IEC TS 62994

Edition 1.0 2019-01

TECHNICAL SPECIFICATION

colour inside

Photovoltaic (PV) modules through the life cycle – Environmental health and safety (EH&S) risk assessment – General principles and nomenclature

IEC TS 62994:2019-01(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC TS 62994

Edition 1.0 2019-01

TECHNICAL SPECIFICATION

colour inside

Photovoltaic (PV) modules through the life cycle – Environmental health and safety (EH&S) risk assessment – General principles and nomenclature

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160 ISBN 978-2-8322-6419-5

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

PHOTOVOLTAIC (PV) MODULES THROUGH THE LIFE CYCLE – ENVIRONMENTAL HEALTH AND SAFETY (EH&S) RISK ASSESSMENT –

General principles and nomenclature

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62994, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
82/1370/DTS	82/1504/RVDTS

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This Technical Specification establishes definitions of terms of environmental health and safety (EH&S) risk assessment and also basic principles and general methods for the EH&S risk assessment for the PV module through its life cycle.

EH&S risk assessment is a method to characterize and evaluate potential adverse impacts to human health or environment in order to develop policies to control and reduce them. Although PV technologies have environmental advantages over conventional energy technologies, PV modules can contain some hazardous materials. Therefore, EH&S risk assessment of PV modules is very important for the safe and sustainable manufacture, use, and end-of-life treatment of PV modules.

Though there are many standards relating to EH&S and risk assessment, there is no published IEC standard for the EH&S risk assessment of the PV module at present.

This technical specification was developed in cooperation with IEA PVPS task 12 (PV Environmental, Health and Safety Activities). The objectives of the task are to ‘quantify the environmental profile of PV in comparison to other energy technologies’ and ‘to define and address EH&S and sustainability issues that are important for PV market growth’. IEA PVPS task 12 and IEC TS 62994 Project team had joint meetings and established a liaison officer to work on this technical specification on the EH&S for the PV.

PHOTOVOLTAIC (PV) MODULES THROUGH THE LIFE CYCLE – ENVIRONMENTAL HEALTH AND SAFETY (EH&S) RISK ASSESSMENT –

General principles and nomenclature

1 Scope

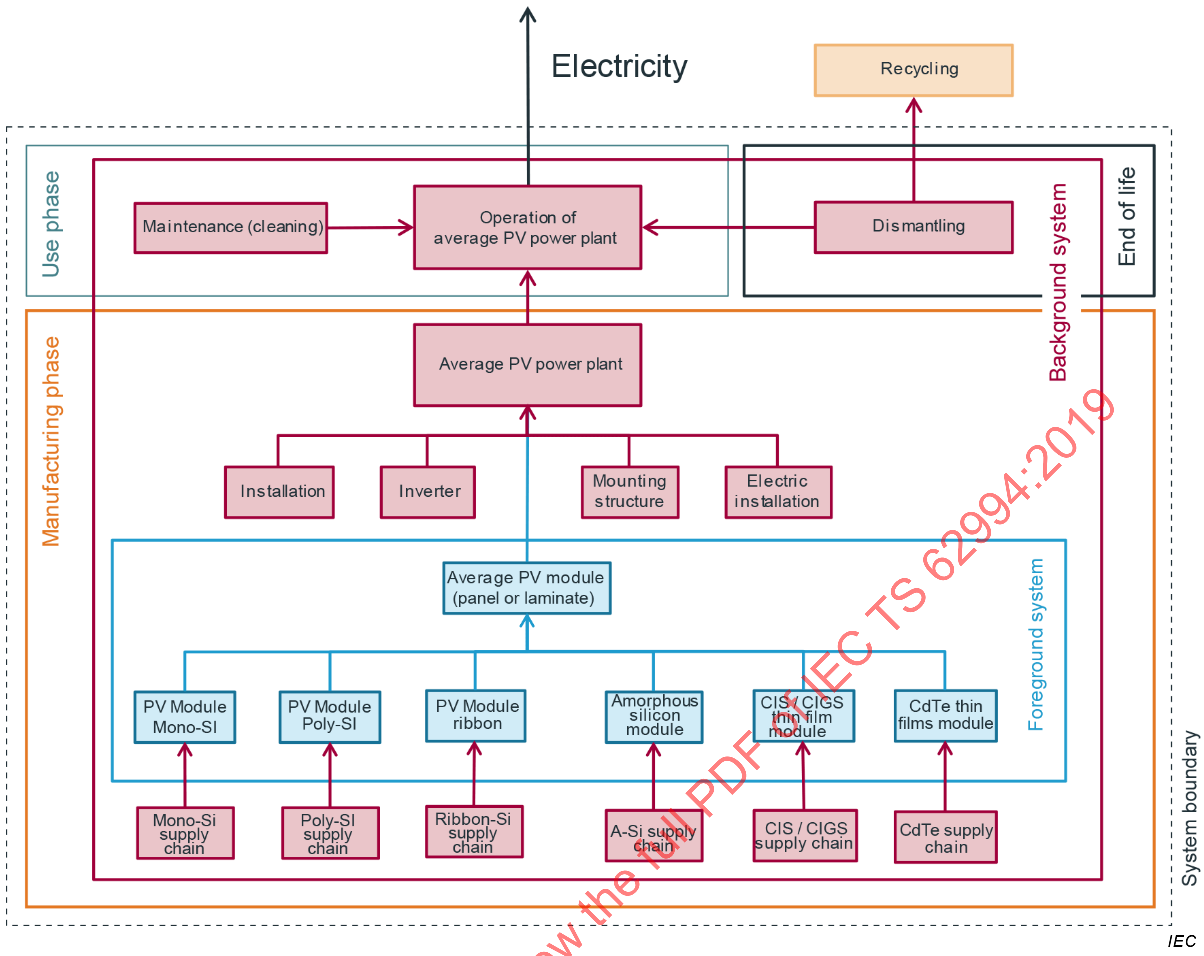
This document specifies definitions of terms and introduces evaluation methods for EH&S risk assessment for the PV module over the product life cycle. Environmental health and safety (EH&S) risk assessment is a method to characterize and evaluate potential adverse impacts to human health or environment and make it possible to take measures to reduce them. EH&S risk assessment of PV modules is very important for the safe and sustainable manufacture, use, and end of life treatment of PV modules. The definition of terms can be applied to the EH&S risk assessment through the life cycle of PV modules. Generally, evaluation methods for the EH&S risk assessment can be divided in two cases:

- ordinary foreseen routine operation, in which life cycle assessment method is applied;
- abnormal non-routine operation, in which risk assessment method is applied.

The scope of the two general cases is described below.

When assessing the environmental impacts of routine operation of PV electricity production with life cycle assessment, the product system includes the manufacturing phase, the use phase and the end of life phase (see Figure 1). Electronic installation, mounting structure and power conversion equipment (such as inverters) are included as part of the PV system to be analysed.

When assessing the risk of non-routine operation of PV modules, the system analysed is limited to the PV module, its supply chain, operation and end of life treatment, and its direct electrical and mechanical interfaces with the balance of system, i.e. the electric installation, mounting structure and inverters.



Processes of the foreground and background system are marked with blue and red colour, respectively (lighter coloured line and darker coloured line respectively for monochrome printed version).

Figure 1 – Product system of electricity produced with photovoltaic modules

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61724-1, *Photovoltaic system performance – Part 1: Monitoring*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

ISO/IEC Guide 51, *Safety aspect – Guidelines for their inclusion in standards*

ISO 14001, *Environmental management system – Requirements with guidance for use*

ISO 14004:2016, *Environmental management systems- General guidelines on implementation*

ISO 14040, *Environmental management -Life cycle assessment – Principles and framework*

ISO 14044:2006, *Environmental management – Life cycle assessment – Requirements and guidelines*

OHSAS 18001: 2009, *Guide to implementing a Health & Safety Management System*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14001, OHSAS 18001, IEC TS 61836 and ISO/IEC Guide 51 as well as the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
Life Cycle Assessment
LCA
compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

[SOURCE: ISO 14044:2006,3.2]

3.2
Life Cycle Impact Assessment
LCIA
phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product

[SOURCE: ISO 14044:2006, 3.4]

3.3
Energy Pay Back Time
EPBT
period required for an energy system to generate the same amount of energy (in terms of primary energy equivalent) that was used to produce the system itself

[SOURCE: Frischknecht R., Heath G., Raugei M., Sinha P. and de Wild-Scholten M.,2015, Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity, 3rd edition. International Energy Agency, IEA, Paris]

3.4
environmental impact mitigation potentials
quantity of environmental mitigation achievable relative to a baseline or reference case. Mitigation means the elimination or reduction of frequency, magnitude or severity of exposure to risks, or minimization of a threat.

3.5
harm
physical injury or damage to persons and livestock

[SOURCE: IEC Guide 116:2010, 3.2, IEC 60050-903:2013, 903-01-01]

3.6
hazard
potential source of harm

[SOURCE: ISO/IEC Guide 51:1999, 3.5, IEC 60050-903:2013, 903-01-02, modified: “Note 2” deleted]

3.7
risk
combination of the probability of occurrence of harm and the severity of that harm

[SOURCE: IEC Guide 116:2010, 3.13, IEC 60050-903:2013, 903-01-07, modified: “Note 1” deleted].

3.8
risk analysis
systematic use of available information to identify hazards and to estimate the risk

[SOURCE: ISO/IEC Guide 51:1999, 3.10, IEC 60050-903:2013, 903-01-08]

3.9
risk evaluation
procedure based on the risk analysis to determine whether the tolerable risk has been achieved

[SOURCE: ISO/IEC Guide 51:1999, 3.11, IEC 60050-903:2013, 903-01-09]

3.10
risk assessment
overall process comprising a risk analysis and a risk evaluation

[SOURCE: IEC Guide 116:2010, 3.15, IEC 60050-903:2013, 903-01-10]

3.11
sustainability
endurance of systems and processes, and in ecology it refers to how biological systems remain diverse and productive. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, and that permit fulfilling the social, economic and other requirements of present and future generations

4 Basic principles of EH&S risk assessment for the PV module

4.1 Basic concepts

Although PV technology has environmental advantages over conventional energy technologies, the PV industry also uses hazardous materials. Substances that are the subject of EH&S risk assessment for the PV include flammable, explosive, corrosive, or toxic materials used in PV industry. Understanding environmental health and safety impacts during the routine product life cycle and prevention of accidental release of hazardous substances during non-routine events and reduction of adverse effects are very important for the sustainability of PV modules. EH&S risk assessment of PV focuses on the emissions of such substances during the life cycle of PV (usually by the LCA) to characterize environmental health and safety impacts. EH&S risk assessment for PV also includes consideration of adverse health or environmental effects resulting from exposures to hazardous agents or situations (by the Environmental Health & Risk Assessment; EHRA).

4.2 Life cycle assessment (LCA) of PV

4.2.1 Fundamentals

4.2.1.1 General

These fundamentals describe the basis for the subsequent requirements in this document. The quantification and reporting of an LCA in accordance with this document are based on the principles of the LCA methodology provided in ISO 14040 and ISO 14044.

4.2.1.2 Life cycle perspective

The development of LCA quantification and communication takes into consideration all stages of the life cycle of PV electricity production, including raw material acquisition, production, use and the end of life stage.

4.2.1.3 Iterative approach

When applying the four phases of LCA (goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation, see 4.2.3 to 4.2.5) to a LCA study, use an iterative approach (continuous reassessment as needed when refining the LCA study). The iterative approach will contribute to the consistency of the LCA study and the reported results.

4.2.1.4 Scientific approach

When making decisions within a LCA, give preference to natural science (such as physics, chemistry, biology). If that is impossible, use other scientific approaches (such as social and economic sciences) or refer to approaches contained in conventions relevant and valid within the geographical scope valid for the LCA study. Permit decisions within a LCA based on value choices, as appropriate, only if neither a natural scientific basis exists nor a justification based on other scientific approaches or international conventions is possible, and explain the rationale for such value choices.

4.2.1.5 Relevance

Select data and methods appropriate to the assessment of the emissions and resource consumptions arising from the product system being studied.

4.2.1.6 Completeness

Include all emissions and resource consumptions, unit processes and life cycle stages that provide a significant contribution to the environmental impacts of the product system being studied.

4.2.1.7 Consistency

Apply assumptions, methods and data in the same way throughout the LCA study to arrive at conclusions in accordance with the goal and scope definition.

4.2.1.8 Coherence

Select methodologies, standards and guidance documents already recognized and adopted for PV electricity production to enhance comparability between LCA studies within this specific product category.

4.2.1.9 Accuracy

Ensure that LCA quantification and communication are accurate, verifiable, relevant and not misleading and that bias and uncertainties are reduced as far as is practical.

4.2.1.10 Transparency

Address and document all relevant issues in an open, comprehensive and understandable presentation of information. Notify any relevant assumptions and make appropriate references to the methodologies and data sources used. Clearly explain any estimates and avoid bias so that the LCA report faithfully represents its purpose.

Ensure that LCA communication is available to the intended audience and its intended meaning is presented in a way that is clear, meaningful and understandable. Include information on functional unit, data assumptions, calculation methods and other characteristics to make limitations in the comparisons of LCAs transparent and clear to the target group. Present LCA information so that it is accurate, verifiable, relevant and not misleading.

4.2.2 Photovoltaics-specific aspects

4.2.2.1 Life expectancy

The recommended life expectancy to be used in LCA of photovoltaic components and systems and differences between the components are as follows (If there is ascribed or declared life expectancy by manufacturer, use it instead):

- Modules: 30 years for mature module technologies [1] (e.g., glass-glass or glass-Tedlar encapsulation).
- Inverters: 15 years for small plants (residential PV), 30 years with 10 % parts replacement for large size plants (utility scale PV) [2] .
- Transformers: 30 years.
- Structure: 30 years for roof-top and façades, and between 30 to 60 years for ground mount installations on metal supports. Sensitivity analyses should be carried out by varying the service life of the ground-mount supporting structures within the same time span.
- Cabling: 30 years.
- Manufacturing plants (capital equipment): The lifetime is 10 to 20 years but in some cases may be shorter than 10 years, due to the rapid development of technology. Assumptions need to be listed.

4.2.2.2 Irradiation

The irradiation collected by modules depends on their location and orientation. Depending on the goal of the study, recommendations are given as below:

- Analysis of industry average- and best case-systems:

  Assume for all systems on ground that the panels on an array plane are optimally oriented and tilted at angles equal to the latitude (except when a specific system under study is laid out differently). Also, assume that roof-top installations are optimally oriented and tilted.

  Assume either optimally oriented or case-specific orientation of panels of façade systems.

  Additionally, 1-axis or 2-axis tracking systems may be assumed.

In case of higher altitudes and a high diffuse percentage, the optimum tilt angle will be significantly lower than the latitude. The optimum tilt angle needs to be selected.

---

[1] Life expectancy may be lower for modules with foil-only encapsulation; this life expectancy is based on typical PV module warranties

[2] It is recommended that important consumable parts such as cooling fan, MCC board, PLC and PLD should be replaced every 3 to 4 years.

- Analysis of the average of installed systems in a grid network:

  The average actual orientation, shading and irradiation should be used.

IEC 61724-1 offers a description of irradiance (W/m^2) and irradiation (kWh/m^2/yr).

4.2.2.3 Performance ratio

Using either site-specific PR values or a default value of 0,75 is recommended for roof-top and 0,80 for ground-mounted utility installations.

Use actual performance data (actual energy yield in kWh/kWp) of installed technology whenever available, or make reasonable assumptions that reflect actual performance data when analysing the average of installed systems in a grid network.

NOTE The performance ratio (PR) (also called derate factor) describes the difference between the modules' (DC) rated performance and the actual (AC) electricity generation.

4.2.2.4 Degradation

The degradation of the modules reduces efficiency over the life time. The following degradation rates are recommended:

- Mature module technologies: Assume a linear degradation declining to 80 % of the initial efficiency at the end of a 30 years lifetime (i.e., 0,7 %/year, or 10 % on average during the entire lifetime), unless actual data exist, in which case documentation has to be provided. When extrapolated from site-specific data, it should be clearly stated whether degradation is considered or not.
- Use a degradation rate of 0,5 %/year until the end of life (30 years) in a sensitivity analysis, resulting in an average reduction in the annual yield of 7,5 %.

If a different degradation rate is applied, supporting scientific evidence and test results should be provided in the LCA report.

- The initial nameplate capacity of the PV module – as printed in the data sheet – shall be used as the starting point of the degradation curve. Since measurement uncertainties on performance measurements are factored in the performance tolerance provided on the data sheet, e.g. +2,5 %/-0 %, the lower value of the nameplate capacity shall be used.

4.2.2.5 Back-up system

Back-up systems such as temporal storage, hydroelectric or gas combined cycle power plants, or hybrid PV (combinations of PV and diesel aggregates) are considered to be outside the system boundary of PV LCA.

4.2.3 Life cycle inventory modelling aspects

4.2.3.1 System models

Life cycle inventory (LCI) is the data collection portion of LCA and result of LCIA. The appropriate system model depends on the goal of the LCA. Depending on the goal and scope of the study, an attributional, decisional or consequential approach as below can be chosen.

a) Reporting environmental impacts of PV currently installed in a utility's network, comparisons of PV systems, or of electricity-generating technologies: retrospective / attributional LCA.

b) Choice of a PV electricity-supplier, or switch of raw material or energy suppliers: short-term prospective / decisional LCA.

c) Future energy supply situation; comparison of future PV systems or of future electricity-generating technologies: use long-term prospective LCA / future attributional LCA to model future static situations.

d) Large scale, long-term energy supply transition; large scale-up of PV in electricity grids of nations and regions: use consequential LCA to model such transitions.

The following recommendations apply to all goals:

- The product system shall be divided into foreground- and background-processes: Foreground processes are those which the decision-maker or product-owner can influence directly and background processes are all remaining processes of the particular product system (see Figure 1).
- It is recommended to use conventional process-based LCA and follow ISO standards.
- Input-Output- based LCA method: This approach is not recommended for PV system. (More confidence is needed for its application).
- If a hybrid approach is chosen, report transparently and provide justification for using it.

The following recommendations apply to goal **'a'** described above (i.e., reporting environmental impacts of PV currently installed; comparisons of PV systems):

- Assume the present average electricity grid mix for the relevant country (e.g., Europe (EU 27, including Norway and Switzerland), United States, Korea, China, or Japan) when modelling the manufacture of current PV components. Specify the year for which the data are valid.
- If a PV material is produced in a specific country, by a limited number of companies, or if the PV material production generally involves a specific type of electricity supply, then an argument can be made for selecting a country or company-specific electricity mix. An example here is hydropower for producing silicon feedstock in Norway.
- However, country- or company-specific cases shall be clearly reported so that data are not unintentionally projected to different scales and regions.

The following recommendations apply to goal **'b'** (choice of a PV electricity-supplier; switch of feedstock or energy suppliers):

- Assume an annual marginal electricity grid mix for the relevant country. Specify the time span for which the changes in the grid mix are applicable. Use grid mix data from relevant national or regional electricity scenario reports to derive the marginal mix.
- Specify the environmental performance and energy efficiency of the power plants contributing to this marginal electricity mix. The performance of these specific power plants may differ from national or utility portfolio averages.
- Specify mid-term future marginal market mixes of PV material feedstocks, chemicals, energy carriers etc. which may contribute significantly to the PV life cycle-based environmental impacts and where average and marginal mixes may differ substantially.

The following recommendations apply to goal **'c'** (future energy supply situation):

- Use an annual-average future electricity mix for the relevant country when modelling future production of PV components. Specify the year for which the forecasted data are applicable. Use grid mix data from relevant national or regional electricity future scenario reports.
- Specify the environmental performance and energy efficiency of the power plants contributing to this future electricity mix. Being power plants operated in the future, they should represent possible future states.
- If a PV material is expected to be produced in a specific country, by a limited number of companies, or if the material production generally uses a specific type of electricity supply, an argument can be made for choosing a country- or company-specific electricity mix, e.g., hydropower for producing silicon feedstock production in Norway. However, in prospective analyses, the availability of country-specific resources to the projected market volumes shall be documented. Country- or company-specific cases shall be identified clearly, so

that data are not used unintentionally for projections to different market volumes and regions.

- Adapt the efficiency of material supply-, transport-, and waste-management-services so that they represent a possible future state, consistent with the underlying energy-policy scenario.

The following recommendations apply to goal **'d'** (large scale, long-term energy supply transition):

- Identify the main and significant changes in the economy (world-wide) which are caused by a large scale-up of PV panel installation and production and consequently electricity production. This may be done by expert interviews, general or partial equilibrium models, or back casting techniques.
- Identify marginal technologies within the most relevant markets affected by the changes in the economy. Use forecasting reports published by official bodies or industry associations.
- Establish life cycle inventories of these marginal technologies.
- Adapt the efficiency of future production of materials, transport-, and waste-management-services so that they represent a possible future state, consistent with the underlying economic scenario.
- Further aspects such as rebound effects and spill over effects may be taken into account using economic models (e.g., general or partial equilibrium models), scenario techniques or other suitable approaches.
- Because consequential LCA is an emerging field and in its short history has not typically been applied to PV, analysts should conduct a careful literature review to be aware of the latest developments in the field.

4.2.3.2 Functional unit and reference flow

The functional unit allows consistent comparisons to be made of various PV systems and of other electricity-generating systems that can provide the same function. The reference flow is used as the denominator of the cumulative emissions and resource consumptions and the environmental impacts of the product system under study, whereas the functional unit specifies the quantified performance of a product system.

The following functional units for PV systems are recommended:

- AC electricity delivered to the grid quantified in kWh is used for comparing PV technologies, module technologies, and electricity-generating technologies in general. For grid-connected systems use the kWh of alternate current electricity fed into the grid. For PV systems with dedicated transformers (e.g., utility solar farms), use the electricity-output downstream of the transformer.

Alternatively, the reference flows "m^2" or “kWp (rated DC peak power under STC – Standard Test Conditions)” may be used. However, these reference flows are not suitable for comparisons of PV technologies.

- m^2 module is used for quantifying the environmental impacts of a particular building, or of supporting structures (excluding PV modules and inverters). Square metre is not suited for comparisons of PV technologies because of differences in module and inverter efficiencies and performance ratios.
- kWp is used for quantifying the environmental impacts of electrical parts, including inverter, transformer, wire, grid connection and grounding devices. The kWp may also serve as the reference flow in quantifying the environmental impacts of an individual module technology. However, the comparisons of module technologies shall not be based on nominal power (kWp) figures because the amount of kWh fed to the grid may differ between the systems analysed.

The location, the module technology used, the voltage level, and whether and how the transmission and distribution losses are accounted for, shall be specified.

AC electricity may differ in dispatchability and intermittency. Electricity production with one technology hardly meets all the demand at all times; thus mixtures of power generating technologies are typically deployed. Aspects of dispatchability or intermittency of AC electricity produced with different technologies shall not be addressed on technology level but on the level of grid mixes provided by utilities.

4.2.3.3 System boundaries

The following parts should be included in the system boundaries.

a) Production stage
   - Raw material and energy supply
   - Manufacture of the panels
   - Manufacture of the mounting system
   - Manufacture of the cabling
   - Manufacture of the inverters
   - Manufacture of all further components needed to produce electricity and supply it to the grid (e.g., transformers for utility-scale PV)

Manufacturing in the product stage of the LCI should cover the following: energy- and material-flows caused by manufacturing and storage, climate control, ventilation, lighting for production halls, on-site emissions and their abatement, and on-site waste treatments. PV manufacturing equipment may be included if data are available.

b) Construction process stage
   - Transports to the power plant site (where the plant is operated)
   - Construction and installation, including foundation, supporting structures and fencing
c) Use stage
   - Auxiliary electricity demand
   - Cleaning of panels
   - Maintenance
   - Repair and replacements, if any
d) End of life stage
   - Deconstruction, dismantling
   - Transports
   - Waste processing
   - Recycling and reuse
   - Disposal

The following parts should be excluded:

- Commuting (transportation to and from work)
- Administration, marketing, and research and development (R&D) activities.

4.2.3.4 Modelling allocation and recycling

Consistent allocation rules are demanded for all multifunction processes, recycling of materials, and employing waste heat (e.g., heat recovery in municipal-waste incinerators). Following ISO 14044:2006, 4.3.4 is recommended.

It is recommended to perform several analyses on material recycling using the recycled content (cut-off) allocation approach as default and the end of life (avoided burden) recycling approach in a sensitivity analysis.

Building integrated PV (BIPV) is a special case of multi-functionality as these PV modules serve as weather protection and energy producing elements. If required, an allocation of the manufacturing efforts of BIPV panels shall be done based on clearly described criteria, avoiding credits as far as possible.

In case system expansion is applied and environmental benefits and environmental impacts beyond the system boundary are quantified (e.g., using the end of life (avoided burden) recycling approach), these benefits and loads shall be reported separately. The benefits and impacts shall be quantified in relation to the net amount of surplus secondary materials or fuels leaving the product system (all outputs of a secondary material minus all inputs of that secondary material).

If allocation of multi-output and recycling processes is based on system expansion, the identification of technologies being displaced is key and choices and assumptions shall be reasoned and described.

4.2.3.5 Databases

PV specific datasets as well as background LCI (Life Cycle Inventory) databases used to establish PV LCAs, should comply with transparent documentation and provide unit process information and data.

4.2.4 Life cycle impact assessment (LCIA)

While a variety of life cycle impact assessment methods are currently available, most widely used categories and indicators are summarized in Table 1. The following midpoint indicators are recommended in environmental life cycle impact assessment of PV electricity.

Table 1 – Impact categories and indicators

Impact category	Indicator
Climate change	Radiative forcing as Global Warming Potential (GWP 100)
Ozone depletion	Ozone Depletion Potential (ODP)
Human toxicity, cancer- effects	Comparative Toxic Unit for humans (CTUh)
Human toxicity, non-cancer effects	Comparative Toxic Unit for humans (CTUh)
Particulate matter/ Respiratory inorganics	Intake fraction for fine particles (kg PM2.5-eq/kg)
Ionising radiation, human health	Human exposure efficiency relative to U235
Ionising radiation, ecosystems	Interim
Photochemical ozone formation	Tropospheric ozone concentration increase
Acidification	Accumulated Exceedance (AE)
Eutrophication, terrestrial	Accumulated Exceedance (AE)
Eutrophication, aquatic	Fraction of nutrients reaching fresh water end compartment(P) or marine end compartment
Ecotoxicity (freshwater)	Comparative Toxic Unit for ecosystems (CTUe)
Land use	Soil organic matter
Resource depletion, water	Water use related to local scarcity of water
Resource depletion, mineral	Scarcity
Primary energy demand, non renewable	Cumulative energy demand, non renewable
Nuclear waste	Radiotoxicity potential of nuclear waste

[SOURCE: European Commission 2013]

a) Climate change: Global Warming Potential calculating the radiative forcing over a time horizon of 100 years.

b) Ozone depletion: Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years.

c) Human toxicity, cancer effects: Comparative Toxic Unit for humans (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a carcinogen emitted (cases per kilogramme).

d) Human toxicity, non-cancer effects: Comparative Toxic Unit for humans (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a non-carcinogen emitted (cases per kilogramme).

e) Particulate matter: Quantification of the impact of premature death or disability that particulates/respiratory inorganics have on the population, in comparison to $PM_{2.5}$. It includes the assessment of primary (PM_{10} and $PM_{2.5}$) and secondary PM (including creation of secondary PM due to SO_x, NO_x and NH_3 emissions).

f) Ionizing radiation HH (human health): Quantification of the impact of ionizing radiation on the population, in comparison to Uranium 235.

g) Ionizing radiation E (ecosystems): Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a radionucleide emitted (PAF m^3 year/kg). Fate of radionucleide based on USEtox consensus model (multimedia model). Relevant for freshwater ecosystems.

h) Photochemical ozone formation: Expression of the potential contribution to photochemical ozone formation.

i) Acidification: Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area in terrestrial and main freshwater ecosystems, to which acidifying substances deposit.

j) Terrestrial eutrophication: Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area, to which eutrophying substances deposit.

k) Freshwater eutrophication: Expression of the degree to which the emitted nutrients reaches the freshwater end compartment (phosphorus considered as limiting factor in freshwater).

l) Marine eutrophication: Expression of the degree to which the emitted nutrients reaches the marine end compartment (nitrogen considered as limiting factor in marine water).

m) Freshwater ecotoxicity: Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m^3 year/kg).

n) Land use: Soil Organic Matter (SOM) based on changes in SOM, measured in (kg C/m2/year). Biodiversity impacts not covered by the data set.

o) Water resource depletion: Freshwater scarcity (scarcity-adjusted amount of water used).

p) Mineral, resource depletion: Scarcity of mineral resource with the scarcity calculated as 'Reserve base'. It refers to identified resources that meet specified minimum physical and chemical criteria related to current mining practice. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics.

q) Primary energy demand, non-renewable: The primary energy demand is calculated using the upper heating values of non-renewable energy resources.

r) Nuclear waste: Nuclear waste is generated by nuclear power plants and their supply chains as part of the electricity mixes used in the supply chains of photovoltaic electricity. The nuclear wastes are assessed according their radiotoxicity potential (RTI).

4.2.5 Interpretation

4.2.5.1 Summary

Interpretation is the final phase of the LCA procedure, in which the results of an LCI (life cycle inventory analysis) or an LCIA (life cycle impact assessment), or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the definition of the goal and scope of the LCA.

Some of the impact indicators described below and calculated in the impact assessment phase may further be processed into payback times (either energy, EPBT, or environmental impacts such as climate change, IMP), or into energy return on investment (EROI).

4.2.5.2 Energy Payback Time (EPBT) and Non-Renewable Energy Payback Time (NREPBT)

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

$$EPBT = (E_{mat} + E_{manuf} + E_{trans} + E_{inst} + E_{EOL}) \,/\, ((E_{\mathrm{agen}} / \eta_{\mathrm{G}}) - E_{\mathrm{O\&M}})$$

where

E_{mat} is the primary energy demand to produce materials comprising PV system (MJ oil-eq);

E_{manuf} is the primary energy demand to manufacture PV system (MJ oil-eq);

E_{trans} is the primary energy demand to transport materials used during the life cycle (MJ oil-eq);

E_{inst} is the primary energy demand to install the system (MJ oil-eq);

E_{EOL} is the primary energy demand for end-of-life management (MJ oil-eq);

E_{agen} is the annual electricity generation (kWh);

η_{G} is the grid efficiency, the average primary energy to electricity conversion efficiency at the demand side (kWh / MJ oil-eq);

$E_{\mathrm{O\&M}}$ is the annual primary energy demand for operation and maintenance (MJ oil-eq).

The reasoning and assumptions applied to identify the relevant grid mix shall be documented.

Based on the above definition, there are two existing conceptual approaches to calculate the EPBT of PV power systems.

a) PV as replacement of the set of energy resources used in the power grid mix. This approach calculates the time needed to compensate for the total (renewable and non-renewable) primary energy required during the life cycle of a PV system (except the direct solar radiation input during the operation phase, which is not accounted for as part of $E_{\mathrm{O\&M}}$). The annual electricity generation (E_{agen}) is converted into its equivalent primary energy, based on the efficiency of electricity conversion at the demand side, using the current average or the long term marginal grid mix where the PV plant is being installed.

b) PV as replacement of the non-renewable energy resources used in the power grid mix. This approach calculates the EPBT by using the non-renewable primary energy only; renewable primary energy is not accounted for, neither on the demand side, nor during the operation phase. This approach calculates the time needed to compensate for the non-renewable energy required during the life cycle of a PV system. The annual electricity generation (E_{agen}) is likewise converted to primary energy equivalent considering the non-renewable primary energy to electricity conversion efficiency of the average (in attributional LCAs) or the long term marginal (in decisional/ consequential LCAs) grid mix where the PV plant is being installed. The result of using this approach shall be identified as Non-Renewable Energy Payback Time (NREPBT) to clearly distinguish it from the EPBT derived from the 1st approach. The formula of NREPBT is identical to that of EPBT described above except replacing “primary energy” with “non-renewable primary energy”. Accordingly, grid efficiency, η_G, accounts for only non-renewable primary energy.

4.2.5.3 Environmental impact mitigation potentials (IMP)

Similar to the energy payback times, environmental impact mitigation potentials (IMP) can be quantified. This may comprise mitigation potentials regarding climate change impacts or high-level nuclear waste. These IMPs are quantified on a life time basis. On one hand the life cycle-based impacts potentially avoided with the lifetime production of electricity with a PV system in a given economic, national or regional context is quantified. On the other hand, the life cycle-based impacts caused by material supply, manufacturing, installation, operation, maintenance and end-of-life management are determined. Below the example of climate change mitigation potential is shown.

$$Climate\ Change\ IMP = EI_{agen} \times CC_G - (CC_{mat} + CC_{manuf} + CC_{trans} + CC_{inst} + CC_{EOL} + CC_{O\&M})$$

where

CC_{mat} is the climate change impact (in kg CO_2-eq) of producing materials comprising PV system.

CC_{manu} is the climate change impact (in kg CO_2-eq) of manufacturing PV system.

CC_{trans} is the climate change impact (in kg CO_2-eq) of transporting materials used during the life cycle.

CC_{inst} is the climate change impact (in kg CO_2-eq) of installing the system.

CC_{EOL} is the climate change impact (in kg CO_2-eq) of end-of-life management.

El_{agen} is the life time electricity generation (in kWh).

$CC_{O\&M}$ is the life time climate change impact (in kg CO_2-eq) of operation and maintenance.

CC_G is the climate change impact (in kg CO_2-eq/kWh) of grid electricity at the demand side.

4.2.6 Reporting and communication

The life cycle assessment, energy payback time, environmental impact mitigation potential results should come along with information about key parameters and other important aspects characterising the PV system(s) analysed. The list of items is separated in key parameters required in the captions of figures and tables showing the results of the LCA (items a) to f)) and further important aspects which should be documented elsewhere in the same LCA report.

Key parameters to be documented in captions of figures and tables:

a) PV technology (e.g., mono and poly-crystalline silicon, CdTe, CIS/CIGS, amorphous silicon, micro-amorphous silicon);
b) Type of system (e.g., roof-top, ground mount, fixed tilt or tracker);
c) Module-rated efficiency and degradation rate;
d) Lifetime of PV and BOS;
e) Location of installation;
f) Annual irradiation, and expected annual electricity production with the given orientation and inclination or system’s performance ratio;

Important aspects to be documented in the LCA report:

g) Time-frame of data;

h) Life cycle stages included;

i) The place/country/region of production modelled (e.g., average grid medium voltage European grid (Entso-e), site-specific power use (e.g., hydropower, coal));

j) Explicit goal of the study including

- Purpose of the study
- Technical and modelling assumptions (e.g., static or prospective LCA, prototype or commercial production, current performance or expected future development);
- Type of LCA model applied (attributional, consequential, etc.)
- The name of the entity commissioning the study;

k) LCA approach used (process-based, environmentally-extended input-output tables, hybrid analysis);

l) LCA tool used (e.g., Simapro, GaBi, other), LCI database(s) used (e.g., ecoinvent, GaBi, ELCD, Franklin, NREL, IDEA, other), and impact category indicators used, always including the version numbers;

m) Assumptions related to the production of major input materials, e.g. solar grade silicon, aluminium (primary and/or secondary production), and electricity source if known.

Since a major part of the environmental impacts of PV systems is due to emissions from the “background system”, (i.e., from producing electricity and from the production of common materials like glass, aluminium, plastics, and steel), separating the contributions of "background" and "foreground" is recommended.

4.3 Environmental and Health Risk Assessment (EHRA) of PV module

4.3.1 Principle

Environmental and Health Risk Assessment (EHRA) is the systematic process to examine the risk of human health and environmental harm from a non-routine event. EHRA requires systematic scientific characterization of potential adverse health or environmental effects resulting from exposures to hazardous agents or situations.

In the case of human health risk assessment, EHRA consists of the four main steps of hazard identification, dose-response assessment, exposure analysis, and risk characterization. The process for conducting ecological risk assessment is similar to human health risk assessment, but begins with a more comprehensive problem formulation process, due to the wider variety of potential receptors impacted.

EHRA for the PV module is used to estimate the potential impact of a chemical or physical hazard on a human population or an ecological system. In this document, EHRA is considered over the life cycle of the product including manufacturing, use, and end-of-life treatment of the PV module. The scope includes potential health impacts of chemical pollutants and contamination of air, water and soil.

Health and environmental screening thresholds can be used to indicate tolerable risk related to exposure to chemical or physical hazards over the life cycle of the PV module. A screening approach to risk assessment incorporates conservative assumptions to avoid underestimating risk. Exceedance of a screening level indicates the potential for risk and the need for more detailed investigation to assess risk.

NOTE Specific methodologies for conducting EHRA can vary by country, depending upon country-specific regulations. This subclause covers the four main steps of EHRA in relation to PV modules.

4.3.2 Process

4.3.2.1 Hazard identification

Hazard identification is the process to examine the plausible capacity of a substance to cause adverse health and environmental effects. It uses toxicological data and complementary information such as structure-activity analysis.

In manufacturing PV cells, health of workers and environment of working place may be adversely affected by different classes of chemical and physical hazards. In this process, chemical properties such as material toxicity, corrosivity, flammability, and explosiveness of all chemicals should be investigated.

These hazards differ for different PV technologies and semiconductor deposition processes. Some of the main hazards associated with specific PV technologies are summarized below and include HF acid burns, SiH4 fires/explosions, and Pb solder/module disposal for c-Si; SiH_4 fires/explosions for a-Si; Cd toxicity and module disposal for CdTe; H_2Se toxicity and module disposal for CIS, CIGS; As toxicity, H_2 flammability, and module disposal from GaAs; Pb toxicity and module disposal for perovskite.

- Asphyxiant: argon, helium, methane, nitrogen trifluoride
- Corrosive: boron trifluoride, hydrochloric acid, hydrofluoric acid, silicon tetrachloride, sodium hydroxide
- Irritating: ammonia, boron trifluoride, diborane, hydrogen selenide, hydrogen sulfide, phosphorus oxychloride
- Flammable or explosive: hydrogen, hydrogen sulfide, methane, phosphine, silane
- Toxic: lead, arsenic, cadmium, indium, selenium, hexavalent chromium.

4.3.2.2 Dose response evaluation

Dose response assessment is the process in which the quantitative relationships between exposure and the effects of concern are examined. The determination of whether there is a hazard is often dependent on whether a dose–response relationship is present.

Important issues include:

- The relationship between the extrapolation models selected and available information on biological mechanisms
- How appropriate datasets were selected from those that show the range of possible potencies both in laboratory animals and humans
- The basis for selecting inter-species scaling factors to account for scaling doses from experimental animals to humans
- Relevance of the exposure routes used in the studies to a particular assessment and the interrelationships of potential effects from different exposure routes
- The relevance to the assessment of the expected duration of exposure and the exposure durations in the studies forming the basis of the dose–response assessment
- The potential for differing susceptibilities in population sub-groups
- Dose averaging/averaging exposure.

NOTE 1 More detailed information can be obtained from 'Environmental Health Risk Assessment Guidelines for assessing human health risks from environmental hazards enHealth (Commonwealth of Australia 2012)'.

Human health dose response data for a large database of chemicals is maintained in the U.S. EPA Integrated Risk Information System (IRIS). The data covers the ingestion and inhalation exposure routes and includes non-cancer reference doses, cancer slope factors, and inhalation unit risks as well as supporting toxicological studies and uncertainty factors. A large database for human health dose response data is also maintained in the EU by the European Chemicals Agency (ECHA).

NOTE 2 U.S. EPA. 2015. Integrated Risk Information System. Available: http://www.epa.gov/iris/European Chemicals Agency. 2015. Information on Chemicals. Available: http://echa.europa.eu/web/guest.

Ecological dose response data for a large database of chemicals is maintained in the U.S. EPA ECOTOX database. It includes toxicity data for aquatic life, terrestrial plants and wildlife.

NOTE 3 U.S. EPA. 2015. ECOTOX Database, Version 4.0. Available: http://cfpub.epa.gov/ecotox/index.html.

4.3.2.3 Exposure assessment

4.3.2.3.1 General

Exposure assessment is the process which quantitatively and/or qualitatively evaluates human or ecological exposure to hazardous substances. Exposure assessment requires a determination of the magnitude, frequency, extent, character and duration of the exposures in the past, currently and in the future. Identification of exposed populations and potential exposure pathways is also included. Exposure assessment is one of the most critical and complex areas of risk assessment, including for PV. It includes evaluation of potential emissions, environmental fate, and exposure by a given receptor.

4.3.2.3.2 Emissions

Potential emissions of hazardous materials can occur during non-routine events such as fire, field breakage, or disposal of a PV module.

- Emissions from fire**:**
  - Existing methodologies for measuring potential emissions from PV fire include use of tube furnace and UL1256 and ASTM E119-98 fire test standards.
  - Existing methodologies for measuring potential emissions from emergency response to PV fire include measurements of flue gas, fire residue, and fire water analysis.
- Emissions from field breakage or disposal**:**
  - Existing methodologies for evaluating potential leaching of hazardous materials from disposal of waste, including PV modules, are provided in standard leaching tests such as U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1312 (SPLP), EN 12457-4:01-03, GB 5085.3-2007 and JIS K 0102:2013 method (JLT-13).

4.3.2.3.3 Environmental fate

Environmental fate characterizes the movement and transformation of a chemical from the point of emissions to the point of exposure, and can include impact pathways such as soil, water, and air.

- Environmental fate of emissions from fire:
  - Existing methodologies for evaluating environmental fate of PV fire emissions downwind in air include VDI Guideline 3783 for Gaussian plume dispersion.
  - Existing methodologies for evaluating environmental fate from emergency response to PV fire include use of the U.S. EPA SCREEN3 Gaussian plume dispersion model and USEPA soil screening guidance, including soil-soil water partitioning coefficients for soil dispersion and dilution-attenuation factor for groundwater dispersion.
- Environmental fate of emissions from field breakage or disposal:
  - Existing methodologies for evaluating environmental fate of PV emissions from field breakage include use of the USEPA soil screening guidance, including soil-soil water partitioning coefficients for soil dispersion and dilution-attenuation factor for groundwater dispersion.

– Existing methodologies for evaluating environmental fate of emissions from PV landfill disposal include use of U.S. EPA Delisting Risk Assessment Software (DRAS), including chemical dispersion in groundwater, soil, and air, and biological uptake in fish.

4.3.2.3.4 Exposure factors

In the PV technology, environmental exposure to chemicals can be direct – as a result of emission to the environment (air, land, water) of a substance through manufacture, use or disposal – or indirect through drinking water or food chain. A detailed database of human exposure factors is maintained in the U.S. EPA Exposure Factors Handbook. The Handbook includes ingestion, inhalation, dermal exposure, and food intake rates, as well as body weight and lifetime distributions, and activity factors. A similar range of ecological exposure factors for birds, mammals, reptiles and amphibians, and other species is maintained in the U.S. EPA Wildlife Exposure Factors Handbook.

NOTE Refer to U.S. EPA. Exposure Factors Handbook. EPA/600/R-09/052F, 2011. U.S. EPA. Wildlife Exposure Factors Handbook. EPA/600/R-93/187, 1993.

4.3.2.4 Risk characterization

Risk characterization is the final step in the risk assessment process and the integration of hazard identification, hazard characterization, including dose-response, and exposure assessment.

Risk characterization policy calls for principles of TCCR (transparency, clarity, consistency, reasonableness) in the risk characterization. The principles of TCCR need to be fully applied throughout every aspect of the risk assessment process. By applying TCCR principles from the planning and scoping stages, through the actual risk assessment, and then to all the communication and documentation of the risk assessment, the whole process will benefit and help better ensure success of all assessment efforts and products (including the risk characterization).

NOTE 1 U.S. EPA. 2000. Science Policy Council Handbook: Risk Characterization. EPA-100-B-00-002.

With respect to characterizing risk, human health screening benchmarks corresponding to tolerable risk thresholds for a wide range of chemicals are maintained by U.S. EPA in the Regional Screening Levels (RSL) database. The benchmarks cover potential human exposure to chemicals in soil, water, and air.

Ecological screening benchmarks for exposure to chemicals in soil is provided in the U.S. EPA Ecological Soil Screening Levels (Eco-SSL) database .

NOTE 2 U.S. EPA. 2015. Ecological Soil Screening Level. Available: http://www.epa.gov/ecotox/ecossl/.

In the case of occupational health during PV manufacturing, benchmarks corresponding to tolerable risk thresholds for worker safety are maintained by the Labour Administration of a given country.

U.S.A: Occupational Safety and Health Administration permissible exposure limits (PELs) provide occupational health benchmarks for a wide range of chemicals .

NOTE 3 Reference: U.S. Department of Labour. 2015. Permissible Exposure Limits. Available at https://www.osha.gov/dsg/annotated-pels/.

Germany: Federal Ministry of Labour and Social Affairs establishes occupational exposure limits for a wide range of chemicals based on review of values of the DFG Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area (DFG: German Research Foundation), indicative OELs of the European Commission, and international limit values .

NOTE 4 Reference: Deutsche Forschungsgemeinschaft. MAK- und BAT-Werte-Liste 2014: Maximale Arbeitsplatzkonzentrationen und Biologische Arbeitsstofftoleranzwerte Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe, Mitteilung 50. DOI: 10.1002/9783527682010.

China: Ministry of Health, and State Administration of Work Safety occupational exposure limits provide occupational health benchmarks for a wide range of chemicals .

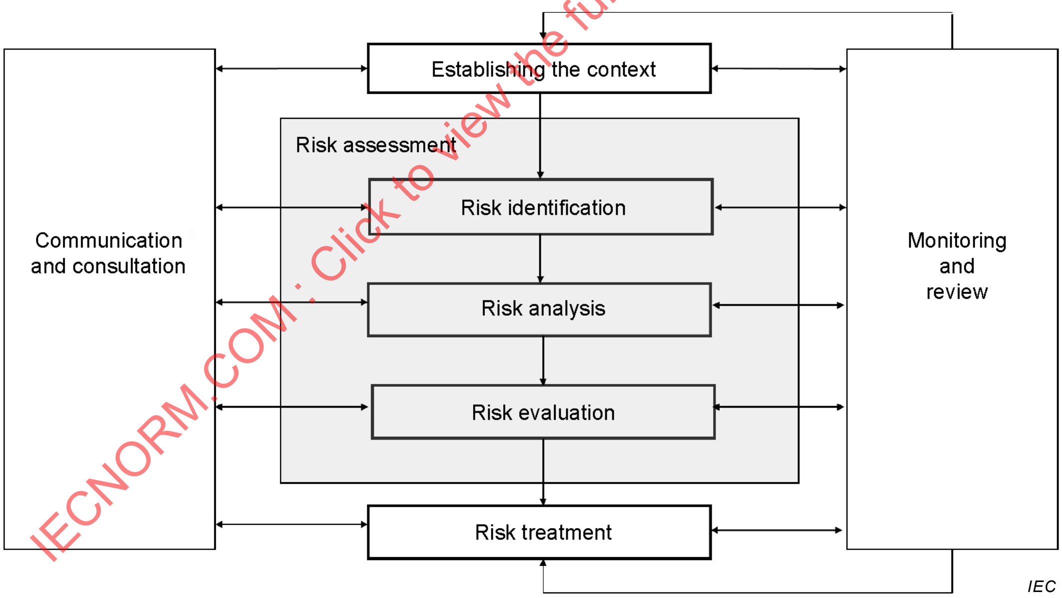
NOTE 5 Reference: Ministry of Health. GBZ 2.1-2007. Occupational exposure limits for hazardous agents in the workplace Part 1. People's Republic of China.

Japan: The Japanese Ministry of Health, Labour, and Welfare establishes occupational exposure limits for a wide range of chemicals based on review of Threshold Limit Values (TLV) originating from the American Conference of Governmental Industrial Hygienists (ACGIH) and occupational exposure limits (OEL) originating from the Japan Society for Occupational Health (JSOH) .

NOTE 6 Reference: Japan Society for Occupational Health. Recommendation of Occupational Exposure Limits. Available at http://www.sanei.or.jp/?mode=view&cid=310.

4.3.3 Risk assessment and risk management

Risk assessment should be linked closely with risk management for the efficient control of risk. The results and information from the risk assessment provides an improved understanding of risks to the decision-makers and can serve as a basis for adequate and effective controls. Figure 2 shows contribution of risk assessment to the risk management process. Various framework models that interlink the process of EHRA and stakeholder consultation show the relationship of risk assessment with other stages of risk management, and also show problem formulation and planning as precursors to the formal steps of quantitative risk assessment.



[SOURCE: ISO/IEC 31010, 2009]

Figure 2 – Contribution of risk assessment to the risk management process

4.3.4 Risk assessment of PV related equipment

This document deals with risk assessment of PV through the life cycle including design, manufacture, use, waste and recycling process of PV cell, module and BOS components with direct interface to the PV module. CENELEC Guide 32 provides guidelines for conducting a risk assessment and risk reduction for low voltage equipment which is applicable to the PV related equipment. Important elements concerns are as follows:

– Protection against electrical hazards (leakage current; energy supply; stored charges; arcs; electric shocks; burns).
– Protection against mechanical hazards (instability; break-down during operation; falling or ejected objects; inadequate surfaces; edges or corners; moving parts; improper fitting of parts).
– Protection against other hazards (explosion; explosion; electromagnetic fields and other ionizing and non-ionizing radiation; electromagnetic disturbances; optical radiation; fire; temperature; acoustic noise; biological and chemical effects; emissions, production and/or use of hazardous substances; unattended operation; connection to and interruption from power supply; combination of equipment; implosion; hygiene conditions; ergonomics).
– Functional safety and reliability (equipment design; type related hazards; system faults).
– Safety-related security (protection against casual or incidental violation; protection against intentional violation).

4.4 EH&S management system

4.4.1 General

EH&S management is the process for systematically achieving a desired level of EH&S performance. An EH&S management system involves EH&S policy, planning, implementation and operation of necessary systems, programs, and procedures to achieve that level of performance, checking the results and making adjustments to ensure the level of performance is achieved as shown in Figure 3.

EH&S management has two general objectives: Prevention of incidents or accidents that might result from abnormal operating conditions and reduction of adverse effects.

ISO 14001 for environmental management and OHSAS 18001 for occupational health and safety management are representative standards for EH&S management system. These standards provide frameworks for environmental management and occupational health and safety, respectively, that is applicable to manage EH&S in PV manufacturing.

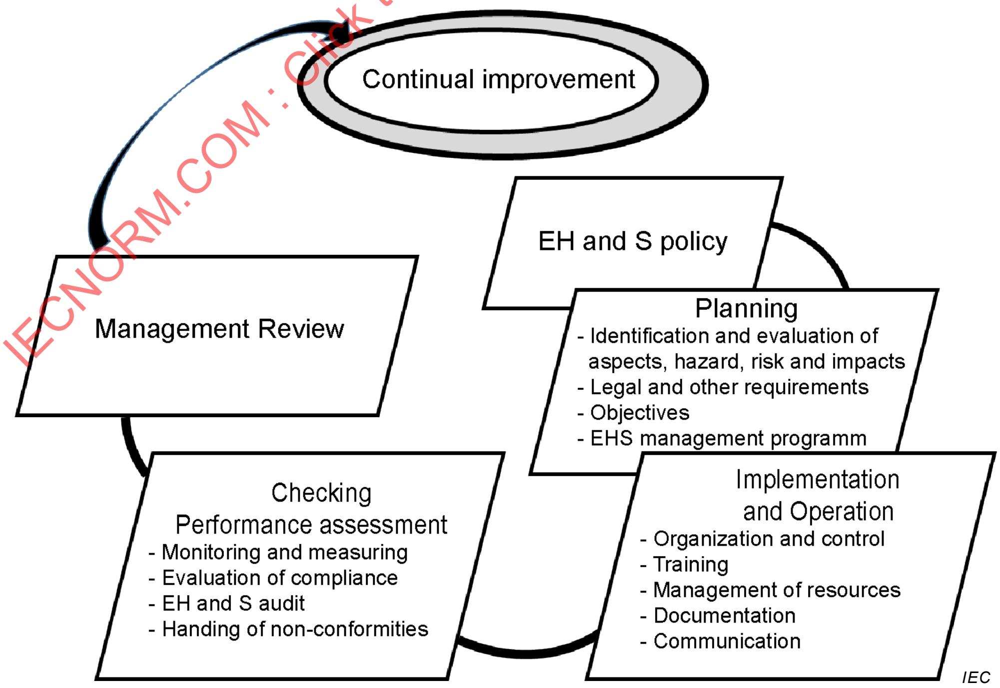


Figure 3 – Environmental management system model

[SOURCE: modified from ISO 14004:2016]

4.4.2 EH&S Policy

EH&S policy is a statement by an organization of its intentions and principles in relation to its overall environmental and occupational health performance which provides a framework for action and for the setting of its EH&S objectives and targets.

In developing policy, consider the following:

- Coordination with other organizational policies
- Specific local or regional conditions
- Life cycle thinking
- Involvement and communication with interested parties
- Work toward sustainable development.

4.4.3 Planning

EH&S planning is critical for determining and taking the actions needed to ensure the EH&S management system can achieve its intended outcomes. It is an ongoing process, used both to establish and implement elements of the EH&S management system and to maintain and improve them.

The organization should have a planning process including as follows:

- Recognition and determination of environmental and occupational health aspects
- Compliance obligations and requirements
- EH&S objectives and planning to achieve them.

Planning of EH&S management systems is designed to establish hierarchical safety protocols, including occupational hazard analyses, trainings, audits, and workplace safety internal controls and committees (Galland, 2012).

NOTE Galland. 2012. Best Practices in Photovoltaics Manufacturing. IEEE PVSC, Austin, TX.

The organization should establish performance indicators for monitoring its progress in achieving EH&S objectives and continual improvement. The indicators should be appropriate to the organization's activities, products and services and consisted with its EH&S policy, practical, cost-effective and technological feasible. Example of performance indicators are as below:

- Quantity of raw materials or energy used
- Quantity of emissions, such as CO_2
- Waste produced per quantity of final product
- Efficiency of material and energy used
- Number of incidents (such as excursions above limits)
- Number of accidents (such as unplanned release)
- Percentage waste recycled
- Percentage recycled material used in packaging
- Number of service vehicle kilometers per unit of production
- Quantity of specific pollutant emitted, e.g. NO_x, SO_x, CO, VOCs, Pb, and CFCs
- Investment in environmental protection
- Number of prosecutions
- Land area set aside for wildlife habitat.