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Life Cycle Assessment of National PV Electricity Mixes

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Abbreviations and Acronyms

a	year (annum)
AC	alternating current
APAC	Asia / Pacific
a-Si	amorphous silicon
BOS	balance of system
CdTe	cadmium-telluride
CH	Switzerland
CIS	copper-indium-gallium-selenide
c-Si	crystalline silicon
DC	direct current
EF	environmental footprint
ENTSO-E	European Network of Transmission System Operators for Electricity
GLO	global average
IEA	International Energy Agency
kWh	kilowatt hour
kWp	kilowatt peak
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
micro-Si	micromorphous silicon
MJ	megajoule
mono-Si	monocrystalline silicon
multi-Si	multicrystalline silicon
p	piece
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)
UVEK	Federal Department of the Environment, Transport, Energy and Communication

Summary

The life cycle inventories of the photovoltaic (PV) electricity mixes of individual countries include the shares of different PV technologies, installation types and system sizes. The present study aimed at updating existing and compiling new life cycle inventories of national PV electricity mixes in order to take the strong growth in the worldwide installed PV capacity and the advances in PV module efficiency into account. In total, 33 countries in Europe, Asia, North and South America, Oceania and Africa were considered. The functional unit of this analysis is the production of 1 kWh alternating current (AC) electricity by an average grid-connected PV system in a specific country. The lifetime of the PV systems was assumed to be 30 years. The life cycle inventories presented in this report are meant to be used in the context of modelling national or utility electricity mixes, which include electricity production from fossil, nuclear and renewable energy sources. They should not be used to compare the environmental performance of PV electricity with electricity produced with other technologies such as wind power or geothermal power production.

The most important factor influencing the environmental impacts of PV systems is the average annual yield. Statistical data on the PV electricity generation and the installed capacity were available for the United Kingdom and Switzerland. The annual yield of PV systems installed in China was reported by a country expert. For all other countries, the annual yield was calculated based on the population density weighted average solar irradiation for fixed optimally tilted PV systems. The default performance ratios of 0.80 for utility-scale PV systems and 0.75 for rooftop PV systems were found to overestimate the annual yield, which is probably due to the fact that PV systems are not always optimally oriented. A correction factor of 80 % was estimated based on a comparison of statistical yield data with yield data based on solar irradiation and default performance ratios for the United Kingdom, China and Switzerland. The default performance ratios were adjusted accordingly. The average annual yield was then used to calculate specific yields of centralised, rooftop and façade systems in each country.

The technology breakdown was estimated based on generic data for most countries. According to worldwide production volumes in 2016, multicrystalline silicon (multi-Si; 69.6 %) and monocrystalline silicon (mono-Si; 24.5 %) PV modules dominate the PV market. The cadmium-telluride (CdTe), copper-indium-gallium-selenide (CIS) and micromorphous silicon (micro-Si) PV technologies have production shares of 3.8 %, 1.6 % and 0.6 %, respectively. Country-specific data on the technology breakdown were available for Austria, China, Japan, Korea and the USA. The module efficiencies were updated based on data published in 2018 (mono-Si: 17.5 %; multi-Si: 16.5 %; CdTe: 16.0 %; CIS: 14.0 %). The efficiency of micro-Si PV modules (10.0 %) was not updated due to the lack of recent data.

Country-specific data on the installation type breakdown of PV systems were mainly limited to the share of centralised PV systems. The shares of mounted and integrated slanted roof systems, flat roof systems and mounted and integrated façade systems in

Switzerland, Austria, the USA and Japan were estimated using available specific information. The Japanese installation type breakdown for decentralised PV systems was used as an approximation for all other countries (slanted roof, mounted: 50 %; slanted roof, integrated: 3 %; flat roof: 45 %; façade, mounted: 1 %; façade, integrated: 1 %).

The total environmental impacts of the national PV electricity mixes were quantified using the environmental footprint (EF) method and range from 5.89 µPt/kWh in South Africa to 13.1 µPt/kWh in Ireland. The pattern of the environmental impacts is similar for most impact categories since it is mainly determined by the average annual yield of PV systems installed in a given country. The technology breakdown and the installation type breakdown usually cause a variation of about 10 % between the countries with the lowest environmental impacts and the countries with the highest environmental impacts.

The quality of the data used to update the life cycle inventories of national PV electricity mixes is considered as moderate. The use of default assumptions for the technology breakdown and the installation type breakdown for many countries means that potential country-specific differences are only partly reflected in the life cycle inventories of national PV electricity mixes. The spatial and temporal variations in the environmental impacts of PV electricity are high because of the distinct variability in solar irradiation and the increase in both installed capacity and module efficiency.

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1 Introduction

Life cycle inventories (LCI) of the production of photovoltaic (PV) modules and systems have been established many years ago and updated regularly since then (see e.g. Frischknecht et al. 2015a). The life cycle inventories of the PV electricity mixes of individual countries include the shares of different PV technologies, installation types and system sizes. In life cycle inventory databases, the national PV electricity mixes are used to model the share of PV electricity in the electricity production and supply mixes of the corresponding countries. The life cycle inventories of country-specific PV electricity mixes were compiled several years ago by Jungbluth et al. (2012) and are published in an IEA PVPS Task 12 report (Frischknecht et al. 2015a).

The worldwide installed PV capacity grew exponentially in recent years and increased twentyfold between 2008 and 2016 (IEA-PVPS 2017). At the same time, significant advances have been made in the efficiency of PV modules (Fraunhofer ISE 2018). The present study aims at taking these developments into account by updating the existing life cycle inventories of national PV electricity mixes and compiling new life cycle inventories of the PV electricity mixes of specific countries. Changes and improvements within the PV supply chains are currently under investigation. They are not integrated in life cycle inventories of the supply chains and the analyses presented in this report.

The objective and scope of this study are described in Chapter 2. The life cycle inventories of the national PV electricity mixes are presented in Chapter 3. Chapter 4 contains the results of the life cycle impact assessment. The data quality and the sources of uncertainty are documented in Chapter 5.

2 Objective and scope

2.1 Objective

The objective of this study was to update existing and establish new life cycle inventories of national PV electricity mixes.[1] To this end, country-specific data on the average yield and the shares of different PV technologies, installation types and system sizes were collected. Another objective was to update the life cycle inventories of PV systems with the latest information on the efficiency of commercially available PV modules. The environmental impacts of the national PV electricity mixes were analysed based on one single score and seven midpoint indicators.

2.2 Functional unit

The functional unit of this analysis is the production of 1 kWh alternating current (AC) electricity by an average grid-connected PV system in a specific country.

2.3 Data sources

The most important data sources used for the compilation of the national PV electricity mixes were the trends report by IEA PVPS Task 1 (2017), the photovoltaics report by Fraunhofer ISE (2018) and the country-specific annual yields reported by Breyer and Schmid (2010). These data were complemented by country-specific information obtained from the experts of the IEA PVPS Task 12 member countries. Several other experts in the PV industry were asked for additional information or requested to validate specific assumptions.

The life cycle inventories were linked to UVEK life cycle inventory data DQRv2:2018 (KBOB et al. 2018), 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 is used by the Swiss administration. The analyses were performed with SimaPro v8.5.2 (PRé Consultants 2018).

[1] The life cycle inventories of the PV electricity mixes of the following 26 countries were updated: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom and the USA. New life cycle inventories of PV electricity mixes were established for 7 countries: Chile, China, Israel, Malaysia, Mexico, South Africa and Thailand.

2.4 Impact assessment indicators

The environmental impacts of the national PV electricity mixes were quantified with the environmental footprint (EF) impact assessment method (Fazio et al. 2018). A SimaPro-compatible (“adapted”) version of this method was used, which accounts for additional elementary flows that are frequently used in this software.[2] Additional adjustments were made in the impact category “water scarcity” in order to quantify water consumption rather than water withdrawal in combination with UVEK LCI data DQRv2:2018.[3] To this end, the country-specific elementary flows for water emitted to air and for water embodied in product were taken into account using the characterisation factors provided in the EF impact assessment method. The water scarcity impacts of water withdrawal in unspecified regions were assessed following default assumptions. Frischknecht and Büsser Knöpfel (2013) reported that approximately 10 % of process water and 5 % of cooling water are typically evaporated. The global average characterisation factors of the EF impact assessment method were adjusted accordingly to assess the 10 % and 5 % water lost (consumed) and not the water withdrawn.

According to the procedure described in the product environmental footprint category rules (PEFCR) guidance (European Commission 2017) the three toxicity related impact categories were excluded from the analysis. The normalization and weighting factors described in European Commission (2017) were applied to quantify the total environmental impacts (single score). Long-term emissions were not included in the impact assessment.

The following five impact categories on midpoint level, which were previously identified as most relevant for PV electricity (TS PEF Pilot PV 2018), are analysed in more detail:

- Climate change (sum fossil, biogenic, land transformation);
- Respiratory inorganics;
- Resource use, energy carriers;
- Resource use, minerals and metals;
- Acidification terrestrial and freshwater.

The non-renewable cumulative energy demand and the renewable cumulative energy demand based on Frischknecht et al. (2015c) were used as additional indicators.

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[2] Personal communication Michiel Oele, Pré Consultants, 06.02.2019.

[3] The amounts of water withdrawn from nature and of water evaporated, embodied in product or released to nature or a wastewater treatment plant are usually not balanced in UVEK life cycle inventory data DQRv2:2018. This results in an overestimation of water scarcity impacts according to the EF impact assessment method.

3 Life cycle inventories

3.1 Overview

The life cycle inventories of national PV electricity mixes are based on data on the annual yield, the technology breakdown and the installation type breakdown in different countries. The data sources, assumptions and calculations for the annual yield are documented in Subchapter 3.2. The shares of different module technologies in the national PV electricity mixes are described in Subchapter 3.3. An overview of the module efficiencies of different PV technologies is given in Subchapter 3.4. The derivation of the installation type breakdown and the size distribution of PV systems in the analysed countries are explained in Subchapter 3.5. The shares of individual PV systems and life cycle inventories of national PV electricity mixes are presented in Subchapter 3.6 and Subchapter 3.7.

3.2 Annual yield

3.2.1 Average yield

The annual yield describes the amount of electricity that is produced per unit of installed PV capacity and per year and is given in kWh/(kWp·a). It depends strongly on the solar irradiation, which in turn exhibits a distinct geographic variability. The average annual yield of all PV systems installed in a country is therefore difficult to determine. Different data sources and approaches were considered.

Gaiddon and Jedliczka (2006) and IEA PVPS Task 1 (2017) report the annual yield for the capital city, which may not be representative of the entire country. The yield may also be calculated using statistical data on the amount of electricity generated (IEA 2017) and the cumulative installed PV capacity (IEA-PVPS 2017) in a specific country for a given year. Another approach is to use high-resolution measurement data on the solar irradiation to determine a weighted average for a specific country. Breyer and Schmid (2010) calculated the population density weighted and the area weighted average solar irradiation of fixed-tilted and tracking PV systems for numerous countries and regions. The solar irradiation data given in kWh/(m^2·a) can then be used to estimate the yield of PV systems by employing a performance ratio. This parameter links the effective electricity generation of PV modules to the maximum power output measured under standard conditions by accounting for degradation, occasional defects and the electricity loss at the inverter. The life cycle assessment (LCA) methodology guidelines for PV electricity published by IEA PVPS Task 12 specify generic performance ratios of 0.75 and 0.80 for rooftop and ground-mounted utility PV systems, respectively (Frischknecht et al. 2015b). The share of utility (centralised) PV systems in the total installed capacity for most of the countries considered is reported by IEA PVPS Task 1 (2017).

The annual yield determined based on the population density weighted average solar irradiation for fixed optimally tilted PV systems (Breyer & Schmid 2010) and the default performance ratios (Frischknecht et al. 2015b) were used in the life cycle inventories of PV electricity mixes of most countries. The solar irradiation data are available for all countries considered except for Luxembourg and represent an average of the entire country. The average annual yield of Belgium was used as an approximation for Luxembourg. The population density weighted average irradiation accounts for the fact that PV systems are usually clustered in proximity to urban areas.[4]

Statistical data on the PV electricity generation and the installed capacity for the years 2012 to 2016 were used to calculate the average annual yield for the United Kingdom (BEIS 2017). The average annual yield of PV systems installed in China is based on specific information obtained from the respective country expert in IEA PVPS Task 12.[5] For Switzerland, the average annual yield of PV systems was calculated based on the Swissolar market surveys for the years 2012 to 2016 (Hostettler 2013, 2014, 2015, 2016, 2017). The annual yields of PV systems in the United Kingdom, China and Switzerland were adjusted by the default linear degradation rate of 0.7 % per year, which corresponds to an average reduction of 10.5 % over the lifetime of 30 years (TS PEF Pilot PV 2018).

The yields obtained based on statistical data for the United Kingdom, China and Switzerland are 20-24 % lower than the yields calculated by using solar irradiation data and default performance ratios. It is assumed that PV systems are not always optimally oriented, which results in a lower irradiation than predicted. The performance ratio does not take account of the reduced irradiation due to the suboptimal orientation of PV modules. The average annual yields determined based on irradiation data were multiplied by 80 % in order to account for the lower yield observed for PV systems installed in the United Kingdom, China and Switzerland. The actual performance ratios applied in combination with the population density weighted average solar irradiation reported by Breyer and Schmid (2010) are therefore 0.60 for rooftop PV systems and 0.64 for utility-scale PV systems.

The resulting solar irradiation and annual yield data represent an average of all PV systems installed in a given country. These data were then used to calculate the specific annual yield of centralised, rooftop and façade PV systems, as described in the Sections 3.2.2 and 3.2.3.

3.2.2 Yield of centralised PV systems

The specific annual yield of centralised PV systems was calculated based on the population density weighted average solar irradiation for fixed optimally tilted PV systems (Breyer & Schmid 2010), the default performance ratio of ground-mounted utility PV

[4] Personal communication Parikhit Sinha, First Solar, 23.03.2018.

[5] Personal communication Jia Zhang, Institute of Electrical Engineering, Chinese Academy of Sciences, 22.12.2017.

systems of 0.80 (Frischknecht et al. 2015b) and the correction factor of 80 % to account for the discrepancy between modelled and measured electricity production (see Section 3.2.1). In countries with high solar irradiation, centralised PV systems are increasingly equipped with tracking systems[4] (see e.g. Bolinger et al. 2017). However, the LCIs of ground-mounted PV systems published in Frischknecht et al. (2015a) and Stolz et al. (2016) do not account for a tracking system. The solar irradiation data for fixed tilted PV systems were therefore used for all countries in order to align the yield data with the LCIs of the PV systems.

The annual yield of centralised PV systems in China, Switzerland and the United Kingdom was estimated by multiplying the average yield according to the country-specific data source (see Section 3.2.1) by the ratio of the yield of utility and average PV systems as determined using solar irradiation data and the performance ratios (Breyer & Schmid 2010; Frischknecht et al. 2015b).

3.2.3 Yield of rooftop and façade PV systems

The average yield of decentralised PV systems (including both rooftop and façade systems) was obtained by multiplying the solar irradiation data reported by Breyer and Schmid (2010) by the performance ratio of 0.75 (Frischknecht et al. 2015b). The reduced yield due to the fact that PV modules are not always optimally oriented was taken into account by applying a correction factor of 80 % (see Section 3.2.1). The specific yield of rooftop and façade systems was then calculated based on the assumption that the yield of PV modules mounted vertically in a façade is approximately 70 % of the yield of PV modules mounted on the roof (Jungbluth et al. 2012). The shares of façade installations in different countries are described in Subchapter 3.4.

3.2.4 Overview of irradiation and yield data

The population density weighted average solar irradiation, the average yield and the specific yield of rooftop, façade and centralised PV system for the countries considered in this study are listed in Tab. 3.1.

Tab. 3.1 Overview of the population density weighted average irradiation of fixed optimally tilted PV systems (Breyer & Schmid 2010), the average yield and the yield of rooftop, façade and centralised PV systems for the countries considered. Country-specific data sources were used to determine the yield of PV systems installed in China, Switzerland and the United Kingdom. The yield data include the degradation of PV modules. (n.a.: not available)

Country	Avg. Irradiation fixed optimally tilted (pop-weighted)	Average Yield	Yield rooftop	Yield façade	Yield centralized
	kWh/(m^{2}a)	kWh/(kWp·a)	kWh/(kWp·a)	kWh/(kWp·a)	kWh/(kWp·a)
Australia	1'914	1'154	1'155	809	1'225
Austria	1'389	834	835	585	889
Belgium	1'203	731	726	508	770
Canada	1'554	976	938	657	995
Chile	2'124	1'359	1'282	897	1'359
China	1'631	985	936	655	993
Czech Republic	1'251	768	755	529	801
Denmark	1'287	784	777	544	824
Finland	1'181	710	713	499	756
France	1'441	885	870	609	922
Germany	1'222	746	738	516	782
Greece	1'753	1'076	1'058	741	1'122
Hungary	1'445	887	872	611	925
Ireland	1'055	647	637	446	675
Israel	2'247	1'391	1'356	949	1'438
Italy	1'720	1'073	1'038	727	1'101
Japan	1'578	966	953	667	1'010
Korea	1'770	1'124	1'068	748	1'133
Luxembourg	n.a.	731	726	508	770
Malaysia	1'766	1'061	1'066	746	1'130
Mexico	2'136	1'325	1'289	903	1'367
Netherlands	1'242	746	750	525	795
New Zealand	1'644	991	992	695	1'052
Norway	1'103	662	666	466	706
Portugal	1'891	1'180	1'141	799	1'210
South Africa	2'166	1'386	1'307	915	1'386
Spain	1'886	1'163	1'138	797	1'207
Sweden	1'218	734	735	515	780
Switzerland	1'467	867	867	607	924
Thailand	1'903	1'218	1'149	804	1'218
Turkey	1'839	1'176	1'110	777	1'177
United Kingdom	1'128	690	679	475	720
USA	1'796	1'121	1'084	759	1'149

3.3 Technology breakdown

The global production volumes of the different PV technologies in 2016 reported by Fraunhofer ISE (2018) were used to estimate the technology breakdown for most countries since specific information on the shares of installed PV module technologies is available only for a few countries. Monocrystalline silicon (mono-Si or single-Si), multicrystalline silicon (multi-Si), cadmium-telluride (CdTe), copper-indium-gallium-selenide (CIS or CIGS) and micromorphous silicon (micro-Si) PV modules were considered. The life cycle inventories of micromorphous silicon PV modules were used to approximate the share of the amorphous silicon (a-Si) technology. Based on the 2016 production volumes, multi-Si (69.6 %) and mono-Si (24.5 %) PV modules dominate the generic technology mix. The thin-film PV technologies CdTe, CIS and micro-Si have production shares of 3.8 %, 1.6 % and 0.6 %, respectively (Fraunhofer ISE 2018).

Country-specific information on the technology breakdown is available for Austria, China, Japan, Korea and the USA. In Austria, the shares of mono-Si, multi-Si and thin-film PV technologies installed in 2010-2015 were determined based on a survey (BMVIT 2016). The technology shares for the year 2015 were used for the life cycle inventory of the Austrian PV electricity mix. Multi-Si and mono-Si PV modules contribute 92 % and 6 % to the total installation volume in 2015 (BMVIT 2016). The share of thin-film PV modules (2 %) was divided into the individual technologies CdTe, CIS and micro-Si based on the generic technology breakdown (Fraunhofer ISE 2018).

For China, the country expert in IEA PVPS Task 12 estimated the share of crystalline silicon PV modules at 98 %. Thin-film PV modules contribute less than 2 % to the installed PV capacity.[5] The generic technology breakdown was then used to further differentiate between the individual PV technologies.

The technology breakdown of PV modules installed in Japan was estimated by the respective country expert in IEA PVPS Task 12. The multi-Si and mono-Si technologies contribute approximately 59 % and 32 % to the installed capacity, respectively. CIS PV modules also have a relevant share (9.0 %), whereas the share of micro-Si and CdTe is negligible.[6]

The installation of CdTe and CIS PV modules is not allowed in Korea.[7] The shares of the mono-Si, multi-Si and micro-Si PV technologies were scaled according to the generic technology breakdown based on Fraunhofer ISE (2018).

For the technology breakdown in the USA, it was distinguished between centralised and decentralised PV systems. Data from the NREL Open PV Project Database[8] were used to determine the technology shares for decentralised PV systems. This database mainly contains data from smaller-scale PV systems that are voluntarily shared by solar incentive programmes, utilities, installers and the general public. The shares of mono-Si and multi-Si PV modules in the technology breakdown of decentralised PV systems are

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6 Personal communication Keiichi Komoto, Mizuho Information & Research Institute, 11.04.2018.

7 Personal communication Jin-Seok Lee, Korea Institute of Energy Research, 26.03.2018.

8 https://openpv.nrel.gov/ (accessed on 27.02.2018).

35 % and 63 %, respectively. Thin-film technologies have individual contributions of less than 1 %. The technology shares in centralised PV systems installed in the USA were reported by Bolinger et al. (2017). Crystalline silicon modules account for a share of 67 %, which was further divided into mono-Si and multi-Si based on the generic technology breakdown (Fraunhofer ISE 2018). CdTe PV modules contribute about 97 % to the share of thin-film technologies, with the remainder being covered by CIS modules (Bolinger et al. 2017).

3.4 Module efficiency

The conversion efficiency of mono-Si, multi-Si, CdTe and CIS PV modules was updated in order to take the developments in PV technology in the last years into account. For micro-Si PV modules, recent information about the module efficiency was not available. The module efficiency of micro-Si PV modules therefore remained unchanged at 10.0 % (Flury et al. 2012).

The most important manufacturers of mono-Si and multi-Si PV modules were identified based on Colville (2018). The efficiencies of commercial PV modules were compiled based on factsheets published by these manufacturers. For mono-Si PV modules, the efficiency ranged from 16.8 % to 18.5 %. The module efficiency of multi-Si PV modules produced by the selected manufacturers was between 15.6 % and 17.1 %. The average module efficiencies showed good agreement with the Photovoltaics Report published by Fraunhofer ISE (2018).

For CdTe and CIS PV modules, the most important manufacturers were selected based on information from PV thin.[9] The efficiency of the considered CdTe modules exhibited significant variation (11.8 % to 17.6 %). CIS PV module efficiencies ranged from 13.3 % to 14.9 %. Fraunhofer ISE (2018) reported efficiencies for CdTe and CIS PV modules, which are close to the average of the analysed sample.

The efficiency data from Fraunhofer ISE (2018) were used to update the module demand in the life cycle inventories of PV systems in UVEK LCI data DQRv2:2018 (see Tab. 3.2). The use of current data for the total installed PV capacity appears justifiable since PV is a rapidly evolving technology with high growth rates (IEA-PVPS 2017).

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[9] http://pvthin.org/ (accessed on 20.04.2018).

Tab. 3.2 Average efficiency of commercial PV modules of different technologies based on Fraunhofer ISE (2018) and Flury et al. (2012).

Technology	Module efficiency
monocrystalline silicon (mono-Si)	17.5%
multicrystalline silicon (multi-Si)	16.5%
micromorphous silicon (micro-Si)	10.0%
cadmium-telluride (CdTe)	16.0%
copper-indium-gallium-selenide (CI(G)S)	14.0%

3.5 Installation type breakdown and size distribution

The installation type breakdown comprises the shares of centralised and decentralised PV systems as well as the sub-division of decentralised PV into mounted and integrated slanted roof systems, flat roof systems and mounted and integrated façade systems. For slanted roof and flat roof PV systems, it is further distinguished between the capacity categories below and above 50 kWp.

The cumulative capacity of centralised and decentralised grid-connected PV systems in member countries of IEA PVPS is reported by IEA PVPS Task 1 (IEA-PVPS 2017). These data were used to calculate the share of centralised PV systems, which were modelled with life cycle inventories of ground-mounted PV systems (see Subchapter 3.6 and Tab. 3.3). The installed capacity weighted average share of centralised PV systems was determined for the regions Europe, America, Asia, Africa and Oceania based on the available data (IEA-PVPS 2017). These average shares of centralised PV were then used as an approximation for countries with missing data (Czech Republic, Greece, Hungary, Ireland, Luxembourg, New Zealand, United Kingdom).

Data on the installation type breakdown for decentralised PV systems are only available for very few countries, so assumptions were necessary for most of the countries considered. For Switzerland detailed, validated estimates on the share of different installation types were obtained from Swissolar.[10] Flat roof PV systems have a share of about 50 % in the total capacity of decentralised PV. The share of integrated and mounted slanted roof PV systems is approximately 30 % and 20 %, respectively. Façade systems currently play a minor role in the Swiss PV market (mounted: 0.2 %, integrated: 0.1 %). The rooftop PV systems (mounted slanted roof, integrated slanted roof and flat roof) were further divided based on the maximum power output. In Switzerland, approximately 37 % of the installed capacity of rooftop PV systems is covered by systems with a capacity of less than 50 kWp. The remaining 63 % of the flat roof and slanted roof PV

[10] Personal communication David Stickelberger, Swissolar, 09.04.2018.

systems are larger than 50 kWp.[11] These PV systems were modelled with different life cycle inventories (see Subchapter 3.6 and Tab. 3.3).

The installation type breakdown of decentralised PV systems installed in Austria was mainly based on BMVIT (2016). The share of mounted rooftop systems (98 %) was equally allocated to slanted roof and flat roof PV systems based on the installation type breakdown of Switzerland. Integrated slanted roof PV systems contribute 1.5 % to the installed capacity of decentralised PV systems in Austria. The size distribution was assumed to be similar to Switzerland, with about one third of the PV systems having a capacity below 50 kWp. This estimate was validated by two experts of IEA PVPS Task 12.[12] Façade integrated PV systems have a share of 0.7 % in the Austrian installation type breakdown.

The shares of different installation types in the USA were estimated based on the U.S. Solar Market Insight 2017 (GTM Research & SEIA 2017). Based on information of the respective country expert in IEA PVPS Task 12, it was assumed that residential PV systems are mainly mounted or integrated on a slanted roof, while most commercial PV systems are installed on a flat roof.[13] The shares of mounted slanted roof, integrated slanted roof and flat roof PV systems were estimated at 51 %, 2 % and 45 %, respectively. The size distribution of these PV systems was assumed to be similar to Switzerland, with about one third of the PV systems having a capacity below 50 kWp. The share of façade systems in the installation type breakdown of decentralised PV systems in the USA was estimated at 1 % each for integrated and mounted systems.

The installation type breakdown of Japan was estimated by the respective country expert in IEA PVPS Task 12.[6] The share of mounted and integrated slanted roof PV systems is 50 % and 3 %, respectively. Approximately 45 % of the installed capacity of decentralised PV systems is covered by flat roof PV systems. Mounted and integrated façade systems have a share of 1 % each. The size distribution of PV systems mounted on a slanted roof, integrated in a slanted roof and mounted on a flat roof was estimated based on the data for Switzerland, where about one third of these PV systems have a capacity of less than 50 kWp.

For countries with missing information about the installation type breakdown, the shares of different installation types in Japan were used as an approximation. These shares are based on reliable estimates and are similar to the installation type breakdown of Austria and the USA, for which some data are available.

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[11] Personal communication Thomas Hostettler, Ingenieurbüro Hostettler, 25.04.2018.

[12] Personal communication Parikhit Sinha, First Solar, 14.05.2018, and Andreas Wade, First Solar, 18.05.2018.

[13] Personal communication Parikhit Sinha, First Solar, 04.04.2018.

3.6 Share of individual PV systems

Most of the life cycle inventories used to model the rooftop and the façade PV systems were already available in UVEK LCI data DQRv2:2018. For some system sizes and technologies, new life cycle inventories were created based on existing datasets. The life cycle inventories of utility-scale ground mounted PV systems for all technologies and of residential-scale micro-Si PV systems were taken from the PEF screening study (Stolz et al. 2016). The datasets of crystalline silicon modules used to model national PV mixes represent approximately 80 % Chinese, 14 % European and 6 % Asian-Pacific (APAC) production (Frischknecht et al. 2015a) irrespective of where the panels are installed. An overview of the life cycle inventories of different PV systems is given in Tab. 3.3.

Tab. 3.3 Overview of the life cycle inventories of PV systems used in the life cycle inventories of the national PV electricity mixes (CH: Switzerland, RER: Europe, p: piece).

Installation type	Dataset name	Geography	Unit
Façade	3kWp facade installation, single-Si, laminated, integrated, at building	RER	p
	3kWp facade installation, single-Si, panel, mounted, at building	RER	p
	3kWp facade installation, multi-Si, laminated, integrated, at building	RER	p
	3kWp facade installation, multi-Si, panel, mounted, at building	RER	p
Flat Roof	3kWp flat roof installation, single-Si, on roof	RER	p
	156 kWp flat-roof installation, single-Si, on roof 1)	CH	p
	3kWp flat roof installation, multi-Si, on roof	RER	p
	156 kWp flat-roof installation, multi-Si, on roof	CH	p
Slanted Roof Thin-Film	3kWp slanted-roof installation, CdTe, laminated, integrated, on roof	CH	p
	3kWp slanted-roof installation, CdTe, panel, mounted, on roof	CH	p
	3kWp slanted-roof installation, CIS, laminated, integrated, on roof	CH	p
	3kWp slanted-roof installation, CIS, panel, mounted, on roof	CH	p
	3kWp slanted-roof installation, micro-Si, laminated, integrated, on roof 2)	RER	p
	3kWp slanted-roof installation, micro-Si, panel, mounted, on roof 2)	RER	p
Slanted Roof c-Si >50kWp	93 kWp slanted-roof installation, single-Si, laminated, integrated, on roof	CH	p
	93 kWp slanted-roof installation, single-Si, panel, mounted, on roof 1)	CH	p
	93 kWp slanted-roof installation, multi-Si, laminated, integrated, on roof 1)	CH	p
	93 kWp slanted-roof installation, multi-Si, panel, mounted, on roof 1)	CH	p
Slanted Roof c-Si <50kWp	3kWp slanted-roof installation, single-Si, laminated, integrated, on roof	RER	p
	3kWp slanted-roof installation, single-Si, panel, mounted, on roof	RER	p
	3kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	RER	p
	3kWp slanted-roof installation, multi-Si, panel, mounted, on roof	RER	p
Centralized	570 kWp open ground installation, single-Si, on open ground 2)	RER	p
	570 kWp open ground installation, multi-Si, on open ground 2)	RER	p
	570 kWp open ground installation, CdTe, on open ground 2)	RER	p
	570 kWp open ground installation, CIS, on open ground 2)	RER	p
	570 kWp open ground installation, micro-Si, on open ground 2)	RER	p

1) Life cycle inventory compiled in this study based on an existing dataset.

2) Life cycle inventory based on PEF screening study, adapted with module efficiency and inverter (Stolz et al. 2016).

The share of individual PV systems in a given country is determined by the technology breakdown (see Subchapter 3.3) and the installation type breakdown (see Subchapter 3.5). The share of utility-scale PV systems was calculated by multiplying the total share of centralised PV systems of each country by the corresponding technology breakdown.

A stepwise approach was followed to estimate the shares of individual decentralised PV systems in the national mixes. The shares of residential-scale thin-film PV systems were calculated first since life cycle inventories for these technologies were only available for integrated and mounted slanted roof systems (see Tab. 3.3). Similarly, the existing life cycle inventories of façade, flat roof and larger scale (>50 kWp) slanted roof PV systems only contain mono-Si and multi-Si modules. The share of each of these systems was therefore determined by the installation type breakdown and the technology breakdown, respectively. The shares of the remaining PV systems (integrated or mounted slanted roof systems with a maximum power output <50 kWp and with mono-Si or multi-Si modules) were calculated at the end. This procedure ensures that the technology breakdown and the installation type breakdown are met for each country. The shares of individual PV systems in the national PV electricity mixes are shown in Tab. 3.4.

Tab. 3.4 Shares of individual PV systems in the national PV electricity mixes. It is distinguished between different PV technologies and installation types.

Country	Code	Façade				Flat Roof				Slanted Roof Thin-Film					
		3kWp facade installation, single-Si, laminated, integrated, at building	3kWp facade installation, single-Si, panel, mounted, at building	3kWp facade installation, multi-Si, laminated, integrated, at building	3kWp facade installation, multi-Si, panel, mounted, at building	3kWp flat roof installation, single-Si, on roof	156 kWp flat-roof installation, single-Si, on roof	3kWp flat roof installation, multi-Si, on roof	156 kWp flat-roof installation, multi-Si, on roof	3kWp slanted-roof installation, CdTe, laminated, integrated, on roof	3kWp slanted-roof installation, CdTe, panel, mounted, on roof	3kWp slanted-roof installation, CIS, laminated, integrated, on roof	3kWp slanted-roof installation, CIS, panel, mounted, on roof	3kWp slanted-roof installation, micro-Si, laminated, integrated, on roof	3kWp slanted-roof installation, micro-Si, panel, mounted, on roof
		Share	Share	Share	Share	Share	Share	Share	Share	Share	Share	Share	Share	Share	Share
Australia	AU	2.41E-03	2.41E-03	6.87E-03	6.87E-03	3.62E-02	7.24E-02	1.03E-01	2.06E-01	1.97E-03	3.29E-02	8.27E-04	1.38E-02	3.18E-04	5.30E-03
Austria	AT	4.17E-04	0.00E+00	6.39E-03	0.00E+00	9.92E-03	1.98E-02	1.52E-01	3.04E-01	3.70E-04	1.22E-02	1.55E-04	5.12E-03	5.97E-05	1.97E-03
Belgium	BE	2.10E-03	2.10E-03	5.98E-03	5.98E-03	3.15E-02	6.30E-02	8.97E-02	1.79E-01	1.72E-03	2.86E-02	7.20E-04	1.20E-02	2.77E-04	4.62E-03
Canada	CA	7.72E-04	7.72E-04	2.20E-03	2.20E-03	1.16E-02	2.31E-02	3.29E-02	6.59E-02	6.30E-04	1.05E-02	2.64E-04	4.41E-03	1.02E-04	1.69E-03
Chile	CL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
China	CN	3.44E-04	3.44E-04	9.80E-04	9.80E-04	5.16E-03	1.03E-02	1.47E-02	2.94E-02	9.48E-05	1.58E-03	3.98E-05	6.63E-04	1.53E-05	2.55E-04
Czech Republic	CZ	1.72E-03	1.72E-03	4.89E-03	4.89E-03	2.57E-02	5.15E-02	7.33E-02	1.47E-01	1.40E-03	2.34E-02	5.88E-04	9.80E-03	2.26E-04	3.77E-03
Denmark	DK	2.02E-03	2.02E-03	5.76E-03	5.76E-03	3.03E-02	6.07E-02	8.64E-02	1.73E-01	1.65E-03	2.75E-02	6.93E-04	1.16E-02	2.67E-04	4.44E-03
Finland	FI	2.50E-03	2.50E-03	7.13E-03	7.13E-03	3.76E-02	7.51E-02	1.07E-01	2.14E-01	2.05E-03	3.41E-02	8.58E-04	1.43E-02	3.30E-04	5.50E-03
France	FR	1.67E-03	1.67E-03	4.74E-03	4.74E-03	2.50E-02	5.00E-02	7.12E-02	1.42E-01	1.36E-03	2.27E-02	5.71E-04	9.52E-03	2.20E-04	3.66E-03
Germany	DE	1.92E-03	1.92E-03	5.48E-03	5.48E-03	2.89E-02	5.77E-02	8.21E-02	1.64E-01	1.57E-03	2.62E-02	6.59E-04	1.10E-02	2.54E-04	4.23E-03
Greece	GR	1.72E-03	1.72E-03	4.89E-03	4.89E-03	2.57E-02	5.15E-02	7.33E-02	1.47E-01	1.40E-03	2.34E-02	5.88E-04	9.80E-03	2.26E-04	3.77E-03
Hungary	HU	1.72E-03	1.72E-03	4.89E-03	4.89E-03	2.57E-02	5.15E-02	7.33E-02	1.47E-01	1.40E-03	2.34E-02	5.88E-04	9.80E-03	2.26E-04	3.77E-03
Ireland	IE	1.72E-03	1.72E-03	4.89E-03	4.89E-03	2.57E-02	5.15E-02	7.33E-02	1.47E-01	1.40E-03	2.34E-02	5.88E-04	9.80E-03	2.26E-04	3.77E-03
Israel	IL	1.36E-03	1.36E-03	3.87E-03	3.87E-03	2.04E-02	4.08E-02	5.80E-02	1.16E-01	1.11E-03	1.85E-02	4.66E-04	7.76E-03	1.79E-04	2.99E-03
Italy	IT	1.05E-03	1.05E-03	3.00E-03	3.00E-03	1.58E-02	3.16E-02	4.50E-02	8.99E-02	8.60E-04	1.43E-02	3.61E-04	6.01E-03	1.39E-04	2.31E-03
Japan	JP	2.43E-03	2.43E-03	4.55E-03	4.55E-03	3.65E-02	7.29E-02	6.83E-02	1.37E-01	0.00E+00	0.00E+00	3.56E-03	5.93E-02	7.91E-05	1.32E-03
Korea	KR	3.16E-04	3.16E-04	9.00E-04	9.00E-04	4.74E-03	9.49E-03	1.35E-02	2.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.40E-05	7.34E-04
Luxembourg	LU	1.72E-03	1.72E-03	4.89E-03	4.89E-03	2.57E-02	5.15E-02	7.33E-02	1.47E-01	1.40E-03	2.34E-02	5.88E-04	9.80E-03	2.26E-04	3.77E-03
Malaysia	MY	2.54E-03	2.54E-03	7.22E-03	7.22E-03	3.81E-02	7.61E-02	1.08E-01	2.17E-01	2.07E-03	3.46E-02	8.70E-04	1.45E-02	3.34E-04	5.57E-03
Mexico	MX	1.26E-03	1.26E-03	3.60E-03	3.60E-03	1.90E-02	3.79E-02	5.40E-02	1.08E-01	1.03E-03	1.72E-02	4.33E-04	7.22E-03	1.67E-04	2.78E-03
Netherlands	NL	2.55E-03	2.55E-03	7.25E-03	7.25E-03	3.82E-02	7.64E-02	1.09E-01	2.17E-01	2.08E-03	3.47E-02	8.72E-04	1.45E-02	3.36E-04	5.59E-03
New Zealand	NZ	2.41E-03	2.41E-03	6.87E-03	6.87E-03	3.62E-02	7.24E-02	1.03E-01	2.06E-01	1.97E-03	3.29E-02	8.27E-04	1.38E-02	3.18E-04	5.30E-03
Norway	NO	2.60E-03	2.60E-03	7.40E-03	7.40E-03	3.90E-02	7.80E-02	1.11E-01	2.22E-01	2.12E-03	3.54E-02	8.91E-04	1.48E-02	3.43E-04	5.71E-03
Portugal	PT	1.03E-03	1.03E-03	2.94E-03	2.94E-03	1.55E-02	3.10E-02	4.41E-02	8.81E-02	8.43E-04	1.41E-02	3.54E-04	5.89E-03	1.36E-04	2.27E-03
South Africa	ZA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Spain	ES	1.53E-03	1.53E-03	4.35E-03	4.35E-03	2.29E-02	4.58E-02	6.52E-02	1.30E-01	1.25E-03	2.08E-02	5.23E-04	8.72E-03	2.01E-04	3.35E-03
Sweden	SE	2.44E-03	2.44E-03	6.94E-03	6.94E-03	3.66E-02	7.31E-02	1.04E-01	2.08E-01	1.99E-03	3.32E-02	8.35E-04	1.39E-02	3.21E-04	5.36E-03
Switzerland	CH	2.89E-04	5.78E-04	8.22E-04	1.64E-03	4.77E-02	8.22E-02	1.36E-01	2.34E-01	1.48E-02	2.24E-02	6.21E-03	9.39E-03	2.39E-03	3.61E-03
Thailand	TH	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	TR	3.67E-05	3.67E-05	1.05E-04	1.05E-04	5.51E-04	1.10E-03	1.57E-03	3.14E-03	3.00E-05	5.00E-04	1.26E-05	2.10E-04	4.84E-06	8.07E-05
United Kingdom	GB	1.72E-03	1.72E-03	4.89E-03	4.89E-03	2.57E-02	5.15E-02	7.33E-02	1.47E-01	1.40E-03	2.34E-02	5.88E-04	9.80E-03	2.26E-04	3.77E-03
USA	US	1.41E-03	1.41E-03	2.55E-03	2.55E-03	2.10E-02	4.20E-02	3.79E-02	7.58E-02	5.68E-05	1.36E-03	1.11E-04	2.67E-03	7.60E-05	1.82E-03

Tab. 3.4 Shares of individual PV systems in the national PV electricity mixes. It is distinguished between different PV technologies and installation types. (continued)

Country	Code	Slanted Roof c-Si >50kWp				Slanted Roof c-Si <50kWp				Centralized				
		93 kWp slanted-roof installation, single-Si, laminated, integrated, on roof	93 kWp slanted-roof installation, single-Si, panel, mounted, on roof	93 kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	93 kWp slanted-roof installation, multi-Si, panel, mounted, on roof	3kWp slanted-roof installation, single-Si, laminated, integrated, on roof	3kWp slanted-roof installation, single-Si, panel, mounted, on roof	3kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	3kWp slanted-roof installation, multi-Si, panel, mounted, on roof	570 kWp open ground installation, single-Si, on open ground	570 kWp open ground installation, multi-Si, on open ground	570 kWp open ground installation, CdTe, on open ground	570 kWp open ground installation, CIS, on open ground	570 kWp open ground installation, micro-Si, on open ground
		Share	Share	Share	Share	Share	Share	Share	Share	Share	Share	Share	Share	Share
Australia	AU	4.83E-03	8.04E-02	1.37E-02	2.29E-01	1.60E-03	2.67E-02	4.56E-03	7.60E-02	1.76E-02	5.01E-02	2.70E-03	1.13E-03	4.36E-04
Austria	AT	6.02E-04	1.98E-02	9.23E-03	3.04E-01	2.65E-04	8.74E-03	4.07E-03	1.34E-01	3.81E-04	5.85E-03	8.04E-05	3.37E-05	1.30E-05
Belgium	BE	4.20E-03	7.01E-02	1.20E-02	1.99E-01	1.40E-03	2.33E-02	3.97E-03	6.62E-02	4.69E-02	1.33E-01	7.19E-03	3.02E-03	1.16E-03
Canada	CA	1.54E-03	2.57E-02	4.39E-03	7.32E-02	5.12E-04	8.54E-03	1.46E-03	2.43E-02	1.72E-01	4.90E-01	2.64E-02	1.11E-02	4.26E-03
Chile	CL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.45E-01	6.96E-01	3.75E-02	1.57E-02	6.05E-03
China	CN	6.88E-04	1.15E-02	1.96E-03	3.27E-02	3.05E-04	5.09E-03	8.69E-04	1.45E-02	2.21E-01	6.29E-01	1.10E-02	4.60E-03	1.77E-03
Czech Republic	CZ	3.43E-03	5.72E-02	9.77E-03	1.63E-01	1.14E-03	1.90E-02	3.25E-03	5.41E-02	8.31E-02	2.37E-01	1.28E-02	5.35E-03	2.06E-03
Denmark	DK	4.05E-03	6.74E-02	1.15E-02	1.92E-01	1.34E-03	2.24E-02	3.82E-03	6.37E-02	5.43E-02	1.55E-01	8.33E-03	3.49E-03	1.34E-03
Finland	FI	5.01E-03	8.34E-02	1.43E-02	2.38E-01	1.66E-03	2.77E-02	4.73E-03	7.89E-02	9.06E-03	2.58E-02	1.39E-03	5.83E-04	2.24E-04
France	FR	3.33E-03	5.55E-02	9.49E-03	1.58E-01	1.11E-03	1.84E-02	3.15E-03	5.25E-02	8.78E-02	2.50E-01	1.35E-02	5.65E-03	2.17E-03
Germany	DE	3.85E-03	6.41E-02	1.10E-02	1.83E-01	1.28E-03	2.13E-02	3.64E-03	6.06E-02	6.36E-02	1.81E-01	9.76E-03	4.09E-03	1.57E-03
Greece	GR	3.43E-03	5.72E-02	9.77E-03	1.63E-01	1.14E-03	1.90E-02	3.25E-03	5.41E-02	8.31E-02	2.37E-01	1.28E-02	5.35E-03	2.06E-03
Hungary	HU	3.43E-03	5.72E-02	9.77E-03	1.63E-01	1.14E-03	1.90E-02	3.25E-03	5.41E-02	8.31E-02	2.37E-01	1.28E-02	5.35E-03	2.06E-03
Ireland	IE	3.43E-03	5.72E-02	9.77E-03	1.63E-01	1.14E-03	1.90E-02	3.25E-03	5.41E-02	8.31E-02	2.37E-01	1.28E-02	5.35E-03	2.06E-03
Israel	IL	2.72E-03	4.53E-02	7.74E-03	1.29E-01	9.03E-04	1.50E-02	2.57E-03	4.28E-02	1.17E-01	3.32E-01	1.79E-02	7.51E-03	2.89E-03
Italy	IT	2.11E-03	3.51E-02	5.99E-03	9.99E-02	6.99E-04	1.17E-02	1.99E-03	3.32E-02	1.46E-01	4.14E-01	2.23E-02	9.36E-03	3.60E-03
Japan	JP	4.86E-03	8.10E-02	9.11E-03	1.52E-01	1.16E-03	1.94E-02	2.18E-03	3.64E-02	9.53E-02	1.79E-01	0.00E+00	2.72E-02	6.03E-04
Korea	KR	6.33E-04	1.05E-02	1.80E-03	3.00E-02	3.05E-04	5.08E-03	8.68E-04	1.45E-02	2.27E-01	6.46E-01	0.00E+00	0.00E+00	5.62E-03
Luxembourg	LU	3.43E-03	5.72E-02	9.77E-03	1.63E-01	1.14E-03	1.90E-02	3.25E-03	5.41E-02	8.31E-02	2.37E-01	1.28E-02	5.35E-03	2.06E-03
Malaysia	MY	5.08E-03	8.46E-02	1.44E-02	2.41E-01	1.69E-03	2.81E-02	4.80E-03	8.00E-02	5.82E-03	1.66E-02	8.94E-04	3.75E-04	1.44E-04
Mexico	MX	2.53E-03	4.21E-02	7.20E-03	1.20E-01	8.40E-04	1.40E-02	2.39E-03	3.98E-02	1.26E-01	3.58E-01	1.93E-02	8.09E-03	3.11E-03
Netherlands	NL	5.09E-03	8.49E-02	1.45E-02	2.42E-01	1.69E-03	2.82E-02	4.81E-03	8.02E-02	5.04E-03	1.44E-02	7.74E-04	3.25E-04	1.25E-04
New Zealand	NZ	4.83E-03	8.04E-02	1.37E-02	2.29E-01	1.60E-03	2.67E-02	4.56E-03	7.60E-02	1.76E-02	5.01E-02	2.70E-03	1.13E-03	4.36E-04
Norway	NO	5.20E-03	8.67E-02	1.48E-02	2.47E-01	1.73E-03	2.88E-02	4.92E-03	8.19E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Portugal	PT	2.06E-03	3.44E-02	5.87E-03	9.79E-02	6.85E-04	1.14E-02	1.95E-03	3.25E-02	1.47E-01	4.20E-01	2.26E-02	9.49E-03	3.65E-03
South Africa	ZA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.45E-01	6.96E-01	3.75E-02	1.57E-02	6.05E-03
Spain	ES	3.05E-03	5.09E-02	8.69E-03	1.45E-01	1.01E-03	1.69E-02	2.89E-03	4.81E-02	1.01E-01	2.87E-01	1.55E-02	6.50E-03	2.50E-03
Sweden	SE	4.88E-03	8.13E-02	1.39E-02	2.31E-01	1.62E-03	2.70E-02	4.61E-03	7.68E-02	1.52E-02	4.33E-02	2.33E-03	9.79E-04	3.76E-04
Switzerland	CH	3.20E-02	4.84E-02	9.11E-02	1.38E-01	1.25E-02	1.89E-02	3.55E-02	5.37E-02	2.04E-03	5.80E-03	3.13E-04	1.31E-04	5.04E-05
Thailand	TH	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.45E-01	6.96E-01	3.75E-02	1.57E-02	6.05E-03
Turkey	TR	7.35E-05	1.22E-03	2.09E-04	3.49E-03	2.44E-05	4.07E-04	6.95E-05	1.16E-03	2.41E-01	6.86E-01	3.70E-02	1.55E-02	5.97E-03
United Kingdom	GB	3.43E-03	5.72E-02	9.77E-03	1.63E-01	1.14E-03	1.90E-02	3.25E-03	5.41E-02	8.31E-02	2.37E-01	1.28E-02	5.35E-03	2.06E-03
USA	US	2.01E-03	4.83E-02	3.63E-03	8.71E-02	9.18E-04	2.20E-02	1.66E-03	3.98E-02	1.05E-01	2.98E-01	1.97E-01	5.12E-03	0.00E+00

3.7 Life cycle inventories of PV electricity mixes

The life cycle inventories of the production of 1 kWh national PV electricity mixes contain the shares of different PV systems (see Subchapter 3.6), the converted solar energy, the waste heat due to power losses and the water used for module cleaning including the treatment of wastewater. The amount of PV systems required to produce 1 kWh electricity is determined by the country-specific annual yield, the lifetime of the PV system and the degradation rate of the PV modules. The degradation of PV modules is accounted for in the annual yield (see Subchapter 3.2). A lifetime of PV systems of 30 years is used in accordance with the PEFCR PV electricity (TS PEF Pilot PV 2018).

The amount of converted solar energy per kWh AC electricity was calculated assuming an inverter efficiency of 93.5 % (Frischknecht et al. 2015c). The power losses, which are accounted for as emissions of waste heat, therefore amount to 0.25 MJ/kWh. The water demand for module cleaning was estimated at 20 L/m^2 over the lifetime of 30 years (TS PEF Pilot PV 2018). The share of evaporated water was estimated at 10 % (Frischknecht & Büsser Knöpfel 2013). The wastewater was assumed to be released to a sewer system and treated in a wastewater treatment plant. Country-specific life cycle inventories and elementary flows were used to allow for a regionalised assessment of the water scarcity impacts.

In the following tables, the life cycle inventories of national PV electricity mixes of Switzerland (Tab. 3.5), European countries (Tab. 3.6 and Tab. 3.7), countries in Asia, Oceania and Africa (Tab. 3.8) and of North and South American countries (Tab. 3.9) are presented.

Tab. 3.5 Life cycle inventory of the Swiss PV electricity mix.

	Name	Location	InfrastructureProcess	Unit	electricity, production mix photovoltaic, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				kWh			
resource, in air	Energy, solar, converted	-	-	MJ	3.85E+0	1	1.09	(2,2,1,1,1,3); Energy loss in the system is included
technosphere	tap water, at user	CH	0	kg	4.64E-3	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.17E-6	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	93 kWp slanted-roof installation, single-Si, laminated, integrated, on roof	CH	1	unit	1.32E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	93 kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	CH	1	unit	3.76E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	93 kWp slanted-roof installation, single-Si, panel, mounted, on roof	CH	1	unit	2.00E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	93 kWp slanted-roof installation, multi-Si, panel, mounted, on roof	CH	1	unit	5.69E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	156 kWp flat-roof installation, multi-Si, on roof	CH	1	unit	5.77E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	156 kWp flat-roof installation, single-Si, on roof	CH	1	unit	2.03E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	570 kWp open ground installation, single-Si, on open ground	RER	1	unit	1.29E-10	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	570 kWp open ground installation, multi-Si, on open ground	RER	1	unit	3.67E-10	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	570 kWp open ground installation, CdTe, on open ground	RER	1	unit	1.98E-11	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	570 kWp open ground installation, CIS, on open ground	RER	1	unit	8.30E-12	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	570 kWp open ground installation, micro-Si, on open ground	RER	1	unit	3.19E-12	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp facade installation, single-Si, laminated, integrated, at building	CH	1	unit	5.29E-9	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp facade installation, single-Si, panel, mounted, at building	CH	1	unit	1.06E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp facade installation, multi-Si, laminated, integrated, at building	CH	1	unit	1.51E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp facade installation, multi-Si, panel, mounted, at building	CH	1	unit	3.01E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp flat roof installation, single-Si, on roof	CH	1	unit	6.12E-7	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp flat roof installation, multi-Si, on roof	CH	1	unit	1.74E-6	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, single-Si, laminated, integrated, on roof	CH	1	unit	1.60E-7	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, single-Si, panel, mounted, on roof	CH	1	unit	2.42E-7	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	CH	1	unit	4.55E-7	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, multi-Si, panel, mounted, on roof	CH	1	unit	6.88E-7	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, CdTe, laminated, integrated, on roof	CH	1	unit	1.90E-7	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, CdTe, panel, mounted, on roof	CH	1	unit	2.87E-7	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, CIS, panel, mounted, on roof	CH	1	unit	1.20E-7	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, CIS, laminated, integrated, on roof	CH	1	unit	7.96E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, micro-Si, laminated, integrated, on roof	RER	1	unit	3.06E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
	3kWp slanted-roof installation, micro-Si, panel, mounted, on roof	RER	1	unit	4.63E-8	1	1.24	(3,2,1,1,1,3); Calculation with average annual yield (based on Swissolar statistics 2012-2016) and share of technologies. Lifetime: 30a, Average degradation over lifetime: 10.5%.
emission air	Heat, waste	-	-	MJ	2.50E-1	1	1.05	(1,na,na,na,na,na);
	Water, CH	-	-	kg	4.64E-4	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	electricity, production mix photovoltaic, at plant	CH	0	kWh	1.00E+0			

Tab. 3.6 Life cycle inventories of the PV electricity mixes of different European countries, part 1.

	Name	Location	InfrastructureProcess	Unit	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				AT	BE	CZ	DK	FI	FR	DE	GR	HU	IE			
	InfrastructureProcess				0	0	0	0	0	0	0	0	0	0			
	Unit				kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh			
resource, in air	Energy, solar, converted	-	-	MJ	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	1	1.09	(2,2,1,1,1,3); Energy loss in the system
technosphere	tap water, water balance according to MoeK 2013, at user	AT	0	kg	4.85E-3	-	-	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	BE	0	kg	-	5.51E-3	-	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	CZ	0	kg	-	-	5.25E-3	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	DK	0	kg	-	-	-	5.14E-3	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	FI	0	kg	-	-	-	-	5.67E-3	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	FR	0	kg	-	-	-	-	-	4.55E-3	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	DE	0	kg	-	-	-	-	-	-	5.40E-3	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	GR	0	kg	-	-	-	-	-	-	-	3.74E-3	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	HU	0	kg	-	-	-	-	-	-	-	-	4.54E-3	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	IE	0	kg	-	-	-	-	-	-	-	-	-	6.22E-3	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	4.36E-6	4.96E-6	4.72E-6	4.62E-6	5.10E-6	4.09E-6	4.86E-6	3.37E-6	4.09E-6	5.60E-6	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	93 kWp slanted-roof installation, single-Si, laminated, integrated, on roof	CH	1	unit	2.58E-10	2.07E-9	1.63E-9	1.87E-9	2.52E-9	1.37E-9	1.87E-9	1.16E-9	1.41E-9	1.93E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	CH	1	unit	3.96E-9	5.91E-9	4.64E-9	5.31E-9	7.17E-9	3.91E-9	5.32E-9	3.31E-9	4.02E-9	5.50E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, single-Si, panel, mounted, on roof	CH	1	unit	8.51E-9	3.46E-8	2.72E-8	3.11E-8	4.20E-8	2.29E-8	3.12E-8	1.94E-8	2.35E-8	3.22E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, multi-Si, panel, mounted, on roof	CH	1	unit	1.31E-7	9.84E-8	7.73E-8	8.85E-8	1.19E-7	6.52E-8	8.87E-8	5.52E-8	6.69E-8	9.17E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	156 kWp flat-roof installation, multi-Si, on roof	CH	1	unit	7.78E-8	5.28E-8	4.15E-8	4.75E-8	6.41E-8	3.50E-8	4.76E-8	2.96E-8	3.59E-8	4.92E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	156 kWp flat-roof installation, single-Si, on roof	CH	1	unit	5.08E-9	1.86E-8	1.46E-8	1.67E-8	2.25E-8	1.23E-8	1.67E-8	1.04E-8	1.26E-8	1.73E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, single-Si, on open ground	RER	1	unit	2.51E-11	3.56E-9	6.07E-9	3.85E-9	7.01E-10	5.57E-9	4.76E-9	4.33E-9	5.25E-9	7.20E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, multi-Si, on open ground	RER	1	unit	3.85E-10	1.01E-8	1.73E-8	1.10E-8	1.99E-9	1.58E-8	1.35E-8	1.23E-8	1.50E-8	2.05E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, CdTe, on open ground	RER	1	unit	5.29E-12	5.46E-10	9.31E-10	5.91E-10	1.08E-10	8.54E-10	7.30E-10	6.65E-10	8.06E-10	1.10E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, CIS, on open ground	RER	1	unit	2.22E-12	2.29E-10	3.91E-10	2.48E-10	4.51E-11	3.58E-10	3.06E-10	2.79E-10	3.38E-10	4.63E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, micro-Si, on open ground	RER	1	unit	8.54E-13	8.81E-11	1.50E-10	9.54E-11	1.73E-11	1.38E-10	1.18E-10	1.07E-10	1.30E-10	1.78E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, single-Si, laminated, integrated, at building	RER	1	unit	7.92E-9	4.59E-8	3.61E-8	4.13E-8	5.57E-8	3.04E-8	4.14E-8	2.57E-8	3.12E-8	4.28E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, single-Si, panel, mounted, at building	RER	1	unit	-	4.59E-8	3.61E-8	4.13E-8	5.57E-8	3.04E-8	4.14E-8	2.57E-8	3.12E-8	4.28E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, multi-Si, laminated, integrated, at building	RER	1	unit	1.21E-7	1.31E-7	1.03E-7	1.18E-7	1.59E-7	8.66E-8	1.18E-7	7.33E-8	8.89E-8	1.22E-7	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, multi-Si, panel, mounted, at building	RER	1	unit	-	1.31E-7	1.03E-7	1.18E-7	1.59E-7	8.66E-8	1.18E-7	7.33E-8	8.89E-8	1.22E-7	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp flat roof installation, single-Si, on roof	RER	1	unit	1.32E-7	4.82E-7	3.79E-7	4.34E-7	5.85E-7	3.19E-7	4.35E-7	2.70E-7	3.28E-7	4.49E-7	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp flat roof installation, multi-Si, on roof	RER	1	unit	2.02E-6	1.37E-6	1.08E-6	1.24E-6	1.67E-6	9.09E-7	1.24E-6	7.70E-7	9.34E-7	1.28E-6	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, single-Si, laminated, integrated, on roof	RER	1	unit	3.53E-9	2.14E-8	1.68E-8	1.92E-8	2.59E-8	1.41E-8	1.92E-8	1.20E-8	1.45E-8	1.99E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, single-Si, panel, mounted, on roof	RER	1	unit	1.16E-7	3.56E-7	2.80E-7	3.20E-7	4.32E-7	2.36E-7	3.21E-7	2.00E-7	2.42E-7	3.32E-7	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	RER	1	unit	5.41E-8	6.08E-8	4.78E-8	5.47E-8	7.38E-8	4.02E-8	5.48E-8	3.41E-8	4.13E-8	5.66E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, multi-Si, panel, mounted, on roof	RER	1	unit	1.78E-6	1.01E-6	7.96E-7	9.12E-7	1.23E-6	6.71E-7	9.13E-7	5.68E-7	6.89E-7	9.44E-7	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.

Tab. 3.6 Life cycle inventories of the PV electricity mixes of different European countries, part 1. (continued)

	Name	Location	InfrastructureProcess	Unit	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				AT	BE	CZ	DK	FI	FR	DE	GR	HU	IE			
	InfrastructureProcess				0	0	0	0	0	0	0	0	0	0			
	Unit				kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh			
	3kWp slanted-roof installation, CdTe, laminated, integrated, on roof	CH	1	unit	4.93E-9	2.63E-8	2.06E-8	2.36E-8	3.19E-8	1.74E-8	2.37E-8	1.47E-8	1.79E-8	2.45E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CdTe, panel, mounted, on roof	CH	1	unit	1.62E-7	4.38E-7	3.44E-7	3.94E-7	5.31E-7	2.90E-7	3.95E-7	2.45E-7	2.98E-7	4.08E-7	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CIS, panel, mounted, on roof	CH	1	unit	6.81E-8	1.84E-7	1.44E-7	1.65E-7	2.23E-7	1.22E-7	1.65E-7	1.03E-7	1.25E-7	1.71E-7	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CIS, laminated, integrated, on roof	CH	1	unit	2.07E-9	1.10E-8	8.65E-9	9.91E-9	1.34E-8	7.29E-9	9.93E-9	6.18E-9	7.49E-9	1.03E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, micro-Si, laminated, integrated, on roof	RER	1	unit	7.94E-10	4.24E-9	3.33E-9	3.81E-9	5.14E-9	2.81E-9	3.82E-9	2.38E-9	2.88E-9	3.95E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, micro-Si, panel, mounted, on roof	RER	1	unit	2.62E-8	7.06E-8	5.55E-8	6.35E-8	8.57E-8	4.68E-8	6.37E-8	3.96E-8	4.80E-8	6.58E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
emission air	Heat, waste	-	-	MJ	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	1	1.05	(1,na,na,na,na,na); Calculation with average annual output and share of technologies; Average degradation of 10.5% included
	Water, AT	-	-	kg	4.85E-4	-	-	-	-	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, BE	-	-	kg	-	5.51E-4	-	-	-	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, CZ	-	-	kg	-	-	5.25E-4	-	-	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, DK	-	-	kg	-	-	-	5.14E-4	-	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, FI	-	-	kg	-	-	-	-	5.67E-4	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, FR	-	-	kg	-	-	-	-	-	4.55E-4	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, DE	-	-	kg	-	-	-	-	-	-	5.40E-4	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, GR	-	-	kg	-	-	-	-	-	-	-	3.74E-4	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, HU	-	-	kg	-	-	-	-	-	-	-	-	4.54E-4	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, IE	-	-	kg	-	-	-	-	-	-	-	-	-	6.22E-4	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
product	electricity, production mix photovoltaic, at plant	AT	0	kWh	1	0	0	0	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	BE	0	kWh	0	1	0	0	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	CZ	0	kWh	0	0	1	0	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	DK	0	kWh	0	0	0	1	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	FI	0	kWh	0	0	0	0	1	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	FR	0	kWh	0	0	0	0	0	1	0	0	0	0			
	electricity, production mix photovoltaic, at plant	DE	0	kWh	0	0	0	0	0	0	1	0	0	0			
	electricity, production mix photovoltaic, at plant	GR	0	kWh	0	0	0	0	0	0	0	1	0	0			
	electricity, production mix photovoltaic, at plant	HU	0	kWh	0	0	0	0	0	0	0	0	1	0			
	electricity, production mix photovoltaic, at plant	IE	0	kWh	0	0	0	0	0	0	0	0	0	1			

Tab. 3.7 Life cycle inventories of the PV electricity mixes of different European countries, part 2.

	Name	Location	InfrastructureProcess	Unit	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				IT	LU	NL	NO	PT	ES	SE	GB	TR			
	InfrastructureProcess				0	0	0	0	0	0	0	0	0			
	Unit				kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh			
resource, in air	Energy, solar, converted	-	-	MJ	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	1	1.09	(2,2,1,1,1,3); Energy loss in the system
	tap water, water balance according to MoeK 2013, at user	IT	0	kg	3.75E-3	-	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	LU	0	kg	-	5.45E-3	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	NL	0	kg	-	-	5.40E-3	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	NO	0	kg	-	-	-	6.08E-3	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	PT	0	kg	-	-	-	-	3.41E-3	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	ES	0	kg	-	-	-	-	-	3.46E-3	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	SE	0	kg	-	-	-	-	-	-	5.49E-3	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	GB	0	kg	-	-	-	-	-	-	-	5.83E-3	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	TR	0	kg	-	-	-	-	-	-	-	-	3.42E-3	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	3.38E-6	4.91E-6	4.86E-6	5.47E-6	3.07E-6	3.12E-6	4.94E-6	5.25E-6	3.07E-6	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	93 kWp slanted-roof installation, single-Si, laminated, integrated, on roof	CH	1	unit	7.27E-10	1.69E-9	2.43E-9	2.80E-9	6.48E-10	9.61E-10	2.38E-9	1.81E-9	2.37E-11	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	CH	1	unit	2.07E-9	4.82E-9	6.93E-9	7.97E-9	1.84E-9	2.74E-9	6.77E-9	5.16E-9	6.75E-11	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, single-Si, panel, mounted, on roof	CH	1	unit	1.21E-8	2.82E-8	4.06E-8	4.67E-8	1.08E-8	1.60E-8	3.96E-8	3.02E-8	3.95E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, multi-Si, panel, mounted, on roof	CH	1	unit	3.45E-8	8.04E-8	1.16E-7	1.33E-7	3.07E-8	4.56E-8	1.13E-7	8.60E-8	1.13E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	156 kWp flat-roof installation, multi-Si, on roof	CH	1	unit	1.85E-8	4.31E-8	6.20E-8	7.12E-8	1.65E-8	2.45E-8	6.05E-8	4.61E-8	6.04E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	156 kWp flat-roof installation, single-Si, on roof	CH	1	unit	6.50E-9	1.52E-8	2.18E-8	2.50E-8	5.79E-9	8.60E-9	2.13E-8	1.62E-8	2.12E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, single-Si, on open ground	RER	1	unit	7.73E-9	6.31E-9	3.71E-10	-	7.13E-9	4.89E-9	1.14E-9	6.75E-9	1.20E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, multi-Si, on open ground	RER	1	unit	2.20E-8	1.80E-8	1.06E-9	-	2.03E-8	1.39E-8	3.25E-9	1.92E-8	3.41E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, CdTe, on open ground	RER	1	unit	1.19E-9	9.69E-10	5.69E-11	-	1.09E-9	7.50E-10	1.75E-10	1.04E-9	1.84E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, CIS, on open ground	RER	1	unit	4.97E-10	4.06E-10	2.39E-11	-	4.59E-10	3.15E-10	7.34E-11	4.34E-10	7.71E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, micro-Si, on open ground	RER	1	unit	1.91E-10	1.56E-10	9.18E-12	-	1.76E-10	1.21E-10	2.82E-11	1.67E-10	2.97E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, single-Si, laminated, integrated, at building	RER	1	unit	1.61E-8	3.75E-8	5.39E-8	6.20E-8	1.43E-8	2.13E-8	5.26E-8	4.01E-8	5.25E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, single-Si, panel, mounted, at building	RER	1	unit	1.61E-8	3.75E-8	5.39E-8	6.20E-8	1.43E-8	2.13E-8	5.26E-8	4.01E-8	5.25E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, multi-Si, laminated, integrated, at building	RER	1	unit	4.58E-8	1.07E-7	1.53E-7	1.76E-7	4.08E-8	6.06E-8	1.50E-7	1.14E-7	1.50E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, multi-Si, panel, mounted, at building	RER	1	unit	4.58E-8	1.07E-7	1.53E-7	1.76E-7	4.08E-8	6.06E-8	1.50E-7	1.14E-7	1.50E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp flat roof installation, single-Si, on roof	RER	1	unit	1.69E-7	3.94E-7	5.66E-7	6.51E-7	1.51E-7	2.24E-7	5.53E-7	4.21E-7	5.52E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp flat roof installation, multi-Si, on roof	RER	1	unit	4.81E-7	1.12E-6	1.61E-6	1.85E-6	4.29E-7	6.36E-7	1.57E-6	1.20E-6	1.57E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, single-Si, laminated, integrated, on roof	RER	1	unit	7.48E-9	1.74E-8	2.51E-8	2.88E-8	6.67E-9	9.90E-9	2.45E-8	1.87E-8	2.44E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, single-Si, panel, mounted, on roof	RER	1	unit	1.25E-7	2.91E-7	4.18E-7	4.80E-7	1.11E-7	1.65E-7	4.08E-7	3.11E-7	4.07E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	RER	1	unit	2.13E-8	4.97E-8	7.13E-8	8.20E-8	1.90E-8	2.82E-8	6.97E-8	5.31E-8	6.95E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, multi-Si, panel, mounted, on roof	RER	1	unit	3.55E-7	8.28E-7	1.19E-6	1.37E-6	3.16E-7	4.70E-7	1.16E-6	8.85E-7	1.16E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.

Tab. 3.7 Life cycle inventories of the PV electricity mixes of different European countries, part 2. (continued)

	Name	Location	InfrastructureProcess	Unit	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				IT	LU	NL	NO	PT	ES	SE	GB	TR			
	InfrastructureProcess				0	0	0	0	0	0	0	0	0			
	Unit				kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh			
	3kWp slanted-roof installation, CdTe, laminated, integrated, on roof	CH	1	unit	9.21E-9	2.15E-8	3.08E-8	3.55E-8	8.21E-9	1.22E-8	3.01E-8	2.30E-8	3.01E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CdTe, panel, mounted, on roof	CH	1	unit	1.53E-7	3.58E-7	5.14E-7	5.91E-7	1.37E-7	2.03E-7	5.02E-7	3.83E-7	5.01E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CIS, panel, mounted, on roof	CH	1	unit	6.44E-8	1.50E-7	2.16E-7	2.48E-7	5.74E-8	8.51E-8	2.10E-7	1.60E-7	2.10E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CIS, laminated, integrated, on roof	CH	1	unit	3.86E-9	9.00E-9	1.29E-8	1.49E-8	3.44E-9	5.11E-9	1.26E-8	9.63E-9	1.26E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, micro-Si, laminated, integrated, on roof	RER	1	unit	1.49E-9	3.46E-9	4.97E-9	5.72E-9	1.32E-9	1.96E-9	4.86E-9	3.70E-9	4.85E-11	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, micro-Si, panel, mounted, on roof	RER	1	unit	2.48E-8	5.77E-8	8.29E-8	9.53E-8	2.21E-8	3.27E-8	8.09E-8	6.17E-8	8.08E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
emission air	Heat, waste	-	-	MJ	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	1	1.05	(1,na,na,na,na,na); Calculation with average annual output and share of technologies; Average degradation of 10.5% included
	Water, IT	-	-	kg	3.75E-4	-	-	-	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, LU	-	-	kg	-	5.45E-4	-	-	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, NL	-	-	kg	-	-	5.40E-4	-	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, NO	-	-	kg	-	-	-	6.08E-4	-	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, PT	-	-	kg	-	-	-	-	3.41E-4	-	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, ES	-	-	kg	-	-	-	-	-	3.46E-4	-	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, SE	-	-	kg	-	-	-	-	-	-	5.49E-4	-	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, GB	-	-	kg	-	-	-	-	-	-	-	5.83E-4	-	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, TR	-	-	kg	-	-	-	-	-	-	-	-	3.42E-4	1	1.51	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	electricity, production mix photovoltaic, at plant	IT	0	kWh	1	0	0	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	LU	0	kWh	0	1	0	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	NL	0	kWh	0	0	1	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	NO	0	kWh	0	0	0	1	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	PT	0	kWh	0	0	0	0	1	0	0	0	0			
	electricity, production mix photovoltaic, at plant	ES	0	kWh	0	0	0	0	0	1	0	0	0			
	electricity, production mix photovoltaic, at plant	SE	0	kWh	0	0	0	0	0	0	1	0	0			
	electricity, production mix photovoltaic, at plant	GB	0	kWh	0	0	0	0	0	0	0	1	0			
	electricity, production mix photovoltaic, at plant	TR	0	kWh	0	0	0	0	0	0	0	0	1			

Tab. 3.8 Life cycle inventories of the PV electricity mixes of different countries in Asia, Oceania and Africa.

	Name	Location	InfrastructureProcess	Unit	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				JP	AU	KR	NZ	CN	IL	MY	ZA	TH			
	InfrastructureProcess				0	0	0	0	0	0	0	0	0			
	Unit				kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh			
resource, in air	Energy, solar, converted	-	-	MJ	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	3.85E+0	1	1.09	(2,2,1,1,1,3); Energy loss in the system
technosphere	tap water, water balance according to MoeK 2013, at user	JP	0	kg	4.19E-3	-	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	AU	0	kg	-	3.49E-3	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	KR	0	kg	-	-	3.56E-3	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	NZ	0	kg	-	-	-	4.06E-3	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	CN	0	kg	-	-	-	-	4.06E-3	-	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	IL	0	kg	-	-	-	-	-	2.89E-3	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	MY	0	kg	-	-	-	-	-	-	3.79E-3	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	ZA	0	kg	-	-	-	-	-	-	-	2.90E-3	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	TH	0	kg	-	-	-	-	-	-	-	-	3.30E-3	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	3.77E-6	3.14E-6	3.20E-6	3.66E-6	3.65E-6	2.60E-6	3.41E-6	2.61E-6	2.97E-6	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	93 kWp slanted-roof installation, single-Si, laminated, integrated, on roof	CH	1	unit	1.83E-9	1.50E-9	2.12E-10	1.74E-9	2.64E-10	7.18E-10	1.71E-9	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	CH	1	unit	3.43E-9	4.26E-9	6.04E-10	4.96E-9	7.50E-10	2.04E-9	4.86E-9	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, single-Si, panel, mounted, on roof	CH	1	unit	3.05E-8	2.49E-8	3.54E-9	2.90E-8	4.39E-9	1.20E-8	2.84E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, multi-Si, panel, mounted, on roof	CH	1	unit	5.71E-8	7.10E-8	1.01E-8	8.27E-8	1.25E-8	3.41E-8	8.10E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	156 kWp flat-roof installation, multi-Si, on roof	CH	1	unit	3.06E-8	3.81E-8	5.40E-9	4.44E-8	6.71E-9	1.83E-8	4.34E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	156 kWp flat-roof installation, single-Si, on roof	CH	1	unit	1.64E-8	1.34E-8	1.90E-9	1.56E-8	2.36E-9	6.42E-9	1.53E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, single-Si, on open ground	RER	1	unit	5.52E-9	8.41E-10	1.17E-8	9.79E-10	1.30E-8	4.75E-9	3.01E-10	1.03E-8	1.17E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, multi-Si, on open ground	RER	1	unit	1.03E-8	2.39E-9	3.33E-8	2.79E-9	3.71E-8	1.35E-8	8.58E-10	2.94E-8	3.34E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, CdTe, on open ground	RER	1	unit	-	1.29E-10	-	1.50E-10	6.47E-10	7.28E-10	4.62E-11	1.58E-9	1.80E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, CIS, on open ground	RER	1	unit	1.57E-9	5.41E-11	-	6.30E-11	2.71E-10	3.05E-10	1.94E-11	6.64E-10	7.56E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, micro-Si, on open ground	RER	1	unit	3.49E-11	2.08E-11	2.90E-10	2.42E-11	1.04E-10	1.17E-10	7.46E-12	2.55E-10	2.91E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, single-Si, laminated, integrated, at building	RER	1	unit	4.05E-8	3.31E-8	4.70E-9	3.86E-8	5.84E-9	1.59E-8	3.78E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, single-Si, panel, mounted, at building	RER	1	unit	4.05E-8	3.31E-8	4.70E-9	3.86E-8	5.84E-9	1.59E-8	3.78E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, multi-Si, laminated, integrated, at building	RER	1	unit	7.59E-8	9.43E-8	1.34E-8	1.10E-7	1.66E-8	4.53E-8	1.08E-7	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, multi-Si, panel, mounted, at building	RER	1	unit	7.59E-8	9.43E-8	1.34E-8	1.10E-7	1.66E-8	4.53E-8	1.08E-7	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp flat roof installation, single-Si, on roof	RER	1	unit	4.25E-7	3.48E-7	4.93E-8	4.05E-7	6.13E-8	1.67E-7	3.97E-7	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp flat roof installation, multi-Si, on roof	RER	1	unit	7.97E-7	9.91E-7	1.40E-7	1.15E-6	1.74E-7	4.75E-7	1.13E-6	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, single-Si, laminated, integrated, on roof	RER	1	unit	1.36E-8	1.54E-8	3.17E-9	1.79E-8	3.62E-9	7.39E-9	1.76E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, single-Si, panel, mounted, on roof	RER	1	unit	2.26E-7	2.57E-7	5.28E-8	2.99E-7	6.04E-8	1.23E-7	2.93E-7	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	RER	1	unit	2.55E-8	4.39E-8	9.03E-9	5.11E-8	1.03E-8	2.10E-8	5.00E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, multi-Si, panel, mounted, on roof	RER	1	unit	4.24E-7	7.31E-7	1.50E-7	8.51E-7	1.72E-7	3.51E-7	8.34E-7	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.

Tab. 3.8 Life cycle inventories of the PV electricity mixes of different countries in Asia, Oceania and Africa. (continued)

	Name	Location	InfrastructureProcess	Unit	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				JP	AU	KR	NZ	CN	IL	MY	ZA	TH			
	InfrastructureProcess				0	0	0	0	0	0	0	0	0			
	Unit				kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh			
	3kWp slanted-roof installation, CdTe, laminated, integrated, on roof	CH	1	unit	-	1.90E-8	-	2.21E-8	1.13E-9	9.10E-9	2.16E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CdTe, panel, mounted, on roof	CH	1	unit	-	3.16E-7	-	3.68E-7	1.88E-8	1.52E-7	3.60E-7	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CIS, panel, mounted, on roof	CH	1	unit	6.92E-7	1.33E-7	-	1.54E-7	7.87E-9	6.36E-8	1.51E-7	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CIS, laminated, integrated, on roof	CH	1	unit	4.15E-8	7.95E-9	-	9.26E-9	4.72E-10	3.81E-9	9.06E-9	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, micro-Si, laminated, integrated, on roof	RER	1	unit	9.22E-10	3.06E-9	4.58E-10	3.56E-9	1.82E-10	1.47E-9	3.49E-9	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, micro-Si, panel, mounted, on roof	RER	1	unit	1.54E-8	5.10E-8	7.63E-9	5.93E-8	3.03E-9	2.45E-8	5.81E-8	-	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
emission air	Heat, waste	-	-	MJ	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	2.50E-1	1	1.05	(1,na,na,na,na,na); Calculation
	Water, JP	-	-	kg	4.19E-4	-	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, AU	-	-	kg	-	3.49E-4	-	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, KR	-	-	kg	-	-	3.56E-4	-	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, NZ	-	-	kg	-	-	-	4.06E-4	-	-	-	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, CN	-	-	kg	-	-	-	-	4.06E-4	-	-	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, IL	-	-	kg	-	-	-	-	-	2.89E-4	-	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, MY	-	-	kg	-	-	-	-	-	-	3.79E-4	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, ZA	-	-	kg	-	-	-	-	-	-	-	2.90E-4	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, TH	-	-	kg	-	-	-	-	-	-	-	-	3.30E-4	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	electricity, production mix photovoltaic, at plant	JP	0	kWh	1	0	0	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	AU	0	kWh	0	1	0	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	KR	0	kWh	0	0	1	0	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	NZ	0	kWh	0	0	0	1	0	0	0	0	0			
	electricity, production mix photovoltaic, at plant	CN	0	kWh	0	0	0	0	1	0	0	0	0			
	electricity, production mix photovoltaic, at plant	IL	0	kWh	0	0	0	0	0	1	0	0	0			
	electricity, production mix photovoltaic, at plant	MY	0	kWh	0	0	0	0	0	0	1	0	0			
	electricity, production mix photovoltaic, at plant	ZA	0	kWh	0	0	0	0	0	0	0	1	0			
	electricity, production mix photovoltaic, at plant	TH	0	kWh	0	0	0	0	0	0	0	0	1			

Tab. 3.9 Life cycle inventories of the PV electricity mixes of different North and South American countries.

	Name	Location	InfrastructureProcess	Unit	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	electricity, production mix photovoltaic, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				US	CA	MX	CL			
	InfrastructureProcess				0	0	0	0			
	Unit				kWh	kWh	kWh	kWh			
resource, in air	Energy, solar, converted	-	-	MJ	3.85E+0	3.85E+0	3.85E+0	3.85E+0	1	1.09	(2,2,1,1,1,3); Energy loss in the system
technosphere	tap water, water balance according to MoeK 2013, at user	US	0	kg	3.59E-3	-	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	CA	0	kg	-	4.12E-3	-	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	MX	0	kg	-	-	3.04E-3	-	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	tap water, water balance according to MoeK 2013, at user	CL	0	kg	-	-	-	2.95E-3	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	3.23E-6	3.71E-6	2.73E-6	2.66E-6	1	1.09	(2,2,1,1,1,3); Estimation 20l/m2 panel
	93 kWp slanted-roof installation, single-Si, laminated, integrated, on roof	CH	1	unit	6.65E-10	5.90E-10	7.03E-10	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	CH	1	unit	1.20E-9	1.68E-9	2.00E-9	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, single-Si, panel, mounted, on roof	CH	1	unit	1.60E-8	9.83E-9	1.17E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	93 kWp slanted-roof installation, multi-Si, panel, mounted, on roof	CH	1	unit	2.88E-8	2.80E-8	3.33E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	156 kWp flat-roof installation, multi-Si, on roof	CH	1	unit	1.49E-8	1.50E-8	1.79E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	156 kWp flat-roof installation, single-Si, on roof	CH	1	unit	8.28E-9	5.27E-9	6.29E-9	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, single-Si, on open ground	RER	1	unit	5.32E-9	1.01E-8	5.37E-9	1.05E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, multi-Si, on open ground	RER	1	unit	1.51E-8	2.88E-8	1.53E-8	2.99E-8	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, CdTe, on open ground	RER	1	unit	1.00E-8	1.55E-9	8.25E-10	1.61E-9	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, CIS, on open ground	RER	1	unit	2.60E-10	6.51E-10	3.46E-10	6.77E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	570 kWp open ground installation, micro-Si, on open ground	RER	1	unit	-	2.50E-10	1.33E-10	2.60E-10	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, single-Si, laminated, integrated, at building	RER	1	unit	2.07E-8	1.31E-8	1.56E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, single-Si, panel, mounted, at building	RER	1	unit	2.07E-8	1.31E-8	1.56E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, multi-Si, laminated, integrated, at building	RER	1	unit	3.73E-8	3.72E-8	4.43E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp facade installation, multi-Si, panel, mounted, at building	RER	1	unit	3.73E-8	3.72E-8	4.43E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp flat roof installation, single-Si, on roof	RER	1	unit	2.15E-7	1.37E-7	1.63E-7	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp flat roof installation, multi-Si, on roof	RER	1	unit	3.88E-7	3.90E-7	4.65E-7	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, single-Si, laminated, integrated, on roof	RER	1	unit	9.41E-9	6.07E-9	7.24E-9	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, single-Si, panel, mounted, on roof	RER	1	unit	2.26E-7	1.01E-7	1.21E-7	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, multi-Si, laminated, integrated, on roof	RER	1	unit	1.70E-8	1.73E-8	2.06E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, multi-Si, panel, mounted, on roof	RER	1	unit	4.08E-7	2.88E-7	3.43E-7	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CdTe, laminated, integrated, on roof	CH	1	unit	5.82E-10	7.47E-9	8.90E-9	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CdTe, panel, mounted, on roof	CH	1	unit	1.40E-8	1.24E-7	1.48E-7	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CIS, panel, mounted, on roof	CH	1	unit	2.73E-8	5.22E-8	6.22E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, CIS, laminated, integrated, on roof	CH	1	unit	1.14E-9	3.13E-9	3.73E-9	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, micro-Si, laminated, integrated, on roof	RER	1	unit	7.79E-10	1.20E-9	1.44E-9	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
	3kWp slanted-roof installation, micro-Si, panel, mounted, on roof	RER	1	unit	1.87E-8	2.01E-8	2.39E-8	-	1	1.22	(2,2,1,1,1,3); Calculation with average annual yield and share of technologies. Lifetime: 30a.
emission air	Heat, waste	-	-	MJ	2.50E-1	2.50E-1	2.50E-1	2.50E-1	1	1.05	(1,na,na,na,na,na); Calculation
	Water, US	-	-	kg	3.59E-4	-	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, CA	-	-	kg	-	4.12E-4	-	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, MX	-	-	kg	-	-	3.04E-4	-	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	Water, CL	-	-	kg	-	-	-	2.95E-4	1	1.09	(2,2,1,1,1,3); Assumption: 10% of water used is evaporated
	electricity, production mix photovoltaic, at plant	US	0	kWh	1	0	0	0			
	electricity, production mix photovoltaic, at plant	CA	0	kWh	0	1	0	0			
	electricity, production mix photovoltaic, at plant	MX	0	kWh	0	0	1	0			
	electricity, production mix photovoltaic, at plant	CL	0	kWh	0	0	0	1			

4 Life cycle impact assessment

4.1 Overview

The environmental impacts of the national PV electricity mixes were assessed with the most relevant impact categories of the EF method according to the PEFCR PV electricity (TS PEF Pilot PV 2018). The total normalised and weighted environmental impacts were also quantified using the EF method. In addition, the non-renewable and renewable cumulative energy demand of the national PV electricity mixes were analysed (Frischknecht et al. 2015c). The impact assessment results for the EF method and the cumulative energy demand are presented in Subchapter 4.2 and Subchapter 4.3, respectively.

4.2 Environmental Footprint (EF) Method

The total normalised and weighted environmental impacts of the national PV electricity mixes of 33 countries according to the EF method are shown in Fig. 4.1. The impact categories human toxicity, cancer and non-cancer effects, and freshwater toxicity were excluded and long-term emissions were not taken into account (European Commission 2017). The total environmental impacts of the national PV electricity mixes range from 5.89 µPt/kWh in South Africa to 13.1 µPt/kWh in Ireland. PV systems installed in South Africa have a high yield. In addition, South Africa has only centralised PV systems, which cause smaller environmental impacts than rooftop or façade systems and reach a higher performance ratio. PV systems in Ireland have the lowest annual yield of the countries analysed.

The main determinant of this high variation is the average annual yield. Normalising the total environmental impacts of the national PV electricity mixes to a given yield (e.g. 1’000 kWh/(kWp·a)) shows that country-specific differences in the technology breakdown and the installation type breakdown cause a variation of about 10 % between the country with the lowest environmental impacts (USA) and the countries with the highest environmental impacts (Norway, Switzerland and the Netherlands). The USA have the lowest share of crystalline silicon PV modules in the PV electricity mix, whose production typically causes higher specific environmental impacts compared to thin-film PV modules (Stolz et al. 2016). The technology breakdown for Norway, Switzerland and the Netherlands was modelled based on the default assumption, where multi-Si and mono-Si PV modules have a share of 69.6 % and 24.5 %, respectively (see Subchapter 3.3). Moreover, these countries have very small capacities of centralised PV systems.

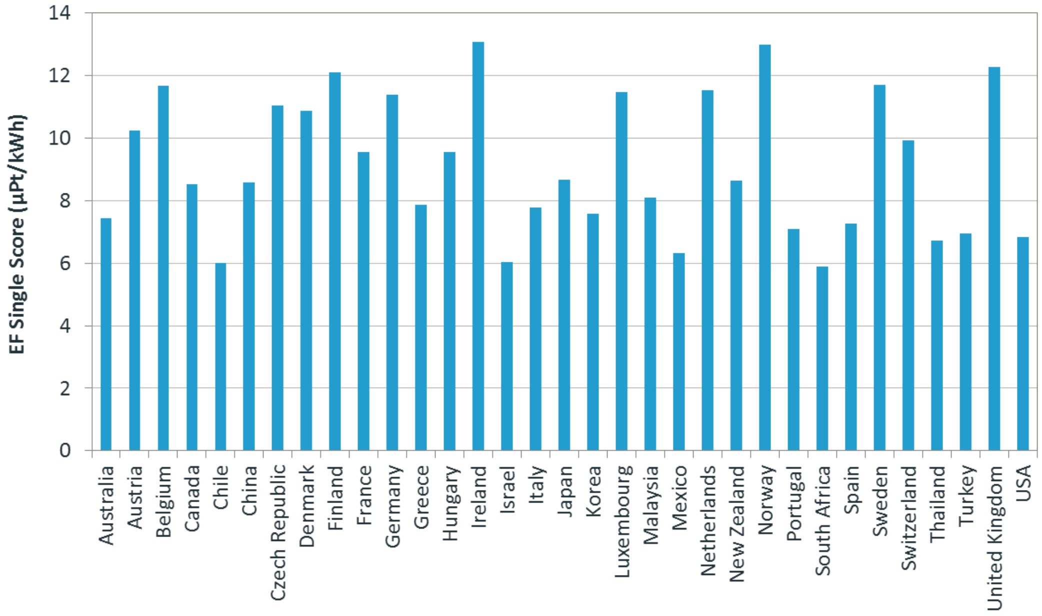

Fig. 4.1 Total normalised and weighted environmental impacts in micro-Points (µPt) of the national PV electricity mixes per kWh AC electricity according to the EF impact assessment method.

The characterised environmental impacts of the national PV electricity mixes for the five most relevant impact categories of the EF method according to the PEFCR PV electricity (TS PEF Pilot PV 2018) are listed in Tab. 4.1. The pattern among the different countries is very similar to the total normalised and weighted environmental impacts shown in Fig. 4.1. This is due to the strong influence of the annual yield on the environmental impacts of PV electricity.

The different technology breakdown in the national PV electricity mixes becomes visible after normalising the environmental impacts by the annual yield. The PV electricity mixes in the USA and in Austria generally cause lower environmental impacts than those in most other analysed countries. A noteworthy exception is the impact category mineral and metal resource use, in which the Austrian PV electricity mix causes the highest impacts. Austria has a high share of multi-Si PV modules, which cause environmental impacts below the average technology mix for most impact categories of the EF method but higher impacts with regard to mineral and metal resource use. This is due to the silver contained in the metallization paste. The demand of metallization paste in multi-Si PV cell production is significantly higher in comparison to the demand in mono-Si PV cell production (Frischknecht et al. 2015a).

Average PV electricity produced in South Korea, China and Japan has relatively high environmental impacts compared to that of other countries when excluding differences in the annual yield. The share of crystalline silicon PV modules in the total installed capacity in China and South Korea amounts to 98 % and 99 %, respectively. The Japanese PV electricity mix contains the highest shares of mono-Si modules (32 %) and CIS modules (9 %).

Tab. 4.1 Characterised environmental impacts of the national PV electricity mixes per kWh AC electricity according to the most relevant impact categories of the EF method.

Country	Climate change	Respiratory inorganics	Resource use, mineral & metals	Resource use, energy carriers	Acidification
	g CO_2 eq/kWh	µg PM2.5 eq/kWh	mg Sb eq/kWh	MJ oil-eq/kWh	mmol H+ eq/kWh
Australia	48.6	4.89	2.47	0.558	0.411
Austria	61.7	5.98	3.73	0.719	0.518
Belgium	77.1	7.76	3.84	0.886	0.651
Canada	58.9	5.91	2.66	0.680	0.492
Chile	42.8	4.29	1.81	0.495	0.355
China	60.0	6.07	2.63	0.691	0.501
Czech Republic	73.8	7.43	3.58	0.850	0.621
Denmark	72.0	7.25	3.56	0.828	0.607
Finland	78.8	7.94	4.03	0.905	0.667
France	64.1	6.44	3.09	0.738	0.539
Germany	75.8	7.62	3.72	0.871	0.638
Greece	52.7	5.30	2.55	0.606	0.443
Hungary	63.9	6.43	3.10	0.736	0.538
Ireland	87.6	8.81	4.24	1.008	0.737
Israel	41.0	4.12	1.93	0.472	0.344
Italy	53.4	5.36	2.46	0.616	0.447
Japan	60.5	6.08	2.67	0.697	0.506
Korea	53.1	5.39	2.32	0.611	0.444
Luxembourg	76.8	7.72	3.72	0.884	0.646
Malaysia	52.7	5.31	2.70	0.605	0.447
Mexico	43.1	4.33	2.02	0.496	0.361
Netherlands	75.0	7.55	3.84	0.860	0.635
New Zealand	56.6	5.70	2.88	0.649	0.479
Norway	84.5	8.51	4.35	0.969	0.716
Portugal	48.5	4.87	2.24	0.560	0.406
South Africa	42.0	4.20	1.78	0.486	0.348
Spain	48.9	4.92	2.34	0.563	0.411
Sweden	76.4	7.69	3.89	0.877	0.646
Switzerland	64.1	6.47	3.34	0.736	0.544
Thailand	47.8	4.78	2.03	0.553	0.396
Turkey	49.4	4.95	2.10	0.572	0.410
United Kingdom	82.1	8.26	3.98	0.945	0.691
USA	47.1	4.62	2.14	0.548	0.393

4.3 Cumulative energy demand

The non-renewable cumulative energy demand of the national PV electricity mixes is depicted in Fig. 4.2. It ranges from 0.500 MJ oil-eq/kWh (Israel) to 1.07 MJ oil-eq/kWh (Ireland) and mainly reflects the annual yield in the respective countries. The pattern of the non-renewable cumulative energy demand of the national PV electricity mixes analysed is very similar to the total environmental impacts according to the EF method (see Fig. 4.1).

Fig. 4.3 shows the renewable cumulative energy demand of the PV electricity mixes of the 33 countries analysed. The renewable cumulative energy demand is very uniform and spans from 3.91 MJ oil-eq/kWh (Israel and South Africa) to 3.98 MJ oil-eq/kWh

(Ireland and Norway). The converted solar energy is by far the most important contributor to the renewable cumulative energy demand.

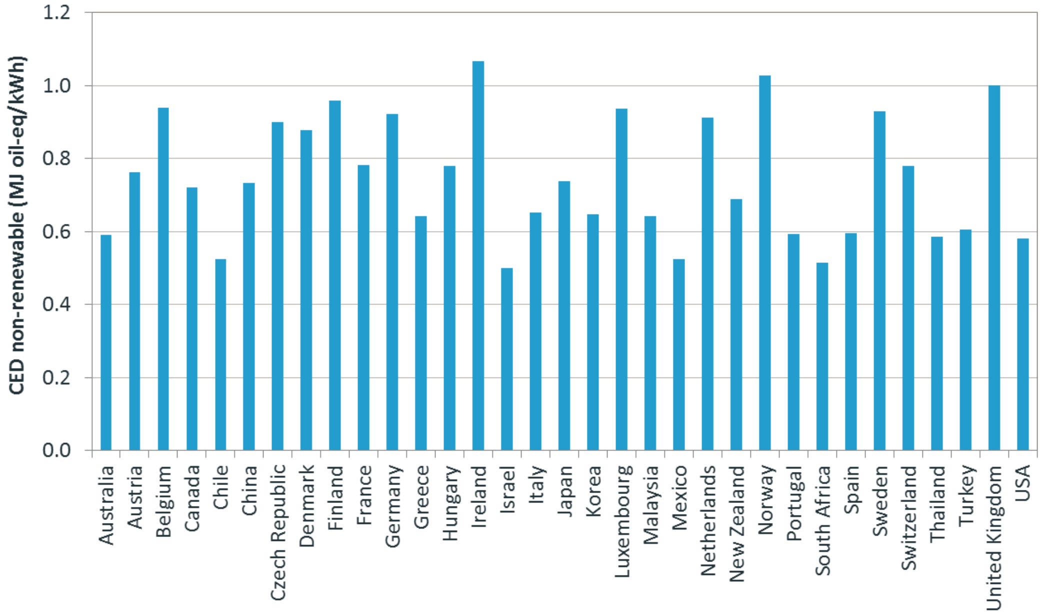

Fig. 4.2 Non-renewable cumulative energy demand of the national PV electricity mixes per kWh AC electricity according to the Frischknecht et al. (2015c).

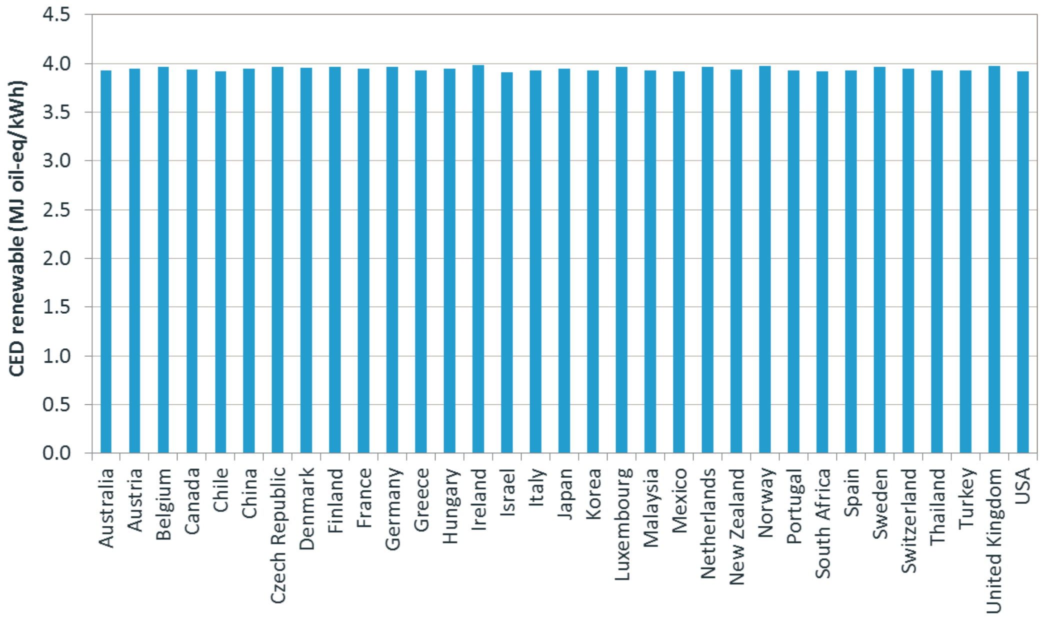

Fig. 4.3 Renewable cumulative energy demand of the national PV electricity mixes per kWh AC electricity according to the Frischknecht et al. (2015c).

5 Data quality and uncertainty

The quality of the data used to update the life cycle inventories of national PV electricity mixes is considered as moderate. The availability of data on the technology breakdown or the installation type breakdown was very limited. For many countries, these data were missing completely, which made assumptions necessary. This means that potential country-specific differences in the share of different PV technologies or in the fractions of flat roof, slanted roof and façade systems are only partly reflected in the life cycle inventories of national PV electricity mixes. However, specific data on the annual yield and the share of centralised PV systems were available for almost all analysed countries.

The annual yield is the most important parameter determining the environmental impacts of national PV electricity mixes. It mainly depends on the solar irradiation, which exhibits a high spatial variability. The population-weighted average irradiation was found to be the best approximation among different approaches, even though it does not capture the conditions at the actual location of the PV systems in a given country. This particularly applies to countries with a high share of centralised PV systems (e.g. Chile, South Africa, Thailand and Turkey; IEA-PVPS 2017), which do not necessarily have to be installed in the proximity of populated areas. The country-specific annual yields determined based on solar irradiation data were adjusted in order to account for the fact that PV systems are not always optimally oriented. The correction factor was estimated based on statistical data for three countries (United Kingdom, China and Switzerland) and is considered to be rather uncertain. An extended data basis may contribute to determining the effective performance ratio to be applied on the PV power plant portfolio operated in a country combined with irradiation data for optimally oriented PV systems.

Another source of uncertainty arises from the temporal variability of the highly dynamic PV industry. Continuous improvements in PV technologies result in a significant increase in module efficiencies. Since the global installed capacity grows exponentially, the module demand of the national PV electricity mixes was calculated based on most recent data about the current module efficiencies. This procedure seems justifiable from a global perspective but underestimates the area of PV modules installed in countries where most of the PV capacity was deployed several years ago (e.g. Spain, Italy, Belgium and Germany; IEA-PVPS 2017).

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