6, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RAS			
	InfrastructureProcess				0			
	Unit				kg			
	product	electrolyte, LiPF6, at plant	RAS	0	kg	1		
technosphere	lithium hexafluorophosphate, at plant	CN	0	kg	1.20E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	ethylene carbonate, at plant	CN	0	kg	8.80E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	transport, freight, rail	RER	0	tkm	6.00E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >32t, EURO3	RER	0	tkm	1.00E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	chemical plant, organics	RER	1	unit	4.10E-10	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information



Table 92: Life cycle inventory of the separator

	Name	Location	InfrastructureProcess	Unit	separator, lithium-ion battery, at plant			GeneralComment
	Location				UncertaintyType	StandardDeviation	95%	
	InfrastructureProcess							
	Unit							
product	separator, lithium-ion battery, at plant	RAS	0	kg	1			
technosphere	polypropylene, granulate, at plant	RER	0	kg	1.00E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	injection moulding	RER	0	kg	1.00E+0	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	transport, freight, rail	RER	0	tkm	2.00E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >32t, EURO3	RER	0	tkm	1.00E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	plastics processing factory	RER	1	unit	7.40E-10	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information



Table 93: Life cycle inventory of the battery management system

product	Name	Location	InfrastructureProcess	Unit	battery-managment-system, at plant	Uncertainty Type	StandardDeviation95%	GeneralComment
	Location				RAS			
	InfrastructureProcess				0			
	Unit				kg			
	battery-managment-system, at plant	RAS	0	kg	1			
technosphere	printed wiring board, through-hole mounted, unspec., Pb free, at plant	GLO	0	kg	8.93E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	transport, freight, rail	RER	0	tkm	3.69E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >32t, EURO3	RER	0	tkm	1.71E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	nylon 66, at plant	RER	0	kg	1.70E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	electronic component, passive, unspecified, at plant	GLO	0	kg	1.29E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	injection moulding	RER	0	kg	4.46E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	electronic component production plant	GLO	1	unit	1.82E-8	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	steel, low-alloyed, at plant	RER	0	kg	3.40E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	aluminium, production mix, at plant	RER	0	kg	3.64E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	synthetic rubber, at plant	RER	0	kg	1.06E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	polyethylene terephthalate, granulate, amorphous, at plant	RER	0	kg	1.69E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	copper, primary, at refinery	GLO	0	kg	6.91E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	copper, secondary, at refinery	RER	0	kg	1.23E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	polyphenylene sulfide, at plant	GLO	0	kg	9.57E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	tin, at regional storage	RER	0	kg	5.02E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	cable, ribbon cable, 20-pin, with plugs, at plant	GLO	0	kg	1.34E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	steel product manufacturing, average metal working	RER	0	kg	3.40E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	aluminium product manufacturing, average metal working	RER	0	kg	3.64E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	copper product manufacturing, average metal working	RER	0	kg	8.14E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	metal product manufacturing, average metal working	RER	0	kg	5.02E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information



Table 94: Life cycle inventory of the battery cooling system

	Name	Location	InfrastructureProcess	Unit	battery-cooling-system, passive, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RAS			
	InfrastructureProcess				0			
	Unit				kg			
product	battery-cooling-system, passive, at plant	RAS	0	kg	1			
technosphere	ethylene glycol, at plant	RER	0	kg	4.78E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	transport, freight, rail	RER	0	tkm	4.10E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	transport, lorry >32t, EURO3	RER	0	tkm	1.95E-1	1	2.12	(1,4,1,5,3,5,BU:2); ; Ellingsen, 2014 supporting information
	aluminium, production mix, at plant	RER	0	kg	9.11E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	sheet rolling, aluminium	RER	0	kg	8.73E-1	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	aluminium casting, plant	RER	1	unit	1.40E-10	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	aluminium product manufacturing, average metal working	RER	0	kg	3.82E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	steel, low-alloyed, at plant	RER	0	kg	2.29E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	steel product manufacturing, average metal working	RER	0	kg	2.29E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	metal working factory	RER	1	unit	1.05E-11	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	polyvinylchloride, at regional storage	RER	0	kg	7.16E-4	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	synthetic rubber, at plant	RER	0	kg	2.39E-4	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	injection moulding	RER	0	kg	2.08E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
	plastics processing factory	RER	1	unit	1.56E-11	1	3.12	(1,4,1,5,3,5,BU:3); ; Ellingsen, 2014 supporting information
	glass fibre, at plant	RER	0	kg	1.99E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information
silicon, electronic grade, at plant	DE	0	kg	5.96E-3	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information	
	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	RER	0	kg	1.19E-2	1	1.34	(1,4,1,5,3,5,BU:1.05); ; Ellingsen, 2014 supporting information



## Medium-large PV installations in Europe

This section has not been updated.

<b>Name</b>	<b>Real photovoltaic power plants in Europe</b>
<b>Time period</b>	2004-2009
<b>Geography</b>	Europe
<b>Technology</b>	Mixed data
<b>Representative-ness</b>	Individual real installations
<b>Date</b>	09.02.2010
<b>Collection method</b>	Data from system installers, operators and literature.
<b>Comment</b>	Photovoltaic power plants operating in Switzerland, Germany, and Spain Reference [99]



Table 95: LCI of PV Power Plants in Europe

Capacity		93 kWp	280 kWp	156 kWp	1.3 MWp	324 kWp	450 kWp	569 kWp	570 kWp	
Type of module		single-Si laminate	single-Si panel	multi-Si panel	multi-Si panel	multi-Si panel	single-Si panel	multi-Si panel	multi-Si panel	
Type of mounting system:		Slanted roof integrated	Flat roof mounted	Flat roof mounted	Slanted roof mounted	Flat roof mounted	Flat roof mounted	Open ground	Open ground	
Location		Switzerland	Switzerland	Switzerland	Switzerland	Germany	Germany	Spain	Spain	
<b>Products</b>	<b>Unit</b>	<b>Amount</b>	<b>Amount</b>	<b>Amount</b>	<b>Amount</b>	<b>Amount</b>	<b>Amount</b>	<b>Amount</b>	<b>Amount</b>	<b>Comment</b>
Photovoltaic installation	unit	1	1	1	1	1	1	1	1	Refers to capacity above
Annual Electricity yield	kWh/m <sup>2</sup>	131	155	120	128	141	136	238	198	3.85 MJ converted solar energy per kWh
<b>Components/fuels</b>										
Electricity consumption	kWh	7.13E+00	2.15E+01	1.19E+01	1.03E+02	2.48E+01	3.45E+01	3.60E+01	3.60E+01	Erection of plant
Diesel consumption	MJ	0	0	0	0	0	0	7.66E+03	7.67E+03	
Inverter weight	kg	123	2420	1590	6600	2600	3535	4675	4675	This amount is replaced every 15 years.
Mounting system	m <sup>2</sup>	6.84E+02	2.08E+03	1.17E+03	1.01E+04	2.55E+03	3.38E+03	4.27E+03	4.27E+03	
Photovoltaic module	m <sup>2</sup>	7.05E+02	2.14E+03	1.21E+03	1.04E+04	2.63E+03	3.48E+03	4.29E+03	4.40E+03	Including 2% replaces during lifetime and 1% rejects



Table 95 (continued): LCI of PV Power Plants in Europe

<u>Electric installations (excluding inverter)</u>			93 kWp	280 kWp	156 kWp	1.3 MWp	324 kWp	450 kWp	569 kWp	570 kWp	
Copper	kg		7.06E+01	3.18E+02	3.03E+02	3.87E+03	3.77E+02	3.81E+02	7.41E+02	7.41E+02	Drawn to wire
Brass	kg		5.46E-01	1.02E+00	6.82E-01	7.50E+00	1.36E+00	1.36E+00	1.36E+00	1.36E+00	
Zinc	kg		1.09E+00	2.05E+00	1.36E+00	1.50E+01	2.73E+00	2.73E+00	2.73E+00	2.73E+00	
Steel	kg		2.24E+01	4.12E+01	2.81E+01	2.90E+02	5.29E+01	5.29E+01	5.29E+01	5.29E+01	
Nylon 61	kg		6.28E+00	1.18E+01	7.84E+00	8.63E+01	1.57E+01	1.57E+01	1.57E+01	1.57E+01	
Polyethylene1	kg		6.07E+01	3.15E+02	2.80E+02	3.73E+03	4.12E+02	4.17E+02	7.09E+02	7.09E+02	
Polyvinylchloride1	kg		8.69E-01	2.61E+01	2.17E+01	2.36E+02	4.17E+01	4.35E+01	4.49E+01	4.49E+01	
Polycarbonate1	kg		5.46E-02	1.02E-01	6.82E-02	7.50E-01	1.36E-01	1.36E-01	1.36E-01	1.36E-01	
Epoxy resin1	kg		5.46E-02	1.02E-01	6.82E-02	7.50E-01	1.36E-01	1.36E-01	1.36E-01	1.36E-01	
<b>Transport</b>	tkm										
Lorry	tkm		4.23E+03	1.82E+04	9.64E+03	8.34E+04	2.10E+04	2.96E+04	3.51E+04	3.52E+04	500 km modules
Transoceanic freight ship	tkm		1.69E+04	7.28E+04	3.86E+04	3.34E+05	8.14E+04	1.18E+05	1.41E+05	1.41E+05	2'000 km modules
Van	tkm		8.91E+02	4.12E+03	2.24E+03	1.80E+04	4.72E+03	6.62E+03	7.96E+03	7.98E+03	100 km system

ISBN 978-1-923734-08-1



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