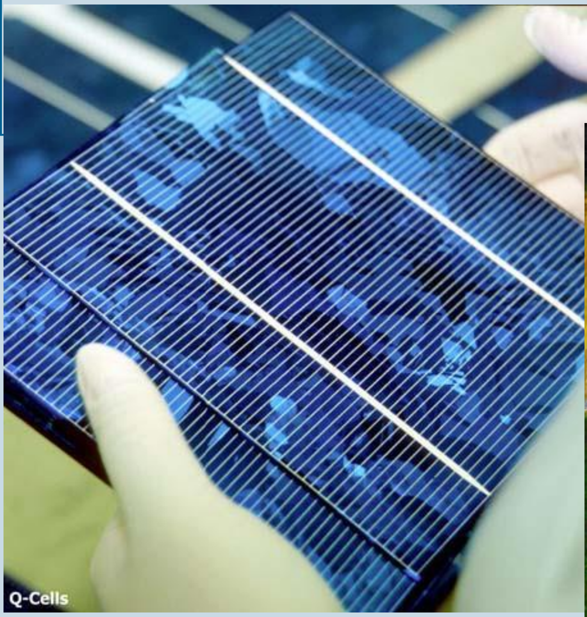
IEA INTERNATIONAL ENERGY AGENCY

Water Footprint of European Rooftop Photovoltaic Electricity based on Regionalised Life Cycle Inventories



Q-Cells

Karlstadt Laudenbach, Germany (810 kW); Phoenix Solar

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T12-11:2017

INTERNATIONAL ENERGY AGENCY PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Water Footprint of European Rooftop Photovoltaic Electricity based on Regionalised Life Cycle Inventories

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Abbreviations and Acronyms

a	year (annum)
AC	alternating current
APAC	Asia / Pacific
AWARE	Available WAter REmaining
BOS	balance of system
CdTe	cadmium telluride
DC	direct current
ENTSO-E	European Network of Transmission System Operators for Electricity
eq	equivalent
GLO	global average
GWP	global warming potential
IEA	International Energy Agency
KBOB	Coordination Group for Construction and Property Services (Koordinationskonferenz der Bau- und Liegenschaftsorgane des Bundes)
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
MJ	megajoule
mono-Si	monocrystalline silicon
PEF	product environmental footprint
PEFCR	product environmental footprint category rule
PV	photovoltaic
PVPS	photovoltaic power systems
RER	Europe
tkm	tonne kilometre (unit for transportation services)
TS	Technical Secretariat
UCTE	Union for the Coordination of the Transmission of Electricity

Summary

The water use of photovoltaic (PV) electricity has been investigated in very few studies so far, which may be due to the low water demand of PV systems during operation. In this study, the water consumption and water withdrawal of electricity generated by PV systems were assessed by considering all life cycle stages and by taking account of country-level regional differences in water availability. The life cycle inventories of the manufacture of monocrystalline silicon (mono-Si) and cadmium telluride (CdTe) PV modules are based on data collected between 2010 and 2013 and take account of the shares of different countries in total global production. The water use in the life cycle inventories of European rooftop PV systems and conventional electricity generation technologies was regionalised to the country or region (such as continents, political or geographic entities of several countries) level and complemented by the share of water lost by evaporation. The AWARE (Available WAter REmaining) method was used to assess the water stress impact caused by water consumption and water withdrawal of electricity generation by European rooftop PV systems as well as by reservoir hydroelectric power plants and large-scale hard coal and nuclear power plants in Europe. The functional unit of this analysis is 1 kWh of alternating current (AC) electricity (at busbar). The life cycle inventories were linked to KBOB (Coordination Group for Construction and Property Services) life cycle inventory data DQRv2:2016, which are based on ecoinvent data v2.2 and contain updated life cycle inventory data in relevant economic sectors.

The water consumption of electricity generated by mono-Si and CdTe PV systems amounts to 1.5 and 0.25 L/kWh, respectively. The volume of water withdrawn from nature is 7.2 L/kWh for electricity generated by mono-Si PV systems and 0.73 L/kWh for electricity from CdTe PV systems. The water stress impact caused by water consumption of electricity generated by European rooftop mono-Si and CdTe PV systems is 32 and 2.3 L water-eq/kWh, respectively. Electricity from reservoir hydropower plants causes a water stress impact based on water consumption similar to mono-Si PV electricity (37 L water-eq/kWh) and the water stress impact of electricity generated by European hard coal and nuclear power plants is significantly higher (170 and 69 L water-eq/kWh, respectively).

The electricity demand in the production of mono-Si and CdTe PV modules is an important driver of the total water stress impact. Many processes in the supply chain of PV modules require a significant amount of electricity, which is currently still provided by conventional power plants. The share of electricity supply in the water stress impact caused by water consumption of electricity generated by mono-Si and CdTe PV systems is approximately 82 % and 78 %, respectively. The water stress impact of process or cooling water used directly in the manufacture of PV modules amounts to 16 % for the mono-Si and 3 % for the CdTe technology, whereas the input materials contribute 2 % and 20 % to the water stress impact, respectively. Water consumption during operation of the European rooftop mono-Si and CdTe PV systems is negligible (<1 %).

The data quality is classified as good according to the data quality assessment criteria of the Product Environmental Footprint (PEF) Guide. However, some critical parameters are based on estimates or extrapolations and should be determined more accurately in the future. The share of consumptive water use of electricity generation by fossil and nuclear power plants was determined based on a study of the power sector in the USA and was used to include the amount of evaporated water in the life cycle inventories of electricity generation by fossil and nuclear power plants in different world regions (mainly Europe). Additionally, the fractions of power plants relying on tower and once-through cooling systems were estimated more than ten years ago. The share of consumptive water use of the manufacture of mono-Si PV modules was identified as another critical parameter but was based on generic estimates due to the lack of specific water consumption data for the individual process steps. The geographical resolution of the life cycle inventory database also represents a source of uncertainty in the assessment of water consumption using national and regional water scarcity factors.

This study was financed by the Swiss Federal Office of Energy (SFOE) and carried out in the framework of the Task 12 of the Photovoltaic Power Systems Programme (PVPS) of the International Energy Agency (IEA).

Foreword

The IEA PVPS is one of the collaborative R&D Agreements established within the IEA, and was established in 1993. The overall programme is headed by an Executive Committee composed of representatives from each participating country and/or organisation, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. By early 2015, fifteen Tasks were established within the PVPS programme, of which six are currently operational.

The IEA PVPS Implementing Agreement presently has 29 members and covers the majority of countries active in photovoltaics, both in R&D, production and installation. The programme deals with the relevant applications of photovoltaics, both for on-grid and off-grid markets. It operates in a task-shared mode whereby member countries and/or organisations contribute with their experts to the different Tasks. The co-operation deals with both technical and non-technical issues relevant to a wide-spread use of photovoltaics in these different market segments.

The mission of the IEA PVPS 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.” The underlying assumption is that the market for PV systems is rapidly expanding to significant penetrations in grid-connected markets in an increasing number of countries, connected to both the distribution network and the central transmission network. At the same time, the market is gradually shifting from a policy to a business driven approach.

Task 12 aims at fostering international collaboration in safety and sustainability that are crucial for assuring that PV growth to levels enabling it to make a major contribution to the needs of the member countries and the world.

The overall objectives of Task 12 are to accomplish the following:

1. Quantify the environmental profile of PV in comparison to other energy technologies;
2. Define and address environmental health & safety and sustainability issues that are important for market growth.

The first objective of this task is well served by life cycle assessments (LCAs) that describe the energy-, material-, and emission-flows in all the stages of the life of PV. The second objective will be addressed by assisting the collective action of PV companies in defining material availability and product-recycling issues, and on communicating “lessons learned” from incidents or potential ones in PV production facilities. A third objective (i.e., dissemination) will be accomplished by presentations to broad audiences, producing simple fact sheets documented by comprehensive reports, and engaging industrial associations and the media in the spreading this information.

Within Task 12, there are three targets of Subtask 2.0 “Life Cycle Assessment”: To quantify the environmental profile of electricity produced with PV systems (compared to that from other sources); to show trends in the improvement of PV's environmental profile; and, to assess this profile with the help of "external" costs, and other life-cycle-impact assessment methods.

Task 12 was initiated by Brookhaven National Laboratory under the auspices of the U.S. Department of Energy and is now operated jointly by the National Renewable Energy Laboratory (NREL) and Energy Center of the Netherlands (ECN). Support from DOE and ECN are gratefully acknowledged. Further information on the activities and results of the Task can be found at: http://www.iea-pvps.org.

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1 Introduction

The water use of photovoltaic (PV) electricity has been investigated in very few studies so far, which may be due to the low water demand of PV systems during operation. According to Meldrum et al. (2013), the amount of water used for operation of PV power plants, such as occasional washing of PV modules, is much lower than the operational water demand of thermoelectric power plants, especially from cooling water demand, or the water evaporation from hydropower plants. The low operational water demand of PV systems is particularly advantageous during periods of drought. Macknick et al. (2011) report several instances of reduced water levels in the USA, which forced fossil and nuclear power plants to reduce their capacity or shut down completely. In Switzerland, nuclear power plants with once-through cooling had to curtail their power generation during the last heat wave in 2015 (BAFU 2016).

Even though the operational water use of PV electricity is low, the amount of water required in the manufacture and disposal of PV modules and balance of system (BOS) components may still be relevant. The water use of PV systems should therefore be assessed based on their entire life cycle. A review of water footprint studies published by Meldrum et al. (2013) revealed that the life cycle water consumption of PV electricity is low compared to most other electricity generation technologies analysed. The availability of water varies strongly between different countries and regions[1]. Since the production of PV modules often occurs in a distant location from the place of installation of the PV system, it is important to account for the differences in water availability. This can be done by using life cycle inventories regionalised to the country or region level in combination with country- and region-specific water scarcity factors for water use.

In this study, the life cycle inventories of rooftop PV systems are regionalised with regard to water use and complemented by the share of water lost by evaporation. The water consumption and water withdrawal of PV electricity are then quantified by considering the whole life cycle of the PV systems and by using country- and region-specific water scarcity factors based on an internationally accepted impact assessment method. This approach also allows for a meaningful comparison of electricity generated with PV systems and conventional power plants.

The objective and scope of this study are described in chapter 2. The life cycle inventories are introduced in chapter 3 and the impact assessment results are presented in chapter 4. In chapter 5, the data quality is described and the uncertainty is evaluated.

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[1] In this report, we define regions as an aggregation of several countries. For instance, life cycle inventories of monocrystalline silicon PV module production are available for the regions Asia / Pacific (APAC) and Europe. The specific water availability in these regions is taken into account in the water footprint of electricity generation.

Conclusions are drawn and an outlook is given in chapter 6. A detailed documentation and a list of the life cycle inventories that were regionalised to the country or region level can be found in the appendices A and B.

2 Objective and scope

2.1 Objective

This study aims to assess the water consumption of electricity generated with monocrystalline silicon (mono-Si) and cadmium telluride (CdTe) PV systems over the whole life cycle. The life cycle assessment is carried out following an attributional (i.e., descriptive) approach. The life cycle inventories are regionalised to the country or region level and complemented by the share of water lost by evaporation. Country- and region-specific water scarcity factors are used to weight the water consumption and withdrawal in different countries and regions in order to account for variations in water availability. The main processes contributing to the life cycle water consumption and withdrawal of PV electricity are identified and compared to the water use of electricity generated with hard coal, nuclear and reservoir hydro power plants.

2.2 Functional unit and system design

The functional unit of this analysis is 1 kWh of alternating current (AC) electricity (at busbar) generated by residential scale[2] 3 kWp mono-Si and CdTe PV systems mounted on a slanted rooftop. The same functional unit is used for electricity produced in reservoir hydropower plants, hard coal power plants and nuclear power plants. The power plants considered are representative for Europe.

The life cycle inventories of the PV module production are based on data collected between 2010 and 2013 (Frischknecht et al. 2015). The efficiency of the mono-Si and CdTe PV modules considered is 15.1 % and 14.0 %, respectively. The annual yield of 975 kWh/kWp is representative for average European conditions and includes linear degradation of 0.7 % per year. The lifetime of the PV systems (though not every component, e.g., the inverter) is estimated at 30 years (Stolz et al. 2016).

2.3 Data sources

The rooftop PV systems, including their water use, were modelled based on the life cycle inventories published in previous studies (Frischknecht et al. 2015; Stolz et al. 2016). The water use in the life cycle inventories of the PV supply chain as well as of electricity generation and water supply and purification were regionalised to the country

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[2] In comparison to residential scale systems, large scale PV systems may require significantly less or even no water for cleaning (personal communication Parikhit Sinha, FirstSolar, 25.03.2017). The volume of water used strongly depends on the cleaning method applied (Komoto et al. 2015). However, specific data for a detailed assessment of the water footprint of large scale PV systems were not available.

or region level. The amount of evaporated cooling water used in power plants was estimated based on data published by Macknick et al. (2012) and added to the life cycle inventories. The share of consumptive use of process and cooling water was taken from Frischknecht and Büsser Knöpfel (2013) in cases where process-specific data were not available.

The life cycle inventories are linked to KBOB (Coordination Group for Construction and Property Services) life cycle inventory data DQRv2:2016 (KBOB et al. 2016), which are based on ecoinvent data v2.2 (ecoinvent Centre 2010). This data source contains extensive updates on energy supply and material production datasets. It ensures methodological continuity with former versions of the ecoinvent database and it is used by the Swiss administration. The analyses were performed with SimaPro v8.3.0 (PRé Consultants 2016).

2.4 Water stress impact: the AWARE method

The water stress impact of electricity generation is quantified with the AWARE (Available WAter REmaining) impact assessement method (Boulay et al. 2017). In this method, the present water demand of humans and ecosystems is subtracted from the amount of available water in each watershed and for each month to estimate the net water available for other anthropogenic uses. The water scarcity factors are then calculated as the inverse of the available water remaining in a specific country or region and normalised to the world average water availability minus demand of humans and ecosystems (Boulay et al. 2017). The higher the water scarcity factor is, the lower is the water availability minus demand and the higher is the water scarcity. The unit of the water scarcity factors is m^3 water-equivalents per m^3 water (m^3 water-eq/m^3 water). The water-equivalents are used to make water consumption in a given country comparable to world average water.[3] The global average water scarcity factor equals 20.3 m^3 water-eq/m^3 water, which means that using 1 m^3 of unspecific water results in a water stress impact of 20.3 m^3 water-eq. The AWARE impact assessment method is recommended by the UNEP / SETAC Life Cycle Initiative and provides country- and region-specific water scarcity factors for unspecific, agricultural and non-agricultural water use (Frischknecht & Jolliet 2016).

In water use assessments, water withdrawal and water consumption are distinguished. A large part of the water withdrawn from nature is released into the same watershed after a short time period. In contrast, evaporated water or water embodied in products is consumed and therefore no longer available in the watershed considered. In this study, we mainly focus on water consumption and employ the annual country- and region-specific water scarcity factors for non-agricultural water use from the AWARE impact

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[3] This approach is similar to the global warming potential (GWP), which relates the radiative forcing of different greenhouse gases to the climate impact of carbon dioxide (CO_2) (IPCC 2013).

assessment method. Boulay et al. (2017) also recommend assessing water consumption rather than water withdrawal.

3 Life cycle inventories

Water is used in many processes in the supply chain of PV systems. The most relevant contributors to direct and indirect water use were identified in a preliminary analysis at the beginning of this study. To this end, the water consumption of electricity generated with mono-Si and CdTe PV systems was quantified by adding up the amounts of water consumed. This analysis showed that besides the direct water consumption in the manufacturing of PV modules, the water consumed indirectly by fossil, nuclear and hydro power plants supplying electricity to PV module manufacturers contributes a significant share to the total water consumption. Purified water used in power plants and in the production of crystalline silicon and CdTe PV modules is also relevant. Based on this finding, the life cycle inventories of water purification and electricity generation were also regionalised to the country or region level with regard to water consumption in order to adequately take regional differences in water availability into account.

The regionalisation of water use is accomplished by replacing the unspecific water flows by new elementary flows labelled with the code of the country or region where a process takes place. For instance, the production of tap water in China uses the specific elementary flow “water, unspecified natural origin, CN” as an input instead of the generic resource flow “water, unspecified natural origin”. The regionalised life cycle inventories are complemented by the consumptive water use, which is modelled as evaporation of water. The water emissions to air are also labelled with a specific country code (e.g., “water, CN”).

The regionalised life cycle inventories of water purification, electricity generation and the supply chains of mono-Si PV modules and of CdTe PV modules are described in Appendix A. A table listing all the geographies distinguished in the regionalised life cycle inventories is presented in Appendix B.

4 Life cycle impact assessment

4.1 Overview

The regionalised life cycle inventories described in Chapter 3 and Appendix A were used to quantify the water consumption and water withdrawal of electricity generation by considering all life cycle stages and taking regional differences in water availability into account. The water consumption and water withdrawal of 1 kWh AC electricity generated by mono-Si and CdTe PV systems are compared to the water use of conventional technologies. The inventory results for water consumption and water withdrawal are reported in subchapter 4.2. The water stress impact based on water consumption and withdrawal of PV electricity is presented in subchapters 4.3 and 4.4, respectively.

4.2 Inventory results: water consumption and water withdrawal

The water consumption and water withdrawal of electricity generated by mono-Si and CdTe European rooftop PV systems was quantified by adding up the amounts of water consumed or withdrawn along the entire supply chain without weighting by water availability. The water consumption is 1.5 L/kWh and 0.25 L/kWh for electricity from mono-Si and CdTe PV systems, respectively. The life cycle water withdrawal without weighting by water availability caused by electricity generation with mono-Si and CdTe PV systems is 7.2 L/kWh and 0.73 L/kWh. The resulting share of consumptive water use, defined as the amount of water consumed divided by the volume of water withdrawn, is 20 % for electricity generated by the mono-Si PV system and 34 % for the CdTe PV system. In the supply chain of the mono-Si PV system, the cooling water used in the production of electronic grade silicon and silicon ingot contributes approximately 70 % to the total water withdrawal. It is assumed that 5 % of the volume of cooling water are evaporated (see section A.3.1). The water withdrawal of the CdTe European rooftop PV system is mainly caused by electricity and material supply for the production of CdTe PV modules and BOS components. The share of consumptive water use of electricity generated by large-scale thermoelectric power plants is typically around 50 % (see below). The higher contribution of electricity supply to the water withdrawal of the CdTe PV system is therefore the main reason for the higher overall share of consumptive water use compared to electricity generated by the mono-Si PV system.

The water consumption of electricity generated by European reservoir hydropower plants is slightly higher compared to electricity generated by mono-Si PV systems (1.8 L/kWh). Electricity from nuclear and hard coal power plants in Europe causes a significantly higher water consumption than the other generation sources (3.4 L/kWh and 19 L/kWh, respectively). The water withdrawal exceeds the water consumption by a factor of 2 in the case of hard coal and nuclear power plants. This finding corresponds well with the assumed share of consumptive cooling water withdrawal for hard coal and nuclear (see section A.2.1 and Tab. A.5). In contrast, the difference between water withdrawal and water consumption is insignificant for electricity generated by hydropower plants because the use of turbine water is not taken into account when assessing water withdrawal.

4.3 Water stress impact based on water consumption

The water stress impact based on water consumption of electricity generated with European rooftop mono-Si and CdTe PV systems and with reservoir hydropower plants, hard coal power plants and nuclear power plants in Europe according to the AWARE method is presented in Fig. 4.1. Electricity from CdTe PV systems causes a substantially lower life cycle water stress impact (2.3 L water-eq/kWh) than all other electricity generation technologies considered. The water stress impact of electricity generated by mono-Si PV systems (32 L water-eq/kWh) and reservoir hydropower plants (37 L water-eq/kWh) is approximately one order of magnitude higher. Electricity from nuclear power plants (69 L water-eq/kWh) and hard coal power plants (170 L water-eq/kWh) causes a 2-5 times higher water stress impact than electricity generated by PV systems and reservoir hydropower plants.

The contributions of the operation stage (including fuel supply in case of hard coal and nuclear) and the construction, maintenance and deconstruction of the power plant (i.e., non-operational water consumption) to the total water stress impact are shown separately for the three conventional technologies. For electricity generated by residential scale CdTe PV systems, the contributions of the production of CdTe modules, the production of the BOS components and the cleaning of the modules during operation are distinguished. In case of the mono-Si PV system, the shares of the following processes in the water stress impact based on water consumption are presented separately: The production of silicon, Czochralski mono-Si ingot, wafers, cells, modules and BOS as well as the operational water consumption.

The life cycle water stress impact of the considered conventional power plants is strongly dominated by the operation stage. This means that the evaporation of cooling water outweighs the water stress impact of fuel supply and the power plant infrastructure. In contrast, the contribution of PV module washing to the total water stress impact of PV systems is minor and amounts to <1 % for both CdTe and mono-Si PV systems. Manufacturing of the BOS components and the PV modules cause 57 % and 42 % of the water stress impact of electricity generated with CdTe PV systems, respectively. The processes of silicon (34 %) and silicon ingot (41 %) production are the most important contributors to the life cycle water stress impact of mono-Si PV systems. The production of mono-Si wafers, cells and modules contribute 11 %, 5 % and 4 % to the total water stress impact, respectively. The share of the BOS components in the water stress impact of electricity generated by mono-Si PV systems is 4 %. The large difference in the share of the BOS in the water stress impact of mono-Si and CdTe PV system is mainly due to their differing absolute water stress impact based on water consumption. In absolute terms, the water stress impact caused by the production of the

BOS components is very similar for the mono-Si and the CdTe PV system and amounts to roughly 1.3 L/kWh.

The electricity demand in the production of mono-Si and CdTe PV modules is an important driver of the total water stress impact. Many processes in the supply chain of PV modules require a significant amount of electricity, which is usually provided by conventional power plants. The share of electricity supply in the water stress impact caused by water consumption of electricity generated by mono-Si and CdTe PV systems is approximately 82 % and 78 %, respectively. The water stress impact of process or cooling water used directly in the manufacture of PV modules amounts to 16 % for the mono-Si and 3 % for the CdTe technology, whereas the input materials contribute 2 % and 20 % to the water stress impact, respectively.

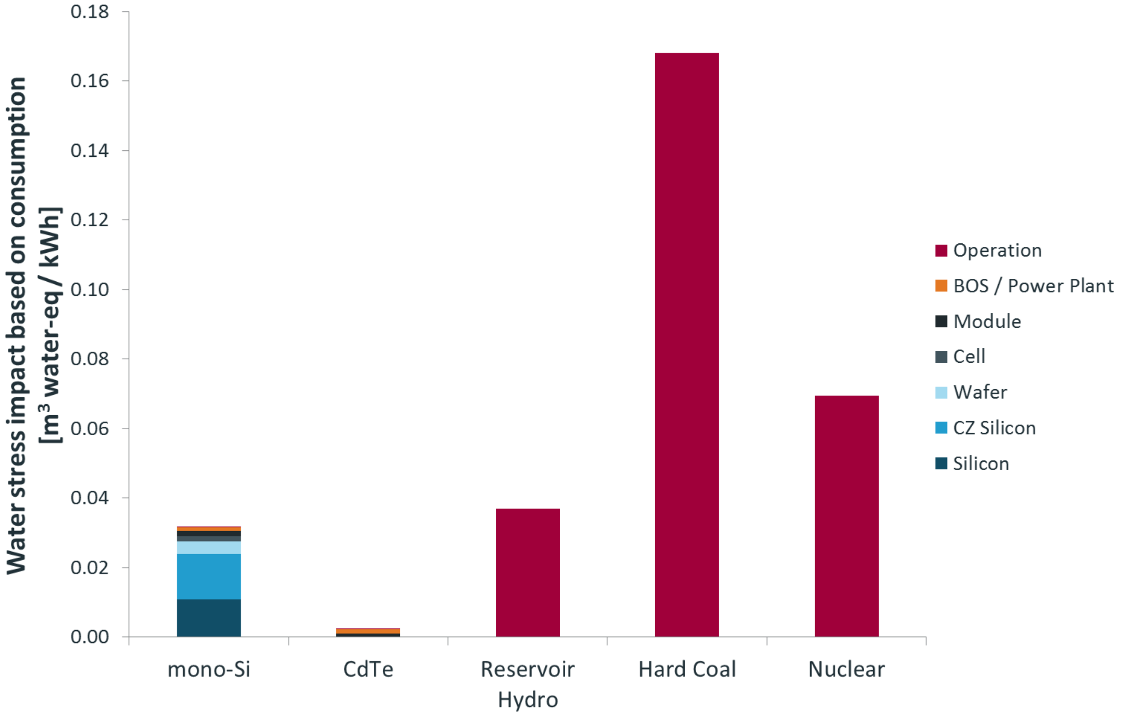

Fig. 4.1 Water stress impact based on application of the AWARE method that is caused by water consumption from the life cycle of electricity generated with European rooftop mono-Si and CdTe PV systems and reservoir hydropower plants, hard coal power plants and nuclear power plants based on regionalised life cycle inventories. The contributions of the most important processes are shown separately.

The water stress impact based on the AWARE method and the water consumption based on the inventory results (see subchapter 4.2) of electricity generation are listed in Tab. 4.1. The ratio of the water stress impact and the water consumption based on the inventory results allows the calculation of an average water scarcity factor of each electricity generation technology considered, which can then be compared to the water scarcity factors of the most important production countries. The water stress impact caused by water consumption is approximately 10-20 times higher than the water consumption obtained without weighting by water availability (see Tab. 4.1). The global average water scarcity factor is equal to 20.3 m^3 water-eq/m^3 water (see subchapter 2.4).

Tab. 4.1 Comparison of the water stress impact and the water consumption based on the life cycle inventories (LCI) of electricity generated from European rooftop mono-Si and CdTe PV systems and reservoir hydropower plants, hard coal power plants and nuclear power plants.

Water Consumption	**Water stress impact based on consumption**	**Water consumption based on LCI**	**Water stress impact / LCI**
	m^3 water-eq / kWh	**m^3 / kWh**	**m^3 water-eq / m^3**
mono-Si	3.2E-02	1.5E-03	22
CdTe	2.3E-03	2.5E-04	9.0
Reservoir Hydro	3.7E-02	1.8E-03	21
Hard Coal	1.7E-01	1.9E-02	8.8
Nuclear	6.9E-02	3.4E-03	20

The most important countries and regions contributing to the water stress impact based on water consumption of electricity generated by mono-Si PV systems are China (84 %) and Europe (9 %). These shares are similar to the European supply mix of mono-Si PV modules, which consists of approximately 79.6 % of PV modules manufactured in China, 14.5 % in Europe and 5.9 % in the Asian and Pacific region (Frischknecht et al. 2015). The quotient of the water stress impact and the water consumption based on the life cycle inventory results yields 22 m^3 water-eq/m^3 water for electricity generated by the mono-Si PV system (see Tab. 4.1), which is in between the water scarcity factors of Europe (21.0 m^3 water-eq/m^3 water) and China (27.7 m^3 water-eq/m^3 water). The vulnerability of electricity generated by European rooftop mono-Si PV systems to the risk of water availability is therefore slightly higher than the world average since the ratio of the water stress impact and the water consumption based on the inventory results is above the global average water scarcity factor.

The ratio of the water stress impact and the water consumption based on the life cycle inventory results of electricity generated by CdTe PV systems is 9.0 m^3 water-eq/m^3 water (see Tab. 4.1). The lower ratio compared to electricity from mono-Si PV systems is due to the fact, that CdTe PV modules are produced in Malaysia (84.5 %) and the USA (15.5 %). Both countries have a water scarcity factor below the world average (Malaysia: 0.587 m^3 water-eq/m^3 water; USA: 9.51 m^3 water-eq/m^3 water). Hence, the vulnerability of European rooftop CdTe PV systems to the risk of water availability is below the world average.

The water stress impact caused by water consumption of electricity generated by reservoir hydropower plants and nuclear power plants is approximately 21 times higher than the water consumption obtained from the life cycle inventories, which is similar to the European rooftop mono-Si PV system. However, the ratio between the two methods to quantify water consumption is only 8.8 m^3 water-eq/m^3 water for electricity from hard coal power plants. This is because of the different structure of the life cycle inventory for hard coal power plants in the UCTE (Union for the Coordination of the Transmission of Electricity)[4] region compared to hydropower and nuclear power plants. The life cycle inventory of an average European hard coal power plant is composed of the shares of individual countries (e.g. Germany, Spain) in the total hard coal electricity production in the UCTE region and linked to life cycle inventories of coal power generation in those countries. Germany has a high share in the total electricity generated by coal power plants (46.5 %) and a low water scarcity factor (0.124 m^3 water-eq/m^3 water). This yields a ratio of the water stress impact and the water consumption based on the life cycle inventory results, which is below the average European water scarcity factor.

4.4 Water stress impact based on water withdrawal

The water stress impact caused by water withdrawal of different electricity generation technologies is shown in Fig. 4.2. Electricity generation with European rooftop mono-Si and CdTe PV systems causes a water stress impact of 150 L water-eq/kWh and 9.8 L water-eq/kWh, respectively. The water stress impact based on water withdrawal of electricity from mono-Si PV systems is therefore higher than the water stress impact caused by electricity from reservoir hydropower plants (38 L water-eq/kWh) and comparable to nuclear electricity (160 L water-eq/kWh). Electricity generated by hard coal power plants causes the highest water stress impact based on water withdrawal (340 L water-eq/kWh).

The water stress impact based on water withdrawal of electricity generated by mono-Si PV systems is mainly caused in the direct supply chain of the PV modules (70 %). The Czochralski process for the production of mono-Si ingots and the manufacture of electronic-grade silicon require large amounts of water, of which presumably only a minor share is evaporated (see section A.3.1). The electricity supply for the production of mono-Si PV modules contributes approximately 28 % to the water stress impact caused by water withdrawal. The water stress impact associated with the production of raw materials is 2 %.

Electricity generated by CdTe PV systems has a lower water stress impact based on water withdrawal than all other electricity generation technologies considered. The main contributors to the total water withdrawal are the supply of materials (59 %) and of electricity (39 %) used for the production of CdTe PV modules and BOS components. The washing of the PV system in the operation phase has a share of 2 % in the water stress impact caused by water withdrawal.

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[4] The UCTE is no longer technically in existence and has been superseded by ENTSO-E (European Network of Transmission System Operators for Electricity). The geography of some life cycle inventories of electricity generation in the KBOB life cycle inventory data DQRv2:2016 has not been adapted to reflect this change.

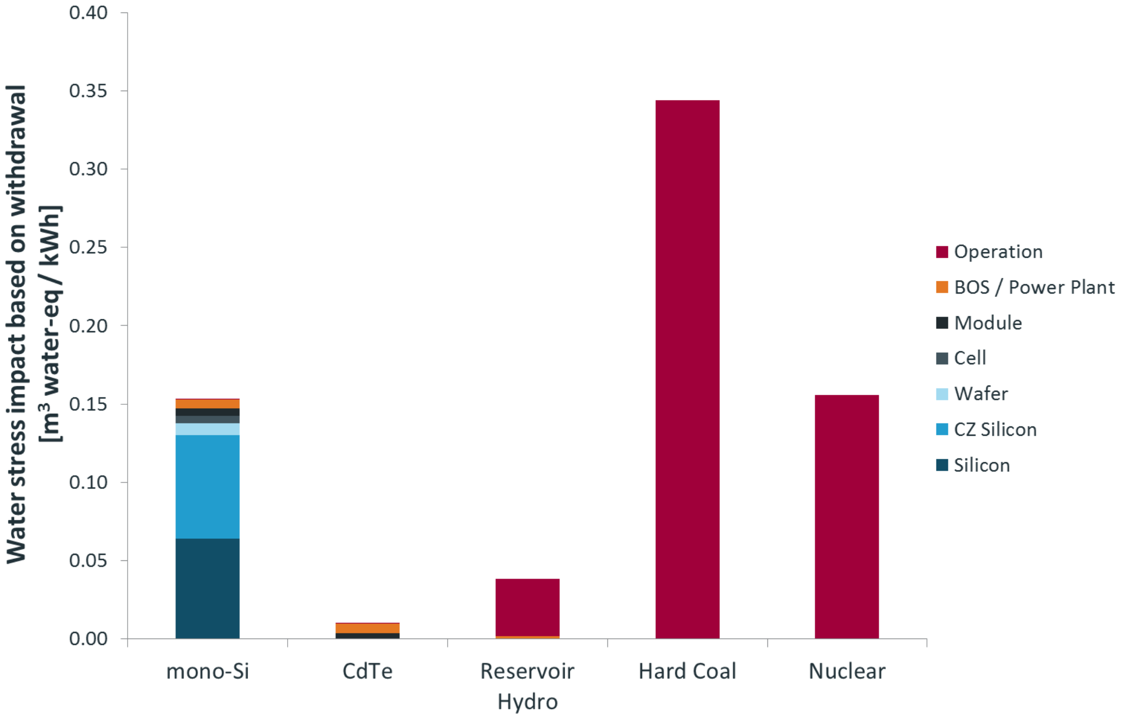


Fig. 4.2 Water stress impact based on application of the AWARE method that is caused by water withdrawal from the life cycle of electricity generated with mono-Si and CdTe PV systems and reservoir hydropower plants, hard coal power plants and nuclear power plants in Europe based on regionalised life cycle inventories. The contributions of the most important processes are shown separately.

The water stress impact based on the AWARE method and the water withdrawal based on the inventory results of electricity generation are listed in Tab. 4.2. The ratios of the water stress impact and the water withdrawal are very similar to the results for water consumption shown in Tab. 4.1. The only exception is electricity generated by CdTe PV systems, which has a significantly higher ratio when considering water withdrawal compared to water consumption. The reason for this difference is that the supply of raw materials contributes a high share to the total water withdrawal. The life cycle inventories of material production were not regionalised. The water stress impact caused by water withdrawal is therefore quantified using the world average water scarcity factor. Since the water scarcity factors for the production countries of CdTe PV modules, Malaysia and the USA, are lower than the world average, the quotient of the water stress impact and the water withdrawal is higher than for water consumption.

Tab. 4.2 Comparison of the water stress impact and the water withdrawal based on the life cycle inventories (LCI) of electricity generated with European rooftop mono-Si and CdTe PV systems and reservoir hydropower plants, hard coal power plants and nuclear power plants.

Water Withdrawal	Water stress impact based on withdrawal	Water withdrawal based on LCI	Water stress impact / LCI
	m^3 water-eq / kWh	m^3 / kWh	m^3 water-eq / m^3
mono-Si	1.5E-01	7.2E-03	21
CdTe	9.8E-03	7.3E-04	13
Reservoir Hydro	3.8E-02	1.8E-03	21
Hard Coal	3.4E-01	3.8E-02	9.0
Nuclear	1.6E-01	7.6E-03	20

5 Data quality and uncertainty

The quality of the data used to assess the water footprint of electricity generation by PV systems and conventional technologies is classified as good according to the data quality assessment criteria of the Product Environmental Footprint (PEF) Guide (European Commission 2013) and the PEF screening study of PV electricity (Stolz et al. 2016). However, there are some critical issues which would deserve more attention in future updates of this assessment.

One critical parameter is the share of consumptive water use, which reflects the amount of water evaporated per unit of water withdrawal. These shares were estimated based on data from a study of the power sector in the USA (Macknick et al. 2012) and applied to the life cycle inventories of nuclear and fossil power plants in different world regions (mainly Europe). The fractions of power plants relying on tower and once-through cooling systems were determined based on estimations in the reports of ecoinvent data v2.2 (Dones et al. 2007; Faist Emmenegger et al. 2007; Jungbluth 2007). Some extrapolations were necessary since the shares of different cooling systems were not available for all technologies. The share of consumptive cooling water use of electricity generation is particularly important since the electricity supply for the manufacture of PV modules contributes a high share to the life cycle water consumption of PV electricity.

The comparison of water consumption and water withdrawal of electricity generated with mono-Si PV systems showed that the share of consumptive water use is equally important for processes in the production of mono-Si PV modules. The manufacture of electronic-grade silicon and mono-Si ingots require large amounts of water but the share of consumptive water use is based on a generic estimate (Frischknecht & Büsser Knöpfel 2013) rather than on specific data for these processes. It is recommended to more accurately account for the water withdrawal and water emissions to air and water in future updates of the life cycle inventories of the PV supply chain.

The geographical resolution of the life cycle inventory data represents another source of uncertainty. For instance, the elctricity generation by natural gas power plants were regionalised and life cycle inventories are available for more than twenty different countries and regions. However, the life cycle inventories of electricity generation in the UCTE region are used in many country electricity mixes where specific life cycle inventories are not available. This was the case for the Malaysian electricity mix, which is used in the manufacture of CdTe PV modules. The higher water scarcity factor for water use in Europe compared to Malaysia results in an overestimation (about 6 %) of the water stress impact caused by water consumption of electricity generated by CdTe PV systems. The geographical resolution and consistency of the database with regard to the regionalisation of water use and the inclusion of water emissions to air are issues that go beyond the scope of this study. Nevertheless, regionalised life cycle inventories were compiled for the most relevant processes in the manufacture of mono-Si and CdTe PV modules and for electricity generation technologies.

6 Conclusions

The water stress impact caused by water consumption of PV electricity generated in Europe is significantly lower than the water stress impact of electricity generated by reservoir hydroelectric power plants and large-scale nuclear and hard coal power plants. The main contributor to the water stress impact of mono-Si and CdTe PV electricity is the water consumption of thermoelectric power plants supplying electricity used in the supply chain of PV systems. The operational water consumption of PV electricity is negligible.

The water stress impact based on water withdrawal of electricity generated by CdTe PV systems is significantly lower than the water stress impact of all other power generation technologies considered. Electricity from mono-Si PV systems causes a higher water stress impact than electricity generated by reservoir hydropower plants. The share of electricity supply in the water stress impact based on water withdrawal of PV electricity is lower compared to the water stress impact based on water consumption. The direct water withdrawal dominates the water stress impact of electricity generated by mono-Si PV systems whereas the supply of raw materials contributes a high share to the total water withdrawal of CdTe PV electricity.

We recommend assessing the water stress impact based on water consumption rather than based on water withdrawal. The amount of water lost to air or embodied in products is no longer available in the watershed considered, thereby leading to an increase in water scarcity. In contrast, the water withdrawn from and released into the same watershed is available for reuse in other processes after a short time period.

The most effective measure to reduce the uncertainty of the water stress impact of electricity generation quantified in this study is to collect more accurate data on the share of consumptive water use in the manufacture of mono-Si PV modules and in the electricity generation by thermoelectric power plants.

References

BAFU 2016	BAFU (2016) Hitze und Trockenheit im Sommer 2015. Auswirkungen auf Mensch und Umwelt. Bundesamt für Umwelt BAFU, Bern, CH, retrieved from: https://www.bafu.admin.ch/dam/bafu/de/dokumente/klima/uz-umwelt-zustand/Hitze%20und%20Trockenheit%20im%20Sommer%202015.pdf.download.pdf/UZ-1629-D.pdf.
Boulay et al. 2017	Boulay A.-M., Bare J., Benini L., Berger M., Lathuillière M., Manzardo A., Margni M., Motoshita M., Núñez M., Pastor A. V., Ridoutt B., Oki T., Worbe S. and Pfister S. (2017) The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on Available WAter REmaining (AWARE). In: The International Journal of Life Cycle Assessment, pp. 1-11, 10.1007/s11367-017-1333-8.
Dones et al. 2007	Dones R., Bauer C. and Röder A. (2007) Kohle. In: Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz, Vol. ecoinvent report No. 6-VI, v2.0 (Ed. Dones R.). Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH retrieved from: www.ecoinvent.org.
ecoinvent Centre 2010	ecoinvent Centre (2010) ecoinvent data v2.2, ecoinvent reports No. 1-25. Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland, retrieved from: www.ecoinvent.org.
European Commission 2013	European Commission (2013) Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. Official Journal of the European Union.
Faist Emmenegger et al. 2007	Faist Emmenegger M., Heck T., Jungbluth N. and Tuchschmid M. (2007) Erdgas. In: Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz, Vol. ecoinvent report No. 6-V, v2.0 (Ed. Dones R.). Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH retrieved from: www.ecoinvent.org.
Frischknecht et al. 2007	Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G. and Spielmann M. (2007) Overview and Methodology. ecoinvent report No. 1, v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org.

Frischknecht & Büsser Knöpfel 2013	Frischknecht R. and Büsser Knöpfel S. (2013) Swiss Eco-Factors 2013 according to the Ecological Scarcity Method. Methodological fundamentals and their application in Switzerland. Environmental studies no. 1330. Federal Office for the Environment, Bern, retrieved from: http://www.bafu.admin.ch/publikationen/publikation/01750/index.html?lang=en.
Frischknecht et al. 2015	Frischknecht R., Itten R., Sinha P., de Wild Scholten M., Zhang J., Fthenakis V., Kim H. C., Raugei M. and Stucki M. (2015) Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems. International Energy Agency (IEA) PVPS Task 12.
Frischknecht & Jolliet 2016	Frischknecht R. and Jolliet O. (2016) Global Guidance for Life Cycle Impact Assessment Indicators: Volume 1. UNEP United Nations Environment Programme, Paris, FR.
IPCC 2013	IPCC (2013) The IPCC fifth Assessment Report - Climate Change 2013: the Physical Science Basis. Working Group I, IPCC Secretariat, Geneva, Switzerland.
Jungbluth 2003	Jungbluth N. (2003) Photovoltaik. In: Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz (Ed. Dones R.). Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH retrieved from: www.ecoinvent.org.
Jungbluth 2007	Jungbluth N. (2007) Erdöl. In: Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz, Vol. ecoinvent report No. 6-IV, v2.0 (Ed. Dones R.). Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH retrieved from: www.ecoinvent.org.
KBOB et al. 2016	KBOB, eco-bau and IPB (2016) KBOB-Empfehlung 2009/1:2016: Ökobilanzdaten im Baubereich, Stand Juli 2016. Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren c/o BBL Bundesamt für Bauten und Logistik, retrieved from: http://www.bbl.admin.ch/kbob/00493/00495/index.html?lang=de.
Komoto et al. 2015	Komoto K., Ehara T., Xu H., Lv F., Wang S., Sinha P., Cunow E., Wade A., Faiman D., Araki K., Perez M., Megherbi K., Enebish N., Breyer C. and Bogdanov D. (2015) Energy from the Desert: Very Large Scale PV Power Plants for Shifting to Renewable Energy Future. IEA PVPS Task8.
Macknick et al. 2011	Macknick J., Newmark R., Heath G. and Hallett K. (2011) A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies. NREL National Renewable Energy Laboratory, Golden, CO.

Macknick et al. 2012	Macknick J., Newmark R., Heath G. and Hallett K. C. (2012) Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. In: Environmental Reserach Letters, 7, pp. 1-10, doi:10.1088/1748-9326/7/4/045802.
Meldrum et al. 2013	Meldrum J., Nettles-Anderson S., Heath G. and Macknick J. (2013) Life cycle water use for electricity generation: a review and harmonization of literature estimates. In: Environmental Research Letters, 8, pp. 1-18, doi:10.1088/1748-9326/8/1/015031.
PRé Consultants 2016	PRé Consultants (2016) SimaPro 8.3.0, Amersfoort, NL.
Stolz et al. 2016	Stolz P., Frischknecht R., Wyss F. and de Wild Scholten M. (2016) PEF screening report of electricity from photovoltaic panels in the context of the EU Product Environmental Footprint Category Rules (PEFCR) Pilots, version 2.0. treeze Ltd. commissioned by the Technical Secretariat of the PEF Pilot "Photovoltaic Electricity Generation", Uster, Switzerland.
TS PEF Pilot PV 2016	TS PEF Pilot PV (2016) Product Environmental Footprint Category Rules: Photovoltaic Modules used in Photovoltaic Power Systems for Electricity Generation (NACE/CPA class 27.90 "Manufacturing of other electrical equipment"). treeze Ltd., commissioned by the Technical Secretariat of the PEF Pilot "Photovoltaic Electricity Generation", Uster, Switzerland.

A Appendix: Regionalised life cycle inventories

A.1 Water purification

A.1.1 Regionalisation and water balance

The life cycle inventories of the supply of tap water, decarbonised water, deionised water and completely softened water were regionalised to the country level with regard to water use for the most relevant countries. The water withdrawal in the existing processes of the KBOB life cycle inventory data DQRv2:2016 was replaced by the county-specific elementary flow. In addition, water emissions to water (representing the share of water released to the same water basin as it was withdrawn from) were added in order to balance the amounts of water withdrawn from nature, the water embodied in the product and treated wastewater. Water consumption is quantified by assessing the amount of water emitted to air (which equals the difference between water withdrawn and the volume of water returned to water bodies). The electricity mix used for water purification was changed to the respective country- or region-specific supply mix. The process efficiency, material inputs, pollutant emissions as well as the amount of water withdrawn were not adapted.

A.1.2 Life cycle inventories of water purification

National water purification processes were derived from existing European life cycle inventories. As an example, the life cycle inventories of the production of tap water, decarbonised water, deionised water and completely softened water in China are shown in Tab. A.1 to Tab. A.4. The regionalised life cycle inventories for water purification in other countries only differ in the geography of the water elementary flows and the electricity mix. A list of the regionalised life cycle inventories of water purification is provided in Tab. B.1 in Appendix B.

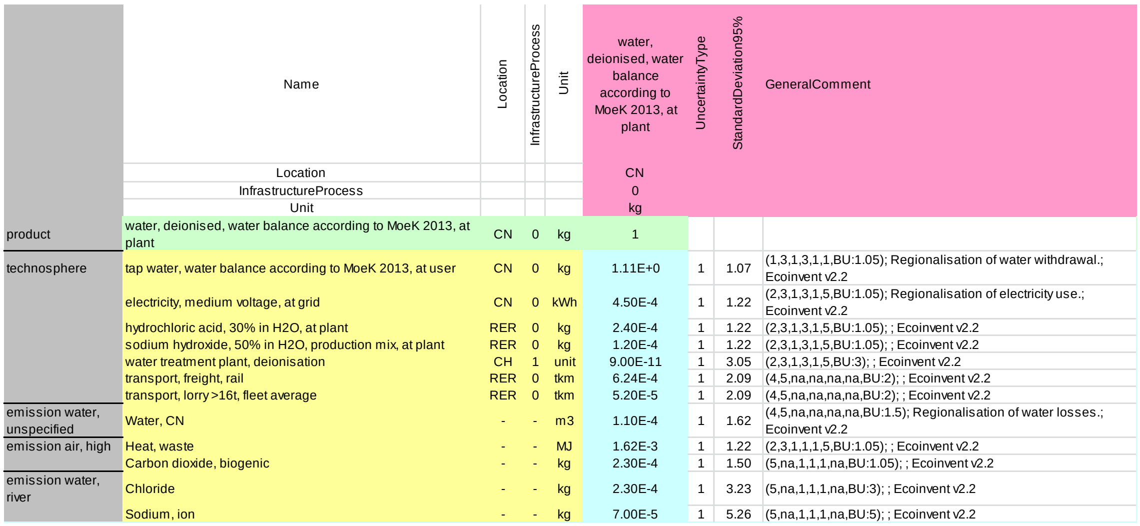
Tab. A.1 Life cycle inventory of the production of 1 kg tap water with regionalised water withdrawal, water emissions and electricity mix (China is shown as an example)

	Name	Location	InfrastructureProcess	Unit	tap water, water balance according to MoeK 2013, at user	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN			
	InfrastructureProcess				0			
	Unit				kg			
product	tap water, water balance according to MoeK 2013, at user	CN	0	kg	1			
resource, in water	Water, unspecified natural origin, CN	-	-	m3	1.13E-3	1	1.07	(1,3,1,3,1,1,BU:1.05); Regionalisation of water withdrawal.; Ecoinvent v2.2
technosphere	electricity, medium voltage, at grid	CN	0	kWh	3.90E-4	1	1.22	(2,3,1,3,1,5,BU:1.05); Regionalisation of electricity use.; Ecoinvent v2.2
	chlorine, liquid, production mix, at plant	RER	0	kg	1.00E-7	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	hydrogen peroxide, 50% in H2O, at plant	RER	0	kg	8.80E-7	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	ozone, liquid, at plant	RER	0	kg	3.33E-6	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	charcoal, at plant	GLO	0	kg	4.17E-6	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	aluminium sulphate, powder, at plant	RER	0	kg	6.33E-6	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	water supply network	CH	1	km	3.14E-10	1	3.05	(2,3,1,3,1,5,BU:3); ; Ecoinvent v2.2
	pump station	CH	1	unit	2.06E-11	1	3.05	(2,3,1,3,1,5,BU:3); ; Ecoinvent v2.2
	water storage	CH	1	unit	2.06E-11	1	3.05	(2,3,1,3,1,5,BU:3); ; Ecoinvent v2.2
	water works	CH	1	unit	1.19E-11	1	3.05	(2,3,1,3,1,5,BU:3); ; Ecoinvent v2.2
	transport, freight, rail	RER	0	tkm	8.89E-6	1	2.09	(4,5,na,na,na,na,BU:2); ; Ecoinvent v2.2
	transport, lorry >16t, fleet average	RER	0	tkm	1.48E-6	1	2.09	(4,5,na,na,na,na,BU:2); ; Ecoinvent v2.2
emission water, unspecified	Water, CN	-	-	m3	1.11E-4	1	1.62	(4,5,na,na,na,na,BU:1.5); Regionalisation of water losses.; Ecoinvent v2.2
emission air, high	Heat, waste	-	-	MJ	1.40E-3	1	1.22	(2,3,1,1,1,5,BU:1.05); ; Ecoinvent v2.2
emission water, river	Aluminium	-	-	kg	1.29E-6	1	5.26	(5,na,1,1,1,na,BU:5); ; Ecoinvent v2.2
	Chlorine	-	-	kg	1.00E-7	1	3.23	(5,na,1,1,1,na,BU:3); ; Ecoinvent v2.2
	Chloride	-	-	kg	5.04E-6	1	3.23	(5,na,1,1,1,na,BU:3); ; Ecoinvent v2.2
technosphere	disposal, wood untreated, 20% water, to municipal incineration	CH	0	kg	4.17E-6	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	1.77E-5	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2

Tab. A.2 Life cycle inventory of the production of 1 kg decarbonised water with regionalised water withdrawal and water emissions (China is shown as an example)

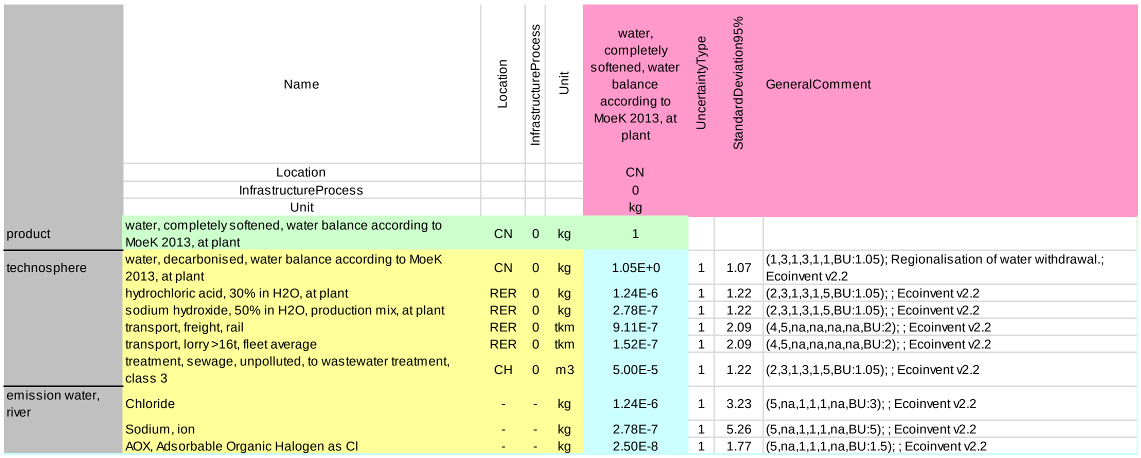
	Name	Location	InfrastructureProcess	Unit	water, decarbonised, water balance according to MoeK 2013, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN			
	InfrastructureProcess				0			
	Unit				kg			
product	water, decarbonised, water balance according to MoeK 2013, at plant	CN	0	kg	1			
resource, in water	Water, unspecified natural origin, CN	-	-	m3	1.03E-3	1	1.07	(1,3,1,3,1,1,BU:1.05); Regionalisation of water withdrawal.; Ecoinvent v2.2
technosphere	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	1.55E-8	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	lime, hydrated, packed, at plant	CH	0	kg	2.06E-7	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	iron (III) chloride, 40% in H2O, at plant	CH	0	kg	2.21E-7	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	transport, freight, rail	RER	0	tkm	2.66E-7	1	2.06	(2,3,1,3,1,5,BU:2); ; Ecoinvent v2.2
	transport, lorry >16t, fleet average	RER	0	tkm	4.43E-8	1	2.06	(2,3,1,3,1,5,BU:2); ; Ecoinvent v2.2
	disposal, decarbonising waste, 30% water, to residual material landfill	CH	0	kg	5.55E-7	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	2.50E-5	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
emission water, unspecified	Water, CN	-	-	m3	5.00E-6	1	1.62	(4,5,na,na,na,na,BU:1.5); Regionalisation of water losses.; Ecoinvent v2.2
emission water, river	Chloride	-	-	kg	1.60E-7	1	3.23	(5,na,1,1,1,na,BU:3); ; Ecoinvent v2.2

Tab. A.3 Life cycle inventory of the production of 1 kg deionised water with regionalised water withdrawal, water emissions and electricity mix (China is shown as an example)



	Name	Location	InfrastructureProcess	Unit	water, deionised, water balance according to MoeK 2013, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN			
	InfrastructureProcess				0			
	Unit				kg			
product	water, deionised, water balance according to MoeK 2013, at plant	CN	0	kg	1			
technosphere	tap water, water balance according to MoeK 2013, at user	CN	0	kg	1.11E+0	1	1.07	(1,3,1,3,1,1,BU:1.05); Regionalisation of water withdrawal.; Ecoinvent v2.2
	electricity, medium voltage, at grid	CN	0	kWh	4.50E-4	1	1.22	(2,3,1,3,1,5,BU:1.05); Regionalisation of electricity use.; Ecoinvent v2.2
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	2.40E-4	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	1.20E-4	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	water treatment plant, deionisation	CH	1	unit	9.00E-11	1	3.05	(2,3,1,3,1,5,BU:3); ; Ecoinvent v2.2
	transport, freight, rail	RER	0	tkm	6.24E-4	1	2.09	(4,5,na,na,na,na,BU:2); ; Ecoinvent v2.2
	transport, lorry >16t, fleet average	RER	0	tkm	5.20E-5	1	2.09	(4,5,na,na,na,na,BU:2); ; Ecoinvent v2.2
emission water, unspecified	Water, CN	-	-	m3	1.10E-4	1	1.62	(4,5,na,na,na,na,BU:1.5); Regionalisation of water losses.; Ecoinvent v2.2
emission air, high	Heat, waste	-	-	MJ	1.62E-3	1	1.22	(2,3,1,1,1,5,BU:1.05); ; Ecoinvent v2.2
	Carbon dioxide, biogenic	-	-	kg	2.30E-4	1	1.50	(5,na,1,1,1,na,BU:1.05); ; Ecoinvent v2.2
emission water, river	Chloride	-	-	kg	2.30E-4	1	3.23	(5,na,1,1,1,na,BU:3); ; Ecoinvent v2.2
	Sodium, ion	-	-	kg	7.00E-5	1	5.26	(5,na,1,1,1,na,BU:5); ; Ecoinvent v2.2

Tab. A.4 Life cycle inventory of the production of 1 kg completely softened water with regionalised water withdrawal and water emissions (China is shown as an example)



	Name	Location	InfrastructureProcess	Unit	water, completely softened, water balance according to MoeK 2013, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN			
	InfrastructureProcess				0			
	Unit				kg			
product	water, completely softened, water balance according to MoeK 2013, at plant	CN	0	kg	1			
technosphere	water, decarbonised, water balance according to MoeK 2013, at plant	CN	0	kg	1.05E+0	1	1.07	(1,3,1,3,1,1,BU:1.05); Regionalisation of water withdrawal.; Ecoinvent v2.2
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	1.24E-6	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	2.78E-7	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
	transport, freight, rail	RER	0	tkm	9.11E-7	1	2.09	(4,5,na,na,na,na,BU:2); ; Ecoinvent v2.2
	transport, lorry >16t, fleet average	RER	0	tkm	1.52E-7	1	2.09	(4,5,na,na,na,na,BU:2); ; Ecoinvent v2.2
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	5.00E-5	1	1.22	(2,3,1,3,1,5,BU:1.05); ; Ecoinvent v2.2
emission water, river	Chloride	-	-	kg	1.24E-6	1	3.23	(5,na,1,1,1,na,BU:3); ; Ecoinvent v2.2
	Sodium, ion	-	-	kg	2.78E-7	1	5.26	(5,na,1,1,1,na,BU:5); ; Ecoinvent v2.2
	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	2.50E-8	1	1.77	(5,na,1,1,1,na,BU:1.5); ; Ecoinvent v2.2

A.2 Electricity generation

A.2.1 Regionalisation and water balance

The water use in the life cycle inventories of electricity generation in fossil, nuclear and reservoir hydro power plants was regionalised to the country or region level for the most relevant countries and regions. The water withdrawal in the existing processes of the KBOB life cycle inventory data DQRv2:2016 was replaced by the country- or region-specific elementary flow. In addition, the water evaporation from reservoir hydropower plants was regionalised. The water emissions to air were added to the life cycle inventories of electricity generation in fossil and nuclear power plants in order to account for evaporation of cooling water. The share of consumptive water use was estimated using data on the water withdrawal and water consumption of power plants with different cooling systems (Macknick et al. 2012). Power plants with once-through cooling withdraw large amounts of water and release most of it at a higher temperature after a short period of time. In contrast, power plants with tower cooling have a lower water withdrawal combined with a high share of water evaporation. The weighted average share of consumptive water use of the two cooling systems was calculated for different power generation technologies (Tab. A.5). The fraction of hard coal and lignite power plants using tower cooling was estimated at 75 % by Dones et al. (2007). This share of consumptive water use was used globally and also applied for nuclear power plants due to lack of specific data. In accordance with Faist Emmenegger et al. (2007), it was assumed that all natural gas power plants in Europe rely on tower cooling. The fraction of heavy fuel oil power plants using tower cooling was estimated at 50 % (Jungbluth 2007) and the share of consumptive water use of the two cooling systems was assumed to be identical to those used in coal power plants.

Tab. A.5 Share of consumptive water use in total water consumption of fossil and nuclear power plants based on Macknick et al. (2012), Dones et al. (2007), Faist Emmenegger et al. (2007) and Jungbluth et al. (2007)

Electricity generation	**Share of consumptive water use (%)**		**Share of tower cooling (%)**	**Average share of consumptive water use (%)**	**Comment**
	Once-through	**Tower**			
Nuclear power plants	0.6%	61.0%	75.0%	45.9%	Share of tower cooling assumed to be the same as for coal power plants
Hard coal power plants	0.7%	68.4%	75.0%	51.5%	No differentiation between hard coal and lignite power plants
Lignite power plants	0.7%	68.4%	75.0%	51.5%	No differentiation between hard coal and lignite power plants
Natural gas power plants	0.9%	78.3%	100.0%	78.3%	
Heavy fuel oil power plants	0.7%	68.4%	50.0%	34.6%	Shares of consumptive water use assumed to be the same as for coal power plants

The efficiency of the country specific power plants, material inputs, pollutant emissions as well as the amount of water withdrawal were not adapted. The regionalised life cycle inventories were linked to the electricity mixes of the KBOB life cycle inventory data DQRv2:2016, which were not changed. The only exception are the additional life cycle inventories of electricity generated in reservoir hydropower plants which were created for several countries and linked to the respective country electricity mixes (see section A.2.4).

A.2.2 Life cycle inventories of fossil power plants

The life cycle inventories of electricity generation in hard coal, lignite, natural gas and heavy fuel oil power plants were regionalised with regard to water withdrawal and complemented by water emissions to air. The procedure described in section A.2.1 was applied for all countries with existing life cycle inventories in the KBOB life cycle inventory data DQRv2:2016.

All life cycle inventories are structured identically although specific material inputs and pollutant emissions may vary between different countries. The following Tab. A.6 to Tab. A.9 show the life cycle inventory of electricity generation in fossil power plants in one exemplary country for each technology. A list of the regionalised life cycle inventories of electricity generation in fossil power plants is provided in Tab. B.1 in Appendix B.

Tab. A.6 Life cycle inventory of burning 1 MJ of hard coal in the power plant with regionalised water withdrawal and water emissions (China is shown as an example)

	Name	Location	Infrastructure-Process	Unit	hard coal, burned in power plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN			
	InfrastructureProcess				0			
	Unit				MJ			
Outputs	hard coal, burned in power plant	CN	0	MJ	1.00E+0			
Technosphere	chlorine, liquid, production mix, at plant	RER	0	kg	1.00E-5	1	1.65	(5,4,3,2,3,5); rough guess
	light fuel oil, at regional storage	RER	0	kg	1.70E-5	1	1.20	(3,4,3,3,1,3); typical value for hard coal plant in DE
	water, completely softened, water balance according to MoeK 2013, at plant	CN	0	kg	6.00E-3	1	1.40	(4,5,3,2,3,3); estimate based on literature
	water, decarbonised, water balance according to MoeK 2013, at plant	CN	0	kg	1.50E-1	1	1.40	(4,5,3,2,3,3); estimate based on literature
	disposal, residue from cooling tower, 30% water, to sanitary landfill	CH	0	kg	5.00E-6	1	1.50	(5,1,1,1,1,1); calculated from mass balance
	hard coal power plant	CN	1	p	1.30E-12	1	3.02	(3,3,2,3,1,3);
	hard coal supply mix	CN	0	kg	4.53E-2	1	1.30	own assumption, for 300 MW unit Shandong (1999) assumed average for China; in original dataset 1.17, based on uncertainty on power plant data base and coal quality (mismatch between regional supply mix and input coal)
	transport, lorry >16t, fleet average	RER	0	tkm	6.75E-7	1	3.00	own assumption; original 2.10 '(4,2,2,3,1,5); average distance is guesstimate
	transport, coal freight, rail	CN	0	tkm	1.35E-6	1	3.00	own assumption; original 2.10 '(4,2,2,3,1,5); average distance is guesstimate
	disposal, hard coal ash, 0% water, to residual material landfill	PL	0	kg	7.15E-3	1	1.58	(5,1,1,5,3,1); calculated from mass balance
resource, in water	Water, cooling, unspecified natural origin, CN			m3	3.50E-3	1	1.40	(4,5,3,2,1,5); estimate based on literature
	Water, CN			kg	1.88E+0	1	1.40	assumption: 51.4% evaporation of water; Macknick et al. 2011
air, high population density	Heat, waste			MJ	5.67E-1	1	1.07	(2,1,1,1,1,1); calculated from energy balance
	Antimony			kg	1.98E-9	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Arsenic			kg	1.21E-8	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Barium			kg	1.22E-7	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Benzene			kg	2.17E-7	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Benzo(a)pyrene			kg	2.00E-13	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Boron			kg	7.00E-7	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Bromine			kg	5.71E-7	1	2.70	own assumption; original 2.28 (5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Butane			kg	1.90E-8	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Cadmium			kg	1.16E-9	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Carbon dioxide, fossil			kg	9.50E-2	1	1.11	(3,1,1,1,1,1); based on available literature
	Carbon monoxide, fossil			kg	8.00E-6	1	6.00	own assumption; original 5.09 (3,4,3,2,1,5); based on available literature
	Chromium			kg	1.14E-8	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Chromium VI			kg	1.41E-9	1	4.00	based on range of data
	Cobalt			kg	4.72E-9	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Copper			kg	1.53E-8	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Dinitrogen monoxide			kg	5.00E-7	1	2.00	own assumption; original 1.61 (3,4,3,2,1,5); based on available literature
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	7.00E-15	1	4.00	own assumption; original 3.12 (3,5,3,2,1,5); based on available literature
	Ethane			kg	4.10E-8	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Formaldehyde			kg	5.80E-8	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Hydrocarbons, aliphatic, alkanes, unspecified			kg	2.19E-7	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Hydrocarbons, aliphatic, unsaturated			kg	2.16E-7	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Hydrogen chloride			kg	3.05E-5	1	3.00	own assumption; original 2.28 (5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Hydrogen fluoride			kg	2.73E-6	1	3.00	own assumption; original 2.28 (5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Iodine			kg	2.92E-7	1	3.00	own assumption; original 2.28 (5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Lead			kg	6.32E-8	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Lead-210			kBq	1.21E-4	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Manganese			kg	6.03E-8	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Mercury			kg	3.20E-9	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Methane, fossil			kg	1.00E-6	1	2.50	own assumption; original 1.61 (3,4,3,2,1,5); based on available literature
	Molybdenum			kg	2.15E-9	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Nickel			kg	3.33E-8	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Nitrogen oxides			kg	4.08E-4	1	2.00	own assumption; original 1.52 (3,1,1,1,1,1); see power plant data base for details
	PAH, polycyclic aromatic hydrocarbons			kg	1.00E-9	1	4.00	own assumption; original 3.12 (3,5,3,2,1,5); based on available literature
	Particulates, < 2.5 um			kg	4.23E-5	1	4.00	own assumption; original 3.27 (5,1,1,1,1,5); see power plant data base for details
	Particulates, > 10 um			kg	1.06E-5	1	2.50	own assumption; original 1.83 (5,1,1,1,1,5); see power plant data base for details
	Particulates, > 2.5 um, and < 10um			kg	4.97E-6	1	3.50	own assumption; original 2.28 (5,1,1,1,1,5); see power plant data base for details
	Pentane			kg	1.47E-7	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Polonium-210			kBq	2.22E-4	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Potassium-40			kBq	2.99E-5	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Propane			kg	3.50E-8	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Propene			kg	1.60E-8	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Radium-226			kBq	3.14E-5	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Radium-228			kBq	9.28E-6	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Radon-220			kBq	6.50E-4	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Radon-222			kBq	3.66E-4	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain

Tab. A.6 Life cycle inventory of burning 1 MJ of hard coal in the power plant with regionalised water withdrawal and water emissions (China is shown as an example) (continued)

	Name	Location	Infrastructure-Process	Unit	hard coal, burned in power plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN			
	InfrastructureProcess				0			
	Unit				MJ			
	Selenium			kg	9.89E-9	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Strontium			kg	1.11E-7	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Sulfur dioxide			kg	7.73E-4	1	2.00	own assumption; original 1.11 (3,1,1,1,1,1); see power plant data base for details
	Thorium-228			kBq	5.00E-6	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Thorium-232			kBq	7.86E-6	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Toluene			kg	1.09E-7	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Uranium-238			kBq	2.61E-5	1	5.00	own assumption; extrapol. from previously estimated 3.27 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Vanadium			kg	2.79E-8	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
	Xylene			kg	9.22E-7	1	2.50	own assumption; original 1.65 (3,5,3,2,1,5); based on available literature
	Zinc			kg	7.70E-8	1	6.00	own assumption; extrapol. from previously estimated 5.31 (5,1,1,1,1,5); calc. from trace element balance, input uncertain
water, unspecified	Heat, waste			MJ	1.45E-1	1	1.07	(2,1,1,1,1,1); calculated from energy balance

Tab. A.7 Life cycle inventory of burning 1 MJ of lignite in a power plant with regionalised water withdrawal and water emissions (Germany is shown as an example)

	Name	Location	Infrastructure-Process	Unit	lignite, burned in power plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE			
	InfrastructureProcess				0			
	Unit				MJ			
Outputs	lignite, burned in power plant	DE	0	MJ	1.00E+0			
Technosphere	lignite power plant	RER	1	p	9.72E-13	1	3.02	(3,3,2,3,1,3);
	lignite, at mine	RER	0	kg	1.15E-1	1	1.07	(2,1,1,1,1,1); see power plant data base for details
	chlorine, liquid, production mix, at plant	RER	0	kg	1.00E-5	1	1.65	(5,4,3,2,3,5); rough guess
	water, completely softened, water balance according to MoeK 2013, at plant	DE	0	kg	6.00E-3	1	1.40	(4,5,3,2,3,3); estimate based on literature
	water, decarbonised, water balance according to MoeK 2013, at plant	DE	0	kg	1.50E-1	1	1.40	(4,5,3,2,3,3); estimate based on literature
	sOx retained, in lignite flue gas desulphurisation	GLO	0	kg	9.92E-4	1	1.11	(3,1,1,1,1,1); see power plant data base for details
	nOx retained, in SCR	GLO	0	kg	2.02E-4	1	1.52	(3,1,1,1,1,1); see power plant data base for details
	transport, freight, rail	RER	0	tkm	7.50E-6	1	2.10	(4,2,2,3,1,5); average distance is guesstimate
	disposal, lignite ash, 0% water, to opencast refill	DE	0	kg	7.13E-3	1	1.50	(5,1,1,1,1,1); calculated from mass balance
resource, in water	Water, cooling, unspecified natural origin, DE			m3	3.50E-3	1	1.40	(4,5,3,2,1,5); estimate based on literature
air, low population density	Water, DE			kg	1.88E+0	1	1.40	(4,5,3,2,1,5); assumption: 51.4% evaporation of water; Macknick et al. 2011
air, low population density	Heat, waste			MJ	6.72E-1	1	1.07	(2,1,1,1,1,1); calculated from energy balance
	Antimony			kg	1.31E-11	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Arsenic			kg	7.38E-10	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Barium			kg	4.36E-9	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Benzene			kg	2.17E-7	1	1.65	(3,5,3,2,1,5); based on available literature
	Benzo(a)pyrene			kg	2.00E-13	1	1.65	(3,5,3,2,1,5); based on available literature
	Boron			kg	2.07E-6	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Bromine			kg	2.76E-8	1	2.28	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Butane			kg	1.90E-8	1	1.65	(3,5,3,2,1,5); based on available literature
	Cadmium			kg	1.53E-11	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Carbon dioxide, fossil			kg	1.08E-1	1	1.11	(3,1,1,1,1,1); based on available literature
	Carbon monoxide, fossil			kg	2.00E-5	1	5.09	(3,4,3,2,1,5); based on available literature
	Chromium			kg	1.94E-10	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Chromium VI			kg	2.40E-11	1	4.00	based on range of data
	Cobalt			kg	8.73E-11	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Copper			kg	2.01E-10	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Dinitrogen monoxide			kg	2.59E-6	1	1.61	(3,4,3,2,1,5); based on available literature
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	7.00E-15	1	3.12	(3,5,3,2,1,5); based on available literature
	Ethane			kg	4.10E-8	1	1.65	(3,5,3,2,1,5); based on available literature
	Formaldehyde			kg	5.80E-8	1	1.65	(3,5,3,2,1,5); based on available literature
	Hydrocarbons, aliphatic, alkanes, unspecified			kg	2.19E-7	1	1.65	(3,5,3,2,1,5); based on available literature
	Hydrocarbons, aliphatic, unsaturated			kg	2.16E-7	1	1.65	(3,5,3,2,1,5); based on available literature
	Hydrogen chloride			kg	2.93E-6	1	2.28	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Hydrogen fluoride			kg	8.17E-7	1	2.28	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Iodine			kg	2.59E-8	1	2.28	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Lead			kg	5.24E-10	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Lead-210			kBq	1.25E-6	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Manganese			kg	1.09E-9	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Mercury			kg	2.30E-9	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Methane, fossil			kg	1.00E-6	1	1.61	(3,4,3,2,1,5); based on available literature
	Molybdenum			kg	8.73E-11	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Nickel			kg	4.32E-10	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Nitrogen oxides			kg	7.15E-5	1	1.52	(3,1,1,1,1,1); see power plant data base for details
	PAH, polycyclic aromatic hydrocarbons			kg	1.00E-9	1	3.12	(3,5,3,2,1,5); based on available literature
	Particulates, < 2.5 um			kg	4.84E-6	1	3.27	(5,1,1,1,1,5); see power plant data base for details
	Particulates, > 10 um			kg	5.29E-6	1	1.83	(5,1,1,1,1,5); see power plant data base for details
	Particulates, > 2.5 um, and < 10um			kg	5.70E-7	1	2.28	(5,1,1,1,1,5); see power plant data base for details
	Pentane			kg	1.47E-7	1	1.65	(3,5,3,2,1,5); based on available literature
	Polonium-210			kBq	2.29E-6	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Potassium-40			kBq	8.12E-7	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain

Tab. A.7 Life cycle inventory of burning 1 MJ of lignite in a power plant with regionalised water withdrawal and water emissions (Germany is shown as an example) (continued)

	Name	Location	Infrastructure-Process	Unit	lignite, burned in power plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE			
	InfrastructureProcess				0			
	Unit				MJ			
	Propane			kg	3.50E-8	1	1.65	(3,5,3,2,1,5); based on available literature
	Propene			kg	1.60E-8	1	1.65	(3,5,3,2,1,5); based on available literature
	Radium-226			kBq	3.24E-7	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Radium-228			kBq	3.16E-7	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Radon-220			kBq	1.38E-4	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Radon-222			kBq	2.45E-4	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Selenium			kg	2.98E-9	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Strontium			kg	4.58E-10	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Sulfur dioxide			kg	5.27E-5	1	1.11	(3,1,1,1,1,1); see power plant data base for details
	Thorium-228			kBq	1.70E-7	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Thorium-232			kBq	2.67E-7	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Toluene			kg	1.09E-7	1	1.65	(3,5,3,2,1,5); based on available literature
	Uranium-238			kBq	2.70E-7	1	3.27	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Vanadium			kg	1.09E-10	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
	Xylene			kg	9.22E-7	1	1.65	(3,5,3,2,1,5); based on available literature
	Zinc			kg	7.64E-10	1	5.31	(5,1,1,1,1,5); calculated from trace element balance, input uncertain
water, river	Heat, waste			MJ	1.77E-1	1	1.07	(2,1,1,1,1,1); calculated from energy balance

Tab. A.8 Life cycle inventory of burning 1 MJ of natural gas in a power plant with regionalised water withdrawal and water emissions (Germany is shown as an example)

	Name	Location	Infrastructure-Process	Unit	natural gas, burned in power plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE			
	InfrastructureProcess				0			
	Unit				MJ			
Outputs	natural gas, burned in power plant	DE	0	MJ	1.00E+0			
Technosphere	gas power plant, 100MWe	RER	1	p	6.79E-12	1	2.00	uncertainty of life time
	water, decarbonised, water balance according to MoeK 2013, at plant	DE	0	kg	2.00E-1	1	2.50	range of values from differnet references
	water, completely softened, water balance according to MoeK 2013, at plant	DE	0	kg	6.00E-3	1	2.50	range of values from differnet references
	disposal, residue from cooling tower, 30% water, to sanitary landfill	CH	0	kg	1.00E-6	1	8.00	rough estimate, high uncertainty
	natural gas, high pressure, at consumer	DE	0	MJ	1.00E+0	1	1.00	0
air, unspecified	Water, DE			kg	1.61E-1			Assumption: 78.3% evaporation of water; Macknick et al. 2011
air, high population density	Heat, waste			MJ	6.63E-1	1	1.05	heating value and efficiency
	Nitrogen oxides			kg	3.57E-5	1	3.00	estimate from range of values from different references
	Carbon monoxide, fossil			kg	1.70E-6	1	3.00	estimate from range of values from different references
	Carbon dioxide, fossil			kg	5.60E-2	1	1.05	composition of natural gas
	Sulfur dioxide			kg	5.00E-7	1	1.10	composition of natural gas
	Particulates, < 2.5 um			kg	3.00E-7	1	3.00	estimate from range of values from different references
	Dinitrogen monoxide			kg	5.00E-7	1	3.00	estimate from range of values from different references
	Mercury			kg	3.00E-11	1	5.00	trace element in natural gas
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	2.90E-17	1	8.00	rough estimate, high uncertainty
	Methane, fossil			kg	1.00E-6	1	5.00	estimate from range of values from different references
	Acetaldehyde			kg	8.00E-10	1	8.00	rough estimate, high uncertainty
	Benzo(a)pyrene			kg	5.29E-13	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	Benzene			kg	9.26E-10	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	Butane			kg	9.26E-7	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	Acetic acid			kg	1.21E-7	1	8.00	rough estimate, high uncertainty
	Formaldehyde			kg	3.31E-8	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	PAH, polycyclic aromatic hydrocarbons			kg	8.00E-9	1	8.00	rough estimate, high uncertainty
	Pentane			kg	1.15E-6	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	Propane			kg	7.05E-7	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	Propionic acid			kg	1.60E-8	1	8.00	rough estimate, high uncertainty
	Toluene			kg	1.50E-9	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	Acenaphthene			kg	7.93E-13	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	Ethane			kg	1.37E-6	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein
	Hexane			kg	7.93E-7	1	5.00	US EPA 1998, high uncertainty reported qulitatively therein

Tab. A.9 Life cycle inventory of burning 1 MJ of heavy fuel oil in a power plant with regionalised water withdrawal and water emissions (Germany is shown as an example)

	Name	Location	Infrastructure-Process	Unit	heavy fuel oil, burned in power plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE			
	InfrastructureProcess				0			
	Unit				MJ			
Outputs	heavy fuel oil, burned in power plant	DE	0	MJ	1.00E+0			
Technosphere	water, decarbonised, water balance according to MoeK 2013, at plant	DE	0	kg	5.00E-2	1	1.13	(2,2,1,1,1,4); Literature data for this country
	water, completely softened, water balance according to MoeK 2013, at plant	DE	0	kg	1.00E-2	1	1.13	(2,2,1,1,1,4); Literature data for this country
	limestone, crushed, washed	CH	0	kg	1.38E-3	1	1.24	(2,4,1,3,1,5); IPPC 2001 for flue gas treatment
	ammonia, liquid, at regional storehouse	RER	0	kg	6.32E-5	1	1.24	(2,4,1,3,1,5); IPPC 2001 for flue gas treatment
	heavy fuel oil, at regional storage	RER	0	kg	2.43E-2	1	1.09	(2,2,1,1,1,3); Literature data for heating value
	oil power plant 500MW	RER	1	p	1.24E-12	1	3.05	(2,na,1,1,1,5); Estimation based on case study
	disposal, separator sludge, 90% water, to hazardous waste incineration	CH	0	kg	1.27E-5	1	1.09	(2,2,1,1,1,3); Literature data for this country
	disposal, residue from cooling tower, 30% water, to sanitary landfill	CH	0	kg	2.40E-6	1	1.09	(2,2,1,1,1,3); Literature data for this country
resource, in water	Water, cooling, unspecified natural origin, DE			m3	1.00E-2	1	3.02	(2,3,1,3,1,4); Estimation with literature data, basic uncertainty estimated = 3
air, high population density	Water, DE			kg	3.47E+0	1	3.02	(2,2,1,1,1,4); assumption: 34.5% evaporation of water; Macknick et al. 2011
air, high population density	Heat, waste			MJ	4.89E-1	1	1.09	(2,1,1,1,1,3); Calculation
	Acetaldehyde			kg	1.82E-7	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Acetone			kg	1.82E-7	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Ammonia			kg	1.00E-7	1	8.17	Calculation from ranges
	Hydrocarbons, aliphatic, alkanes, unspecified			kg	7.45E-7	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Hydrocarbons, aliphatic, unsaturated			kg	3.72E-8	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Hydrocarbons, aromatic			kg	7.45E-9	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Arsenic			kg	2.11E-9	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Benzo(a)pyrene			kg	1.50E-11	1	3.11	(3,3,4,3,3,3); Literature
	Benzene			kg	3.72E-8	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Beryllium			kg	5.58E-11	1	5.04	(3,3,3,3,1,3); Literature
	Calcium			kg	3.00E-8	1	1.60	(3,3,3,3,3,3); Literature
	Cadmium			kg	1.01E-9	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Methane, fossil			kg	3.72E-6	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Cobalt			kg	1.12E-8	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Carbon monoxide, fossil			kg	6.50E-6	1	5.01	(2,2,1,1,1,3); Literature data for this country
	Carbon dioxide, fossil			kg	7.80E-2	1	1.09	(2,2,1,1,1,3); Literature data for this country
	Zinc			kg	7.68E-9	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Vanadium			kg	3.20E-7	1	10.56	Calculation based on particle emission. Deviation calculated from ranges
	Sulfur dioxide			kg	1.38E-4	1	1.09	(2,2,1,1,1,3); Literature data for this country
	Selenium			kg	1.60E-9	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Propane			kg	3.72E-8	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Lead			kg	1.09E-8	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Particulates, > 2.5 um, and < 10um			kg	1.07E-6	1	2.01	(2,2,1,1,1,3); Literature data for this country
	Particulates, < 2.5 um			kg	5.33E-6	1	3.01	(2,2,1,1,1,3); Literature data for this country
	PAH, polycyclic aromatic hydrocarbons			kg	1.80E-9	1	3.06	(2,4,1,3,1,5); Literature
	Nitrogen oxides			kg	5.54E-5	1	1.51	(2,2,1,1,1,3); Literature data for this country
	Nickel			kg	8.83E-8	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Sodium			kg	3.00E-7	1	1.60	(3,3,3,3,3,3); Literature
	Dinitrogen monoxide			kg	1.00E-6	1	1.51	(2,2,1,1,1,3); Literature data for this country

Tab. A.9 Life cycle inventory of burning 1 MJ of heavy fuel oil in a power plant with regionalised water withdrawal and water emissions (Germany is shown as an example) (continued)

	Name	Location	Infrastructure-Process	Unit	heavy fuel oil, burned in power plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE			
	InfrastructureProcess				0			
	Unit				MJ			
	Molybdenum			kg	2.43E-9	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Manganese			kg	3.52E-9	1	8.99	Calculation based on particle emission. Deviation calculated from ranges
	Methanol			kg	3.72E-7	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Mercury			kg	1.50E-10	1	12.83	Calculation from ranges
	Hydrogen fluoride			kg	3.01E-8	1	1.57	(2,3,1,1,3,3); Literature
	Hydrogen chloride			kg	4.51E-8	1	1.57	(2,3,1,1,3,3); Literature
	Formaldehyde			kg	5.59E-7	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Iron			kg	7.00E-8	1	5.09	(3,3,3,3,3,3); Literature
	Ethanol			kg	3.72E-7	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	1.00E-14	1	3.06	(2,4,1,3,1,5); Literature
	Acetic acid			kg	7.45E-7	1	1.83	Calculation based on VOC emission. Deviation calculated from ranges
	Copper			kg	1.50E-8	1	9.90	Calculation based on particle emission. Deviation calculated from ranges
	Chromium VI			kg	3.11E-10	1	20.07	(3,3,3,3,1,2); Literature, basic uncertainity = 20
	Chromium			kg	3.43E-9	1	11.17	Calculation based on particle emission. Deviation calculated from ranges
air, unspecified	Carbon dioxide, fossil			kg	6.18E-4	1	1.22	(2,na,1,1,1,5); Calculation for limestone use
water, river	Heat, waste			MJ	2.63E-1	1	1.14	(3,3,1,1,1,3); Calculation with 35% share of cooling water, electricity supply subtracted
	Hypochlorite			kg	5.90E-7	1	1.61	(3,4,3,3,3,3); Literature
	AOX, Adsorbable Organic Halogen as Cl			kg	4.24E-9	1	1.14	Mean of values for Europe, range of concentrations
	Arsenic			kg	1.19E-10	1	1.00	Mean of values for Europe, range of concentrations
	BOD5, Biological Oxygen Demand			kg	1.68E-6	1	2.96	Mean of values for Europe, range of concentrations
	Cadmium			kg	2.91E-10	1	3.65	Mean of values for Europe, range of concentrations
	Chloride			kg	2.44E-5	1	6.59	Mean of values for Europe, range of concentrations
	Chromium			kg	3.06E-9	1	4.87	Mean of values for Europe, range of concentrations
	Cobalt			kg	2.39E-10	1	1.00	Mean of values for Europe, range of concentrations
	COD, Chemical Oxygen Demand			kg	1.84E-6	1	3.99	Mean of values for Europe, range of concentrations
	Copper			kg	2.54E-9	1	5.48	Mean of values for Europe, range of concentrations
	Fluoride			kg	2.03E-7	1	5.74	Mean of values for Europe, range of concentrations
	Hydrocarbons, unspecified			kg	3.71E-8	1	1.52	Mean of values for Europe, range of concentrations
	Iron			kg	1.26E-7	1	2.65	Mean of values for Europe, range of concentrations
	Lead			kg	4.99E-9	1	4.12	Mean of values for Europe, range of concentrations
	Manganese			kg	3.58E-9	1	1.00	Mean of values for Europe, range of concentrations
	Mercury			kg	1.25E-10	1	4.47	Mean of values for Europe, range of concentrations
	Nickel			kg	1.77E-8	1	3.22	Mean of values for Europe, range of concentrations
	Nitrogen			kg	8.17E-6	1	1.40	Mean of values for Europe, range of concentrations
	Oils, unspecified			kg	5.67E-8	1	1.41	Mean of values for Europe, range of concentrations
	Phosphorus			kg	1.85E-8	1	1.03	Mean of values for Europe, range of concentrations
	Sulfate			kg	2.00E-4	1	1.32	Mean of values for Europe, range of concentrations
	Sulfide			kg	5.38E-8	1	2.83	Mean of values for Europe, range of concentrations
	Sulfite			kg	1.80E-6	1	1.40	Mean of values for Europe, range of concentrations
	Suspended solids, unspecified			kg	1.52E-6	1	1.53	Mean of values for Europe, range of concentrations
	Thallium			kg	3.70E-9	1	1.00	Mean of values for Europe, range of concentrations
	Tin			kg	1.19E-10	1	1.00	Mean of values for Europe, range of concentrations
	TOC, Total Organic Carbon			kg	1.03E-6	1	1.00	Mean of values for Europe, range of concentrations
	Vanadium			kg	3.61E-8	1	5.16	Mean of values for Europe, range of concentrations
	Zinc			kg	6.31E-9	1	2.79	Mean of values for Europe, range of concentrations
water, ocean	Hypochlorite			kg	1.10E-7	1	1.61	(3,4,3,3,3,3); Literature

A.2.3 Life cycle inventories of nuclear power plants

The life cycle inventories of electricity generation in pressure and boiling water reactors were regionalised to the country or region level with regard to water withdrawal and complemented by water emissions to air. The procedure and data sources described in section A.2.1 were applied for all countries with existing life cycle inventories in the KBOB life cycle inventory data DQRv2:2016.

All life cycle inventories are structured identically although specific material inputs and pollutant emissions may vary between different countries. The following Tab. A.10 shows the life cycle inventory of electricity generation in nuclear power plants in Germany, which is used as an example. A list of the regionalised life cycle inventories of electricity generation in nuclear power plants is provided in Tab. B.1 in Appendix B.

Tab. A.10 Life cycle inventory of the production of 1 kWh electricity in nuclear power plants (boiling water reactor and pressure water reactor) with regionalised water withdrawal and water emissions (Germany is shown as an example)

	Name	Location	Infrastructure-Process	Unit	electricity, nuclear, at power plant boiling water reactor	electricity, nuclear, at power plant pressure water reactor	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE	DE			
	InfrastructureProcess				0	0			
	Unit				kWh	kWh			
Outputs	electricity, nuclear, at power plant boiling water reactor	DE	0	kWh	1.00E+0				
	electricity, nuclear, at power plant pressure water reactor	DE	0	kWh		1.00E+0			
Technosphere	water, decarbonised, water balance according to MoeK 2013, at plant	DE	0	kg	3.27E+0	2.68E+0	1	1.20	own estimation
	diesel, burned in diesel-electric generating set	GLO	0	MJ	3.49E-4	3.88E-4	1	1.30	own estimation
	lubricating oil, at plant	RER	0	kg	1.53E-6	1.70E-6	1	1.30	own estimation
	acetylene, at regional storehouse	CH	0	kg	3.40E-8	3.78E-8	1	1.25	own estimation
	anionic resin, at plant	CH	0	kg	1.11E-6	6.75E-8	1	1.15	own estimation
	argon, liquid, at plant	RER	0	kg	2.46E-5	2.74E-5	1	1.30	own estimation
	borax, anhydrous, powder, at plant	RER	0	kg	3.03E-8				
	boric acid, anhydrous, powder, at plant	RER	0	kg	2.42E-8	6.74E-8	1	1.15	own estimation on data from utility
	carbon dioxide liquid, at plant	RER	0	kg	1.58E-7	1.75E-7	1	1.30	own estimation
	cationic resin, at plant	CH	0	kg	1.11E-6	6.75E-8	1	1.15	own estimation
	cement, unspecified, at plant	CH	0	kg	8.10E-6	9.64E-7	1	1.30	own estimation
	chemicals inorganic, at plant	GLO	0	kg	6.30E-7	2.45E-6	1	1.25	own estimation
	chemicals organic, at plant	GLO	0	kg	1.30E-6	1.45E-6	1	1.20	own estimation
	flat glass, coated, at plant	RER	0	kg	4.13E-6	4.59E-6	1	1.30	own estimation
	hydrogen, liquid, at plant	RER	0	kg	9.71E-6	1.08E-5	1	1.30	own estimation
	nitrogen, liquid, at plant	RER	0	kg	5.83E-5	6.48E-5	1	1.30	own estimation
	oxygen, liquid, at plant	RER	0	kg	1.58E-5	1.75E-5	1	1.30	own estimation
	paper, woodfree, coated, at integrated mill	RER	0	kg	6.07E-7	6.75E-7	1	1.30	own estimation
	cast iron, at plant	RER	0	kg	1.21E-7	1.35E-7	1	1.20	extrapolation from another plant type
	steel, low-alloyed, at plant	RER	0	kg	5.70E-6	1.70E-6	1	1.60	own assumption
	reinforcing steel, at plant	RER	0	kg	8.10E-7	4.90E-7	1	1.30	own assumption
	concrete, normal, at plant	CH	0	m3	1.67E-8	1.02E-8	1	1.30	own estimation
	transport, lorry 20-28t, fleet average	CH	0	tkm	4.85E-5	5.45E-5	1	2.10	standard
	nuclear power plant, boiling water reactor 1000MW	DE	1	p	3.03E-12		1	1.05	estimation of total net electricity over a lifetime
	fuel elements BWR, UO2 4.0% & MOX, at nuclear fuel fabrication plant	DE	0	kg	2.63E-6		1	1.20	estimated variation over lifetime
	nuclear spent fuel, in reprocessing, at plant	RER	0	kg	1.05E-6	1.01E-6	1	1.50	own assumption
	nuclear spent fuel, in conditioning, at plant	CH	0	kg	1.58E-6	1.52E-6	1	1.50	own assumption
	radioactive waste, in interim storage, for final repository LLW	CH	0	m3	1.61E-8	1.76E-9	1	1.20	own estimation
	radioactive waste, in interim storage conditioning	CH	0	m3	4.68E-10	4.32E-11	1	1.20	own estimation
	radioactive waste, in final repository for nuclear waste LLW	CH	0	m3	4.25E-8	2.98E-8	1	1.40	own estimation
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	9.16E-7	1.02E-6	1	1.30	own estimation
	disposal, separator sludge, 90% water, to hazardous waste incineration	CH	0	kg	2.06E-6	2.29E-6	1	1.30	own estimation
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.54E-6	1.71E-6	1	1.30	own estimation
	bitumen, at refinery	CH	0	kg		8.10E-7	1	1.30	own estimation
	sodium hypochlorite, 15% in H2O, at plant	RER	0	kg		1.81E-5	1	1.30	own estimation
	nuclear power plant, pressure water reactor 1000MW	DE	1	p		3.06E-12	1	1.05	estimation of total net electricity over a lifetime
	fuel elements PWR, UO2 4.0% & MOX, at nuclear fuel fabrication plant	DE	0	kg		2.53E-6	1	1.15	estimated variation over lifetime
resource, in water	Water, river, DE			m3	4.73E-3	5.75E-3	1	1.20	own estimation
air, low population density	Water, DE			kg	3.67E+0	3.87E+0	1	1.20	assumption: 45.9% evaporation of water; Macknick et al. 2011
air, low population density	Heat, waste			MJ	7.31E+0	7.31E+0	1	1.03	uncertainty on efficiency
	Argon-41			kBq	1.37E-3	3.72E-2	1	1.50	uncertainty declared in reports for radioactive releases
	Hydrogen-3, Tritium			kBq	3.67E-2	7.00E-2	1	1.50	uncertainty declared in reports for radioactive releases
	Iodine-131			kBq	3.67E-2	3.54E-7	1	1.50	uncertainty declared in reports for radioactive releases
	Krypton-85			kBq	1.72E-2	1.11E-1	1	1.50	uncertainty declared in reports for radioactive releases
	Krypton-85m			kBq	3.09E-3	6.43E-4	1	1.50	uncertainty declared in reports for radioactive releases
	Krypton-87			kBq	3.11E-3	1.75E-4	1	1.50	uncertainty declared in reports for radioactive releases
	Krypton-88			kBq	1.49E-3	5.22E-4	1	1.50	uncertainty declared in reports for radioactive releases
	Krypton-89			kBq	1.10E-4	4.92E-5	1	1.50	uncertainty declared in reports for radioactive releases
	Radioactive species, other beta emitters			kBq	3.39E-6	3.47E-7	1	1.50	uncertainty declared in reports for radioactive releases
	Xenon-131m			kBq	1.26E-3	5.57E-3	1	1.50	uncertainty declared in reports for radioactive releases
	Xenon-133			kBq	5.85E-2	1.48E-1	1	1.50	uncertainty declared in reports for radioactive releases
	Xenon-133m			kBq	7.64E-4	9.70E-4	1	1.50	uncertainty declared in reports for radioactive releases
	Xenon-135			kBq	1.46E-1	1.25E-2	1	1.50	uncertainty declared in reports for radioactive releases
	Xenon-135m			kBq	9.72E-2	1.36E-4	1	1.50	uncertainty declared in reports for radioactive releases
	Xenon-137			kBq	6.22E-4	5.99E-6	1	1.50	uncertainty declared in reports for radioactive releases
	Xenon-138			kBq	9.96E-3	2.31E-5	1	1.50	uncertainty declared in reports for radioactive releases

Tab. A.10 Life cycle inventory of the production of 1 kWh electricity in nuclear power plants (boiling water reactor and pressure water reactor) with regionalised water withdrawal and water emissions (Germany is shown as an example) (continued)

	Name	Location	Infrastructure-Process	Unit	electricity, nuclear, at power plant boiling water reactor	electricity, nuclear, at power plant pressure water reactor	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE	DE			
	InfrastructureProcess				0	0			
	Unit				kWh	kWh			
water, river	Antimony-124			kBq	5.58E-8	3.85E-6	1	1.50	uncertainty declared in reports for radioactive releases
	Antimony-125			kBq	2.02E-7	5.62E-7	1	1.50	uncertainty declared in reports for radioactive releases
	Cesium-134			kBq	1.64E-7	4.51E-7	1	1.50	uncertainty declared in reports for radioactive releases
	Cesium-137			kBq	3.79E-6	1.76E-6	1	1.50	uncertainty declared in reports for radioactive releases
	Chromium-51			kBq	1.89E-6	9.18E-8	1	1.50	uncertainty declared in reports for radioactive releases
	Cobalt-58			kBq	7.97E-7	8.51E-7	1	1.50	uncertainty declared in reports for radioactive releases
	Cobalt-60			kBq	1.07E-5	5.04E-6	1	1.50	uncertainty declared in reports for radioactive releases
	Hydrogen-3, Tritium			kBq	2.45E-1	1.51E+0	1	1.50	uncertainty declared in reports for radioactive releases
	Iodine-131			kBq	4.07E-6	2.40E-7	1	1.50	uncertainty declared in reports for radioactive releases
	Niobium-95			kBq	5.62E-8	1.13E-7	1	1.50	uncertainty declared in reports for radioactive releases
	Radioactive species, Nuclides, unspecified			kBq	1.65E-5	5.04E-6	1	1.50	uncertainty declared in reports for radioactive releases
	Silver-110			kBq	2.25E-7	1.23E-6	1	1.50	uncertainty declared in reports for radioactive releases
	Strontium-89			kBq	3.85E-8	1.14E-7	1	1.50	uncertainty declared in reports for radioactive releases
	Strontium-90			kBq	1.00E+0	1.90E-8	1	1.50	uncertainty declared in reports for radioactive releases
	Technetium-99m			kBq	1.15E-7		1	1.50	uncertainty declared in reports for radioactive releases
	Tellurium-123m			kBq	4.94E-10		1	1.50	uncertainty declared in reports for radioactive releases
	Manganese-54			kBq		7.39E-8	1	1.50	uncertainty declared in reports for radioactive releases

A.2.4 Life cycle inventories of reservoir hydropower plants

The KBOB life cycle inventory data DQRv2:2016 contains life cycle inventories of electricity generation by reservoir hydropower plants in alpine, non-alpine and tropical regions. These datasets were used to create analogous life cycle inventories of reservoir hydropower electricity generation in additional countries with regionalised water emissions to air. The demand of infrastructure and materials, the land occupation and pollutant emissions are assumed to be identical for all countries. Exemplary life cycle inventories are shown in Tab. A.11 to Tab. A.13 and a list of countries with regionalised life cycle inventories of electricity generation in reservoir hydropower plants is provided in Tab. B.1 in Appendix B.

The construction of the reservoir hydropower plant as well as the pollutant emissions are fully allocated to the electricity generation even though reservoirs may provide additional services such as flood control and seasonal water storage for irrigation. These functions are assumed to be of minor importance compared to power generation. Consequently, the amount of water evaporated from reservoirs is also allocated to electricity generation. This approach is identical to the approach applied in the KBOB life cycle inventory data DQRv2:2016 to quantify other environmental impacts of electricity from hydropower plants such as impacts on climate change or acidification.

The additional life cycle inventories of electricity generation by reservoir hydropower plants were linked to the electricity mixes of the corresponding countries without changing the share of electricity generated with different technologies.

Tab. A.11 Life cycle inventory of the production of 1 kWh electricity in a reservoir hydropower plant located in an alpine region with regionalised water emissions (France is shown as an example)

	Name	Location	Unit	electricity, hydropower, at reservoir power plant, alpine region	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			FR			
	InfrastructureProcess			0			
	Unit			kWh			
product	electricity, hydropower, at reservoir power plant, alpine region	FR	kWh	1			
technosphere	reservoir hydropower plant, alpine region	RER	unit	3.35E-11	1	3.78	(4,5,1,5,1,5,BU:3); Infrastructure of the storage power station producing the electricity
	sulphur hexafluoride, liquid, at plant	RER	kg	3.40E-10	1	1.67	(4,5,1,5,1,5,BU:1.05); In electric insulation (e.g. switches); based on Vattenfall (2008)
	lubricating oil, at plant	RER	kg	3.24E-8	1	1.67	(4,5,1,5,1,5,BU:1.05); Turbines; based on Vattenfall (2008)
resource, land	Transformation, from unknown	-	m2	2.44E-5	1	2.42	(3,1,1,1,1,1,BU:2); Original area before the construction of the power station; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
	Transformation, to water bodies, artificial	-	m2	2.41E-5	1	2.42	(3,1,1,1,1,1,BU:2); Area covered by the reservoir; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
	Transformation, to industrial area, built up	-	m2	2.41E-7	1	2.46	(4,1,1,1,1,1,BU:2); Area covered by infrastructures other than held-back river; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
	Occupation, water bodies, artificial	-	m2a	3.62E-3	1	1.82	(3,1,1,1,1,1,BU:1.5); Area occupied by the reservoir; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
	Occupation, industrial area, built up	-	m2a	3.62E-5	1	1.87	(4,1,1,1,1,1,BU:1.5); Area occupied by the infrastructure; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
resource, in water	Volume occupied, reservoir	-	m3a	1.64E-1	1	1.34	(3,1,1,1,1,1,BU:1.05); Volume occupied by the reservoir; based on Schweizerisches Talsperrenkomitee (2011)
	Water, turbine use, unspecified natural origin	-	m3	1.40E+0	1	1.34	(3,1,1,1,1,1,BU:1.05); Amount of water turbined for the generation of electricity; based on BWW (1973)
	Energy, potential (in hydropower reservoir), converted	-	MJ	3.79E+0	1	1.34	(3,1,1,1,1,1,BU:1.05); Potential energy of the water
emission air, low population density	Dinitrogen monoxide	-	kg	2.56E-8	1	1.90	(4,3,2,3,1,4,BU:1.5); Nitrous oxide emissions due to the biomass in the reservoirs; calculated based on Diem et al. (2008)
	Methane, biogenic	-	kg	2.64E-7	1	1.88	(4,3,2,3,1,3,BU:1.5); Methane emissions due to the biomass in the reservoirs; calculated based on Diem et al. (2008)
	Carbon dioxide, land transformation	-	kg	1.36E-3	1	1.77	(4,3,2,3,1,3,BU:1.4); Carbon dioxide emissions due to the biomass in the reservoirs; calculated based on Diem et al. (2008)
	Sulfur hexafluoride	-	kg	3.40E-10	1	2.02	(4,5,1,5,1,5,BU:1.5); From electric insulations (e.g. switches); based on Vattenfall (2008)
emission air, unspecified	Water, FR	-	kg	1.75E+0	1	2.27	(4,3,3,2,4,5,BU:1.5); Water evaporated from reservoir; calculated based on Spreafico &
emission water, river	Oils, unspecified	-	kg	2.27E-8	1	2.02	(4,5,1,5,1,5,BU:1.5); From turbines; based on Vattenfall (2008)
emission soil, industrial	Oils, unspecified	-	kg	9.76E-9	1	2.02	(4,5,1,5,1,5,BU:1.5); From turbines; based on Vattenfall (2008)

Tab. A.12 Life cycle inventory of the production of 1 kWh electricity in a reservoir hydropower plant located in a non-alpine region with regionalised water emissions (China is shown as an example)

	Name	Location	Unit	electricity, hydropower, at reservoir power plant, non alpine regions	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CN			
	InfrastructureProcess			0			
	Unit			kWh			
product	electricity, hydropower, at reservoir power plant, non alpine regions	CN	kWh	1			
technosphere	reservoir hydropower plant, non alpine regions	RER	unit	3.35E-11	1	3.78	(4,5,1,5,1,5,BU:3); Infrastructure of the storage power station producing the electricity
	sulphur hexafluoride, liquid, at plant	RER	kg	3.40E-10	1	1.67	(4,5,1,5,1,5,BU:1.05); In electric insulation (e.g. switches); based on Vattenfall (2008)
	lubricating oil, at plant	RER	kg	3.24E-8	1	1.67	(4,5,1,5,1,5,BU:1.05); Turbines; based on Vattenfall (2008)
resource, land	Transformation, from unknown	-	m2	2.44E-4	1	2.42	(3,1,1,1,1,1,BU:2); Original area before the construction of the power station; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
	Transformation, to water bodies, artificial	-	m2	2.41E-4	1	2.42	(3,1,1,1,1,1,BU:2); Area covered by the reservoir; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
	Transformation, to industrial area, built up	-	m2	2.41E-6	1	2.46	(4,1,1,1,1,1,BU:2); Area covered by infrastructures other than held-back river; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
	Occupation, water bodies, artificial	-	m2a	3.62E-2	1	1.82	(3,1,1,1,1,1,BU:1.5); Area occupied by the reservoir; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
	Occupation, industrial area, built up	-	m2a	3.62E-4	1	1.87	(4,1,1,1,1,1,BU:1.5); Area occupied by the infrastructure; recalculated based on Frischknecht et al. (1996) and Schweizerisches Talsperrenkomitee (2011)
resource, in water	Volume occupied, reservoir	-	m3a	1.64E+0	1	1.34	(3,1,1,1,1,1,BU:1.05); Volume occupied by the reservoir; based on Schweizerisches Talsperrenkomitee (2011)
	Water, turbine use, unspecified natural origin	-	m3	1.40E+1	1	1.34	(3,1,1,1,1,1,BU:1.05); Amount of water turbined for the generation of electricity; based on BWW (1973)
	Energy, potential (in hydropower reservoir), converted	-	MJ	3.79E+0	1	1.34	(3,1,1,1,1,1,BU:1.05); Potential energy of the water
emission air, low population density	Dinitrogen monoxide	-	kg	9.51E-7	1	1.90	(4,3,2,3,1,4,BU:1.5); Nitrous oxide emissions due to the biomass in the reservoirs; calculated based on Diem et al. (2008)
	Methane, biogenic	-	kg	4.78E-5	1	1.88	(4,3,2,3,1,3,BU:1.5); Methane emissions due to the biomass in the reservoirs; calculated based on Diem et al. (2008)
	Carbon dioxide, land transformation	-	kg	1.08E-2	1	1.77	(4,3,2,3,1,3,BU:1.4); Carbon dioxide emissions due to the biomass in the reservoirs; calculated based on Diem et al. (2008)
	Sulfur hexafluoride	-	kg	3.40E-10	1	2.02	(4,5,1,5,1,5,BU:1.5); From electric insulations (e.g. switches); based on Vattenfall (2008)
emission air, unspecified	Water, CN	-	kg	2.50E+1	1	2.27	(4,3,3,2,4,5,BU:1.5); Water evaporated from reservoir; calculated based on Pfister et al. (2011)
emission water, river	Oils, unspecified	-	kg	2.27E-8	1	2.02	(4,5,1,5,1,5,BU:1.5); From turbines; based on Vattenfall (2008)
emission soil, industrial	Oils, unspecified	-	kg	9.76E-9	1	2.02	(4,5,1,5,1,5,BU:1.5); From turbines; based on Vattenfall (2008)

Tab. A.13 Life cycle inventory of the production of 1 kWh electricity in a reservoir hydropower plant located in a tropical region with regionalised water emissions (Malaysia is shown as an example)

	Name	Location	Unit	electricity, hydropower, at reservoir power plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			MY			
	InfrastructureProcess			0			
	Unit			kWh			
product	electricity, hydropower, at reservoir power plant	MY	kWh	1			
technosphere	reservoir hydropower plant	BR	unit	8.89E-14	1	3.15	(4,5,3,3,1,5,BU:3); Infrastructure of the storage power station producing the electricity
	sulphur hexafluoride, liquid, at plant	RER	kg	3.40E-13	1	1.65	(5,5,3,5,1,5,BU:1.05); In electric insulation (e.g. switches); based on Vattenfall (2008)
	lubricating oil, at plant	RER	kg	3.24E-8	1	1.65	(5,5,3,5,1,5,BU:1.05); Turbines; based on Vattenfall (2008)
resource, land	Transformation, from tropical rain forest	-	m2	1.21E-4	1	2.10	(4,1,1,3,1,5,BU:2); Original area before the construction of the power station; based on data of the Itaipu
	Transformation, to water bodies, artificial	-	m2	1.20E-4	1	2.10	(4,1,1,3,1,5,BU:2); Area covered by the reservoir; based on data of the Itaipu
	Transformation, to industrial area, built up	-	m2	1.20E-6	1	2.10	(4,1,1,3,1,5,BU:2); Area covered by infrastructures other than held-back river; recalculated based on Frischknecht et al. (1996)
	Occupation, water bodies, artificial	-	m2a	1.80E-2	1	1.62	(4,1,1,3,1,5,BU:1.5); Area occupied by the reservoir; based on data of the Itaipu
	Occupation, industrial area, built up	-	m2a	1.80E-4	1	1.62	(4,1,1,3,1,5,BU:1.5); Area occupied by the infrastructure; based on data of the Itaipu
resource, in water	Volume occupied, reservoir	-	m3a	2.53E-1	1	1.30	(4,1,1,3,1,5,BU:1.05); Volume occupied by the reservoir; ; based on data of the Itaipu
	Water, turbine use, unspecified natural origin	-	m3	2.90E-1	1	1.30	(4,1,1,3,1,5,BU:1.05); Amount of water turbined for the generation of electricity; based on data of the Itaipu
	Energy, potential (in hydropower reservoir), converted	-	MJ	3.79E+0	1	1.11	(3,1,1,1,1,1,BU:1.05); Potential energy of the water
emission air, low population density	Methane, biogenic	-	kg	5.56E-4	1	1.58	(4,3,3,3,1,3,BU:1.5); Methane emissions due to the biomass in the reservoirs; calculated based on Diem et al. (2008)
	Carbon dioxide, land transformation	-	kg	3.09E-2	1	1.49	(4,3,3,3,1,3,BU:1.4); Carbon dioxide emissions due to the biomass in the reservoirs; calculated based on Diem et al. (2008)
	Sulfur hexafluoride	-	kg	3.40E-13	1	1.90	(5,5,3,5,1,5,BU:1.5); From electric insulations (e.g. switches); based on Vattenfall (2008)
	Water, MY	-	kg	2.50E+1	1	1.89	(4,3,3,2,4,5,BU:1.5); Water evaporated from reservoir; calculated based on Pfister et al. (2011)
emission water, river	Oils, unspecified	-	kg	2.27E-8	1	1.90	(5,5,3,5,1,5,BU:1.5); From turbines; based on Vattenfall (2008)
emission soil, industrial	Oils, unspecified	-	kg	9.76E-9	1	1.90	(5,5,3,5,1,5,BU:1.5); From turbines; based on Vattenfall (2008)

A.3 PV supply chain

A.3.1 Mono-Si PV modules

The life cycle inventories of the manufacture of mono-Si PV modules are based on Frischknecht et al. (2015) and Stolz et al. (2016), which are embedded in the KBOB life cycle inventory data DQRv2:2016. The processes with direct water use were adapted in order to account for differences in water availability at the country or region level. The water withdrawal was modelled with the respective country- or region-specific elementary flow and the water emissions to air were added to the life cycle inventories. Since specific data on the share of consumptive water use were not available, it was assumed that 10 % of process water and 5 % of cooling water are evaporated (Frischknecht & Büsser Knöpfel 2013). The demand of raw materials, chemicals and energy as well as the emissions of pollutants to air, water and soil were not adjusted.

The regionalised life cycle inventories of the individual process steps of mono-Si PV module production are compiled in Tab. A.14 to Tab. A.20. An overview and description of the mono-Si PV module manufacturing processes can be found in Frischknecht et al. (2015). Life cycle inventories of the mono-Si PV module supply chain are available for four major countries and regions: China, Asia / Pacific (APAC), Europe and the USA (Frischknecht et al. 2015). In the following, the life cycle inventories of several geographies are shown in a single table event though they are not related. This aggregation is done because many input and output flow do not differ among the countries considered. The life cycle inventories of additional processes in the supply chain of mono-Si PV modules, which do not withdraw or emit water, were not changed and are therefore not shown in this report.

Tab. A.14 Life cycle inventory of the production of 1 kg electronic-grade silicon in Asia / Pacific (APAC) and Germany, respectively, with regionalised water withdrawal and water emissions

	Name	Location	InfrastructureProcess	Unit	silicon, electronic grade, at plant	silicon, electronic grade, off-grade, at plant	silicon, electronic grade, at plant	silicon, electronic grade, off-grade, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				APAC	APAC	DE	DE			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
products	silicon, electronic grade, at plant	DE	0	kg	0	0	1.00E+00	0			
	silicon, electronic grade, off-grade, at plant	DE	0	kg	0	0	0	1.00E+00			
	silicon, electronic grade, at plant	APAC	0	kg	1.00E+00	0	0	0			
	silicon, electronic grade, off-grade, at plant	APAC	0	kg	0	1.00E+00	0	0			
resource, in water	Water, cooling, unspecified natural origin, RAS	-	-	m3	6.23E+1	1.66E+1	0	0	1	1.34	(4,4,3,3,1,5); Literature 1997
resource, in water	Water, cooling, unspecified natural origin, DE	-	-	m3	0	0	6.23E+1	1.66E+1	1	1.34	(4,4,3,3,1,5); Literature 1997
technosphere	MG-silicon, at plant	NO	0	kg	0	0	1.05E+0	1.05E+0	1	1.26	(3,1,3,1,1,5); Literature 1997
	MG-silicon, at plant	APAC	0	kg	1.05E+0	1.05E+0	0	0	1	1.26	(3,1,3,1,1,5); Literature 1998
	polyethylene, HDPE, granulate, at plant	RER	0	kg	6.79E-4	1.81E-4	6.79E-4	1.81E-4	1	1.69	(4,4,4,3,4,5); Literature, Hagedorn, different plastics
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	1.43E+0	3.82E-1	1.43E+0	3.82E-1	1	1.11	(3,na,1,1,1,na); Estimation, produced on site
	hydrogen, liquid, at plant	RER	0	kg	8.97E-2	2.39E-2	8.97E-2	2.39E-2	1	1.34	(4,4,3,3,1,5); Literature 1997, produced on site
	tetrafluoroethylene, at plant	RER	0	kg	6.39E-4	1.70E-4	6.39E-4	1.70E-4	1	1.69	(4,4,4,3,4,5); Hagedorn 1992, fittings
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	4.63E-1	1.24E-1	4.63E-1	1.24E-1	1	1.34	(4,4,3,3,1,5); Literature 1997, neutralization of wastes
	graphite, at plant	RER	0	kg	7.10E-4	1.89E-4	7.10E-4	1.89E-4	1	1.69	(4,4,4,3,4,5); Hagedorn 1992, graphite
transport	transport, lorry >16t, fleet average	RER	0	tkm	2.15E+0	2.15E+0	2.15E+0	2.15E+0	1	2.09	(4,5,na,na,na,na); Standard distances 100km, MG-Si 2000km
	transport, freight, rail	RER	0	tkm	9.31E-2	2.48E-2	9.31E-2	2.48E-2	1	2.09	(4,5,na,na,na,na); Standard distances 200km
	water, completely softened, water balance according to MoeK 2013, at plant	CN	0	kg	1.85E+1	4.94E+0	0	0	1	1.22	(2,2,1,1,3,3); Environmental report 2002
	water, completely softened, water balance according to MoeK 2013, at plant	DE	0	kg	0	0	1.85E+1	4.94E+0	1	1.22	(2,2,1,1,3,3); Environmental report 2002
energy	heat, at cogen 1MWe lean burn, allocation exergy	RER	0	MJ	1.74E+2	4.65E+1	1.74E+2	4.65E+1	1	1.59	(3,1,3,1,1,5); Literature 1997, basic uncertainty = 1.5
	electricity, at cogen 1MWe lean burn, allocation exergy	RER	0	kWh	0	0	1.24E+2	3.31E+1	1	1.59	(3,1,3,1,1,5); Literature 1997, basic uncertainty = 1.5
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	0	0	3.92E+1	1.05E+1	1	1.59	(3,1,3,1,1,5); Literature 1997, basic uncertainty = 1.5
	electricity, medium voltage, at grid	KR	0	kWh	1.63E+2	4.35E+1	0	0	1	1.59	(3,1,3,1,1,5); Literature 1997, basic uncertainty = 1.5
waste	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.32E-3	3.52E-4	1.32E-3	3.52E-4	1	1.69	(4,4,4,3,4,5); Hagedorn 1992
	silicone plant	RER	1	unit	1.07E-11	2.84E-12	1.07E-11	2.84E-12	1	3.05	(1,1,1,1,3,3); Estimation
emission air, high population density	Heat, waste	-	-	MJ	3.92E+2	1.05E+2	3.92E+2	1.05E+2	1	3.05	(1,2,1,1,3,3); Calculation with electricity use minus 180 MJ per kg produced silicon
	Water, RAS	-	-	kg	3.12E+3	8.31E+2	0	0	1	3.05	(1,2,1,1,3,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, DE	-	-	kg	0	0	3.12E+3	8.31E+2	1	3.05	(1,2,1,1,3,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
emission water, river	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	1.26E-5	3.37E-6	1.26E-5	3.37E-6	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	BOD5, Biological Oxygen Demand	-	-	kg	2.05E-4	5.46E-5	2.05E-4	5.46E-5	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	COD, Chemical Oxygen Demand	-	-	kg	2.02E-3	5.39E-4	2.02E-3	5.39E-4	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Chloride	-	-	kg	3.60E-2	9.60E-3	3.60E-2	9.60E-3	1	3.05	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Copper, ion	-	-	kg	1.02E-7	2.73E-8	1.02E-7	2.73E-8	1	5.06	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Nitrogen	-	-	kg	2.08E-4	5.53E-5	2.08E-4	5.53E-5	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Phosphate	-	-	kg	2.80E-6	7.48E-7	2.80E-6	7.48E-7	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Sodium, ion	-	-	kg	3.38E-2	9.01E-3	3.38E-2	9.01E-3	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Zinc, ion	-	-	kg	1.96E-6	5.23E-7	1.96E-6	5.23E-7	1	5.06	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Iron, ion	-	-	kg	5.61E-6	1.50E-6	5.61E-6	1.50E-6	1	5.06	(1,2,1,1,3,3); Environmental report 2002, average Si product
	DOC, Dissolved Organic Carbon	-	-	kg	9.10E-4	2.43E-4	9.10E-4	2.43E-4	1	5.06	(1,2,1,1,3,3); Environmental report 2002, average Si product
	TOC, Total Organic Carbon	-	-	kg	9.10E-4	2.43E-4	9.10E-4	2.43E-4	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product

Tab. A.15 Life cycle inventory of the production of 1 kg electronic-grade silicon in China and the USA, respectively, with regionalised water withdrawal and water emissions

	Name	Location	InfrastructureProcess	Unit	silicon, electronic grade, at plant	silicon, electronic grade, off-grade, at plant	silicon, electronic grade, at plant	silicon, electronic grade, off-grade, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN	CN	US	US			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
	silicon, electronic grade, at plant	CN	0	kg	1	0	0	0			
	silicon, electronic grade, off-grade, at plant	CN	0	kg	0	1	0	0			
	silicon, electronic grade, at plant	US	0	kg	0	0	1	0			
	silicon, electronic grade, off-grade, at plant	US	0	kg	0	0	0	1			
resource, in water	Water, cooling, unspecified natural origin, CN	-	-	m3	6.23E+1	1.66E+1	0	0	1	1.34	(4,4,3,3,1,5); Literature 1997
resource, in water	Water, cooling, unspecified natural origin, US	-	-	m3	0	0	6.23E+1	1.66E+1	1	1.34	(4,4,3,3,1,5); Literature 1997
	MG-silicon, at plant	CN	0	kg	1.05E+0	1.05E+0	0	0	1	1.26	(3,1,3,1,1,5); Literature 1998
	MG-silicon, at plant	US	0	kg	0	0	1.05E+0	1.05E+0	1	1.26	(3,1,3,1,1,5); Literature 1997
	MG-silicon, at plant	APAC	0	kg	0	0	0	0	1	1.26	(3,1,3,1,1,5); Literature 1998
	polyethylene, HDPE, granulate, at plant	RER	0	kg	6.79E-4	1.81E-4	6.79E-4	1.81E-4	1	1.69	(4,4,4,3,4,5); Literature, Hagedorn, different plastics
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	1.43E+0	3.82E-1	1.43E+0	3.82E-1	1	1.11	(3,na,1,1,1,na); Estimation, produced on site
	hydrogen, liquid, at plant	RER	0	kg	8.97E-2	2.39E-2	8.97E-2	2.39E-2	1	1.34	(4,4,3,3,1,5); Literature 1997, produced on site
	tetrafluoroethylene, at plant	RER	0	kg	6.39E-4	1.70E-4	6.39E-4	1.70E-4	1	1.69	(4,4,4,3,4,5); Hagedorn 1992, fittings
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	4.63E-1	1.24E-1	4.63E-1	1.24E-1	1	1.34	(4,4,3,3,1,5); Literature 1997, neutralization of wastes
	graphite, at plant	RER	0	kg	7.10E-4	1.89E-4	7.10E-4	1.89E-4	1	1.69	(4,4,4,3,4,5); Hagedorn 1992, graphite
transport	transport, lorry >16t, fleet average	RER	0	tkm	2.15E+0	2.15E+0	2.15E+0	2.15E+0	1	2.09	(4,5,na,na,na,na); Standard distances 100km, MG-Si 2000km
	transport, freight, rail	RER	0	tkm	9.31E-2	2.48E-2	9.31E-2	2.48E-2	1	2.09	(4,5,na,na,na,na); Standard distances 200km
	water, completely softened, water balance according to MoeK 2013, at plant	CN	0	kg	1.85E+1	4.94E+0	0	0	1	1.22	(2,2,1,1,3,3); Environmental report 2002
	water, completely softened, water balance according to MoeK 2013, at plant	US	0	kg	0	0	1.85E+1	4.94E+0	1	1.22	(2,2,1,1,3,3); Environmental report 2002
energy	heat, at cogen 1MWe lean burn, allocation exergy	RER	0	MJ	1.74E+2	4.65E+1	1.74E+2	4.65E+1	1	1.59	(3,1,3,1,1,5); Literature 1997, basic uncertainty = 1.5
	electricity, medium voltage, at grid	CN	0	kWh	1.63E+2	4.35E+1	0	0	1	1.59	(3,1,3,1,1,5); Literature 1997, basic uncertainty = 1.5
	electricity, medium voltage, at grid	US	0	kWh	0	0	1.63E+2	4.35E+1	1	1.59	(3,1,3,1,1,5); Literature 1997, basic uncertainty = 1.5
waste	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.32E-3	3.52E-4	1.32E-3	3.52E-4	1	1.69	(4,4,4,3,4,5); Hagedorn 1992
	silicone plant	RER	1	unit	1.07E-11	2.84E-12	1.07E-11	2.84E-12	1	3.05	(1,1,1,1,3,3); Estimation
emission air, high population density	Heat, waste	-	-	MJ	3.92E+2	1.05E+2	3.92E+2	1.05E+2	1	3.05	(1,2,1,1,3,3); Calculation with electricity use minus 180 MJ per kg produced silicon
	Water, CN	-	-	kg	3.12E+3	8.31E+2	0	0	1	3.05	(1,2,1,1,3,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, US	-	-	kg	0	0	3.12E+3	8.31E+2	1	3.05	(1,2,1,1,3,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
emission water, river	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	1.26E-5	3.37E-6	1.26E-5	3.37E-6	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	BOD5, Biological Oxygen Demand	-	-	kg	2.05E-4	5.46E-5	2.05E-4	5.46E-5	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	COD, Chemical Oxygen Demand	-	-	kg	2.02E-3	5.39E-4	2.02E-3	5.39E-4	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Chloride	-	-	kg	3.60E-2	9.60E-3	3.60E-2	9.60E-3	1	3.05	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Copper, ion	-	-	kg	1.02E-7	2.73E-8	1.02E-7	2.73E-8	1	5.06	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Nitrogen	-	-	kg	2.08E-4	5.53E-5	2.08E-4	5.53E-5	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Phosphate	-	-	kg	2.80E-6	7.48E-7	2.80E-6	7.48E-7	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Sodium, ion	-	-	kg	3.38E-2	9.01E-3	3.38E-2	9.01E-3	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Zinc, ion	-	-	kg	1.96E-6	5.23E-7	1.96E-6	5.23E-7	1	5.06	(1,2,1,1,3,3); Environmental report 2002, average Si product
	Iron, ion	-	-	kg	5.61E-6	1.50E-6	5.61E-6	1.50E-6	1	5.06	(1,2,1,1,3,3); Environmental report 2002, average Si product
	DOC, Dissolved Organic Carbon	-	-	kg	9.10E-4	2.43E-4	9.10E-4	2.43E-4	1	5.06	(1,2,1,1,3,3); Environmental report 2002, average Si product
	TOC, Total Organic Carbon	-	-	kg	9.10E-4	2.43E-4	9.10E-4	2.43E-4	1	1.56	(1,2,1,1,3,3); Environmental report 2002, average Si product

Tab. A.16 Life cycle inventory of the production of 1 kg Czochralski single crystalline silicon in China, the USA, Asia / Pacific and Europe (RER), respectively, with regionalised water withdrawal and water emissions

	Name	Location	InfrastructureProcess	Unit	CZ single crystalline silicon, photovoltaics, at plant	CZ single crystalline silicon, photovoltaics, at plant	CZ single crystalline silicon, photovoltaics, at plant	CZ single crystalline silicon, photovoltaics, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN	US	APAC	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	CZ single crystalline silicon, photovoltaics, at plant	CN	0	kg	1	0	0	0			
	CZ single crystalline silicon, photovoltaics, at plant	US	0	kg	0	1	0	0			
	CZ single crystalline silicon, photovoltaics, at plant	APAC	0	kg	0	0	1	0			
	CZ single crystalline silicon, photovoltaics, at plant	RER	0	kg	0	0	0	1			
resource, in water	Water, cooling, unspecified natural origin, CN	-	-	m3	5.09E+0	-	-	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	Water, cooling, unspecified natural origin, US	-	-	m3	-	5.09E+0	-	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	Water, cooling, unspecified natural origin, RAS	-	-	m3	-	-	5.09E+0	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	Water, cooling, unspecified natural origin, RER	-	-	m3	-	-	-	5.09E+0	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	-	-	-	6.82E+1	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	electricity, medium voltage, at grid	CN	0	kWh	6.82E+1	-	-	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	electricity, medium voltage, at grid	US	0	kWh	-	6.82E+1	-	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	electricity, medium voltage, at grid	KR	0	kWh	-	-	6.82E+1	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	natural gas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	6.82E+1	6.82E+1	6.82E+1	6.82E+1	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	water, deionised, water balance according to MoeK 2013, at plant	CN	0	kg	4.01E+0	-	4.01E+0	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	water, deionised, water balance according to MoeK 2013, at plant	US	0	kg	-	4.01E+0	-	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	water, deionised, water balance according to MoeK 2013, at plant	RER	0	kg	-	-	-	4.01E+0	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	silicon, production mix, photovoltaics, at plant	GLO	0	kg	-	-	-	7.81E-1	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	silicon, production mix, photovoltaics, at plant	CN	0	kg	7.81E-1	-	-	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	silicon, production mix, photovoltaics, at plant	US	0	kg	-	7.81E-1	-	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	silicon, production mix, photovoltaics, at plant	APAC	0	kg	-	-	7.81E-1	-	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
materials	argon, liquid, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	hydrogen fluoride, at plant	GLO	0	kg	1.00E-2	1.00E-2	1.00E-2	1.00E-2	1	1.36	(3,4,3,3,3,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	nitric acid, 50% in H2O, at plant	RER	0	kg	6.68E-2	6.68E-2	6.68E-2	6.68E-2	1	1.36	(3,4,3,3,3,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	4.15E-2	4.15E-2	4.15E-2	4.15E-2	1	1.36	(3,4,3,3,3,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	ceramic tiles, at regional storage	CH	0	kg	1.67E-1	1.67E-1	1.67E-1	1.67E-1	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	lime, hydrated, packed, at plant	CH	0	kg	2.22E-2	2.22E-2	2.22E-2	2.22E-2	1	1.36	(3,4,3,3,3,5); waste water treatment, Hagedorn 1992
transport	transport, lorry >16t, fleet average	RER	0	tkm	9.12E-1	9.12E-1	9.12E-1	9.12E-1	1	2.09	(4,5,na,na,na,na); Standard distance 100km, sand 50km, silicon 1000km
	transport, freight, rail	RER	0	tkm	1.41E+0	1.41E+0	1.41E+0	1.41E+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 9)
infrastructure	silicone plant	RER	1	unit	1.00E-11	1.00E-11	1.00E-11	1.00E-11	1	3.05	(1,2,1,1,3,3); Estimation
	disposal, waste, Si waferprod., inorg, 9.4% water, to residual material landfill	CH	0	kg	1.67E-1	1.67E-1	1.67E-1	1.67E-1	1	1.24	(1,4,1,2,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
emission air, high population density	Heat, waste	-	-	MJ	2.46E+2	2.46E+2	2.46E+2	2.46E+2	1	1.25	(3,3,2,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	Water, CN	-	-	kg	2.55E+2	-	-	-	1	1.58	(3,3,2,3,1,5); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, US	-	-	kg	-	2.55E+2	-	-	1	1.58	(3,3,2,3,1,5); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RAS	-	-	kg	-	-	2.55E+2	-	1	1.58	(3,3,2,3,1,5); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RER	-	-	kg	-	-	-	2.55E+2	1	1.58	(3,3,2,3,1,5); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Hydroxide	-	-	kg	3.67E-1	3.67E-1	3.67E-1	3.67E-1	1	3.08	(3,4,3,3,1,5); 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	3.23	(5,na,1,1,1,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	-	kg	1.30E-1	1.30E-1	1.30E-1	1.30E-1	1	3.23	(5,na,1,1,1,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	-	kg	4.05E-2	4.05E-2	4.05E-2	4.05E-2	1	3.23	(5,na,1,1,1,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	-	kg	4.05E-2	4.05E-2	4.05E-2	4.05E-2	1	3.23	(5,na,1,1,1,na); Extrapolation for sum parameter
	Nitrogen oxides	-	-	kg	3.39E-2	3.39E-2	3.39E-2	3.39E-2	1	1.61	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)
	Nitrate	-	-	kg	8.35E-2	8.35E-2	8.35E-2	8.35E-2	1	1.61	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (table 9)

Tab. A.17 Life cycle inventory of the production of 1 m^2 single-Si wafer in China, the USA, Asia / Pacific and Europe, respectively with regionalised water withdrawal and water emissions

	Name	Location	InfrastructureProcess	Unit	single-Si wafer, photovoltaics, at plant	single-Si wafer, photovoltaics, at plant	single-Si wafer, photovoltaics, at plant	single-Si wafer, photovoltaics, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN	US	APAC	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				m2	m2	m2	m2			
product	single-Si wafer, photovoltaics, at plant	CN	0	m2	1	0	0	0			
	single-Si wafer, photovoltaics, at plant	US	0	m2	0	1	0	0			
	single-Si wafer, photovoltaics, at plant	APAC	0	m2	0	0	1	0			
	single-Si wafer, photovoltaics, at plant	RER	0	m2	0	0	0	1			
technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	-	-	-	2.57E+1	1	2.07	(3,4,1,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	natural gas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	4.00E+0	4.00E+0	4.00E+0	4.00E+0	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
water	tap water, water balance according to MoeK 2013, at user	CN	0	kg	6.00E-3	-	6.00E-3	-	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	tap water, water balance according to MoeK 2013, at user	US	0	kg	-	6.00E-3	-	-	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	tap water, water balance according to MoeK 2013, at user	RER	0	kg	-	-	-	6.00E-3	1	1.07	(1,2,1,1,1,3); 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	1.80E+1	-	1.80E+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)
	water, deionised, water balance according to MoeK 2013, at plant	US	0	kg	-	1.80E+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)
	water, deionised, water balance according to MoeK 2013, at plant	RER	0	kg	-	-	-	1.80E+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)
	CZ single crystalline silicon, photovoltaics, at plant	RER	0	kg	-	-	-	1.58E+0	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	CZ single crystalline silicon, photovoltaics, at plant	CN	0	kg	1.58E+0	-	-	-	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	CZ single crystalline silicon, photovoltaics, at plant	US	0	kg	-	1.58E+0	-	-	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	CZ single crystalline silicon, photovoltaics, at plant	APAC	0	kg	-	-	1.58E+0	-	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	silicon carbide, at plant	RER	0	kg	6.20E-1	6.20E-1	6.20E-1	6.20E-1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	silicon carbide, recycling, at plant	RER	0	kg	1.41E+0	1.41E+0	1.41E+0	1.41E+0	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	flat glass, uncoated, at plant	RER	0	kg	9.99E-3	9.99E-3	9.99E-3	9.99E-3	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	1.07	(1,2,1,1,1,3); 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	1.07	(1,2,1,1,1,3); 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	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	triethylene glycol, at plant	RER	0	kg	2.18E-1	2.18E-1	2.18E-1	2.18E-1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	triethylene glycol, recycling, at plant	RER	0	kg	1.95E+0	1.95E+0	1.95E+0	1.95E+0	1	1.07	(1,2,1,1,1,3); 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	1.07	(1,2,1,1,1,3); 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	1.07	(1,2,1,1,1,3); 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	2.00E-3	2.00E-3	3.85E-3	2.00E-3	1	1.07	(1,2,1,1,1,3); 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	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	steel, low-alloyed, at plant	RER	0	kg	7.97E-1	7.97E-1	7.97E-1	7.97E-1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	wire drawing, steel	RER	0	kg	8.05E-1	8.05E-1	8.05E-1	8.05E-1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
wastes	disposal, waste, silicon wafer production, 0% water, to underground deposit	DE	0	kg	1.10E-1	1.10E-1	1.70E-1	1.10E-1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
transport	transport, lorry >16t, fleet average	RER	0	tkm	9.29E-1	9.29E-1	9.29E-1	9.29E-1	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 19,25)
	transport, freight, rail	RER	0	tkm	3.84E+0	3.84E+0	3.84E+0	3.84E+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 19,25)
infrastructure	wafer factory	DE	1	unit	4.00E-6	4.00E-6	4.00E-6	4.00E-6	1	3.00	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)

Tab. A.17 Life cycle inventory of the production of 1 m^2 single-Si wafer in China, the USA, Asia / Pacific and Europe, respectively with regionalised water withdrawal and water emissions (continued)

	Name	Location	InfrastructureProcess	Unit	single-Si wafer, photovoltaics, at plant	single-Si wafer, photovoltaics, at plant	single-Si wafer, photovoltaics, at plant	single-Si wafer, photovoltaics, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN	US	APAC	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				m2	m2	m2	m2			
water	Water, CN	-	-	kg	1.80E+0	-	-	-	1	1.51	(1,2,1,1,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, US	-	-	kg	-	1.80E+0	-	-	1	1.51	(1,2,1,1,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RAS	-	-	kg	-	-	1.80E+0	-	1	1.51	(1,2,1,1,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RER	-	-	kg	-	-	-	1.80E+0	1	1.51	(1,2,1,1,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
emission air	Heat, waste	-	-	MJ	9.25E+1	9.25E+1	9.25E+1	9.25E+1	1	1.26	(3,4,1,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	COD, Chemical Oxygen Demand	-	-	kg	2.95E-2	2.95E-2	2.95E-2	2.95E-2	1	1.58	(2,4,1,3,1,5); 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	1.59	(3,4,2,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)
	DOC, Dissolved Organic Carbon	-	-	kg	1.11E-2	1.11E-2	1.11E-2	1.11E-2	1	1.59	(3,4,2,3,1,5); 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	1.59	(3,4,2,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 19,25)

Tab. A.18 Life cycle inventory of the production of 1 m^2 single-Si PV cells in China, the USA, Asia / Pacific and Europe, respectively, with regionalised water withdrawal and water emissions

	Name	Location	InfrastructureProcess	Unit	photovoltaic cell, single-Si, at plant	photovoltaic cell, single-Si, at plant	photovoltaic cell, single-Si, at plant	photovoltaic cell, single-Si, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN	US	APAC	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				m2	m2	m2	m2			
product	photovoltaic cell, single-Si, at plant	CN	0	m2	1	0	0	0			
	photovoltaic cell, single-Si, at plant	US	0	m2	0	1	0	0			
	photovoltaic cell, single-Si, at plant	APAC	0	m2	0	0	1	0			
product	photovoltaic cell, single-Si, at plant	RER	0	m2	0	0	0	1			
technosphere	tap water, water balance according to MoeK 2013, at user	CN	0	kg	1.71E+2	-	1.71E+2	-	1	1.07	(1,2,1,1,1,3); 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	0	kg	-	1.71E+2	-	-	1	1.07	(1,2,1,1,1,3); 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	0	kg	-	-	-	1.71E+2	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	-	-	-	1.44E+1	1	1.07	(1,2,1,1,1,3); 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	kWh	1.44E+1	-	-	-	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	electricity, medium voltage, at grid	US	0	kWh	-	1.44E+1	-	-	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	electricity, medium voltage, at grid	JP	0	kWh	-	-	1.44E+1	-	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	natural gas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	6.08E-2	6.08E-2	6.08E-2	6.08E-2	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
infrastructure	photovoltaic cell factory	DE	1	unit	4.00E-7	4.00E-7	4.00E-7	4.00E-7	1	3.00	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
wafers	single-Si wafer, photovoltaics, at regional storage	RER	0	m2	-	-	-	1.03E+0	1	3.00	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	single-Si wafer, photovoltaics, at plant	CN	0	m2	1.03E+0	-	-	-	1	1.07	(1,2,1,1,1,3); 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	m2	-	1.03E+0	-	-	1	3.00	(1,2,1,1,1,3); 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	m2	-	-	1.03E+0	-	1	3.00	(1,2,1,1,1,3); 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	kg	5.75E-3	5.75E-3	5.75E-3	5.75E-3	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	metallization paste, back side, at plant	RER	0	kg	3.84E-3	3.84E-3	3.84E-3	3.84E-3	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	metallization paste, back side, aluminium, at plant	RER	0	kg	5.59E-2	5.59E-2	5.59E-2	5.59E-2	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
chemicals	ammonia, liquid, at regional storehouse	RER	0	kg	2.19E-2	2.19E-2	2.19E-2	2.19E-2	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	phosphoryl chloride, at plant	RER	0	kg	1.33E-2	1.33E-2	1.33E-2	1.33E-2	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	isopropanol, at plant	RER	0	kg	1.77E-1	1.77E-1	1.77E-1	1.77E-1	1	1.07	(1,2,1,1,1,3); 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	0	kg	6.29E-4	6.29E-4	6.29E-4	6.29E-4	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	hydrogen fluoride, at plant	GLO	0	kg	6.45E-4	6.45E-4	6.45E-4	6.45E-4	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	6.04E-1	6.04E-1	6.04E-1	6.04E-1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	lime, hydrated, packed, at plant	CH	0	kg	1.51E-2	1.51E-2	1.51E-2	1.51E-2	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	refrigerant R134a, at plant	RER	0	kg	3.12E-5	3.12E-5	3.12E-5	3.12E-5	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	nitrogen, liquid, at plant	RER	0	kg	1.15E+0	1.15E+0	1.15E+0	1.15E+0	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	silicon tetrahydride, at plant	RER	0	kg	2.91E-3	2.91E-3	2.91E-3	2.91E-3	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	transport, lorry >16t, fleet average	RER	0	tkm	2.74E-1	2.74E-1	2.74E-1	2.74E-1	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	0	tkm	1.52E+0	1.52E+0	1.52E+0	1.52E+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)
	treatment, PV cell production effluent, to wastewater treatment, class 3	CH	0	m3	1.59E-1	1.59E-1	1.59E-1	1.59E-1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)

Tab. A.18 Life cycle inventory of the production of 1 m^2 single-Si PV cells in China, the USA, Asia / Pacific and Europe, respectively, with regionalised water withdrawal and water emissions (continued)

	Name	Location	InfrastructureProcess	Unit	photovoltaic cell, single-Si, at plant	photovoltaic cell, single-Si, at plant	photovoltaic cell, single-Si, at plant	photovoltaic cell, single-Si, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CN	US	APAC	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				m2	m2	m2	m2			
	disposal, waste, Si waferprod., inorg, 9.4% water, to residual material landfill	CH	0	kg	2.33E+0	2.33E+0	2.33E+0	2.33E+0	1	1.07	(1,2,1,1,1,3); 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	0	kg	1.72E-1	1.72E-1	1.72E-1	1.72E-1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	transport, transoceanic freight ship	OCE	0	tkm	3.06E-2	3.06E-2	3.06E-2	3.06E-2	1	2.00	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
emission air, unspecified	Water, CN	-	-	kg	1.71E+1	-	-	-	1	1.51	(1,2,1,1,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, US	-	-	kg	-	1.71E+1	-	-	1	1.51	(1,2,1,1,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RAS	-	-	kg	-	-	1.71E+1	-	1	1.51	(1,2,1,1,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RER	-	-	kg	-	-	-	1.71E+1	1	1.51	(1,2,1,1,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
emission air, high population density	Heat, waste	-	-	MJ	5.18E+1	5.18E+1	5.18E+1	5.18E+1	1	1.07	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	Aluminium	-	-	kg	7.73E-6	7.73E-6	7.73E-6	7.73E-6	1	5.00	(1,2,1,1,1,3); 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	1.51	(1,2,1,1,1,3); 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	5.00	(1,2,1,1,1,3); 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	5.00	(1,2,1,1,1,3); 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	5.00	(1,2,1,1,1,3); 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	5.00	(1,2,1,1,1,3); 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	1.21	(1,2,1,1,1,3); 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	1.07	(1,2,1,1,1,3); 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	1.51	(1,2,1,1,1,3); 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	1.51	(1,2,1,1,1,3); 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	1.51	(1,2,1,1,1,3); 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	1.51	(1,2,1,1,1,3); 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	1.51	(1,2,1,1,1,3); 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	5.00	(1,2,1,1,1,3); 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	5.00	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	1.26E-2	1.26E-2	1.26E-2	1.26E-2	1	1.51	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)
	Water	-	-	kg	1.16E+1	1.16E+1	1.16E+1	1.16E+1	1	1.51	(1,2,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 30,31)

Tab. A.19 Life cycle inventory of the production of 1 m^2 single-Si PV panels and laminates in China and the USA, respectively with regionalised water withdrawal and water emissions

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, single-Si, at plant	photovoltaic laminate, single-Si, at plant	photovoltaic panel, single-Si, at plant	photovoltaic laminate, single-Si, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	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	1	0	0	0			
	photovoltaic laminate, single-Si, at plant	CN	1	m2	0	1	0	0			
	photovoltaic panel, single-Si, at plant	US	1	m2	0	0	1	0			
	photovoltaic laminate, single-Si, at plant	US	1	m2	0	0	0	1			
energy	electricity, medium voltage, at grid	CN	0	kWh	3.73E+0	3.73E+0	-	-	1	1.14	(3,3,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	electricity, medium voltage, at grid	US	0	kWh	-	-	3.73E+0	3.73E+0	1	1.14	(3,3,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diesel, burned in building machine	GLO	0	MJ	8.75E-3	8.75E-3	8.75E-3	8.75E-3	1	1.29	(3,4,3,3,1,5); 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	3.02	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
materials	photovoltaic cell, single-Si, at plant	CN	0	m2	9.35E-1	9.35E-1	-	-	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, multi-Si, at plant	US	0	m2	-	-	-	-	1	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	photovoltaic cell, single-Si, at plant	US	0	m2	-	-	9.35E-1	9.35E-1	1	1.13	(1,4,1,3,1,3); 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	-	2.13E+0	-	1	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); 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	1.29	(3,4,3,3,1,5); 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	1.24	(1,4,1,3,3,3); 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	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	ethylvinylacetate, foil, at plant	RER	0	kg	8.75E-1	8.75E-1	8.75E-1	8.75E-1	1	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	-	-	1	1.13	(1,4,1,3,1,3); 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	-	-	5.03E+0	5.03E+0	1	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); 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	1.29	(3,4,3,3,1,5); 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	1.29	(3,4,3,3,1,5); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
transport	transport, lorry >16t, fleet average	RER	0	tkm	7.24E+0	7.03E+0	7.24E+0	7.03E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	5.72E+1	5.59E+1	5.72E+1	5.59E+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	1.13	(1,4,1,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, polyvinylfluoride, 0.2% water, to municipal incineration	CH	0	kg	1.12E-1	1.12E-1	1.12E-1	1.12E-1	1	1.13	(1,4,1,3,1,3); Calculation, including disposal of the panel after life time
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.64E+0	1.64E+0	1.64E+0	1.64E+0	1	1.13	(1,4,1,3,1,3); Calculation, including disposal of the panel after life time
	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	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
emissions air	Water, CN	-	-	kg	5.03E-1	5.03E-1	-	-	1	1.52	(1,4,1,3,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, US	-	-	kg	-	-	5.03E-1	5.03E-1	1	1.52	(1,4,1,3,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Heat, waste	-	-	MJ	1.34E+1	1.34E+1	1.34E+1	1.34E+1	1	1.29	(3,4,3,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.61	(3,4,3,3,1,5); 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	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)

Tab. A.20 Life cycle inventory of the production of 1 m^2 single-Si PV panels and laminates in Asia / Pacific and Europe, respectively, with regionalised water withdrawal and water emissions

	Name	Location	InfrastructureProcess	Unit	photovoltaic panel, single-Si, at plant	photovoltaic laminate, single-Si, at plant	photovoltaic panel, single-Si, at plant	photovoltaic laminate, single-Si, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				APAC	APAC	RER	RER			
	InfrastructureProcess				1	1	1	1			
	Unit				m2	m2	m2	m2			
product	photovoltaic panel, single-Si, at plant	APAC	1	m2	1	0	0	0			
	photovoltaic laminate, single-Si, at plant	APAC	1	m2	0	1	0	0			
	photovoltaic laminate, single-Si, at plant	RER	1	m2	0	0	0	1			
	photovoltaic panel, single-Si, at plant	RER	1	m2	0	0	1	0			
energy	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	-	-	3.73E+0	3.73E+0	1	1.14	(3,3,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photov
	electricity, medium voltage, at grid	JP	0	kWh	3.73E+0	3.73E+0	-	-	1	1.14	(3,3,1,1,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	diesel, burned in building machine	GLO	0	MJ	8.75E-3	8.75E-3	8.75E-3	8.75E-3	1	1.29	(3,4,3,3,1,5); 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	3.02	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
materials	photovoltaic cell, single-Si, at plant	RER	0	m2	-	-	9.35E-1	9.35E-1	1	1.13	(1,4,1,3,1,3); 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	9.35E-1	9.35E-1	-	-	1	1.13	(1,4,1,3,1,3); 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	-	2.13E+0	-	1	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); 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	1.29	(3,4,3,3,1,5); 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	1.24	(1,4,1,3,3,3); 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	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
	ethylvinylacetate, foil, at plant	RER	0	kg	8.75E-1	8.75E-1	8.75E-1	8.75E-1	1	1.13	(1,4,1,3,1,3); 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	1.13	(1,4,1,3,1,3); 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	-	-	1	1.13	(1,4,1,3,1,3); 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	-	-	5.03E+0	5.03E+0	1	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); 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	1.29	(3,4,3,3,1,5); 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	1.29	(3,4,3,3,1,5); 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	1.13	(1,4,1,3,1,3); 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	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
transport	transport, lorry >16t, fleet average	RER	0	tkm	7.24E+0	7.03E+0	7.24E+0	7.03E+0	1	2.09	(4,5,na,na,na,na); Standard distance 100km, cells 500km
	transport, freight, rail	RER	0	tkm	5.72E+1	5.59E+1	5.72E+1	5.59E+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	1.13	(1,4,1,3,1,3); Alsema (personal communication) 2007, production waste
	disposal, polyvinylfluoride, 0.2% water, to municipal incineration	CH	0	kg	1.12E-1	1.12E-1	1.12E-1	1.12E-1	1	1.13	(1,4,1,3,1,3); Calculation, including disposal of the panel after life time
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.64E+0	1.64E+0	1.64E+0	1.64E+0	1	1.13	(1,4,1,3,1,3); Calculation, including disposal of the panel after life time
	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	1.13	(1,4,1,3,1,3); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)
emissions air	Water, RAS	-	-	kg	5.03E-1	5.03E-1	-	-	1	1.52	(1,4,1,3,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Water, RER	-	-	kg	-	-	5.03E-1	5.03E-1	1	1.52	(1,4,1,3,1,3); Assumption: 5% evaporation of cooling water, 10% evaporation of process water; Frischknecht & Büsser Knöpfel (2013)
	Heat, waste	-	-	MJ	1.34E+1	1.34E+1	1.34E+1	1.34E+1	1	1.29	(3,4,3,3,1,5); Calculation, electricity use
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.06E-3	8.06E-3	8.06E-3	8.06E-3	1	1.61	(3,4,3,3,1,5); 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	1.29	(3,4,3,3,1,5); de Wild-Scholten (2014) Life Cycle Assessment of Photovoltaics Status 2011, Part 1 Data Collection (Table 37)

A.3.2 CdTe PV modules

The life cycle inventories of the manufacture of CdTe PV modules are based on Frischknecht et al. (2015) and Stolz et al. (2016), which are embedded in the KBOB life cycle inventory data DQRv2:2016. CdTe PV modules are produced in Malaysia and the USA. The use of tap water was replaced by the regionalised life cycle inventories described in section A.1.2 and additional elementary flows were included to account for water emissions to air. The share of consumptive water use of CdTe PV module production in the USA was calculated as the difference of the amount of tap water used and the volume of wastewater treated. This yields a consumptive share of 53 %. The production of CdTe PV modules in Malaysia consumes approximately 46 % of the volume of water withdrawn.[5] The demand of raw materials, chemicals and energy as well as the emissions of pollutants to air, water and soil were not adjusted.

The regionalised life cycle inventories of CdTe PV module production are compiled in Tab. A.21.

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[5] Personal communication Parikhit Sinha, FirstSolar, 25.03.2017.

Tab. A.21 Life cycle inventory of the production of 1 m^2 CdTe PV modules in Malaysia and the USA, respectively, with regionalised water withdrawal and water emissions

	Name	Location	Infrastructure-Process	Unit	photovoltaic laminate, CdTe, at plant	photovoltaic laminate, CdTe, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				MY	US			
	InfrastructureProcess				1	1			
	Unit				m2	m2			
	photovoltaic laminate, CdTe, at plant	MY	1	m2	1				
	photovoltaic laminate, CdTe, at plant	US	1	m2		1			
	electricity, medium voltage, at grid	MY	0	kWh	3.02E+1	-	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in Malaysia
	electricity, medium voltage, at grid	US	0	kWh	-	2.95E+1	1	1.07	(1,1,1,1,1,3,BU:1.05); 2011 data for First Solar in US
	natural gas, burned in boiler modulating >100kW	RER	0	MJ	-	1.16E+1	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
infrastructure	photovoltaic panel factory CdTe	US	1	unit	4.00E-6	4.00E-6	1	3.04	(3,4,3,1,1,3,BU:3); Assumption
materials	cadmium telluride, semiconductor-grade, at plant	US	0	kg	2.34E-2	2.58E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	cadmium sulphide, semiconductor-grade, at plant	US	0	kg	3.52E-3	3.52E-3	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature, incl. Part of Cd compound powder
	copper, at regional storage	RER	0	kg	1.16E-2	1.10E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	flat glass, uncoated, at plant	RER	0	kg	8.13E+0	8.25E+0	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	silicone product, at plant	RER	0	kg	3.07E-3	3.07E-3	1	1.08	(1,2,2,3,1,3,BU:1.05); Fthenakis, literature
	ethylvinylacetate, foil, at plant	RER	0	kg	4.86E-1	4.86E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	glass fibre reinforced plastic, polyamide, injection moulding, at plant	RER	0	kg	1.08E-1	1.08E-1	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature, sum up of several materials
	solar glass, low-iron, at regional storage	RER	0	kg	8.38E+0	8.47E+0	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	tempering, flat glass	RER	0	kg	8.38E+0	8.47E+0	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	tap water, water balance according to MoeK 2013, at user	MY	0	kg	2.11E+2	-	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	tap water, water balance according to MoeK 2013, at user	US	0	kg	-	1.32E+2	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	silica sand, at plant	DE	0	kg	4.68E-2	4.68E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	nitric acid, 50% in H2O, at plant	RER	0	kg	5.72E-2	5.72E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	sulphuric acid, liquid, at plant	RER	0	kg	3.93E-2	3.93E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	sodium chloride, powder, at plant	RER	0	kg	4.53E-2	4.53E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	4.93E-2	4.93E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	hydrogen peroxide, 50% in H2O, at plant	RER	0	kg	1.67E-2	1.67E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	isopropanol, at plant	RER	0	kg	2.08E-3	2.08E-3	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	chemicals inorganic, at plant	GLO	0	kg	3.76E-2	3.76E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
	chemicals organic, at plant	GLO	0	kg	9.74E-3	9.74E-3	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature, sum up of several chemicals
	nitrogen, liquid, at plant	RER	0	kg	7.32E-2	7.32E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	helium, at plant	GLO	0	kg	3.64E-2	3.64E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Fthenakis, literature
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	5.22E-1	5.22E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
transport	transport, lorry >16t, fleet average	RER	0	tkm	4.13E-1	7.75E+0	1	2.00	(1,1,1,1,1,3,BU:2); 2010 data for First Solar in US
	transport, freight, rail	RER	0	tkm	5.35E+0	-	1	2.00	(1,1,1,1,1,3,BU:2); 2010 data for First Solar in Malaysia
	transport, transoceanic freight ship	OCE	0	tkm	2.31E+2	-	1	2.00	(1,1,1,1,1,3,BU:2); 2010 data for First Solar in Malaysia
disposal	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.00E-2	3.00E-2	1	1.16	(1,4,3,3,1,3,BU:1.05); Alsema (personal communication) 2007, production waste
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	7.08E-1	7.08E-1	1	1.16	(1,4,3,3,1,3,BU:1.05); Calculation
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	-	6.16E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); 2010 data for First Solar in US
emissions air	Heat, waste	-	-	MJ	2.09E+2	2.09E+2	1	1.29	(3,4,3,3,1,5,BU:1.05); Calculation
	Water, MY	-	-	kg	9.72E+1	-	1	1.61	(3,4,3,3,1,5,BU:1.5); 46% evaporation of tap water; Personal communication Parikhit Sinha, FirstSolar
	Water, US	-	-	kg	-	7.01E+1	1	1.61	(3,4,3,3,1,5,BU:1.5); Difference of tap water supply and wastewater outflow

Tab. A.21 Life cycle inventory of the production of 1 m^2 CdTe PV modules in Malaysia and the USA, respectively, with regionalised water withdrawal and water emissions (continued)

	Name	Location	Infrastructure-Process	Unit	photovoltaic laminate, CdTe, at plant	photovoltaic laminate, CdTe, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				MY	US			
	InfrastructureProcess				1	1			
	Unit				m2	m2			
	Cadmium	-	-	kg	5.34E-9	5.34E-9	1	5.00	(1,1,1,1,1,3,BU:5); 2010 data for First Solar in US
	Copper	-	-	kg	7.56E-9	7.56E-9	1	5.00	(1,1,1,1,1,3,BU:5); 2010 data for First Solar in US
	Lead	-	-	kg	4.44E-9	4.44E-9	1	5.00	(1,1,1,1,1,3,BU:5); 2010 data for First Solar in US
	Nitric acid	-	-	kg	4.30E-5	4.30E-5	1	5.00	(1,1,1,1,1,3,BU:5); 2010 data for First Solar in US
emissions water	Cadmium	-	-	kg	4.43E-7	4.43E-7	1	3.00	(1,1,1,1,1,3,BU:3); 2010 data for First Solar in US
	Copper	-	-	kg	1.92E-6	1.92E-6	1	3.00	(1,1,1,1,1,3,BU:3); 2010 data for First Solar in US
	Lead	-	-	kg	1.72E-7	1.72E-7	1	3.00	(1,1,1,1,1,3,BU:3); 2010 data for First Solar in US
	Nitrate	-	-	kg	1.50E-2	1.50E-2	1	3.00	(1,1,1,1,1,3,BU:3); 2010 data for First Solar in US

A.3.3 PV systems

The life cycle inventories of the residential-scale (3 kWp) PV systems mounted on a slanted roof are based on a previous study (Stolz et al. 2016). The efficiency of mono-Si and CdTe PV modules is 15.1 % and 14.0 %, respectively. Unlike in Stolz et al. (2016), the impact of inverters was also taken into account since the functional unit is 1 kWh of AC electricity. The production and disposal of inverters was modelled using the life cycle inventory of a 2500 W inverter and by scaling the demand according to the maximum power output of the PV system. The lifetime of inverters is assumed to be 15 years. Hence, the inverter needs to be replaced once in the 30 years lifetime of the PV system. The life cycle inventories of BOS components were published by Frischknecht et al. (2015) and used without adaptations to model the PV systems considered. The water use in the production and disposal of BOS components was not regionalised because of its lower importance compared to other processes.

The life cycle inventories of the construction of 3 kWp mono-Si and CdTe PV systems mounted on a slanted roof are presented in Tab. A.22 and Tab. A.23, respectively.

Tab. A.22 Life cycle inventory of the construction of a 3 kWp mono-Si PV system mounted on a slanted roof in Europe

	Name	Location	InfrastructureProcess	Unit	3kWp slanted-roof installation, mono-Si, panel, mounted, on roof, incl. inverter	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				1			
	Unit				unit			
	3kWp slanted-roof installation, mono-Si, panel, mounted, on roof, incl. inverter	RER	1	unit	1.00E+0			
energy	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh	2.30E-1	1	1.28	(3,4,3,1,1,5,BU:1.05); Energy use for erection of plant
materials	electric installation, photovoltaic plant, at plant	CH	1	unit	1.00E+0	1	3.08	(3,4,3,1,1,5,BU:3);
	slanted-roof construction, mounted, on roof	RER	1	m2	1.99E+1	1	3.08	(3,4,3,1,1,5,BU:3); calculation per m2 panel
	inverter, 2500W, at plant	RER	1	unit	2.40E+0	1	3.08	(3,4,3,1,1,5,BU:3); 1 replacement during the lifetime of the PV system; demand scaled linearly by power output; 2.4
	photovoltaic panel, single-Si, at regional storage	RER	1	m2	2.05E+1	1	3.08	(3,4,3,1,1,5,BU:3); Calculation, 2% of modules repaired in the life time, 1% rejects
transport	transport, lorry 3.5-16t, fleet average	RER	0	tkm	3.96E+1	1	2.09	(3,4,3,1,1,5,BU:2); electric parts and panel 100km to construction place
emissions air	Heat, waste	-	-	MJ	8.28E-1	1	1.28	(3,4,3,1,1,5,BU:1.05); calculated with electricity use

Tab. A.23 Life cycle inventory of the construction of a 3 kWp CdTe PV system mounted on a slanted roof in Europe

	Name	Location	InfrastructureProcess	Unit	3kWp slanted-roof installation, CdTe, panel, mounted, on roof, incl. inverter	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				1			
	Unit				unit			
product	3kWp slanted-roof installation, CdTe, panel, mounted, on roof, incl. inverter	RER	1	unit	1.00E+0			
energy	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh	4.00E-2	1	1.28	(3,4,3,1,1,5); Energy use for erection of 3kWp plant
materials	electric installation, photovoltaic plant, at plant	CH	1	unit	1.00E+0	1	2.09	(3,4,3,1,1,5); Literature
	slanted-roof construction, mounted, on roof	RER	1	m2	2.14E+1	1	1.23	(3,1,1,1,1,na); New estimation with mean value of frame weights, correction for panel area
	photovoltaic laminate, CdTe, mix, at regional storage	RER	1	m2	2.16E+1	1	1.36	(1,1,1,1,1,3); Calculation, 1% rejects
	inverter, 2500W, at plant	RER	1	unit	2.40E+0	1	1.36	(3,4,3,1,1,5); 1 replacement during the lifetime of the PV system; demand scaled linearly by power output
transport	transport, lorry 3.5-16t, fleet average	RER	0	tkm	1.34E+3	1	2.09	(3,4,3,1,1,5); 100km for transport of panels from regional storage, electrical installation, mounting structure and inverter to construction site
emissions air	Heat, waste	-	-	MJ	1.44E-1	1	1.28	(3,4,3,1,1,5); calculated with electricity use

A.3.4 PV electricity generation

The life cycle inventories of electricity generation by the 3 kWp PV systems mounted on a slanted roof were modelled according to the draft version of the Product Environmental Footprint Category Rules (PEFCRs) for PV electricity generation (TS PEF Pilot PV 2016). The annual yield of 975 kWh/kWp is representative for average European conditions and includes linear degradation of 0.7 % per year. The lifetime of the PV systems (though not every component, e.g., the inverter) is estimated at 30 years.

The takeback and recycling of the PV modules at the end of life were also taken into account. Both the PV modules and the BOS components are assumed to be recycled after use and are modelled based on the life cycle inventories published in Stolz et al. (2016). The potential benefits of recovered materials (e.g., glass cullet, scrap aluminium and copper) from the recycling of PV modules and BOS components were not included.

The water used to clean the mono-Si and CdTe PV modules was estimated at 20 L/m^2 over the life time of 30 years based on Jungbluth et al. (2003) and modelled with the region-specific life cycle inventory of tap water supply in Europe. It was assumed that 10 % of the tap water is evaporated (Frischknecht & Büsser Knöpfel 2013) whereby the remainder is discharged into the sewer system and treated in a wastewater treatment plant.

The life cycle inventories of electricity generation by residential scale 3 kWp mono-Si and CdTe PV systems mounted on a slanted roof are shown in Tab. A.24 and Tab. A.25, respectively.

Tab. A.24 Life cycle inventory of 1 kWh electricity generated by a 3 kWp mono-Si PV system mounted on a slanted roof in Europe with regionalised water withdrawal and emissions

	Name	Location	InfrastructureProcess	Unit	electricity, PV, at 3kWp slanted-roof, mono-Si, panel, mounted, incl. inverter & recycling	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kWh			
product	electricity, PV, at 3kWp slanted-roof, mono-Si, panel, mounted, incl. inverter & recycling	RER	0	kWh	1			
infrastructure	3kWp slanted-roof installation, mono-Si, panel, mounted, on roof, incl. inverter	RER	1	unit	1.14E-5	1	3.10	(2,3,1,1,3,5,BU:3); infrastructure; calculation
takeback & recycling	mono-Si PV module takeback + recycling	RER	0	m2	2.33E-4	1	1.31	(2,3,1,1,3,5,BU:1.05); infrastructure, incl. 1% rejects and 2% replacements of modules; calculation
auxiliaries	tap water, water balance according to MoeK 2013, at user	RER	0	kg	4.53E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); water for washing, estimation 20 l per m2 panel; calculation
disposal	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.08E-6	1	1.05	(1,2,1,1,1,1,BU:1.05); waste water treatment of washing water; calculation
emission to air, unspecified	Water, RER	-	-	kg	4.53E-4	1	1.50	(1,2,1,1,1,1,BU:1.5); water evaporation estimated at 10% of water withdrawal; Frischknecht & Büsser Knöpfel (2013)
resource in air	Energy, solar, converted	-	-	MJ	3.60E+0	1	1.31	(2,3,1,1,3,5,BU:1.05); solar energy needed for the production of 1kWh electricity (direct current) ; ecoinvent v2.2

Tab. A.25 Life cycle inventory of 1 kWh electricity generated by a 3 kWp CdTe PV system mounted on a slanted roof in Europe with regionalised water withdrawal and emissions

	Name	Location	InfrastructureProcess	Unit	electricity, PV, at 3kWp slanted-roof, CdTe, panel, mounted, incl. inverter & recycling	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kWh			
product	electricity, PV, at 3kWp slanted-roof, CdTe, panel, mounted, incl. inverter & recycling	RER	0	kWh	1			
infrastructure	3kWp slanted-roof installation, CdTe, panel, mounted, on roof, incl. inverter	RER	1	unit	1.14E-5	1	3.10	(2,3,1,1,3,5,BU:3); infrastructure; calculation
takeback & recycling	CdTe PV module takeback + recycling	RER	0	m2	2.47E-4	1	1.31	(2,3,1,1,3,5,BU:1.05); infrastructure, incl. 1% rejects of modules; calculation
auxiliaries	tap water, water balance according to MoeK 2013, at user	RER	0	kg	4.88E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); water for washing, estimation 20 l per m2 panel; calculation
disposal	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.40E-6	1	1.05	(1,2,1,1,1,1,BU:1.05); waste water treatment of washing water; calculation
emission to air, unspecified	Water, RER	-	-	kg	4.88E-4	1	1.50	(1,2,1,1,1,1,BU:1.5); water evaporation estimated at 10% of water withdrawal; Frischknecht & Büsser Knöpfel (2013)
resource in air	Energy, solar, converted	-	-	MJ	3.60E+0	1	1.31	(2,3,1,1,3,5,BU:1.05); solar energy needed for the production of 1kWh electricity (direct current) ; ecoinvent v2.2

B Appendix: List of regionalised life cycle inventories

Tab. B.1 List of life cycle inventories of water purification and electricity generation of the KBOB life cycle inventory data DQRv2:2016 (KBOB et al. 2016) that were regionalized in this study. The geographies are explained in Frischknecht et al. (2007) and Faist-Emmenegger et al. (2007).

	tap water	decarbon-ised water	deionised water	completely softened water	hard coal	lignite	natural gas	heavy fuel oil	nuclear, PWR	nuclear, BWR	reservoir hydro, alpine	reservoir hydro, non-alpine	reservoir hydro, tropics
AT	x	x	x	x	x	x	x	x			x		
BA	x	x	x	x		x						x	
BE	x	x	x	x	x		x	x					
CA												x	
CH	x	x	x	x					x	x			
CN	x	x	x	x	x					x		x	
CS						x		x				x	
CZ	x	x	x	x	x	x		x				x	
DE	x	x	x	x	x	x	x	x	x	x		x	
DK	x	x	x	x				x					
ES	x	x	x	x	x	x	x	x				x	
FI	x	x	x	x				x			x		
FR	x	x	x	x	x	x	x	x		x	x		
GB	x	x	x	x			x	x					
GR	x	x	x	x		x		x				x	
HR	x	x	x	x	x			x				x	
HU	x	x	x	x		x		x					
ID													x
IE	x	x	x	x				x					
IN	x	x	x	x	x						x	x	x
IS												x	
IT	x	x	x	x	x		x	x			x		
JP	x	x	x	x			x					x	
KR												x	
LU	x	x	x	x			x						
MK	x	x	x	x		x						x	
MY	x												x
NL	x	x	x	x	x		x	x					
NO											x		
PE													x
PL	x	x	x	x	x	x							
PT	x	x	x	x	x			x				x	
RER	x	x	x	x				x					
RS	x	x	x	x									
RU	x	x	x	x	x							x	
SE	x	x	x	x				x			x	x	
SI	x	x	x	x		x		x					
SK	x	x	x	x	x	x		x				x	
TH													x
TR												x	
TZ													x
US	x	x	x	x			x		x	x		x	
ZA													x
UCTE							x		x	x			
CENTREL							x						
NORDEL					x		x						
ASCC							x						
ERCOT					x		x						
FRCC					x		x						
MRO					x		x						
NPCC					x		x						
RFC					x		x						
SERC					x		x						
SPP					x		x						
WECC					x		x						

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