



JRC TECHNICAL REPORTS

Standards for the assessment of the environmental performance of photovoltaic modules, power conditioning components and photovoltaic systems

DG GROW SI2.764246

JRC N° 34713-2017

Dunlop, E.D.

Gracia Amillo, A.

Salis, E.

Sample, T.

Taylor, N.

2018

This publication is a Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication.

Contact information

Name: Ewan Dunlop
Address: v. E. Fermi, 2749 – I-21027 Ispra (VA) Italy
Email: Ewan.DUNLOP@ec.europa.eu

JRC Science Hub

<https://ec.europa.eu/jrc>

JRC111455

EUR 29247 EN

PDF ISBN 978-92-79-86608-1 ISSN 1831-9424 doi:10.2760/89830

Luxembourg: Publications Office of the European Union, 2018

© European Union, 2018

Reuse is authorised provided the source is acknowledged. The reuse policy of European Commission documents is regulated by Decision 2011/833/EU (OJ L 330, 14.12.2011, p. 39).

For any use or reproduction of photos or other material that is not under the EU copyright, permission must be sought directly from the copyright holders.

How to cite this report: Dunlop E.D., Gracia Amillo A., Salis E., Sample T., Taylor N., *Standards for the assessment of the environmental performance of photovoltaic modules, power conditioning components and photovoltaic systems*, EUR 29247 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-86608-1, doi:10.2760/89830, JRC111455

All images © European Union 2018

Contents

- Foreword 1
- 1 Introduction 2
- 2 Photovoltaic Technologies 3
 - 2.1 Crystalline Silicon 3
 - 2.2 Thin-Film Photovoltaics 3
- 3 Test standards 4
 - 3.1 Organisational structure of standardisation 4
 - 3.1.1 European Standards Background 4
 - 3.1.2 IEC Background 6
 - 3.1.3 ISO Background 8
 - 3.2 Analysis of product performance standards 8
 - 3.2.1 PV Modules 8
 - 3.2.1.1 Functional Parameters 9
 - 3.2.1.2 Supporting Standards 10
 - 3.2.1.3 Complementary Standards 11
 - 3.2.2 Power Conditioning Components 21
 - 3.2.2.1 Functional Parameters 21
 - 3.2.2.2 Supporting Standards 24
 - 3.2.2.3 Complementary Standards 24
 - 3.2.2.4 Batteries 30
 - 3.2.3 PV Systems 34
 - 3.2.3.1 Functional Parameters 34
 - 3.2.3.2 Supporting Standards 36
 - 3.2.3.3 Complementary Standards 37
 - 3.2.4 Building-Integrated PV Modules or Systems 47
- 4 Circular economy and material efficiency 51
 - 4.1 Degradation issues, operational service life and lifetime 51
 - 4.1.1 Degradation of PV modules, components and systems 52
 - 4.1.1.1 PV modules 52
 - 4.1.1.2 Power conditioning components 52
 - 4.1.1.3 PV systems 53
 - 4.1.1.4 BIPV systems 53
 - 4.1.2 Operational service life 53
 - 4.1.3 Lifetime of PV modules, components and systems 55
 - 4.2 Quality standards for modules, power-conditioning components and systems 56
 - 4.2.1 PV modules 56

4.2.2	Power conditioning equipment	62
4.2.3	PV systems	62
4.3	The recast Waste Electrical and Electronic Equipment (WEEE) Directive (2012) .	62
4.4	Standards relating to life cycle of PV products, components and systems.....	63
4.4.1	Horizontal standards	63
4.4.2	Sustainability	66
4.4.2.1	Resource use and Emissions During Product Life	66
4.4.2.2	Recyclability aspects	66
4.4.2.3	General sustainability aspects.....	66
5	Conclusions	68
5.1	Product-group definition	68
5.2	Standards.....	68
5.2.1	General overview	68
5.2.2	Compulsory harmonised standards.....	69
5.3	Relevant procedures or methods not available as already existing standards.....	69
5.3.1	Identification of lack of standards	70
References	71
List of abbreviations and definitions	72
List of tables	75
Annexes	76
Annex 1.	Energy rating study related to the Ecodesign project	76

Foreword

The EU has a number of legislative instruments which translate EU energy and climate policy goals into various strands of action. Ecodesign, complemented by energy labelling rules, supports the European Commission's overarching priority to strengthen Europe's competitiveness and boost job creation and economic growth; it ensures a level playing field in the internal market, drives investment and innovation in a sustainable manner, and saves money for consumers while reducing CO₂ emissions. It contributes to the Energy Union 2020 and 2030 energy efficiency targets, the commonly-agreed climate goals and to the objective of a Deeper and Fairer Internal Market.

Following the inclusion of the photovoltaic product group in the Ecodesign Working Plan 2016-19, a preparatory study has been launched on solar photovoltaic panels and inverters, in order to assess the feasibility of proposing Ecodesign and/or Energy Labelling requirements for this product group. This will also investigate in more detail the potential for environmental improvement, including aspects relevant to the circular economy, and provide the elements needed for the identification of policy options in the subsequent impact assessment.

The EU Ecolabel (set up under Regulation EC 66/2010) aims at reducing the negative impact of products and services on the environment, health, climate and natural resources. The Regulation stipulates in Annex I a standard procedure for the development and revision of EU Ecolabel criteria, taking into account the environmental improvement potential along the life cycle of products.

Green public procurement (GPP) is defined in COM(2008)400 as a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact through their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured. The Commission plans to take action on GPP, by emphasizing circular economy aspects in any new criteria, and supporting higher uptake of GPP.

The scope of the work in the present report aims to provide the necessary identification and analysis of measurement and testing standards. In particular, for the product group "solar photovoltaic panels, inverters and systems", it aims to inform and help policy makers to develop minimum Ecodesign requirements, an energy label, EU Ecolabel criteria and/or GPP criteria.

1 Introduction

To support the ongoing preparatory activities on the feasibility of applying the Ecodesign, EU Energy label, EU Ecolabel and Green Public Procurement (GPP) policy instruments to solar photovoltaic (PV) modules, inverters and systems, this report aims to:

- Identify, describe and compare existing standards and new standards under development, relevant to energy performance, reliability, degradation and lifetime.
- Identify aspects not covered by existing standards, for which transitional methods may be needed.

Three categories are considered:

1. Photovoltaic modules (or panels): these are defined as an environmentally protected, essentially planar assembly of solar cells, ancillary parts (such as interconnections and terminals) and protective devices (such as diodes), intended to generate direct-current (DC) power under non-concentrated sunlight. For the purpose of this report, only un-concentrated PV modules are considered due to their dominant market share. The structural (load carrying) member of a module can either be the top layer (superstrate) or the back layer (substrate) with or without a metal frame.
2. Power conditioning components, defined here as electrical equipment, or power electronics are used to convert DC power from a PV array into a form suitable for subsequent use. This is a collective term for inverter (i.e. DC-AC converter), DC-DC converter, battery charge regulator and blocking diode.
3. Photovoltaic systems, defined as a power system designed to supply usable electrical power by means of photovoltaic modules. It consists of an arrangement of several components, including PV modules to absorb and convert sunlight into electricity, an inverter to change the electric current from DC to alternate current (AC), as well as mounting, cabling and any other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline. The specific case of Building Integrated Photovoltaic (BIPV) Systems will also be considered as they also provide or perform environmental protection as part of the building envelope and/or structural integrity.

For each of these three categories, the environmental performance aspects at different stages in the product's and system's life cycle (e.g. production, design, use, end of life) are considered in the context of the Circular Economy and Materials Efficiency.

2 Photovoltaic Technologies

Photovoltaics boast an extensive range of technologies. These can be broadly classified as “commercial”, i.e. being used in mass production and already widely available on the market, “emerging”, i.e. small production volumes and some examples of their introduction into the market, and “novel”, i.e. concept or early laboratory stage. Of the estimated world production in 2017 of 90 to 95 GW [1] mono- and multi-crystalline silicon wafer-based photovoltaics are the dominant commercial technologies on the market, with a share of almost 95%. Thin-film technologies of copper indium/gallium disulphide/diselenide (CIGS), cadmium telluride (CdTe), thin-film silicon (amorphous with or without microcrystalline silicon) make up the remainder. Some organic (OPV) and dye-sensitized (DSSC) solar PV devices have been commercialised up to now, but for the most part this sub-technology remains in the novel and emerging categories.

As mentioned in the PV status report 2017 [1], the “existing PV technology mix is a solid foundation for the future growth of the sector as a whole.” In fact, it would be rather naïve to think that a single technology could meet the requirements and needs of all the PV stakeholders, being these consumers or producers. A wide range of possible applications, from mobile to residential sectors, and the need for a few watts up to multi-megawatt utility-scale power plants need to be properly, specifically and timely addressed. Thanks to the variety of available technologies, situations like material’s supply limitations or technical obstacles that could affect the further growth or development of a single technology pathway would be smoothed out as implementation of solar PV electricity is put in place.

As the standards to which this report refers can mention or be applicable only to specific PV technologies, i.e. specific active materials used in the PV module manufacture, a quick summary of the main PV technologies currently sharing most of the PV market is given here.

2.1 Crystalline Silicon

As said, the current dominant PV technology is represented by the various types of crystalline silicon (c-Si) material, manufactured as cells (typically 156 mm x 156 mm) cut out of wafers with thickness ranging from 120 μm to 250 μm . They include mono-, multi- and heterojunction silicon with various grades of efficiency. These PV cells are usually laminated between a front glass and a back opaque polymer sheet and assembled in modules, although glass-glass modules for architectural use or with bifacial active cells are now entering the market.

2.2 Thin-Film Photovoltaics

In thin-film PV modules a layer of semiconductor material, a few microns or less in thickness, is deposited on a substrate or superstrate. A variety of physical, chemical, electrochemical and hybrid techniques are available. Advantages include a relatively low consumption of raw materials, high automation and production efficiency facilitating continuous or roll-to-roll production, potential and ease of production of large-area modules suitable for building integration combined with improved performance at high ambient temperature.

The most important thin-film product currently in the market is cadmium telluride (CdTe), although not as efficient as the best c-Si modules. The other major thin-film PV technology with a significant presence in the market is the family of the Copper Indium Selenides or Sulphides, mainly as CIS(or Se) and CIGS(or Se). Amorphous silicon (a-Si) was the first commercially successful thin-film PV technology. However, since its energy conversion efficiency has failed to reach acceptable levels compared to that of standard silicon products, its market share is now minimal.

3 Test standards

3.1 Organisational structure of standardisation

The first choice on which to base the European legislation are harmonised standards. As defined by article 2 of the Regulation (EU) 1025/2012, a harmonised standard is a "European standard" that has been adopted by a recognised European Standardisation Organisation (i.e. CEN, CENELEC or ETSI) on the basis of a request made by the European Commission (EC). Such a request is aimed to the application of the requested standard's technical specifications and requirements within the European Union's harmonisation legislation. Manufacturers, other economic operators or conformity assessment bodies can use harmonised standards to demonstrate that products, services or processes comply with the relevant EU legislation that refers to those standards. A "presumption of conformity" is granted for those products that fully comply with harmonised standards.

When harmonised standards are not available, as it is the case of first stages of a new legislation process, other types of (preferably international) standards may be considered to be brought to the level of harmonised standard through the legislative procedure.

The standards considered in the present report originate from the different standardisation organisations, depending on the specific topic and on their current availability. Whenever possible, the standards referred to are those published by the European standardisation organisations CEN and CENELEC for the general and the electrotechnical topics, respectively. In absence of relevant standards set in the specific European context, other equivalent and applicable norms were examined within broader international standardisation bodies like the International Standardization Organisation (ISO) and the International Electrotechnical Commission (IEC) for general and electrotechnical topics, respectively. In few cases lack of standardisation is highlighted.

3.1.1 European Standards Background

CENELEC is the European Standardisation Organisation (ESO) in the electrotechnical field. CEN and CENELEC (+ ETSI for the Information and Communications Technologies) have the European Union's mandate in relation to the "Completion of the Internal Market". The specific mandate for standardisation in the field of solar photovoltaic energy systems and components is M/089 EN (which however does not cover the Ecodesign topic).

The mandate M/089 EN is implemented by CENELEC Technical Committee 82: Solar Photovoltaic Systems. Under the terms of the Frankfurt Agreement¹ between CENELEC and the IEC, CENELEC:

1. offers New Work items for standardisation to the IEC if no IEC work has already been started on the same topic;
2. votes on draft International Standards to transform IEC standards into European standards, usually in a "fast track" procedure of 2 months (called "Parallel voting"), while keeping the document numbers of IEC (see next bullet point). Within this procedure, IEC committee drafts for voting (CDV) are equivalent to CENELEC draft European Standards (prEN) and IEC Final Drafts of International Standards (FDIS) correspond to Final draft of European Standards (FprEN);
3. implements the agreed publication requirements on the standards numbering so that, whenever a European standard (EN) is identical to the corresponding IEC document, the CENELEC reference is in the form EN IEC 6xxxx;

¹ Publicly available at:

http://www.iec.ch/about/globalreach/partners/pdf/IEC-CENELEC_Frankfurt_Agreement%7B2016%7D.pdf
or
ftp://ftp.cencenelec.eu/CENELEC/Guides/CLC/13_CENELECGuide13.pdf

4. offers the conversion of standards developed for and within the European Union into International standards under the IEC scope. If the IEC accepts the proposal, it can launch a parallel vote on the relevant draft standards.

In particular, under the Frankfurt Agreement there is the mutual requirement of notification of standardisation work and the commitment by either party to not engage in topics if the other party is already doing it. CENELEC together with the European National Committees (EU28+EEA) fosters also the translation into national languages, as relevant national standards must be withdrawn if they conflict with EN standards.

Mandates, also called standardisation requests, are the tool by which the European Commission and the European Free Trade Association (EFTA) Secretariat can request the ESOs (i.e. CEN, CENELEC or ETSI, depending on the topic) to develop and adopt EN standards in support of European policies and legislation. The standardisation mechanism is implemented through the following steps²:

1. A provisional draft mandate is received at CEN/CENELEC for possible comments by a due deadline;
2. A draft mandate, including the possible proposed modifications, is sent to the Committee on Standards established under Regulation 1025/2012 on European Standardisation, ensuring a wide consultation of sector authorities at national level;
3. A mandate is then sent for acceptance to CEN/CENELEC, where a Programme Manager coordinates with the relevant Technical Body and ensures feedback to the Technical Board(s);
4. The Technical Board Members are invited (not) to accept the given mandate, with or without restrictions, based on the Technical Body and CEN/CENELEC feedback;
5. Once the Technical Board has taken its decision, CEN/CENELEC informs the EC accordingly.

If the mandate is accepted, the Technical Body is entrusted with the task of starting expected standardisation work within CEN/CENELEC.

Before a European standard can be implemented, it must follow the following steps:

1. Proposal for new work and acceptance.

Businesses, users, consumers, lawmakers and non-governmental organisations can propose a new standard. Specific needs, feasibility and resources are assessed. Once the proposal is accepted, national work is frozen in 31 countries (standstill).

2. Drafting and building of agreement.

An adopted standardisation project is allocated to a CEN Technical Committee/CENELEC Technical Body (experts) for the drafting of the standard at European or international level.

3. Public Enquiry – generate comments.

Once the draft of a European Standard is prepared, it is released for public comment, a process known in CEN and CENELEC as the 'CEN Enquiry' and 'CENELEC Enquiry'. During this stage, everyone who has an interest (e.g. manufacturers, public authorities, consumers, etc.) may comment on the draft. Technical experts analyse the comments and improve the draft which will lead to the final draft to be approved as European Standard.

² The process that is described in the following has been sourced from CENELEC:
www.cenelec.eu/aboutcenelec/whatwestandfor/supportlegislation/europeanmandates.html

4. Adoption by weighted vote

Taking into account the comments resulting from the CEN Enquiry or CENELEC Enquiry, a final version is drafted, which is then submitted to the CEN and/or CENELEC Members for a weighted formal voting. The European Standard is then approved.

5. Ratification and publication of the European Standard (EN)

After ratification by CEN or CENELEC, the National Standardisation Body/National Committee of each of the 31 countries participating to CEN and CENELEC adopts the EN Standard as an identical national standard and withdraws any national standards that conflict with the new EN Standard. Hence, one EN Standard becomes the national standard in the 31 member countries of CEN and/or CENELEC.

A regular revision process is put in place for each standard by the relevant Technical Committee/Technical Body. After this assessment a standard can be confirmed (i.e. no changes are made and the same revision is kept as valid), withdrawn (i.e. the standard is cancelled from the list of valid standards and abandoned) or amended and/or revised (i.e. some changes are made, respectively, without or with a new version released depending on the type and amount of changes).

3.1.2 IEC Background

The International Electrotechnical Commission (IEC) is the partner organisation of the International Organization for Standardization (ISO). Both IEC and ISO are independent organisations and form together with the International Telecommunication Union (ITU) (the United Nations specialised agency for information and communication technologies) the world-wide standardisation process. IEC is entrusted with all standards aspects in the electrotechnical field, and was founded in 1904. Membership is required for all countries which are part of the World Trade Organisation (WTO) as commitment to remove international trade barriers, but it is open to all other United Nations members.

The Technical Committee (TC) 82 deals with Solar Photovoltaic Energy Systems and was established in 1981. Since then it has published more than 105 documents (2018-03-19), which have laid the foundation for the strong increase of trade for PV products. IEC TC 82 currently has 51 Member States (40 Participating countries and 11 Observer countries) as listed hereafter for each of the world's areas:

Africa: Algeria, Egypt, Kenya, Morocco, Nigeria, South Africa

Americas: Brazil, Canada, Chile, Mexico, United States of America

Asia/Pacific: Australia, P.R. China and independent Province of Taiwan, India, Indonesia, Japan, Republic of Korea, Malaysia, New Zealand, Singapore, Thailand

EU28: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden, United Kingdom (20, all but CY, EE, HR, LV, LT, LU, MT, SK)

Europe: Norway, Russian Federation, Serbia, Switzerland, Turkey, Ukraine

Middle East: Iran, Israel, Oman, Saudi Arabia

A simplified standards development process of a TC is outlined in Figure 1.

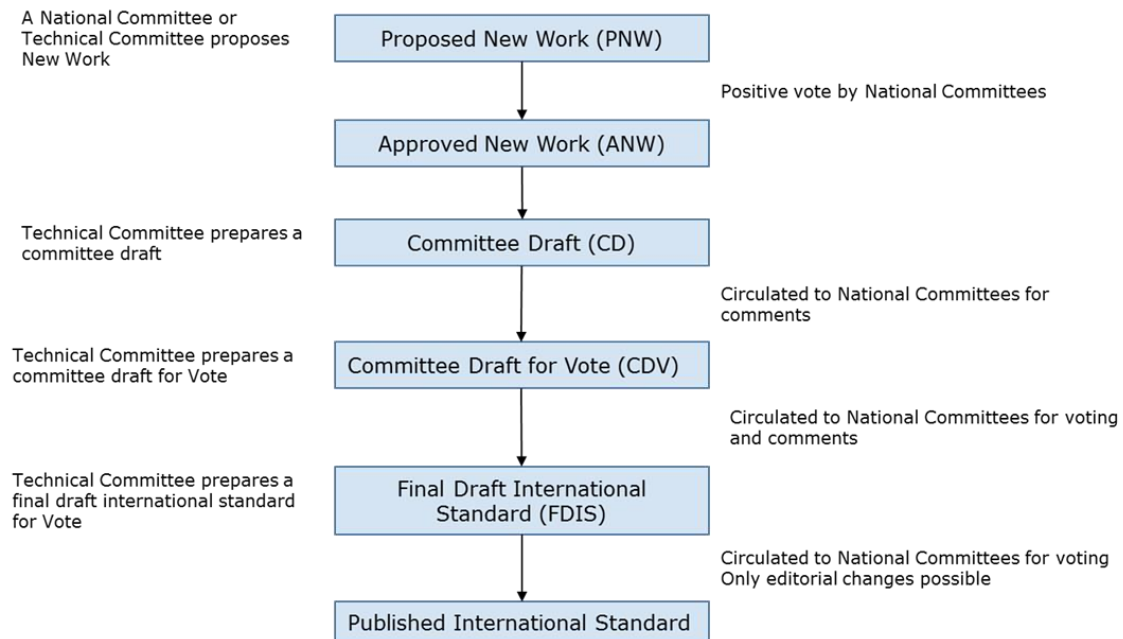


Figure 1. Simplified standards development process followed by a TC.

In addition to the development of new standards, technical committees are also responsible for the maintenance of published standards. Each published document has a stability date which lists the time when the technical committee will verify the applicability of the standard. Where appropriate they will then make a revision of the document to take into account progress in the field or, if no revision is necessary, confirm this fact and establish a new stability date.

The IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications (IECRE System) was formed in 2014 to define how certificates can be issued at system level for three energy sectors: wind, solar and marine energy. Each consists of complex arrangements of sub-systems including structures, which are usually installed outside of any protective environment and whose reliability and performance is affected by direct interaction with the natural environment.

Conformity assessment can be performed and certificates issued for an individual PV power plant on a specific site at various stages of its design and implementation (see Figure 2). It aims to give confidence that a PV plant will safely perform as promised and reduce cost at the same time. It represents a step beyond standards, in that while IEC writes technical standards, IEC does not define how these are used.

The IECE Specific Certificate Categories can include:

- PV Site Qualification certificate
- PV Power Block design qualification certificate
- PV Plant Design qualification certificate
- Conditional PV Project certificate (construction complete / commissioning)
- Annual PV Plant Performance certificate
- PV Asset Transfer certificate
- PV Decommissioning certificate

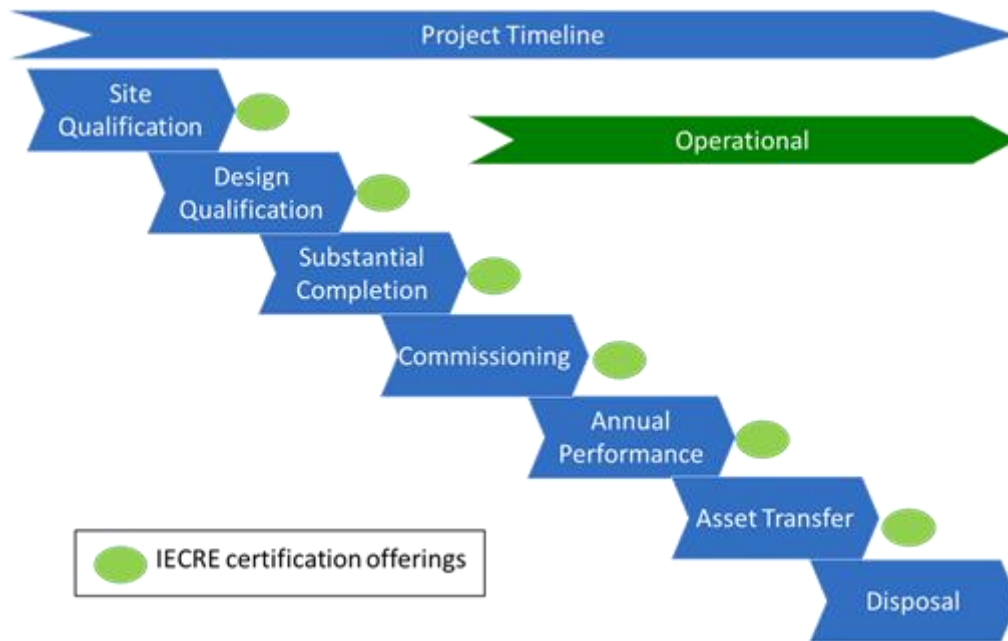


Figure 2. IECRE system timeline view

3.1.3 ISO Background

ISO is an independent, non-governmental international organisation that is committed to develop standards applicable worldwide in order to demolish barriers to the world trade. A standardisation process similar to the IEC organisation's one is followed in the development and revision of international standards. Few standards by ISO are considered in this report, mainly in relation to product's life cycle and building applications.

3.2 Analysis of product performance standards

This section is divided into four subsections. The first three give an overview of the identified relevant PV parameters and their supporting standards, when available, for each product category presented in the Introduction: individual PV modules (see 3.2.1), power conditioning and storage components such as for example inverters and batteries (see 3.2.2), and PV systems including stand-alone and building-added (BaPV) PV systems (see 3.2.3).

An additional subsection (3.2.4) is dedicated to the subject of PV integrated into buildings (Building Integrated Photovoltaics, BIPV), with reference to existing normative work on the topic as well as to possible specific issues known or expected to appear and tools currently available or to be upgraded for their management.

3.2.1 PV Modules

Table 1 gives the overview of the available standards (or the lack of them) for each of the parameters that are deemed essential to describe the function of a PV module as an entity to generate electrical power from natural sunlight under some defined environmental conditions. These essential parameters are therefore labelled as functional parameters (see also 3.2.1.1).

Table 2 lists the standards (or the lack of them) that are referred to in the standards for functional parameters as necessary to perform specific tasks or that are required to

complete the characterisation of a PV module. These secondary documents are therefore considered as supporting standards (see 3.2.1.2).

Table 3 summarises all the available standards that deal with further useful aspects of PV module production and characterisation, especially from the practical point of view, and that thus complete the overall framework for PV norms without being essential for the definition of the functional parameters, though. They are simply considered as complementary standards (see also 3.2.1.3).

3.2.1.1 Functional Parameters

The following functional parameters can be considered essential for supporting the preliminary study on Ecodesign, EU Energy label, EU Ecolabel and GPP policy instruments for solar PV modules. These parameters are included also in Table 1. The order in the list given here is more based on a bottom-up approach, from the most fundamental parameter and measurement to the more extended and in-operation one; the sequence followed in Table 1, instead, is thought to be more suitable to address an operational point of view. The functional parameters are:

1. PV module maximum power (P_{\max}) according to the EN 60904-1 and reported at specific reference conditions, named Standard Test Conditions (STC) and defined by the Technical Specification CLC/TS 61836 (see Table 2);
2. Module Energy Conversion Efficiency, as described in the new edition of the EN 60904-1 under revision;
3. Module Performance Ratio (MPR) calculated according to the series of standards EN 61853 partly still in preparation at the IEC (drafts IEC 61853-3 and IEC 61853-4);
4. Module Energy Yield DC; the DC energy produced by a single PV module following the method of calculation described in the draft IEC 61853-3 for one or all of the Standard Reference Climatic Profiles tabulated in the draft IEC 61853-4, with measurements of PV module power according to EN 61853-1 and corrections for temperature, spectrum and angle-of-incidence losses as described in EN 61853-2;
5. Module Energy Yield AC, derived from Module Energy Yield DC by suitable losses factors (to be defined);
6. Operational Life (see section 4.1.2)
7. Module Annual Degradation Rate (see section 4.1.1)

As the main function of a PV module can be defined as "to generate electrical power and deliver it for the time necessary to the utility to which it is connected", the PV module maximum power P_{\max} is a first measure to compare the performance of different PV modules and is normally defined at STC.

The comparison of PV modules according to the measurement of their energy conversion efficiency (η) at STC (defined as the ratio between the maximum power at STC in watts (W) and the product of the total reference irradiance of 1000 W/m^2 with the module area in m^2) is useful to compare different PV modules or technologies. Efficiency on its own does not however evaluate directly the capability of electrical power delivery of single modules. The power measurement has to be performed at STC following the requirements set by the standard EN 60904-1 (for single-junction (SJ) PV modules). The present edition of this standard does not define the efficiency, though. The next edition currently under preparation at the IEC TC82 WG2 would likely define it. Therefore, it would be possible to refer directly to it for the definition of module conversion efficiency.

A combined parameter integrating several of the above could be defined as:

"A PV module functional unit is 1 kWh of DC power output under predefined climatic and installation conditions for 1 year and assuming an intended service life of 25 years"

The module energy yield proposed in this report, instead, is based on the measurement of the electrical power delivered by a PV module under several conditions of irradiance and temperature, which better represent the real conditions met in the field. Such a set of power measurements at varying irradiance and temperature defines the power matrix (or performance surface) of the PV module and is subject of the standard EN 61853-1. The power matrix is then used as input to the MPR calculation according to the draft standard IEC 61853-3 together with other parameters defined and required by the standard EN 61853-2. The MPR calculation is performed also considering the climatic conditions that represent the typical location at which the PV module will be installed. A set of six Reference Climatic conditions are defined in the draft standard IEC 61853-4, which covers the most common climatic conditions observed in the world. As far as the European continent is concerned, it is possible to cover the variety of the European climatic regions with three of these six data sets (or define three data sets specifically for Europe), which can be described as subtropical, temperate continental and temperate coastal.

Three possible solutions are proposed to be considered to define the necessary European climatic data sets:

1. To use those data sets already included in the draft IEC 61853-4 and representative of the three main European climates;
2. To define climatic data sets specifically for the European continent only in addition to those included in the IEC 61853-4 and either include them explicitly in the future policies or refer to a centralised server to host them as downloadable data;
3. To make site-specific climatic data available through a geographical information system (GIS), from which everyone could download them (this may be more appropriate for systems).

In the case of legislation for individual PV module, the most appropriate choice would be to take the one climatic data set of the IEC 61853-4 based in Europe and define two additional European data sets for use in the European legislation (option 2 of the above list). The second and fastest option would be to take the three climatic data sets appropriate for Europe from IEC 61853-4 and use them directly, with proper identification of the correlation between them and the European regions (option 1 of the above list). We do not consider that site-specific calculations are required for modules.

We note that the Energy Performance of Buildings Directive refers to EN 15316-4-3 for location-specific climatic conditions, and these in turn place a requirement on Member States to make such climate data sets available. However, for the Module Energy Yield calculation as developed in the IEC 61853 series, these national data sets are not sufficiently detailed for full application of the procedure. Similarly, the EN 50583-2 and the EN ISO 52000 series also describe three climatic conditions but are missing key data (such as the ratio of direct and diffuse broadband irradiance and the spectral irradiance) in order to perform correctly the methods in the IEC 61853 series.

3.2.1.2 Supporting Standards

The power measurement, performed according to EN 60904-1, usually requires support of other standards from the series EN 60904 and of the EN 60891 for appropriate corrections, as the actual test conditions rarely match STC definition.

PV technologies including c-Si modules need to be pre-conditioned or brought to a stable state before an STC measurement can be performed. Therefore, the series of standards EN 61215 is of support to both the power measurement and the module performance ratio. Within this series of standards, the general Parts 1 and 2 give requirements and

procedures to check the compliance of all PV modules to the specified criteria. The individual sub-parts of Part 1 set instead the requirements specific to each of the PV technologies that have a significant presence on the market (see Table 2).

3.2.1.3 Complementary Standards

Several other standards are simply complementary to the ones mentioned in subsections 3.2.1.1 and 3.2.1.2 and give specific requirements and criteria to assess secondary aspects of PV modules. They are mainly used and useful in the production of PV modules more than in their assessment according to an energy rating purpose. They are reported here (Table 3) for sake of completeness of the available normative tools and include the safety standards EN 62790 and EN 61730.

Table 1. Standards required for functional parameters of PV modules.

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	Notes
Module Energy Yield DC	EN 61853-1	Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating	Variability of maximum power with total irradiance and module temperature
	EN 61853-2	Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements	Environmental (Spectral, Temperature and Wind) effects on module's maximum power under real conditions
	IEC 61853-3 (in preparation)	Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules	Energy rating of PV modules
	IEC 61853-4 (only in part and in preparation)	Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles	Climate data sets for Europe can be selected from the available six datasets that cover the entire world
Module Energy Yield AC	-	-	A way of converting the DC energy yield to an equivalent AC Yield

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	Notes
Module Performance Ratio (MPR)	EN 61853-1	Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating	Variability of maximum power with total irradiance and module temperature
	EN 61853-2	Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements	Environmental (Spectral, Temperature and Wind) effects on module's maximum power under real conditions
	IEC 61853-3 (in preparation)	Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules	Energy rating of PV modules
	IEC 61853-4 (only in part and in preparation)	Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles	Climate data sets for Europe can be selected from the available six datasets that cover the entire world
Maximum Power at STC	EN 60904-1	Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics	
Module Energy Conversion Efficiency	IEC 60904-1 (edition under revision)	Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics	It will be included in the IEC 60904 1 currently under revision
Module Degradation Rates	-	-	This is expanded under section 4.1.1

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	Notes
Module Operational Life	-	-	This is expanded under section 4.1.2

Table 2. Supporting standards of PV modules.

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	PV technology
Short-circuit current	EN 60904-1	Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics	All SJ
Open-circuit voltage	EN 60904-1	Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics	All SJ
Standard Test Conditions	CLC/TS 61836	Solar photovoltaic energy systems - Terms, definitions and symbols	All SJ
Spectral responsivity	EN 60904-8	Photovoltaic devices - Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device	All SJ
Spectral mismatch factor	EN 60904-7	Photovoltaic devices - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices	All SJ
Reference spectral irradiance	EN 60904-3	Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	All SJ
Linearity	EN 60904-10	Photovoltaic devices - Part 10: Methods of linearity measurement	All SJ
Module temperature	EN 60904-5; EN 61853-2	Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements	All SJ
Absolute Short-circuit current temperature coefficient	EN 60891	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	All SJ

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	PV technology
Relative Short-circuit current temperature coefficient	EN 60891	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	All SJ
Absolute Open-circuit voltage temperature coefficient	EN 60891	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	All SJ
Relative Open-circuit voltage temperature coefficient	EN 60891	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	All SJ
Absolute maximum power temperature coefficient	EN 60891	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	All SJ
Relative maximum power temperature coefficient	EN 60891	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	All SJ
Electrical parameters of bifacial modules	IEC TS 60904-1-2	Photovoltaic devices - Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices	c-Si
Light-induced degradation (LID)	IEC 60904-11 (draft)	Photovoltaic devices - Part 11: Measurement of light-induced degradation of crystalline silicon solar cells	All SJ
-	IEC TS 60904-12 (draft)	Photovoltaic devices - Part 12: Infrared thermography of photovoltaic modules	All SJ
-	IEC TS 60904-13 (draft)	Photovoltaic devices - Part 13: Electroluminescence of photovoltaic modules	All SJ

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	PV technology
Pre-conditioning of the PV module before measurement	EN 61215-1	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements	c-Si
	EN 61215-1-1	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules	
	EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	
Pre-conditioning of the PV module before measurement	EN 61215-1	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements	CdTe
	EN 61215-1-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules	
	EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	
Pre-conditioning of the PV module before measurement	EN 61215-1	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements	a-Si
	EN 61215-1-3	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules	
	EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	PV technology
Pre-conditioning of the PV module before measurement	EN 61215-1	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements	CIGS
	EN 61215-1-4	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se) ₂ based photovoltaic (PV) modules	
	EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	
PV module marking	EN 50380	Marking and documentation requirements for Photovoltaic Modules	All SJ

Table 3. Complementary standards of PV modules.

Relevant Norm/Standard/Regulation	Specific Test Method	Notes
EN 50461	Solar cells - Datasheet information and product data for crystalline silicon solar cells	
EN 50513	Solar wafers - Data sheet and product information for crystalline silicon wafers for solar cell manufacturing	
EN 62790	Junction boxes for photovoltaic modules - Safety requirements and tests	
EN 62979	Photovoltaic module - Bypass diode - Thermal runaway test	
EN 50583-1	Photovoltaics in buildings - Part 1: BIPV modules	
IEC 63092-1 (draft)	Photovoltaics in buildings - Part 1: BIPV modules	Based on EN 50583-1 and further developed
EN 61701	Salt mist corrosion testing of photovoltaic (PV) modules	Based on IEC 60068-2-52
EN TS 62804-1	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon	
EN IEC 61730-1	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction	M/511 on Directive 2014/35/EU
EN IEC 61730-2	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing	M/511 on Directive 2014/35/EU
EN 62716	Photovoltaic (PV) modules - Ammonia corrosion testing	
prEN 62788-1-7	Measurement procedures for materials used in photovoltaic modules - Part 1-7: Test procedure for the optical durability of transparent polymeric PV packaging materials	
prEN 62788-5-1	Measurement procedures for materials used in photovoltaic modules - Part 5-1: Edge seals - Suggested test methods for use with edge seal materials	

Relevant Norm/Standard/Regulation	Specific Test Method	Notes
prEN 62788-5-2	Measurement procedures for materials used in photovoltaic modules - Part 5-2: Edge seals - Edge-seal durability evaluation guideline	
EN 62788-1-2	Measurement procedures for materials used in photovoltaic modules - Part 1-2: Encapsulants - Measurement of volume resistivity of photovoltaic encapsulants and other polymeric materials	
EN 62788-1-4	Measurement procedures for materials used in photovoltaic modules - Part 1-4: Encapsulants - Measurement of optical transmittance and calculation of the solar-weighted photon transmittance, yellowness index, and UV cut-off wavelength	
EN 62788-1-5	Measurement procedures for materials used in photovoltaic modules - Part 1-5: Encapsulants - Measurement of change in linear dimensions of sheet encapsulation material resulting from applied thermal conditions	
EN 62788-1-6	Measurement procedures for materials used in photovoltaic modules - Part 1-6: Encapsulants - Test methods for determining the degree of cure in Ethylene-Vinyl Acetate	
EN 62805-1	Method for measuring photovoltaic (PV) glass - Part 1: Measurement of total haze and spectral distribution of haze	
EN 62805-2	Method for measuring photovoltaic (PV) glass - Part 2: Measurement of transmittance and reflectance	
prEN 62892	Test procedure for extended thermal cycling of PV modules	
IEC TS 63140 (draft)	Photovoltaic (PV) modules – Partial shade endurance testing for monolithically integrated products	
IEC TS 62994	Environmental health and safety (EH&S) risk assessment of the PV module through the life cycle - General principles and definitions of terms	

3.2.2 Power Conditioning Components

The product category of power conditioning equipment (PCE) comprises the electrical and electronic equipment used to convert the electrical power from a PV modules array into a form suitable for subsequent use by a downstream consumer and with the required quality in order to be delivered to the connected electrical appliances. It therefore includes equipment to transform from DC to AC, like inverters, but also other instruments to modify the voltage or frequency like transformers or converters. Other electrical equipment such as batteries, battery-charge regulators and blocking diodes are also considered in this category.

As in the PV modules section, we have grouped the available or needed standards into separate tables, depending on whether they constitute the basis for the functional parameter definition and measurement (Table 4) or they support and complement it (see Table 5).

3.2.2.1 Functional Parameters

The presence of different electrical equipment with different specific functions inside this product category makes it difficult to select a unique functional performance parameter that covers all PCEs and constitutes a unique reference parameter for this category. If we focus on inverters for being the most important PCE for most solar PV installations, there are several parameters that could be considered as the main functional unit.

In accordance with the standard IEC 62894 "Photovoltaic Inverters - Data Sheet and Name Plate" or the withdrawn equivalent EN 50524 "Data sheet and name plate for photovoltaic inverters" there are different variables that could be considered as primary functional parameter like the maximum or minimum input voltage, maximum or minimum grid voltage, the start-up voltage at which the inverters starts energising the utility grid or load, the maximum power point voltage, the frequency or the rated input power or rated grid power.

In addition to these parameters, for commercial purposes, PV manufacturers tend to classify different inverters by the recommended PV array power range (i.e. input power to the inverter), by the maximum efficiency or by the "European efficiency". Inverters and power converters in general do not constantly operate at their maximum efficiency possible, but rather at an efficiency that depends on the input power level. The "European Efficiency" is a parameter that corresponds to an operating efficiency averaged over a year of operation in a middle-European climate. This parameter, defined in Annex D of the standard EN 50530 (see * in Table 4), is at present referenced by most manufacturers. This weighted efficiency is calculated by assigning a percentage of time over the year during which the inverter operates at a given operating range. The "European Efficiency" is calculated according to Equation 1, based on standard EN 50530, whose focus is on grid-connected inverters whose working patterns may differ from that of inverters used in stand-alone PV installations.

$$\text{European Efficiency} = 0.03*\text{Eff}5\% + 0.06*\text{Eff}10\% + 0.13*\text{Eff}20\% + 0.1*\text{Eff}30\% + 0.48*\text{Eff}50\% + 0.2*\text{Eff}100\% \quad (\text{Eq. 1})$$

The California Energy Commission (CEC) proposed other weighting factors, as shown in Equation 2 (included in the above mentioned EN 50530, too). The CEC efficiency considers, for example, less likely that the real working conditions of the inverter would make it work at its maximum efficiency contrary to the European Efficiency definition.

$$\text{CEC Efficiency} = 0.04*\text{Eff}10\% + 0.05*\text{Eff}20\% + 0.12*\text{Eff}30\% + 0.21*\text{Eff}50\% + 0.53*\text{Eff}75\% + 0.05*\text{Eff}100\% \quad (\text{Eq. 2})$$

The efficiency could be an adequate primary functional parameter as it can be applied to all PCEs. Beside the EN 50530 for grid-connected inverters, the standard IEC 61683 "Photovoltaic systems – Power conditioners – Procedure for measuring efficiency" describes the guidelines for measuring the efficiency of power conditioners used both in stand-alone and utility-interactive PV systems where the output is a stable AC voltage of constant frequency or a stable DC voltage. Focusing on grid-connected inverters, the standard EN 50530 would apply providing the procedure for the measurement of the accuracy of the maximum power point tracking (MPPT). Both the static and the dynamic MPPT efficiency are considered in order to calculate the overall inverter efficiency, in addition to defining both the European and CEC efficiencies.

If considered as primary functional unit, the "European efficiency" could be calculated from these efficiency values obtained according to these standards.

An alternative performance-related functional parameter for inverters would be AC energy from a reference PV system consisting of the inverter model under consideration i.e. an integration of the AC energy output in relation to the DC power from the reference modules for fixed climatic conditions for 1 year.

A further elaboration of this approach is to include an assumed service life of 10 to 15 years depending on the size of the inverter (residential PV system or big PV plant). Such a parameter derives from IEA report reference and EN 61724. However, in order to estimate such parameter several assumptions should be adopted so as to model both PV array power output and inverter performance including the effects of degradation.

Besides these parameters, there are others not directly related to the electrical characteristics of the PCEs that could be used as secondary functional parameters to further segment and classify inverters and other PCEs. For example, parameters related to physical characteristics, such as number of DC connectors or cooling principle used, or aspects related to safety or grid integration, such as stand-by consumption, time to start-up, harmonic distortion or different protection techniques like islanding prevention.

Aspects like degradation, lifetime, quality and recyclability of PCEs are presented in sections 4.1.1.2, 4.1.3, 4.2.2 and 4.4, respectively.

A combined parameter integrating several of the above could be defined as:

"PV Inverter functional unit is 1 kWh of AC power output from a reference photovoltaic system (excluding the efficiency of the inverter) under predefined climatic and installation conditions for 1 year and assuming a service life of 10 years"

However, in the case of PCEs we would suggest that this requires the inclusion of the European Inverter Efficiencies to be complete. Also, this requires further harmonisation.

Table 4. Standards available for defining functional parameters for PCEs.

Parameter	Standard	Title	Notes	Description
Input range voltage Grid range voltage Start-up voltage MPP voltage	IEC 62894 EN 50524 (current status withdrawn)	Photovoltaic Inverters - Data Sheet and Name Plate Data Sheet and Name Plate for Photovoltaic Inverters	Data sheet and nameplate for inverters	It describes data sheet and nameplate information for photovoltaic inverters in grid parallel operation. It aims at providing the minimum information required to configure a safe and optimal system with photovoltaic inverters. Data sheet information is a technical description which is a sign of durable construction at or in the photovoltaic inverter
AC output kWh				Proposed from preparatory study for Ecodesign "The functional unit shall be 1 kWh of AC power output from a reference photovoltaic system (excluding the efficiency of the inverter) under predefined climatic and installation conditions for 1 year and assuming a service life of 10 years."
Inverter Efficiency	IEC 61683	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency	PCEs	Describes guidelines for measuring the efficiency of power conditioners used in stand-alone and utility-interactive photovoltaic systems, where the output of the power conditioner is a stable AC voltage of constant frequency or a stable DC voltage
Inverter Efficiency European Inverter Efficiency (*)	EN 50530 (current status withdrawn)	Overall efficiency of grid connected photovoltaic inverters	Inverters	It provides a procedure for the measurement of the accuracy of the maximum power point tracking (MPPT) of inverters, which are used in grid-connected photovoltaic systems. Both the static and dynamic MPPT efficiency are considered. Based on the static MPPT efficiency and conversion efficiency the overall inverter efficiency is calculated. The dynamic MPPT efficiency is indicated separately

3.2.2.2 Supporting Standards

In order to apply some of the previously mentioned standards, others need to be considered as supporting standards (see Table 5). Among them, for example, the standard EN 50160 which describes the main characteristics of line voltages at the supply terminals of a network used in public low, medium and high voltage AC electricity networks.

3.2.2.3 Complementary Standards

There are several complementary standards applicable to PCEs regarding aspects of safety as well as grid-connection requirements from different regulatory levels such as EN, IEC but also country specific regulation that PCEs should comply with in order to operate in certain national networks. As an example, we can cite the RD1699/2011 which regulates the connection of generating plants at low voltage to the Spanish distribution network. Similar regulations exist in other countries with which PCEs installed there should comply.

The IEC TS 62910 provides a test procedure for evaluating the performance of Low Voltage Ride-Through (LVRT) functions in inverters used in utility-interconnected PV systems. It is applicable to large systems where PV inverters are connected to utility high-voltage (HV) distribution systems, although it may also be used for low voltage (LV) installations. The measurement procedures are designed to be as non-site-specific as possible, so that LVRT characteristics measured at one test site can also be considered valid at other sites. This technical specification is for testing PV inverters, although it may also be useful for testing a complete PV power plant consisting of multiple inverters connected at a single point to the utility grid. It further provides a basis for utility-interconnected PV inverter numerical simulation and model validation.

Regarding safety requirements, the standard EN 62477-1 applies to all PCEs and can be used as reference for adjustable speed electric power drive systems (PDS), stand-alone uninterruptible power systems (UPS) or LV stabilized DC power supplies. It provides minimum requirements for their control, protection, monitoring and measurement. It also establishes minimum requirements for the coordination of safety aspects and specifies requirements to reduce risks of fire, electric shock, thermal, energy and mechanical hazards, during use and operation. Also, the standard series EN 62109 with its different parts defines the minimum safety requirements for PCEs used in PV systems.

EN 62909 specifies general aspects of bi-directional grid-connected power converters linking inverters with DC power converters.

Other standards related to safety or grid-connection requirements can be found in Table 5. Most of these standards have been adopted at EN and IEC level simultaneously, while some cases only exist at IEC level.

We have included in Table 5 also some standards under preparation that relate to topics of safety, and PCEs requirements.

Not directly related to their technical performance but possibly applicable for the durability, degradation and lifetime analysis, the standard series IEC 60068 with its several parts constitutes a set of documents containing information on environmental testing procedures for electrical, electro-mechanical and electronic equipment and devices. Some of these testing may be applicable to PCEs for testing degradation due to corrosion or failure due shock, vibration or deposition of dust and sand. Aspects like degradation, lifetime, quality and recyclability of PCEs are presented in sections 4.1.1.2, 4.1.1.3, 4.2.2 and 4.4, respectively.

Table 5. Supporting and complementary standards for PCEs.

Parameter	Standard	Title	Description
Safety	EN 62477-1	Safety requirements for power electronic converter systems and equipment - Part 1: General	This standard applies to Power Electronic Converter Systems (PECS) and equipment, their components for electronic power conversion and electronic power switching, including the means for their control, protection, monitoring and measurement, such as with the main purpose of converting electric power, with rated system voltages not exceeding 1 000 V AC or 1 500 V DC
Safety	EN 62109-1	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements	This standard applies to the power conversion equipment (PCE) for use in photovoltaic systems. This part defines the minimum requirements for the design and manufacture of PCE for protection against: Electric shock, Energy, Fire, Mechanical and Other hazards
Safety	EN 62109-2	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters	This Part 2 of EN 62109 covers the particular safety requirements relevant to DC to AC inverter products as well as products that have or perform inverter functions in addition to other functions, intended for use in photovoltaic power systems. Inverters may be grid-interactive, stand-alone, or multiple mode inverters. Different systems configurations are considered in this standard
Safety	prEN 62109-3	Safety of power converters for use in photovoltaic power systems - Part 3: Particular requirements for electronic devices in combination with photovoltaic elements	

Parameter	Standard	Title	Description
Safety	IEC 62109-4	Safety of power converters for use in photovoltaic power systems - Part 4: Particular requirements for combiner box	
Safety	prEN 50330-1	Photovoltaic semiconductor converters - Part 1: Utility interactive fail safe protective interface for PV-line commutated converters - Design qualification and type approval	
Islanding prevention	EN 62116	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures	It provides a test procedure to evaluate the performance of islanding prevention measures used with utility-interconnected PV systems. This standard describes a guideline for testing the performance of automatic islanding prevention measures installed in or with single or multi-phase utility interactive PV inverters connected to the utility grid

Parameter	Standard	Title	Description
Performance under low voltage conditions	IEC TS 62910	Utility-interconnected photovoltaic inverters - Test procedure for low voltage ride-through measurements	It provides a test procedure for evaluating the performance of Low Voltage Ride-Through (LVRT) functions in inverters used in utility-interconnected PV systems. It is most applicable to large systems where PV inverters are connected to utility HV distribution systems. However, it may also be used for LV installations. The measurement procedures are designed to be as non-site-specific as possible, so that LVRT characteristics measured at one test site, for example, can also be considered valid at other sites. This technical specification is for testing of PV inverters, though it contains information that may also be useful for testing of a complete PV power plant consisting of multiple inverters connected at a single point to the utility grid. It further provides a basis for utility-interconnected PV inverter numerical simulation and model validation
Environmental testing	EN IEC 60068-2-52 and several other parts of the EN IEC 60068 Environmental testing	Environmental testing - Part 2: Tests - Test Kb: Salt mist, cyclic (sodium, chloride solution).	It specifies the application of the cyclic salt mist test to components or equipment designed to withstand a salt-laden atmosphere as salt can degrade the performance of parts manufactured using metallic and/or non-metallic materials
Power conversion equipment testing	EN 62093	Power conversion equipment for photovoltaic systems - Design qualification testing	

Parameter	Standard	Title	Description
Bi-directional power converters	EN 62909-1	Bi-directional grid-connected power converters – Part 1: General requirements	This standard specifies general aspects of bi-directional grid-connected power converters (GCPC), consisting of a grid-side inverter with two or more types of DC-port interfaces on the application side with system voltages not exceeding 1 000 V AC or 1 500 V DC. This document includes terminology, specifications, performance, safety, system architecture, and test-case definitions. The "system architecture" defines interaction between the inverter and converters
Bi-directional power converters	prEN 62909-2	Bi-directional grid connected power converters - Part 2: Interface of GCPC and distributed energy resources and additional requirements to Part 1	
Electromagnetic compatibility	EN 62920	Photovoltaic power generating systems - EMC requirements and test methods for power conversion equipment	It specifies electromagnetic compatibility (EMC) requirements for DC to AC power conversion equipment (PCE) for use in photovoltaic (PV) power systems. The PCE covered can be grid-interactive or stand-alone. It can be supplied by single or multiple photovoltaic modules grouped in various array configurations, and can be intended for use in conjunction with batteries or other forms of energy storage.
Electromagnetic compatibility	EN 61000	Electromagnetic compatibility (EMC)	Multiple parts and subparts applicable to PCEs
Inverter	IEC 62891 ED1	Overall efficiency of grid connected photovoltaic inverters	In progress

Parameter	Standard	Title	Description
Power conversion equipment	IEC TS 63106-1	Basic requirements for simulator used for testing of photovoltaic power conversion equipment - Part 1: AC power simulator	In progress
Power conversion equipment	IEC TS 63106-2	Part 2 DC power simulator	In progress
Power conversion equipment	IEC TS 63156	Power conditioners - Energy evaluation method	In progress. This TS defines a procedure for evaluating energy conversion efficiency, including dynamic energy conversion efficiency, to anticipate the actual quantity of energy produced by PV systems.
Power conversion equipment	IEC TS 63157	Guidelines for effective quality assurance of power conversion equipment for photovoltaic systems	In progress

3.2.2.4 Batteries

The batteries used in PV systems, whether grid-connected or stand-alone, are mainly of two types: lead-acid and lithium-ion. They can be both described by a series of parameters like the capacity or the nominal voltage. The capacity can be defined in two ways: (i) the current capacity in ampere-hour (Ah) that can be drawn from the battery fully charged; (ii) the power capacity in watt-hour (Wh), which would be calculated as the product of the current capacity and the nominal voltage.

The capacity mainly depends on the charging/discharging current rate applied, the battery temperature and the ageing rate of the battery. This in turn depends on the operating conditions. Manufacturers normally provide a static longevity value for a reference temperature of 20 °C, even though normal working temperature can be significantly higher reducing considerably the expected lifetime of the batteries. The batteries can also deteriorate due to use, depending on the number of cycles and the depth of discharge reached at every cycle. Manufacturers normally provide an estimated number of cycles as a function of depth of discharge. These two parameters, number of cycles and depth of discharge, could be considered as primary as well as secondary functional parameters for batteries.

However, the capacity in Ah or Wh is more suitable as primary functional parameter. It is often referenced as C10 or C100 Ah, as the capacity when discharging the battery in 10 or 100 hours respectively. Batteries for PV solar systems are often described by the C100 factor due to their normal operating conditions of storage capacity for 2 to 4 days.

Table 6 summarises the standards related to energy storage systems and batteries.

Table 6. Supporting and complementary standards for batteries.

Parameter	Standard	Title	Description
Batteries. Energy storage systems ESS	EN 62619	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications	It specifies requirements and tests for the safe operation of secondary lithium cells and batteries used in industrial applications including stationary applications
Batteries. Energy storage systems ESS	EN 62620	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications	It specifies marking, tests and requirements for lithium secondary cells and batteries used in industrial applications including stationary applications. This standard applies to cells and batteries
Batteries	EN 61427-1	Secondary cells and batteries for renewable energy storage – General requirements and methods of test. Part 1 photovoltaic off-grid applications	It gives general information relating to the requirements for the secondary batteries used in photovoltaic energy systems (PVES) and to the typical methods of test used for the verification of battery performances. This part deals with cells and batteries used in photovoltaic off-grid applications. This standard is applicable to all types of secondary batteries
Batteries	EN 61427-2	Secondary cells and batteries for renewable energy storage – General requirements and methods of test. Part 2 on-grid applications	It relates to secondary batteries used in on-grid Electrical Energy Storage (EES) applications and provides the associated methods of test for the verification of their endurance, properties and electrical performance in such applications. Amounts of electrical energy from renewable energy sources are fed into it

Parameter	Standard	Title	Description
Batteries	EN 60896	Stationary lead-acid batteries - Several parts	
Batteries	EN 62259	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Nickel-cadmium prismatic secondary single cells with partial gas recombination.	This International Standard specifies marking, designation, dimensions, tests and requirements for vented nickel-cadmium prismatic secondary single cells where special provisions have been made in order to have partial or, under very specific conditions, full gas recombination
Electrical energy storage systems	FprEN 62933-1	Electrical Energy Storage (EES) systems - Part 1: Vocabulary	
Electrical energy storage systems	EN IEC 62933-2-1	Electrical energy storage systems Part 2-1: Unit parameters and testing methods - General specification	IEC 62933-2-1 focuses on unit parameters and testing methods of EES systems. The energy storage devices and technologies are outside the scope of this document. This document deals with EES system performance defining: unit parameters, testing methods
Batteries	IEC TS 62933-4-1	Electrical energy storage systems Part 4-1: Guidance on environmental issues - General specification	EC TS 62933-4-1 describes environmental issues associated with electrical energy storage systems (EES systems), and presents guidelines to address the environmental impacts to and from EES systems including the impacts to humans due to chronic exposure associated with the mentioned environmental impacts
Batteries	IEC TS 62933-5-1	Electrical energy storage systems Part 5-1: Safety considerations for grid-integrated EES systems - General specification	IEC TS 62933-5-1 specifies safety considerations (e.g. hazards identification, risk assessment, risk mitigation) applicable to EES systems integrated with the electrical grid. This document provides criteria to foster the safe application and use of electric energy storage systems of any type or size intended for grid-integrated applications

Parameter	Standard	Title	Description
Batteries	prEN 62902	Secondary batteries: Marking symbols for identification of their chemistry	
Batteries	prEN 62932-1	Flow battery systems for stationary applications Part 1 Terminology	
Batteries	prEN 62932-2-1	Flow battery systems for stationary applications Part 2-2 performance general requirements and test methods	
Batteries	prEN 62932-2-2	Flow battery systems for stationary applications Part 2-2 safety requirements	

3.2.3 PV Systems

PV systems vary widely in terms of possible configurations and functions. EN 61277 “Terrestrial photovoltaic (PV) power generating systems — General and guide” provides a description of the possible components. The main one is obviously the PV module, which is the subject of section 3.2.1. The other components are known collectively as Balance of System (BOS) and include switches, wiring, controls, meters, PCE, utility-grid interface, module/array supporting structures, tracking systems (if present) and electricity storage components. The PCEs including storage are addressed in section 3.2.2.

The energy flow between the major possible elements is shown schematically in Figure 3. In this report the focus is on a simplified configuration consisting of a PV module array and a power-conversion element that supply AC energy to a downstream user. This corresponds effectively to the right hand side block in Figure 3.

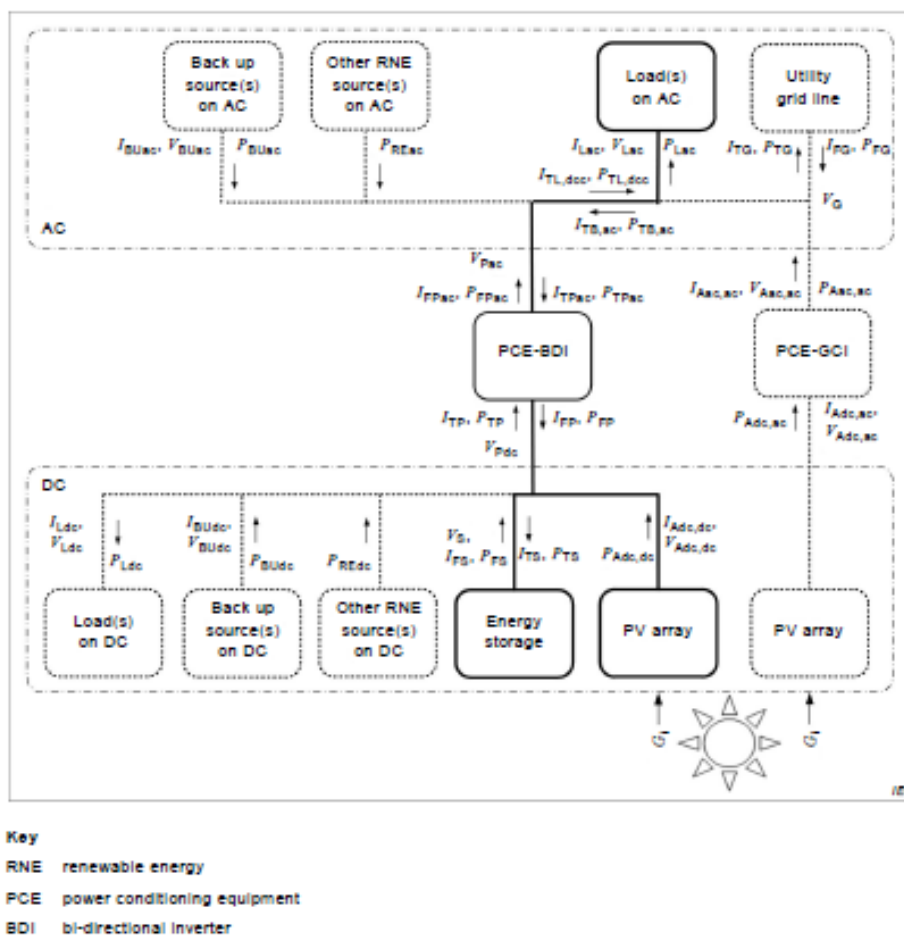


Figure 3 Energy flows between PV system elements (from IEC 61724-1)

3.2.3.1 Functional Parameters

Given that the purpose of a PV system is to provide electrical energy with an adequate quality to a downstream user by converting the received solar radiation into electricity, the following functional parameters can be considered to describe the PV system electrical performance:

1. System Power Output;

2. System Energy Output/Yield;
3. System Performance Ratio, i.e. the ratio of the system energy yield to a reference energy yield, and taking account of losses due to PV array operating temperature and system inefficiencies;
4. System Energy Efficiency.

The following describes the normative approaches available to calculate the above parameters.

System Power output: EN 61724-1 defines the system nominal or rated DC power (labelled W_p) as the arithmetic sum of the power values at STC of the installed PV modules (see section 3.2.1). The AC rated power on the other hand is determined in EN 61724-1 as the lesser of the sum of the array DC power and the sum of the inverter maximum power ratings.

System Energy output/yield: They relate to AC power output, E_o , typically for a one-year reference period³, and energy yield, which is the energy output normalised by the rated DC power as defined above.

There is currently no dedicated standard for calculating the expected⁴ energy output for PV systems. The IEC TS 61724-3 (see Table 8) provides a framework for a generic model that would combine a set of fixed parameters describing a PV system with environmental parameters, but it also explicitly notes that the definition of the model itself is outside its scope. Nonetheless, some concepts and parameters can be useful in the present context.

Several PV system energy models are available as online tools, and these generally combine the following elements:

- DC power delivered by the PV module array(s), as a function of its design and environmental parameters (irradiance, ambient temperature, wind speed). Here, the procedure for determining PV module energy yield as per IEC 61853-3 can provide a basis (see section 3.2.1.1);
- Inverter efficiency, also a function of the power factor if data are available (see section 3.2.2.1).
- Factor(s) to account for other losses (wiring, connections).

The environmental data can be a Standard Reference Climatic profile (as discussed in section 3.2.1.1) or a location specific dataset, such as the Typical Meteorological Year (TMY) data foreseen under the Energy Performance of Buildings Directive, and compliant with the INSPIRE Directive. In the latter case, the resulting energy output value will be specific to a given system configuration and the assumed location/environment.

The EN 15316-4-3 standard "Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies" provides a simple methodology to estimate the energy yield of building integrated system, but it is in principle applicable to any kind of PV system. Its section 6.2 describes a method for calculating the annual electrical energy output of PV system, $E_{el;pv;out}$.

$$E_{el;pv;out} = E_{sol} \cdot P_{pk} \cdot f_{perf} / I_{ref}$$

where E_{sol} is the annual hemispherical solar irradiation on the PV system, determined by the horizontal irradiation multiplied by a factor f_{tilt} to take account of the angle and orientation of the system; P_{pk} is the peak power (in kW), f_{perf} is the system performance factor and I_{ref} is the reference solar irradiance equal to 1000 W/m². The method can also be used with hourly or monthly time steps to arrive at a value for annual energy output.

³ It is also possible to consider the energy output over the service life, including any progressive degradation of the performance of the components (see section 3.2.5).

⁴ In IEC terminology "expected" indicates an ex-ante design calculation using an appropriate system model and historical or reference environment input, "predicted" refers to the theoretical output for given environmental conditions, and "actual" refers to measured values.

The standard notes that those tables for f_{tilt} and f_{perf} shall be made available at national level, but it is not clear to what extent this has been implemented up to now.

System performance ratio: EN 61724-1 applies the definition

$$PR = \frac{Y_f}{Y_{ref}}$$

where

- Y_f is final energy yield, defined as net energy output E_o normalised by the DC rated power, P_o .
- Y_{ref} is the reference energy yield, defined as the in-plane irradiation for the reference period normalised by the reference irradiance $G_{i,ref}$. The latter corresponds to the irradiance condition used to define the nominal DC power, P_o .

One feature of the performance ratio (PR) parameter is that it is sensitive to thermal losses in the PV array, which implies that in hotter climates it will be smaller as the modules operate at a higher temperature. To address this, the EN 61724-1 includes the possibility to calculate a temperature-corrected PR.

For a system in operation, the determination of the PR parameter is straightforward, as the energy output and the irradiation can be measured. The determination of an expected PR value, instead, requires that the system energy output is obtained from a detailed model as described above, which might not always be available. A way of circumventing this would be to rely on a limited number of on-site measurements made during the system commissioning.

System (AC) Efficiency: Another possible functional parameter for PV systems could be its general efficiency, obtained as the ratio of the produced electricity yield and the received solar irradiation. EN 61724-1 defines the system efficiency as:

$$\eta_f = \frac{E_{out}}{H_i \cdot A_a} = \eta_{A,0} \times PR$$

where E_{out} is the system energy output, H_i is the irradiation received, A_a is the total module area and $\eta_{A,0}$ is the rated array efficiency. However, as for the PR parameter, the calculation of an expected value is not straightforward as it implicitly requires a system energy output model. Again, a way of circumventing this would be to rely on a limited number of on-site measurements made during the system commissioning.

Alternatively, if the value of the PR can be assumed or if it has been measured (EN 61724-1), the above equation can be used to specify the AC power output, the energy output E_o and also the energy yield. For instance, the IEA Life Cycle Assessment guidelines [2] uses this approach, proposing either site-specific PR values or a default value of 0.75 for roof-top systems and 0.80 for ground-mounted utility installations.

The EN 61724-1 also defines a power performance index, which is the ratio of the actual power output to the expected power output. Likewise an energy performance index relates the actual or predicted energy to the expected energy.

However, the weakness of the EN 61724-1 is that it does not present a method of predicting the System Final Energy Yield, rather it is a post-installation verification. It is necessary to define a prediction method for the energy yield. This would logically be based on the approach for the Module Energy Yield DC (IEC 61853-3) with additional input of system considerations.

3.2.3.2 Supporting Standards

There exist several standards that could be applied for the PV systems analysis as a whole, like the standard EN 61724-1. Then, those related to single components behaviour could be used as well, like those mentioned in previous sections for PV modules and PCEs which were linked to their power performance and efficiency.

Therefore, we will include in this section only those related to the rest of BOS components.

Table 9 contains some standards focused on BOS like charge controllers, junction-boxes and connectors. This table contains as well some standards related to solar-tracking systems, as for example the EN 62817 that contains the design requirements for this component of PV systems.

Not for single modules but rather for the whole PV array, the standard EN 61829 presents a procedure for on-site measurement of flat-plate PV arrays. It addresses also field uncertainties because on-site measuring capabilities can differ substantially from what available at indoor laboratory measurements.

Some parts of the harmonised standard HD 60364 regarding low-voltage installations apply to PV systems, including those with storage elements (EN 60364-7-712), and to aspects like their energy efficiency.

Other standards for specific PV systems, like stand-alone (EN 61194) or for pumping systems (EN 61702), could be useful to define a methodology for the analysis of the performance of PV systems in general. Regarding grid-connected PV systems, standards like the draft prEN 61727 and the EN 62446-1 define the conditions and requirements that they must comply with when connected to the grid.

A combined parameter integrating several of the above could be defined as:

“PV System functional unit is 1 kWh of AC power output supplied under fixed climatic conditions for 1 year (with reference to IEC 61853-4) and assuming a service life of 25 years”

3.2.3.3 Complementary Standards

Table 9 contains also some standards related to monitoring of PV systems like EN 61850-7-420 and some standards related to installation, safety and protection requirements for low-voltage installations including PV.

Table 7. Standards required for functional parameters of PV systems.⁵

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	Notes
Maximum Power at STC	EN 60904-1 EN 61829	Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics Method for onsite array measurement	
System Energy Output	Not existing	-	To be developed based on EN 61853 parts 1 and 2 , and IEC 61853 parts 3 and 4 model for example Kings model or modified version in PVGIS Simplified model available in EN 15316-4-3 standard (energy performance of buildings) Can be estimated from the performance ratio, if known
System Energy Yield	Not existing		Generic definition in EN 61724-1, but the expected energy output is required To be developed based on EN 61853 parts 1 and 2 , and IEC 61853 parts 3 and 4 model for example Kings model or modified version in PVGIS
System Performance Ratio	EN 61724 -1	-	Generic definition in EN 61724-1, but the expected final Energy Yield is required

⁵ The parameters refer to expected values in IEC terminology, i.e. an ex-ante design calculation using an appropriate system model and historical or reference environment inspection.

Parameter	Relevant Norm/Standard/Regulation	Specific Test Method	Notes
Efficiency	Not existing	-	Generic definition in IEC 61724-1, but the expected energy output is required

Table 8. Supporting standards related to efficiency measurement of PV systems.

Parameter	Standard	Title	Notes	Description
Efficiency	EN 61724-1	Photovoltaic system performance - Part 1: Monitoring	System performance	It outlines equipment, methods, and terminology for performance monitoring and analysis of PV systems. It addresses sensors, installation, and accuracy for monitoring equipment in addition to measured parameter data acquisition and quality checks, calculated parameters, and performance metrics
Efficiency	IEC TS 61724-2	Photovoltaic system performance - Part 2: Capacity evaluation method	System performance	It defines a procedure for measuring and analyzing the power production of a specific PV system to evaluate the quality of the PV system performance. The test is intended to be applied during a relatively short time period (a few relatively sunny days). The intent of this document is to specify a framework procedure for comparing the measured power produced against the expected power from a PV system on relatively sunny days
Efficiency	IEC TS 61724-3	Photovoltaic system performance - Part 3: Energy evaluation method	System performance	It defines a procedure for measuring and analyzing the energy production of a specific photovoltaic system relative to expected electrical energy production for the same system from actual weather conditions as defined by the stakeholders of the test. The energy production is characterized specifically for times when the system is operating (available); times when the system is not operating (unavailable) are quantified as part of an availability metric. The aim of this technical specification is to define a procedure for comparing the measured electrical energy with the expected electrical energy of the PV system

Table 9. Supporting and complementary standards for PV systems.

Parameter	Standard	Title	Description
Solar photovoltaic systems. Definitions	CLC/TS 61836	Solar photovoltaic energy systems – Terms, definitions and symbols	It contains terms, definitions and symbols from national and international solar photovoltaic standards and relevant documents used within the field of solar photovoltaic (PV) energy systems. It includes the terms, definitions and symbols compiled from the published IEC technical committee 82 standards. The main technical change with regard to the previous edition consists of adding / revising terms and definitions which have been discussed and agreed on during recent meetings of the IEC TC 82 terminology working group
Components of PV systems	EN 61277	Terrestrial photovoltaic (PV) power generating systems – General and guide	Gives an overview of terrestrial PV power generating systems and the functional elements of such systems
PV arrays	fprEN 62548	Design requirements for Photovoltaic (PV) arrays	In progress
Systems for rural electrification	IEC TS 62257-7-1	Recommendations for renewable energy and hybrid systems for rural electrification - Part 7-1: Generators - Photovoltaic generators	IEC/TS 62257-7-1 specifies the general requirements for the design and the safety of generators used in decentralized rural electrification systems. Provides requirements for ELV and LV PV arrays. Particular attention must be paid to voltage level, as this is important for safety reasons and has an influence on protective measures and on the skill and ability level of operators. The main technical changes with regard to the previous edition are the following: <ul style="list-style-type: none"> - this new version is focused on small PV generators up to 100 kWp; - it provides case studies
I-V of PV arrays	EN 61829	Photovoltaic (PV) array – On-site measurement of I-V characteristics	It specifies procedures for on-site measurement of flat-plate photovoltaic (PV) array characteristics, the accompanying meteorological conditions, and use of these for translating to standard test conditions (STC) or other selected conditions

Parameter	Standard	Title	Description
Low voltage installations	HD 60364-1	Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions	This part gives the rules for the design, erection, and verification of electrical installations, so as to provide the safety of persons, livestock and property against dangers and damage which may arise in the reasonable use of different types of electrical installations including photovoltaic systems
Low voltage installations	HD 60364-7-712	Low-voltage electrical installations - Part 7-712: Requirements for special installations or locations - Photovoltaic (PV) systems	This section applies to the electrical installation of PV generator intended to supply all or part of an installation and feeding of electricity into the public grid or local distribution. The PV generator may be a PV module or a set of PV modules connected in series with their cables up to the user installation or the utility supply point. Requirements for PV generators with batteries or other energy storage methods are under consideration
Low voltage installations	IEC 60364-8-1	Low voltage electrical installations - Part 8-1: Energy efficiency	This part provides additional requirements, measures and recommendations for the design, erection and verification of all types of low-voltage electrical installation including local production and storage of energy for optimizing the overall efficient use of electricity. It introduces requirements and recommendations for the design of an electrical installation within the framework of an energy efficiency management approach in order to get the best permanent functionally equivalent service for the lowest electrical energy consumption and the most acceptable energy availability and economic balance
Stand alone	EN 61194	Characteristic parameters of stand-alone photovoltaic (PV) systems	Defines the major electrical, mechanical and environmental parameters for the description and performance analysis of stand-alone photovoltaic systems

Parameter	Standard	Title	Description
Stand alone	EN 62124	Photovoltaic (PV) stand-alone systems - Design verification	Verifies system design and performance of stand-alone photovoltaic systems. The performance test consists of a check of the functionality, the autonomy and ability to recover after periods of low state-of-charge of the battery, and hence gives reasonable assurance that the system will not fail prematurely. The testing conditions are intended to represent the majority of climatic zones for which these systems are designed
PV pumping systems	EN 61702	Rating of direct coupled photovoltaic (PV) pumping systems	Defines predicted short-term characteristics (instantaneous and for a typical daily period) of direct coupled photovoltaic (PV) water pumping systems
Pumping systems	EN 62253	Photovoltaic pumping systems - Design qualification and performance measurements	It defines the requirements for design, qualification and performance measurements of photovoltaic (PV) pumping systems in stand-alone operation. The outlined measurements are applicable for either indoor tests with PV generator simulator or outdoor tests using a real PV generator. This standard applies to systems with motor pump sets connected to the PV generator directly or via a converter (DC to DC or DC to AC)
Utility interface	prEN 61727	Photovoltaic (PV) systems – Characteristics of the utility interface	Applies to utility-interconnected photovoltaic (PV) power systems operating in parallel with the utility and utilizing static (solid-state) non-islanding inverters for the conversion of DC to AC. Lays down requirements for interconnection of PV systems to the utility distribution system
Grid-connected system	EN 62446-1	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection	EN 62446-1 defines the information and documentation required to be handed over to a customer following the installation of a grid connected PV system. It also describes the commissioning tests, inspection criteria and documentation expected to verify the safe installation and correct operation of the system. It is for use by system designers and installers of grid connected solar PV systems as a template to provide effective documentation to a customer

Parameter	Standard	Title	Description
Utility interface	prEN 61727	Photovoltaic (PV) systems – Characteristics of the utility interface	Applies to utility-interconnected photovoltaic (PV) power systems operating in parallel with the utility and utilizing static (solid-state) non-islanding inverters for the conversion of DC to AC. Lays down requirements for interconnection of PV systems to the utility distribution system
BOS. Charge controllers	EN 62509	Battery charge controllers for photovoltaic systems - Performance and functioning.	It establishes minimum requirements for the functioning and performance of battery charge controllers (BCC) used with lead acid batteries in terrestrial PV systems
BOS. Charge controllers	EN 62093	Balance-of-system components for photovoltaic systems - Design qualification natural environments.	Establishes requirements for the design qualification of balance-of-system (BOS) components used in terrestrial photovoltaic systems. Is suitable for operation in indoor, conditioned or unconditioned; or outdoor in general open-air climates, protected or unprotected. Is written for dedicated solar components such as batteries, inverters, charge controllers, system diode packages, heat sinks, surge protectors, system junction boxes, maximum power point tracking devices and switch gear, but may be applicable to other BOS components

Parameter	Standard	Title	Description
Solar tracker	EN 62817	Photovoltaic systems - Design qualification of solar trackers	It contains the design qualification standard applicable to solar trackers for photovoltaic systems, but may be used for trackers in other solar applications. The standard defines test procedures for both key components and for the complete tracker system. In some cases, test procedures describe methods to measure and/or calculate parameters to be reported in the defined tracker specification sheet. In other cases, the test procedure results in a pass/fail criterion. This standard ensures the user of the said tracker that parameters reported in the specification sheet were measured by consistent and accepted industry procedures. The tests with pass/fail criteria are engineered with the purpose of separating tracker designs that are likely to have early failures from those designs that are sound and suitable for use as specified by the manufacturer
Solar Trackers	IEC TS 62727	Photovoltaic systems - Specification for solar trackers	IEC/TS 62727 provides guidelines for the parameters to be specified for solar trackers for photovoltaic systems and provides recommendations for measurement techniques. The purpose of this test specification is to define the performance characteristics of trackers and describe the methods to calculate and/or measure critical parameters. This specification provides industry-wide definitions and parameters for solar trackers. Keywords: solar photovoltaic energy, solar trackers
Solar trackers	IEC 63104 ED1	Solar trackers - Safety requirements	In progress
Monitoring PV systems	EN 61850-7-420	Communication networks and systems for power utility automation - Part 7-420: Basic communication structure - Distributed energy resources logical nodes	It defines the information models to be used in the exchange of information with distributed energy resources (DER), which comprise dispersed generation devices and dispersed storage devices, including photovoltaics, combined heat and power, and energy storage

Parameter	Standard	Title	Description
Monitoring PV systems	EN 60870	Telecontrol equipment and systems	
Installation, safety requirements, protection	EN 60269-6	Low-voltage fuses - part 6: supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems	
Installation, safety requirements, protection	FprEN 61643-31	Low-voltage surge protective devices – part 31: surge protective devices connected to the DC side of photovoltaic installations – requirements and test methods	
Installation, safety requirements, protection	FprEN 61643-32	Low-voltage surge protective devices - Part 32: Surge protective devices for specific use including DC - Selection and application principles for SPDs connected to photovoltaic installations	
Safety connectors. UNDER REVISION	EN 62852 ED1	Connectors for DC-application in photovoltaic systems - Safety requirements and tests	It applies to connectors for use in the DC circuits of photovoltaic systems according to class II of IEC 61140 with rated voltages up to 1 500 V DC and rated currents up to 125 A per contact
Safety	prEN 63027	DC arc detection and interruption in photovoltaic power systems	

3.2.4 Building-Integrated PV Modules or Systems

The term building-integrated photovoltaics (BIPV) covers all photovoltaic modules and components that are used with the double function of producing PV energy (primary function) while also replacing conventional construction products maintaining the function of the latter, for example in parts of the building envelope such as the roof, skylights, or facades (secondary function).

At present, only the series EN 50583 published in 2016 addresses specifically the building-integration of PV modules (EN 50583-1) and systems (EN 50583-2). These two standards were passed to the IEC TC 82 via the Frankfurt agreement (see 3.1.1). An IEC project team is now further developing the EN concepts in two standards IEC 63092-1 (for BIPV modules) and IEC 63092-2 (for BIPV systems), currently scheduled to be published in 2019. Additionally, more generic standards belonging to the building sector and in particular to the energy efficiency of the buildings could be considered as starting point to further develop the topic. The overview of the available standards on the topic is given in Table 10.

For structural performance, which is covered by EN 50583-2 and specifically addressed by normative references included in it, compliance is required with Eurocodes under the Construction Product Regulation No. 305/2011. In regard to this, we highlight a possible inconsistency of the EN 50583-2 with the currently valid European legislation, as the European standard EN 50583-2 refers to the Directive 89/106/EEC, which was in fact repealed in 2011 and replaced by the (European Construction Product) Regulation (EU) No. 305/2011. The latter is also the legislative reference of the EN 50583-1, which however deals only with modules as construction products and not for their structural function.

As electrical products with limited voltage output, PV modules are subject to the Low-Voltage Directive 2006/95/EC, which was subsequently recast and repealed by the Directive 2014/35/EU on 20th April 2016, currently in force.

As noted in section 3.2.3.1, the Energy Performance of Buildings Directive (EPBD) 2010/31/EC includes standards for assessing the output of energy generating systems. Specifically the calculation of PV energy contribution to the building performance is covered by EN-15316-4-3 (see Table 10). It is noted that the application of the method requires location specific data, and that responsibility for reference climatic data is given to the Member States. Overall, while the EPBD requirements establish a framework, many details need to be clearly defined (e.g. system performance factors and degradation effects).

There are specific documents related to safety in building installations that are currently under development/revision, e.g. the prEN 50331-1 "Photovoltaic systems in buildings - Part 1: Safety requirements", or already available as technical reports, e.g. the CLC/TR 50670 "External fire exposure to roofs in combination with photovoltaic (PV) arrays - Test method(s)".

A combined parameter integrating several of the above could be defined as:

"PV System functional unit is 1 kWh of AC power output supplied under fixed climatic conditions for 1 year (with reference to IEC 61853-4) and assuming a service life of 25 years"

This requires though to reflect the higher ambient temperatures that are reached in BIPV installations.

Table 10. Standards addressing the topic of BIPV for modules and systems.

Standard/ Regulation	Title	Notes/Scope
EN 50583-1	Photovoltaics in buildings - Part 1: BIPV modules	This document applies to photovoltaic modules used as construction products. It focuses on the properties of these photovoltaic modules relevant to essential building requirements as specified in the European Construction Product Regulation CPR 305/2011, and the applicable electro-technical requirements as stated in the Low Voltage Directive 2006/95/EC / or CENELEC standards. This document references international standards, technical reports and guidelines. For some applications in addition national standards (or regulations) for building products may apply in individual countries, which are not explicitly referenced here and for which harmonized European Standards are not yet available
EN 50583-2	Photovoltaics in buildings - Part 2: BIPV systems	This document applies to photovoltaic systems that are integrated into buildings with the photovoltaic modules used as construction products. It focuses on the properties of these photovoltaic systems relevant to essential building requirements as specified in the European Construction Product Regulation CPR 89/106/EEC, and the applicable electro-technical requirements as stated in the Low Voltage Directive 2006/95/EC / or CENELEC standards
IEC 63092-1 (draft)	Photovoltaics in buildings - Part 1: BIPV modules	Based on EN 50583-1 and further developing
IEC 63092-2 (draft)	Photovoltaics in buildings - Part 2: BIPV systems	Based on EN 50583-1 and further developing
ISO 52000-1	Energy performance of buildings -- Overarching EPB assessment -- Part 1: General framework and procedures	ISO 52000-1:2017 establishes a systematic, comprehensive and modular structure for assessing the energy performance of new and existing buildings (EPB) in a holistic way. It is applicable to the assessment of overall energy use of a building, by measurement or calculation, and the calculation of energy performance in terms of primary energy or other energy-related metrics. It takes into account the specific possibilities and limitations for the different applications, such as building design, new buildings 'as built', and existing buildings in the use phase as well as renovation

Standard/ Regulation	Title	Notes/Scope
EN- 15316-4-3	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-3: Heat generation systems, thermal solar and photovoltaic systems, Module M3-8-3, M8-8-3, M11-8-3	This European Standard specifies the: - required inputs; - calculation method; - required and resulting outputs, for heat generation systems, thermal solar systems (for space heating, domestic hot water production and the combination of both) and for photovoltaic systems applied in buildings. Within this standard, 6 methods are specified each method has its own range of applicability. - Method 1, is applicable for solar domestic hot water systems characterized by the EN 12976 series (factory made) or EN 12977-2 (custom built). The main output of the method is the solar heat and back up heat contribution to the requested heat use. - Method 2, is applicable for systems for domestic hot water and / or space heating with components characterized by EN ISO 9806 and EN 12977-3 or EN 12977-4 with a monthly calculation time step. The main output of the method is the solar heat and back up heat contribution to the requested heat use. - Method 3, is applicable for systems for domestic hot water and / or space heating with components characterized by EN ISO 9806 with an hourly calculation time step. The main output of the method is collector loop heat supplied to the heat storage. - Method 4, is applicable for photovoltaic systems with components characterized by standards and with an annual calculation time step. The output of the method is the produced electricity. - Method 5, is applicable for photovoltaic systems with components characterized by standards and with a monthly calculation time step. The output of the method is the produced electricity. - Method 6, is applicable for photovoltaic systems with components characterized by standards and with an hourly calculation time step. The output of the method is the produced electricity. These three last calculation methods do not take into account: - electrical storage; - PV/thermal photovoltaic systems. Primary energy savings and CO ₂ savings, which can be achieved by photovoltaic systems compared to other systems, are calculated according to EN ISO 52000-1
prEN 50331-1	Photovoltaic systems in buildings - Part 1: Safety requirements	

Standard/ Regulation	Title	Notes/Scope
CLC/TR 50670	"External fire exposure to roofs in combination with photovoltaic (PV) arrays - Test method(s)"	

4 Circular economy and material efficiency

Following the withdrawal of the waste legislative proposals in 2014 and a public consultation process, a revised Circular Economy package was published in late 2015. The 2015 package contains measures to address the whole materials cycle, from production and consumption through to waste management and the use of recycled (secondary) raw materials, with the aim of contributing to “closing the loop” of product lifecycles through greater recycling and re-use.

The action plan seeks to make links to other EU priorities, including creating jobs and growth, industrial innovation and tackling climate change. A direct link is made to product policy, in which it states that the European Commission will⁶:

“...promote the reparability, upgradability, durability, and recyclability of products by developing product requirements relevant to the circular economy in its future work under the Ecodesign Directive, as appropriate and taking into account the specificities of different product groups.”

and that it will also:

“...specifically consider proportionate requirements on durability and the availability of repair information and spare parts in its work on Ecodesign, as well as durability information in future Energy Labelling measures”.

Here we consider specific issues for PV in relation to “reparability, upgradability, durability and recyclability of products”, including the possible use of critical raw materials⁷. The current knowledge and standards related to degradation of PV modules, PCEs and PV systems are summarised and connected to the concept of estimated service life for each product category. Furthermore, published or draft standards (or lack of them) dealing with aspects relevant to the Product Environmental Footprint (PEF) of PV⁸, such as sustainability, operational service life, lifetime and end-of-life stages, are mentioned and discussed.

The present section is divided in four main subsections, addressing respectively:

- all aspects related to operational life of products and systems (section 4.1), including the current knowledge and expertise for PV module and system degradation issues;
- all aspects related to quality assurance and market surveillance of products and systems (section 4.2);
- the recast waste electrical equipment directive (section 4.2.2);
- recyclability of products and systems (section 4.4).

4.1 Degradation issues, operational service life and lifetime

The operational service life of a PV module or PV system is not precisely defined yet in any international standard or other official document. Some suggestions or common practices are available, which are hereafter reported in the relevant subsections.

⁶ COM(2015) 614, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS “Closing the loop - An EU action plan for the Circular Economy”

⁷ COM(2017) 490, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS “on the 2017 list of Critical Raw Materials for the EU”

⁸

<https://webgate.ec.europa.eu/fpfis/wikis/pages/viewpage.action?spaceKey=EUENVFP&title=PEFCR+Pilot%3A+Photovoltaic+electricity+generation>

In fact, assigning to PV modules and systems a predetermined unique single value of operational service life (e.g. in terms of operational years) could be difficult for the wide variety of PV applications and usages and the still limited statistics available on degradation as well as on this specific topic, especially for large scale utilities where different maintenance practices are expected to be put in place compared to residential and small commercial installations. Therefore, this subject in particular would benefit from sharing the available knowledge and experience between all the relevant stakeholders.

In the following subsections, we discuss the current norms and standards that could be adjusted or taken as starting point for developing new product-specific regulations and standards to address this issue.

4.1.1 Degradation of PV modules, components and systems

The determination of the durability of PV modules, components or systems is not a trivial exercise. While there is significant evidence that PV installations have performed mostly as expected [3-5], there have also been cases of some product recalls and observations of new (unexpected) failures. Further feedback data from the field is therefore needed.

4.1.1.1 PV modules

The subject of degradation of PV modules is still under open debate even within the PV community and all the standardisation bodies. The available standards, published or in draft as first edition, dealing with degradation issues are listed in Table 2, Table 3 and section 4.2 with Table 11.

The lack of extended standardisation work on this topic is due mainly to the fact that, although some tests for qualification were developed to set some pass/fail criteria according to which to discard the most probable failing modules (see section 4.2), new and different failure modes of PV modules appear in the field as time passes as well as alternative materials or different environment (climatic) conditions are explored. The previous IEC 61215 (now IEC 61215 series) standard has been demonstrated to be valuable for rapidly uncovering well-known failure mechanisms; however, it is insufficient for assessing long-term risk, evaluating newer or less common materials and designs and establishing field performance degradation [6]. Therefore, the degradation issue for PV modules (and therefore systems) has to be considered still as belonging to the learning curve of the PV scientific community and, as consequence, the operational service life of PV modules will have to be defined by the legislator according to present best criteria to be determined and included in the legislative process (see 4.1.2). However, this opens the possibility for involving the entire PV community in a feedback process that could be the basis for building a European dataset of failure modes, usable then as input to new and improved standardisation activities such as indicated in the prEN 45552.

Today's rapidly changing PV technology requires many companies to launch new versions of their product every few months while requiring warranties that are decades long (typically 80% of power after 25 years). In the absence of a standardised method to determine the durability of PV modules, one can use compiled field data to give educated (scientifically observed) estimates for degradation rates of different technologies. A recent compilation study found median degradation for x-Si technologies in the 0.5-0.6 %/year range with mean degradation in the 0.8-0.9 %/year range. Hetero-interface technology (HIT) and microcrystalline silicon ($\mu\text{c-Si}$) technologies, although not as plentiful, exhibit degradation around 1 %/year and resemble thin-film products more closely than x-Si [3].

4.1.1.2 Power conditioning components

Various reports concluded that the inverter is the element of the PV system which is responsible for the highest number of operation and maintenance events with the subsequent cost burden and loss of power production [7]. In order to reduce these

impacts, some standards are being developed in order to improve the inverter's reliability from quality and testing points of view. In parallel, industry already apply various accelerated tests so as to detect infant failures that would result in premature failure and degradation of the inverter. Some examples are given in [7].

The IEC 62093 "*Balance-of-system components for photovoltaic systems- Design qualification natural environment*" defines several tests applicable to the BOS equipment of terrestrial PV systems including batteries, inverters, charge controllers or protectors, maximum power-point trackers, etc. Tests include visual inspection, functioning tests, insulation test, protection against dust or water or UV test among others. However, this standard was minimally adopted by the industry [7].

The renamed draft second edition IEC 62093 "*Power conversion equipment for photovoltaic systems - Design qualification testing*" has a narrower scope just for inverters and DC/DC optimizers. It contains clauses to perform accelerated life testing including both low and high temperature levels, rapid thermal cycling, vibration and combination of these sequences.

However, the quantitative impact that the possible defects will have in the performance of the PCEs is not defined in the standards.

4.1.1.3 PV systems

To our knowledge there are no standards available for modelling the degradation rates of PV systems, and even though there are publications [8-10] of fault detection and monitoring of PV systems, there are no clear degradation rates for PV systems as there are for PV modules.

Degradation may derive from the modules, wiring, the inverter's maximum power-point tracking system or even other factors, like soiling or presence of shadows. The combined impact of these possible effects is difficult to model. Even if the performance and power output of a PV system had been monitored over long periods of time, the source of the degradation would be difficult to clearly identify. In addition to this, the measurement uncertainty is not negligible in these cases, making the degradation rate difficult to measure and quantify.

4.1.1.4 BIPV systems

In the case of BIPV systems, the degradation is expected to be even more pronounced than in ventilated open mounting structure. This is mainly due to the higher temperatures reached by the PV modules and components because of the poor air circulation around them. Some of the standards included in section 4.2 and Table 11 indirectly address these issues.

4.1.2 Operational service life

As said, no international standards are specifically available on the operational service life (OSL) for PV. However, the ISO 15686 series could be used as starting reference to apply a similar approach to PV as transitional good practice before new ad-hoc standards are developed by the European and international standardisation organisations. For example, the definition of operational service life of a PV system could be built on this approach to give in the end the parameter "PV System Energy Life": this would be the combination of the PV system Energy Yield parameter for a standard climatic year with the operational service life definition combined with the annual linear system degradation rates. This would give for the actual PV Systems a KWh (or MWh) energy expected delivery for the system OSL including expected degradation losses, which could potentially allow direct system to system comparison.

The ISO 15686 series, indeed, deals with "Buildings and constructed assets – Service planning", which includes methods of calculation of estimated service life (ESL). In particular, the ISO 15686-8 describes the "*factor method*", which is one specific method

to calculate the ESL (with UC) of any construction product as installed under specific object-related in-use conditions (ObSCon) with respect to a reference service life (RSL) of an equivalent construction product, whose performance and service life has been previously assessed under specific reference in-use conditions (ReCon). ISO 15686-1 gives the general principle behind the concept of service life planning of buildings and their components, also acknowledging that there is an intrinsic amount of uncertainty in the estimate of the service life because neither all events nor all usages can be fully predicted with 100% of confidentiality. This concept of estimation rather than perfect computation of service life is applicable to the building in its entirety as well as to its components. This is straightforwardly extensible to PV modules and systems, too, as their ESL can depend on several factors, including specific mounting location, climatic conditions and maintenance among others. Also, on the environmental fallout of the ISO 15686 series, it has to be noted that the 2004 edition of ISO 15686-6 (dealing with procedures for considering environmental impacts of buildings and constructed assets) results to be withdrawn at the time of writing and no replacing document is clearly stated to supersede it.

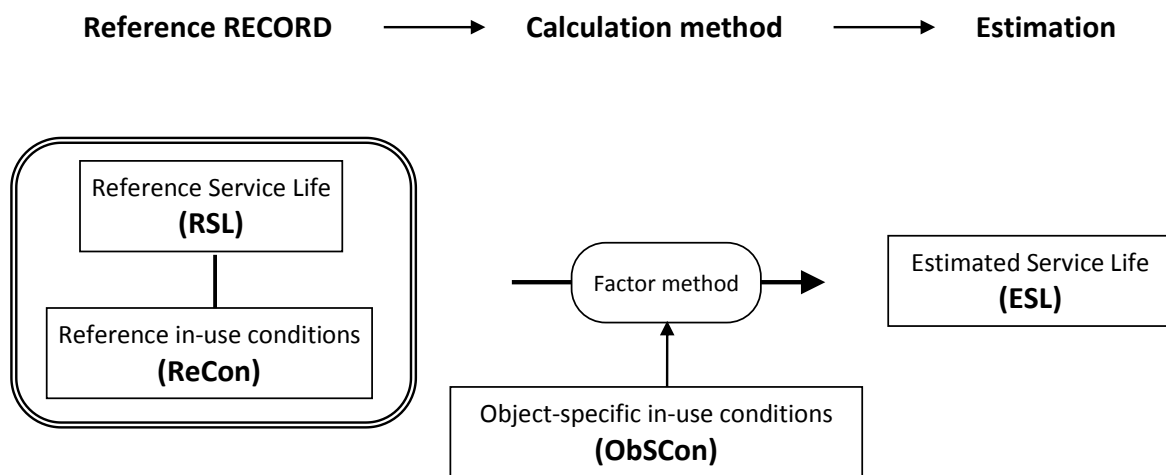


Figure 4. Scheme of the possible workflow for the evaluation of the estimated service life.

According to the factor method given in the ISO 15686-8, the calculation of the ESL has to be done considering the most appropriate reference service-life data record (RSLDR), which is meant to be the RSL jointly considered with the reference in-use conditions to which the RSL is referred (i.e. $RSLDR = RSL + ReCon$) (see Figure 4). Therefore, extreme caution must be applied in service life planning and evaluation when one or more of the ObSCon are not included in the selected RSLDR, because this might affect the outcome of the estimate for the service life for the specific case. A RSLDR has finally to be given in a defined format, specifying some necessary information (see subclause 5.4.4 in ISO 15686-8).

In the factor method, a set of seven categories⁹ is used to distinguish the various agents that can affect or influence the service life of a construction object. Each category contributes to the calculation of the ESL by means of a factor, that the ISO 15686-8 requires to be evaluated by the designer depending on the specific characteristics of the object under design. Furthermore, a grading of the importance of each category and agent has to be done to identify the in-use conditions and/or the degradation agents that are (believed) to have the greatest impact on the performance and thus the service life of the object under study. This is in fact usually done also for PV modules within their

⁹ which are: inherent performance level, design level, work execution level, indoor environment, outdoor environment, usage conditions, maintenance level

design process, considering knowledge and in-field experience that in some cases have been pooled in the form of international standards for PV modules quality assurance (see sections 3.2.1 and 4.2).

Also, appropriateness of the ReCon to serve as reference for the ObSCon has to be verified by three main steps:

1. Identification of the most affecting condition/agent;
2. Comparison of RSLDR to the ObSCon for the object under study, considering the similarity and accurateness of the input RSLDR;
3. Calculate each factor and apply to the method.

The application of the factor method described in the ISO 15686-8 includes four levels of difficulty and accuracy of the output, depending on the accuracy and similarity of the input to the real case. Also, it can be applied to individual components as well as to complete systems, which include interfaces and joints between single components. The four levels of estimate computation are as follows:

1. Simple check-list.
2. Multiplication level. It uses pre-established multiplication factors to derive the specific ESL of the object under study from the most appropriate RSLDR.
3. Function level. It requires model to predict the ESL on the basis of the functionality. It has to specify and to consider the limits of application of the variables used in the model in order to not overshoot the validity range of the model itself.
4. A combination of the previous two computational levels.

Besides specific IEC standards regarding PV module design qualification and testing (see section 4.2) that can be considered for the future development of a definition of PV ESL, other Parts of the ISO 15686 are considered useful to this aim, especially for BIPV. They are:

- Part 2; it might be of interest for the definition of the service-life prediction.
- Part 6, on environmental impacts (although currently officially withdrawn with no stated superseding document).
- Part 7, on how to collect and manage the feedback of service-life data from practice/real world.
- Part 9, on assessment of service life data.
- Part 10, on functional requirements – principles of measurement and use

4.1.3 Lifetime of PV modules, components and systems

The end of life of any product or system is generally defined as the moment in which the product or system stops functioning. For a PV module or a PV system this would mean that the electrical power is not generated anymore. However, depending on the user's specific requirements or needs, the end of life may be met earlier in time although electricity is still produced. If that is the case, there may be two scenarios. In the first, the PV module (or the power-conditioning component) would be replaced by another one compatible with the PV system in order to reset the PV power delivered. In the second, a simple addition of new modules could be considered, especially if space is not a problem. For additional discussion, see sections 4.2 and 4.4.

4.2 Quality standards for modules, power-conditioning components and systems

4.2.1 PV modules

Table 11 lists all the standards that are either published or under development at European or IEC level to deal with quality assurance and safety of PV modules starting from their design stage. They are divided in terms of performance qualification standards and safety qualification standards.

The main pillar of the performance qualification of PV modules is the series of standards EN 61215, which has replaced and grouped in a single consistent series the qualification requirements prescribed by the previous single standard EN 61215 (applicable only to c-Si PV modules) and by the EN 61646 (applicable only to thin-film PV modules). With the latest revision of the standard IEC 61215 (which afterwards went through parallel vote at CENELEC), the IEC TC 82 WG 2 reorganised and rationalised the subject.

The current series EN 61215 consists of two main Parts:

1. *EN 61215-1 Design qualification and type approval - Part 1: Test requirements*, which includes general requirements for testing relevant qualification aspects of PV modules, such as susceptibility to thermal, mechanical and electrical stressors;
2. *EN 61215-2 Design qualification and type approval - Part 2: Test procedures*, which describes the individual tests to be run in order to qualify a PV module type, i.e. the single materials and components chosen for its manufacturing as well as their layout and interconnection that are part of the specific PV module design.

The new holistic approach given to the series EN 61215 "*Design qualification and type approval*" becomes even clearer when the individual material-specific parts in which the EN 61215-1 is split into are considered. Indeed, as listed in the following, they individually address specific requirements for the qualification of PV modules (with higher priority than the general Parts 1 and 2) depending on the active PV material (i.e. the PV technology) that is used in their production:

1. *EN 61215-1-1 Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules*;
2. *EN 61215-1-2 Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules*;
3. *EN 61215-1-3 Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules*;
4. *EN 61215-1-4 Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se)₂ based photovoltaic (PV) modules*.

The testing required by the EN 61215 series for qualification of PV modules consists of a specific sequence of accelerated tests. These aim to simulate, in a much shorter time, the degradation process to which PV modules are likely to be subjected when mounted in real installations and exposed to a foreseeable range of environmental conditions. However, it has to be highlighted that the acceleration factors, which would give a univocal quantitative correspondence between the stressor as applied in the laboratory and the degradation achieved in the field due to exposure to specific environmental conditions, are not yet available, as they indeed depend on climatic conditions to which the PV module is exposed as well as on the specific design of the PV module and the actual installation.

Some accelerated tests are explicitly included in the EN 61215. These are:

- Thermal cycle test, which considers only temperature as stressor;

- Damp heat test, which considers the combination of effects due to temperature and humidity. This test is addressed by the individual sub-parts EN 61215-1-X with parameters specific for each PV technology;
- Humidity freeze test, which aims to causing and revealing possible failures of the sealing materials and components of the PV modules;
- UV test, which can precondition the polymeric components of the PV module;
- Static mechanical load test, which simulates the effect of prolonged continuous mechanical loads on the surface of the PV module, such as those caused by constant wind or homogeneous snow accumulation;
- Hot spot test. It deals with safety issues due to local partial shading on thin-film modules, which can cause the creation of very hot small areas in the PV material and produce failure of the PV module;
- Hail test.

In addition to these, other accelerated tests are available as separate standards, some of which are being considered to be included in the future within the EN 61215 series. They are the following:

- *EN 61701 Salt mist corrosion testing of photovoltaic (PV) modules*, for salt spray testing mainly of connectors, as long-term experience from the field has shown that other PV modules components are not susceptible to this;
- *EN 62716 Photovoltaic (PV) modules - Ammonia corrosion testing*, mainly conceived for testing PV modules resistance to ammonia gas in farms installations;
- *EN 62782 Photovoltaic (PV) modules - Cyclic (dynamic) mechanical load testing*, which introduces load variations on the surface of the PV module as compared to the above-mentioned static mechanical load;
- *EN 62804-1 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon*, for testing c-Si PV modules against potential-induced degradation (PID);
- *EN 62804-1-1 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1-1: Crystalline silicon - Delamination*, which is a specific part of the previous standard for checking delamination due to PID;
- *IEC TS 62804-2 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 2: Thin-film* (draft);
- *IEC 62852 Connectors for DC-application in photovoltaic systems - Safety requirements and tests*;
- *IEC 62916 Photovoltaic modules - Bypass diode electrostatic discharge susceptibility testing*, for testing the susceptibility of by-pass diodes to electrical discharges, depending on their particular design;
- *IEC 62979 Photovoltaic modules - Bypass diode - Thermal runaway test*, specifically aimed to stress and verify the resistance of by-pass diodes, which are a component of the PV module for its own and eventually the user safety, against temperature stressor. This standard is quite recent and it is one of those which need significant feedback from the field in terms of detailed information on failures observed correlated to temperature conditions at which they occur;
- *IEC 62938 Non-uniform snow load testing for photovoltaic (PV) modules* (draft), for non-uniform snow load test. It considers the non-uniformity of the load due to different snow accumulation on an inclined plane, which is the usual condition at which the majority of PV modules are installed;
- *IEC 63126 Guidelines for qualifying PV modules, components and materials for operation at higher temperatures* (early draft), which aims to verify the applicability of some of the previous tests in local climatic conditions characterised by high temperatures, beyond the limits set by the previous standards. These extreme conditions would include for example desert regions as well as BIPV installation for which limited or no air circulation is possible on the back of the PV module;

- *IEC 63140 Photovoltaic (PV) modules – Partial shade endurance testing (draft)*, for advanced testing of protection and performance measurement of thin-film PV modules when exposed to partial-shading conditions;

Further information on the acceleration factors to be used for quantitative analysis of the degradation process might be derived by means of extensive testing applying measurement procedures like those required by the series of standards EN 62788 (see Table 3), which deals with accelerated weathering testing procedures on a wide variety of materials and components for PV modules. In this sense, an increased availability of feedback from the field in terms of information on (known or new) failure modes and the environmental conditions at which they occur would also be extremely valuable.

Furthermore, there is ongoing work to submit a proposal for a new work item on extended testing, which would include longer or more intense test for a specific stressor in order to further improve PV module qualification beyond the basic requirements. This could be used by manufacturers as well as by PV installation designers to check whether the PV products meet specific more aggressive or prolonged stressing conditions.

Today, in addition to qualification testing (IEC 61215 for measurements and IEC 61730 for safety) most PV companies require a robust quality management system that controls many aspects of the manufacturing process (incoming materials, processes, etc.) as well as testing beyond IEC 61215. As the PV industry matures, the methods used for quality control (QC) are evolving to utilize new knowledge and to be more consistent, enabling lower QC costs, as with IEC TS 62941 (see Table 11).

The series EN 62788 (see Table 3) could also be used in the framework of quality controls recommended by the IEC TS 62941 in order to improve confidence in PV module design qualification and testing at production sites. Indeed, the series EN 62788 gives guidelines on many measurement procedures that, for example, could be implemented at the manufacturer factory as quality check of the incoming material/component or of the PV module production process itself and as feedback from the production to the design and engineering stage within the overall quality system of the manufacturer.

Additionally, the standards series IEC 60068 “Environmental testing” contains environmental testing procedures for electrical, electro-mechanical and electronic equipment and devices. Some of these testing may be applicable to PCEs for testing degradation due to corrosion, or failure due shock, vibration, or deposition of dust and sand. The same testing conditions could be applicable to PV modules.

We expect an evolution in the standardisation process to move from pass-fail qualification testing to more sophisticated analyses that provide more quantitative assessment of risk specific to a particular location or type of location, and, thus, enable more quantitative assessment of the value of high-quality components, both in terms of degradation rates and failure rates. One proposed approach to completing a quantitative assessment assigns a Cost Priority Number (CPN) that reflects the cost of repair or loss of revenue associated with a problem [11]. Assignment of a CPN or other rating methodologies [12] relies on being able to link knowledge about the components and system with the anticipated outcomes. The industry has not yet agreed upon the best approaches for gathering and using the information needed for quantifying overall risk.

Table 11. Quality standards for PV modules.

Parameter	Relevant Norm/ Standard/ Regulation	Specific Test Method	Notes
Pre-conditioning of the PV module before measurement	EN 61215-1; EN 61215-1-1; EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	c-Si
Pre-conditioning of the PV module before measurement	EN 61215-1; EN 61215-1-2; EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	CdTe
Pre-conditioning of the PV module before measurement	EN 61215-1; EN 61215-1-3; EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements. Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules. Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures.	a-Si

Parameter	Relevant Norm/ Standard/ Regulation	Specific Test Method	Notes
Pre-conditioning of the PV module before measurement	EN 61215-1; EN 61215-1-4; EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se) ₂ based photovoltaic (PV) modules Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	CIGS
	EN 61701	Salt mist corrosion testing of photovoltaic (PV) modules	Based on IEC 60068-2-52
	EN 62716	Photovoltaic (PV) modules - Ammonia corrosion testing	
	IEC TS 62782	Photovoltaic (PV) modules - Cyclic (dynamic) mechanical load testing	
	EN TS 62804-1	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon	
	IEC TS 62804-1-1	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1-1: Crystalline silicon - Delamination	
	IEC TS 62804-2	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 2: Thin-film	
	IEC 62852	Connectors for DC-application in photovoltaic systems - Safety requirements and tests	
	IEC TS 62916	Photovoltaic modules - Bypass diode electrostatic discharge susceptibility testing	
	IEC 62979	Photovoltaic modules - Bypass diode - Thermal runaway test	
	IEC 62938 (draft)	Non-uniform snow load testing for photovoltaic (PV) modules	

Parameter	Relevant Norm/ Standard/ Regulation	Specific Test Method	Notes
	IEC 63126 (draft)	Guidelines for qualifying PV modules, components and materials for operation at higher temperatures	
	IEC 63140 (draft)	Photovoltaic (PV) modules – Partial shade endurance testing	
	IEC TS 62941	Terrestrial photovoltaic (PV) modules - Guideline for increased confidence in PV module design qualification and type approval	

4.2.2 Power conditioning equipment

Standards like IEC TS 63157 "Guidelines for effective quality assurance of power conversion equipment for photovoltaic systems", EN 62477-1 "Safety requirements for power electronic converter systems and equipment – Part 1: General" or the EN 62109 series "Safety of power converters for use in photovoltaic power systems" contain a series of criteria to guarantee the quality and safety of PCEs integrated in PV systems.

The electrical equipment included in this category should comply with their respective quality and safety regulation, although it may be that special requirements may apply when integrated in a PV system, like in the above mentioned standards.

4.2.3 PV systems

The draft EN 62548 "Design requirements for Photovoltaic (PV) arrays" defines the design requirements for PV arrays including DC wiring, electrical protection devices, switching and earthing provisions. The standard covers all parts of the PV array but excludes the energy storage devices, the power conversion equipment and the loads.

EN 62446-1 "Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection" contains the information and documentation that should be provided to the customer when the PV grid system is installed, and the requirements of inspection and testing that should be done during the system lifetime in order to verify the safe installation and correct operation of the system.

More quality standards for the PV system might be necessary.

4.3 The recast Waste Electrical and Electronic Equipment (WEEE) Directive (2012)

The WEEE Directive¹⁰ requires the establishment at Member State level of schemes to ensure the separate collection and "proper treatment" of Electrical and Electronic Equipment (EEE). From the 15th August 2018 the scope of EEE will be extended to include solar PV modules, which are also identified in the WEEE Directive as a priority for separate collection.

Annexes I - IV of the Directive specifically identifies solar PV "panels" (modules) under EEE category 4(b). No specific collection rate is specified for them, but rather an overall collection rate for EEE is stipulated to rise from 45% in 2016 to 85% in 2019. From the 15th August 2018 for EEE of category 4, an 85% recovery rate and an 80% re-use and recycling rate shall be achieved.

Other system components such as inverters are not specifically identified in the existing EEE categories, but could be interpreted to fall under the new EEE category 5 "Small equipment (no external dimension more than 50 cm)", which refers to equipment "for the generation of electric currents". The new EEE category shall apply from 15th August 2018.

In terms of whether inverters fall within the general scope of the WEEE Directive, the European Commission clarified in 2014 in response to a Frequently Asked Question that inverters¹¹:

"...fall[s] under the definition of EEE given in Article 3(1)(a) and thus fall[s] within the scope of the Directive. An example of an inverter that falls within the scope of

¹⁰ OJ L 197, 24.7.2012, p. 38–71. "Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)"

¹¹ Frequently Asked Questions on Directive 2012/19/EU on Waste Electrical and Electronic Equipment (WEEE), April 2014.

the Directive is one used in a photovoltaic installation. However, an inverter does not fall within the scope of the Directive in the following cases:

- when it is designed and placed on the market as a component to be integrated into another EEE,*
- when it benefits from an exclusion on the basis of Article 2: e.g. it is specifically designed and*
- installed as part of another type of equipment that is excluded from or does not fall within the scope of the Directive, and the inverter can fulfil its function only if it is part of that equipment."*

Based on this interpretation micro-inverters integrated with a photovoltaic module would be treated as a specific product.

To support data collection and tracking the European Commission published in 2017 a new WEEE Calculation Tool which compiles stock placed on the market (POM) and waste data¹². The default disposal rate used is based on a product lifetime that is determined using a Weibull distribution. "Photovoltaic panels (including inverters)" are assigned United Nations University's code (UNU) 0002 and preliminary data can be obtained that has been pre-loaded in the individual Member State calculator spreadsheets. The data obtained for this category should, however, be treated with caution because the inclusion or not of system components such as inverters is not clear from the metadata specification¹³.

Beyond the separate collection and subsequent preparation for the purposes of re-use, recovery or recycling, "*proper treatment*" of EEE shall include the removal of fluids from and selective treatment for the following components which may be of relevance to PV systems, dependent on their configuration and scale:

- Batteries,
- Printed-circuit boards with a surface greater than 10 cm²,
- Plastics containing brominated flame retardants,
- Chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC),
- External electric cables,
- Electrolyte capacitors containing substances of concern (height > 25 mm, diameter > 25 mm or proportionately similar volume).

The WEEE Directive also states that Member States shall encourage co-operation between product manufacturers and recyclers in order to facilitate the re-use, dismantling and recycling of WEEE at product, component and material level.

4.4 Standards relating to life cycle of PV products, components and systems

4.4.1 Horizontal standards

The basis for product-specific standards regarding the various stages of their life cycle, mainly either under preparation at the standardisation bodies or still to be initiated, is set

¹² DG Environment, *Statistical data – WEEE calculation tools*, http://ec.europa.eu/environment/waste/weee/data_en.htm

¹³ ProSum, 0002 Basic metadata catalogue - photovoltaic Panels (incl. inverters), <http://prosum.geology.cz/records/5a0ee62e-9fc0-46ae-8e18-6cda0a010854>

by the draft horizontal standards developed under the mandate M/543. These latter are listed in Table 12 and currently foreseen to be published in 2019.

For PV, product-specific standards are not yet publicly available and therefore a mandate for their development might be necessary on aspects not covered by drafting documents. In fact, at our knowledge the IEC TS 62994 is the only standard being developed specifically in relation to life cycle assessment of PV modules, although aimed at environmental health and safety aspects.

In addition to this, there exist some guidelines and studies developed by stakeholders in the PV sector that can already be helpful to address this topic [2, 13] and that partially contributed to the development of the above-mentioned IEC TS 62994.

Table 12. Draft horizontal standards under Mandate M/543.

Relevant Norm/Standard/Regulation	Standard Title
prEN 45552 (draft)	General method for the assessment of the durability of energy-related products
prEN 45553 (draft)	General method for the assessment of the ability to re-manufacture energy related products
prEN 45554 (draft)	General methods for the assessment of the ability to repair, reuse and upgrade energy related products
prEN 45555 (draft)	General methods for assessing the recyclability and recoverability of energy related products
prEN 45556 (draft)	General method for assessing the proportion of re-used components in an energy related product
prEN 45557 (draft)	General method for assessing the proportion of recycled content in an energy related product
prEN 45558 (draft)	General method to declare the use of critical raw materials in energy related products
prEN 45559 (draft)	Methods for providing information relating to material efficiency aspects of energy related products

4.4.2 Sustainability

Apart from the draft IEC TS 62994, other useful guidance to develop documents on the PV-specific sustainability can be the already-mentioned list of critical raw materials⁷, the IEC/TR 62635 and the EN 15804. The IEC/TR is a guideline for proper end-of-life processing of EEE, so it could be adjustable or even directly applicable to PV modules and PCEs, whenever they are considered EEE. The EN standard deals with construction works Environmental Product Declarations (EPDs) that have to be delivered for each stage of the life cycle of such products. This could become necessary for BIPV and BaPV, but it could be useful for PV systems in general.

4.4.2.1 Resource use and Emissions During Product Life

This will have to be defined from the specific LCA calculations carried out in the dedicated tasks of the study.

4.4.2.2 Recyclability aspects

The IEC TR 62635 deals with end of life and recyclability of EEE and describes the various aspects and steps of the life-cycle assessment to be accounted for in the design of EEE. It also sets the need for exchange of information and reciprocal involvement of the manufacturers on the one side and of the recyclers on the other side in order to make the full chain as sustainable, effective and efficient as possible, in terms of material's usage as well as energy consumption/recovery.

Precise definitions are given about this topic. In particular, it states that recyclability rate (i.e. percentage of object's mass that can be recycled or reused) cannot be based only on product mass approach in order to ensure a material efficient design. However, it is one of the main parameters.

In the whole life-cycle of an EEE, the end-of-life stage is a specific stage out of several. It consists in four phases:

1. pre-treatment removal of hazardous parts (on the basis of manufacturers information), dismantling parts for selective treatment;
2. material separation by mechanical, chemical or thermal methods;
3. energy recovery: the remaining parts may be considered for energy recovery in appropriate facilities;
4. residuals disposal in appropriate landfills.

N.B. It is important to note that end-of-life treatment can be rather variable around the world due to applicable local laws. For Europe, the WEEE creates a common frame to this subject for those products that are included in it (see 4.3).

4.4.2.3 General sustainability aspects

The EN 15804 gives a comprehensive guidance on how to declare the performance (based on the ISO 15686 series, see 4.1.2) and the environmental impact of a product for construction works through its life cycle (similar to IEC/TR 62635) by means of specified Product Category Rules (PCR).

The PCR define what stages of the entire life cycle of the product¹⁴ should be considered in the specific delivered EPD. This standard set the general rules for compiling the life-cycle inventory and the life-cycle impact assessment as well as specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories. The Type III environmental declaration is an environmental declaration providing quantified environmental data by using predetermined parameters

¹⁴ among product stage (including extraction of raw materials, transport, manufacturing), construction process, usage and end-of-life (including waste, disposal, waste processing). Other life stages are optional.

and, where relevant, addition environmental information. For specific and building-specific details see the standard.

Specifically to the PV exploratory study, though, can become useful/applicable the following definitions, in addition to what already considered and discussed in the present report:

- Functional Unit (see also EN ISO 14040:2006 5.2.2 for developing a FU). It is a unit of measure used to:
 - a. Quantify the performance of the product;
 - b. Provide the reference by which material's flows are normalized through each stage of the product's life cycle assessment (IN-OUT data or amount) for construction products. Used for comparison;
 - c. At denominator in formulas, it serves as common denominator (basis) for adding flows (of material) and environmental impacts at any life stage and their sub-stages.

For PV, it could be used as reference parameter's unit common to all stages together with: i) quantified performance information when PV modules/systems are integrated into buildings; ii) RSL + defined in-use conditions.

- Declared Unit. It substitutes the FU when precise function of the product OR scenarios (at building level) is not stated or cannot be precisely known. As such, it has limited application and cannot be used for the entire LCA, but it is acceptable for the assessment of the performance during the in-use stage. It can though be chosen from a restricted list of units, i.e.:
 - a. An item or an assemblage (e.g. 1 window);
 - b. Mass: [kg]
 - c. Length: [m]
 - d. Area: [m²]
 - e. Volume: [m³]
 - f. All others have to be converted to this list, with exception of e.g. energy, for which the kWh is explicitly allowed.
- The end-of-life stage of the construction product is defined to start when the product is replaced, dismantled or deconstructed from the building and does not provide any further functionality (i.e. it cannot be reused with its present functionality). It can also start at the end-of-life of the building, depending on choice of the product's end-of-life scenario.

5 Conclusions

5.1 Product-group definition

There are clear and well-documented definitions of the main categories of equipment considered here, as described below.

- PV modules
 - Photovoltaic modules (or panels): these are defined as an environmentally protected, essentially planar assembly of solar cells, ancillary parts (such as interconnections and terminals) and protective devices (such as diodes), intended to generate DC power under non-concentrated sunlight. In the preparatory study the proposed functional unit is 1 kWh of DC power output under predefined climatic and installation conditions for 1 year and assuming an intended service life of 25 years.
- Power Conditioning Equipment
 - Power conditioning components, defined here as electrical equipment, or power electronics, used to convert DC power from a PV array into a form suitable for subsequent use by a downstream user. This is a collective term for inverter (i.e. DC-AC converter), DC-DC converter, battery charge regulator and blocking diode. In the preparatory study the proposed functional unit is 1 kWh of AC power output from a reference photovoltaic system (excluding the efficiency of the inverter) under predefined climatic and installation conditions for 1 year and assuming a service life of 10 years
- PV Systems
 - Photovoltaic systems (including BIPV), defined as a power system designed to supply usable electrical power by means of PV modules. It consists of an arrangement of several components, including PV modules (panels) to absorb and convert sunlight into electricity, an inverter to change the electric current from DC to AC, as well as mounting, cabling and any other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution. The latter would be subject to the batteries Directive¹⁵. In the preparatory study the proposed functional unit is 1 kWh of AC power output supplied under fixed climatic conditions for 1 year (with reference to IEC 61853 part 4) and assuming a service life of 25 years.

5.2 Standards

5.2.1 General overview

The situation for standards is varied and complex. There over 100 relevant standards covering aspects of used materials, production, PV modules measurement and safety, power conditioning equipment, PV systems and their components and the design, construction and commissioning cycle. However, not all aspects are covered to the same degree:

- PV modules
 - This group is well covered by existing standards for materials efficiency, production, design qualification and type approval, power and energy yield.

¹⁵ OJ L 266, 26.9.2006, p. 1-14. "Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC"

An extensive collection of operational data and correlation with laboratory testing results give confidence in building an appropriate definition of degradation effects, although an intermediate method may be required for quantifying them. The OSL definition is still not fully clarified; however, following the future IEC TS 62994, the IEC/TR 62635 and the guidelines in the ISO 15686 series an agreed method will be achievable. The issues of recyclability, reparability and durability should be covered by the Mandate M/543 pre-norms. PV-specific standards deriving from the horizontal ones will be necessary, although we do not foresee particular problems here.

- Power Conditioning Equipment
 - For the PCEs the standards regarding materials and design are covered. Dedicated standards have been developed for PV inverter performance such as EN 50530. This however is officially marked as withdrawn, although the procedure for determining the “European Efficiency” is still considered technically valid. This would allow a transitional method for calculating a functional parameter in terms of AC power output for a nominal PV array. Regarding the definition of OSL the situation is similar to that for PV modules and again a transitional method may be required, also taking into account field data.
- PV Systems
 - The situation for PV system reflects a combination of the situation for PV modules and power conditioning components, as well as the system location and design. Aspects on PV system design are the subject of new draft norms, including the full construction cycle while local situation that can have a significant effect on the final energy (and therefore on the material balance). On-site power measurement and verification standards exist. However, there is no actual single standard for the calculation of expected energy yield of a PV system. A transitional method would be required here, based on existing monitoring standards or on the module energy rating standards but also integrating a model to include the effects of local environmental relevant to the specific geophysical position.
- Degradation, Operational service lifetime and Circular economy issues.
 - The generic pre-norms being developed under mandate M/543 are applicable to the PV module, Power conditioning and PV system groups definition. PV-products specific standards deriving from the horizontal ones will have to be necessarily developed, coherently with the PEF guidelines developed for PV.

5.2.2 Compulsory harmonised standards

Among all those listed in this report, only one harmonised standard on the low-voltage directive already exists. All other standards or norms are EN, IEC or ISO documents. This will need to be addressed in the future.

5.3 Relevant procedures or methods not available as already existing standards

The following is marked as relevant aspect not covered by an already published or drafting international standard of any kind.

— Power Conditioning equipment

- European Inverter Efficiency (technically relevant, but at present in a withdrawn EN standard);

— PV Systems

- System energy yield: a transitional method is required.

For all product categories, the definition of method for quantifying degradation and/or durability must be defined. In addition, a methodology for the OSL needs to be established.

5.3.1 Identification of lack of standards

Given the results of the analysis of existing standards and standards under development, and taking into account the identified functional parameters per each product category, it can be expected that further technical work could be aimed to the formulation of 'transitional methods' (or parts of them), to be used by stakeholders in absence of relevant standards, for an assessment of:

1. Energy Yield of PV systems
2. Durability of PV modules
3. Durability of PV Inverters
4. Efficiency of PV Inverters (EN standard withdrawn)
5. Dismantlability of PV Modules
6. Disassemblability of PV Systems
7. Remanufacturing of PV Systems

The items listed as 1 to 4 will require the immediate development of transitional methods which will be addressed in the current study. Items 5, 6 and 7 will require the agreement first of the horizontal standards under mandate M/543 which will not be possible under the present study.

References

- [1] Joint Research Centre (European Commission). Jäger-Waldau A 2017 *PV Status Report 2017*, JRC108105
- [2] International Energy Agency. Fthenakis V, Frischknecht R, Raugei M, Kim H C, Alsem E, Held M and de Wild-Scholten M 2011 *Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity*,
- [3] Jordan Dirk C, Kurtz Sarah R, VanSant K and Newmiller J 2016 Compendium of photovoltaic degradation rates *Prog Photovoltaics Res Appl* **24** 978-89
- [4] International Energy Agency. Köntges M, Kurtz Sarah R, Packard C, Jahn U, Berger K A, Kato K, Friesen T, Liu H and Van Iseghem M 2014 *Review on failures of photovoltaic modules*,
- [5] Jordan D and Kurtz Sarah R 2014 Reliability and Geographic Trends of 50,000 Photovoltaic Systems in the USA. In: *29th European Photovoltaic Solar Energy Conference and Exhibition*, (Amsterdam) pp 2208-15
- [6] Kurtz S *et al.* 2017 Qualification Testing versus Quantitative Reliability Testing of PV – Gaining Confidence in a Rapidly Changing Technology. In: *33rd European Photovoltaic Solar Energy Conference and Exhibition*, (Amsterdam) pp 1302 - 11
- [7] Hacke P, Lokanath S, Williams P, Vasan A, Sochor P, TamizhMani G, Shinohara H and Kurtz S 2018 A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols *Renewable and Sustainable Energy Reviews* **82** 1097-112
- [8] Madeti S R and Singh S N 2017 A comprehensive study on different types of faults and detection techniques for solar photovoltaic system *Sol. Energy* **158** 161-85
- [9] Villarini M, Cesarotti V, Alfonsi L and Introna V 2017 Optimization of photovoltaic maintenance plan by means of a FMEA approach based on real data *Energy Conversion and Management* **152** 1-12
- [10] Triki-Lahiani A, Bennani-Ben Abdelghani A and Slama-Belkhodja I 2018 Fault detection and monitoring systems for photovoltaic installations: A review *Renewable and Sustainable Energy Reviews* **82** 2680-92
- [11] Moser D, Del Buono M, Jahn U, Herz M, Richter M and De Brabandere K 2017 Identification of technical risks in the photovoltaic value chain and quantification of the economic impact *Prog Photovoltaics Res Appl* **25** 592-604
- [12] Shrestha S M, Mallineni J K, Yedidi K R, Knisely B, Tatapudi S, Kuitche J and TamizhMani G 2015 Determination of Dominant Failure Modes Using FMECA on the Field Deployed c-Si Modules Under Hot-Dry Desert Climate *IEEE J. Photovoltaics* **5** 174-82
- [13] Fthenakis V and Raugei M 2017 *The Performance of Photovoltaic (PV) Systems*: Woodhead Publishing) pp 209-32

List of abbreviations and definitions

AC	Alternate current
BaPV	Building-added Photovoltaics
BIPV	Building Integrated Photovoltaics
BOS	Balance of System
CDV	IEC committee drafts for voting
CEC	California Energy Commission
CFC	Chlorofluorocarbons
CPN	Cost Priority Number
DC	Direct current
EC	European Commission
EEE	Electrical and Electronic Equipment
EFTA	European Free Trade Association
EPB	Energy Performance of Buildings
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declarations
ESL	Estimated Service Life
ESO	European Standardisation Organisation
FDIS	IEC Final Drafts of International Standards
FprEN	Final draft of European Standards
FU	Functional Unit
GIS	Geographical Information System
HC	Hydrocarbons
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
HV	High Voltage
IEC	International Electrotechnical Commission
IECRE	IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications

ISO	International Organization for Standardization
ITU	International Telecommunication Union
LCA	Life-Cycle Assessment
LV	Low Voltage
LVRT	Low Voltage Ride-Through
MPPT	Maximum Power Point Tracking
MPR	Module Performance Ratio
ObSCon	Object-Related In-Use Conditions
OSL	Operational Service Life
PCE	Power Conditioning Equipment
PCR	Product Category Rules
PDS	Power Drive Systems
PEF	Product Environmental Footprint
POM	Placed on the Market
PR	(System) Performance Ratio
prEN	CENELEC draft European Standards
PV	Photovoltaic (or Photovoltaics)
QC	Quality Control
ReCon	Reference In-Use Conditions
RSL	Reference Service Life
RSLDR	Reference Service-Life Data Record
SJ	Single-junction
STC	Standard Test Conditions
TC	Technical Committee
TMY	Typical Meteorological Year
TR	Technical Report
TS	Technical Specification
UNU	United Nations University

UPS	Uninterruptible Power Systems
WEEE	Waste Electrical and Electronic Equipment
WG	Working group
WTO	World Trade Organisation

List of tables

Table 1. Standards required for functional parameters of PV modules.12

Table 2. Supporting standards of PV modules.15

Table 3. Complementary standards of PV modules.....19

Table 4. Standards available for defining functional parameters for PCEs.23

Table 5. Supporting and complementary standards for PCEs.25

Table 6. Supporting and complementary standards for batteries.31

Table 7. Standards required for functional parameters of PV systems.....38

Table 8. Supporting standards related to efficiency measurement of PV systems.40

Table 9. Supporting and complementary standards for PV systems.41

Table 10. Standards addressing the topic of BIPV for modules and systems.....48

Table 11. Quality standards for PV modules.....59

Table 12. Draft horizontal standards under Mandate M/543.65

Annexes

Annex 1. Energy rating study related to the Ecodesign project

What is Energy Rating?

Energy rating is a simplified parameter that estimates how a PV module technology would perform in a certain climate under generic assumptions of PV installation that are input as reference. For example, it does not consider whether shadows are really present or not on the PV system. It is normally calculated considering one calendar year period and it is always a comparison (i.e. a rating) between at least two entities, being these different PV technologies under the same climatic conditions or different climates to which one PV technology would be exposed.

Energy rating must not be confused with energy yield/production prediction, which is instead an estimate of the PV output expected from a particular real PV module mounted in a specific way in a defined location. In particular, energy yield explicitly considers the module's energy efficiency, which is directly linked to the area required per watt of PV output. Also, in practical cases for energy-yield prediction at specific locations, long-term environmental data (at least ten years) is desirable, as well as to account for effects like shadows, presence of dust or snow on the PV modules even for short periods, and degradation or ageing that would affect the actual PV power output.

All these effects, which would be a particular characteristic of a specific location (e.g. presence of shadows, dust or snow) and PV module (e.g. subjected to different rates of degradation or ageing), are not considered in the energy-rating calculation as it does not aim at analysing the actual achievable performance of a real PV system in a precise location, but rather at estimating the performance that can be expected for a generic PV module/system of a certain PV technology (e.g. crystalline silicon) exposed to different climates. It is therefore a useful tool to compare the performance of different PV technologies in a standardised reference framework that goes beyond the nominal maximum power at Standard Test Conditions (STC) declared by the manufacturers on the module's technical datasheet. At present, indeed, the performance of a PV module is reported for these very specific and conventional reference conditions STC, which are defined by an international standard and correspond to: i) an in-plane total irradiance of 1000 W/m²; ii) a conventional reference solar spectrum (named AM1.5) tabulated in another international standard; iii) a module temperature of 25 °C. These reference conditions, although very useful for setting a common and agreed reference point for comparison of the peak-power output of different PV modules and technologies, are not always representative of the real working conditions to which PV modules are subjected, because total irradiance, sunlight spectrum and module temperature change considerably throughout the day and the year and they can also strongly depend on the climate in which the modules are installed.

The energy-rating concept can also be applied to PV systems if the inverter's efficiency and other losses in the PV system are included. However, the study carried out so far is focused at the PV module level only.

How is Energy Rating calculated?

The parameter used is the Module Performance Ratio (MPR) estimated as the ratio of the energy output of the module to the output it would have produced if it had always had the efficiency declared at the STC. It has therefore no units and is calculated by the general expression shown in Equation A1.

$$MPR = \frac{1000 \cdot E_{tot}}{P_{stc} \cdot H_{tot}} \quad (A1)$$

E_{tot} is the total energy output (kWh) over the time period analysed, which is normally a year and H_{tot} is the total in-plane irradiation received at the module's surface (kWh/m²).

Energy rating calculation

The procedure followed and described here has been proposed to be included in the new standard IEC 61853-3: *Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules*, which is (at the time of this writing) close to the final stage of voting at the International Electrotechnical Commission (IEC).

The proposed procedure is the concatenation of different models used to estimate the intermediate input data required to calculate the MPR of a certain PV technology at a defined location/climate.

For each reference climatic condition (1 year), the hourly values of PV output are integrated to obtain E_{tot} . These are calculated by interpolation of a matrix of measured power values for the PV module of different levels of in-plane irradiance and temperature. Considering the hourly values of effective in-plane irradiance at the considered location and the hourly values of module temperature, by interpolation on the said measured power matrix, we obtain the hourly output power values.

Both in-plane irradiance and module temperature needed for the interpolation are modelled values and depend on intrinsic properties of the PV technology analysed and on the location/climate considered. The irradiance is calculated considering two effects. On the one hand, the increased reflectivity at shallow angles of the impinging irradiance reduces the irradiance potentially absorbed by the module and on the other hand, the spectral responsivity of the PV module active material determines the irradiance effectively absorbed and used by the PV module. The temperature of the module is also calculated by a model that considers the temperature increase due to the received irradiance and also the cooling effect of the wind.

In order to apply this whole procedure, different types of input data are needed. Related to the location or climate being considered the applied procedure requires ambient temperature and wind speed hourly data in addition to in-plane irradiance data integrated in different spectral bands so as to apply the spectral effects calculations. The draft standard IEC 61853-4 (*Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles*) provides full data sets for 6 climatic reference conditions.

Regarding the PV technology under analysis, the procedure applied needs the spectral response values and the technology dependent coefficients used to estimate the temperature of the module. In addition to the matrix of measured power output registered under controlled conditions of irradiance and temperature.

Practical Examples of PV Module Energy rating

The energy rating study presented here has been performed at three European locations with distinct climatic conditions, which can be related to three of the six climatic reference conditions proposed in the standard IEC 61853-4. The six reference climates of the IEC standard cover the most common weather conditions observed in the Earth, while the three ones selected for Europe are well representative of the majority of the climatic conditions that can be met in the European continent. For technical and computational reasons, a choice of a real location for each European climate had to be done. Therefore, the three European representative climates have been located in South Spain –to describe a subtropical climate (zone 1), in Slovakia –for a temperate continental climate (zone 2) – and in Scotland –as representative of a temperate coastal climate (zone 3). Beside these three climates that well represent the general European weather conditions, the other three climatic classifications included in the aforementioned

IEC standard are tropical humid, subtropical coastal and high elevation (>3000m). Among these, the former two are not at all characteristic of European conditions. The third one is instead not significant enough for the European continent because, although there are locations in Europe above 3000 m, these are not numerous enough or likely to be used for PV systems deployment so as to be considered representative European climatic region for this energy rating analysis.

For the calculation, the modules are considered located due south and with the optimal inclination angle at every location.

Even though the current PV market is dominated by crystalline silicon based technologies, besides the c-Si module we have analysed other technologies such as CdTe, amorphous silicon and two different organic PV devices. The latter are an example of one of the emerging technologies in the PV sector.

The MPR values obtained for the three climatic zones considered in Europe are shown in Figure A1. Care should be taken in interpreting and explaining Figure A1 and the information it provides. Indeed, as the MPR is a parameter that is scaled (i.e. normalised) to the maximum power delivered by the PV module at the reference conditions STC (P_{STC} in formula (A1)), it is important to reaffirm that it does not represent a performance of a certain PV technology under the considered climatic conditions in absolute terms (i.e. for example in kWh), but rather a relative gain or loss that that PV technology would achieve with respect to an ideal climate where the environmental conditions were always equal to STC. For example, the MPR result achieved by crystalline silicon (c-Si) in the three zones compared to amorphous silicon (a-Si) or even to the newest organic PV (OPV) says that c-Si is in fact more affected than the other two by the deviations of the climatic conditions from STC. However, as the c-Si PV technology has absolute higher values for P_{STC} (i.e. ultimately for its conversion efficiency μ) and it has typically longer lifetime than for example present OPV technology, the total amount of delivered energy in absolute terms would be favourable to c-Si. On the other side, information as reported in Figure A1 gives a quick overview of the possible better matching of PV technologies to some climatic conditions than others, although under the significant and at present artificial assumption of the same life time and power production for all, thus giving an indication of the potential application of (and therefore investment in) a PV technology in a certain climate more suitably than in another.

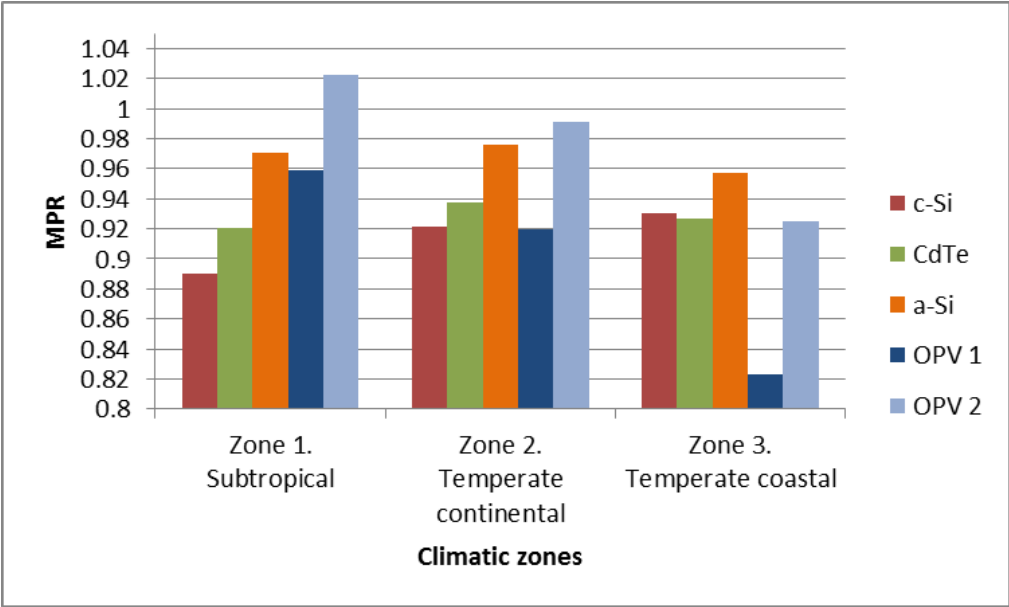


Figure A1. MPR values obtained at the three considered European climatic zones.

As evident in Figure A1, depending on the location and technology the MPR values obtained are generally below the performance level which would be expected (MPR=1) from considering the devices always at STC. This reflects the fact that the modules temperature often differs from the reference 25 °C, being typically higher, resulting for most technologies in a significant decrease of the actual power output with respect to P_{STC} . The latter statement translates in the fact that usually an inverse correlation is observed between the actual PV module temperature and its maximum power output (and so its efficiency), meaning that the delivered power usually decrease when the device temperature increases. On the contrary, the measurements of the second OPV device (OPV 2) showed a direct correlation that is unusual for PV technologies, i.e. its measured maximum power increased with temperature, thus contributing to the MPR value above 1 reached at the subtropical climatic zone. Under the climatic conditions observed in Zone 1, this device would perform better than what would have been expected from an STC assessment only (MPR>1).

The spectral effects could also contribute to these high MPR values, especially for the OPV devices, as in general technologies with narrow spectral responsivity would obtain higher spectral gain. The spectral response values of the considered technologies and devices are shown in Figure A2.

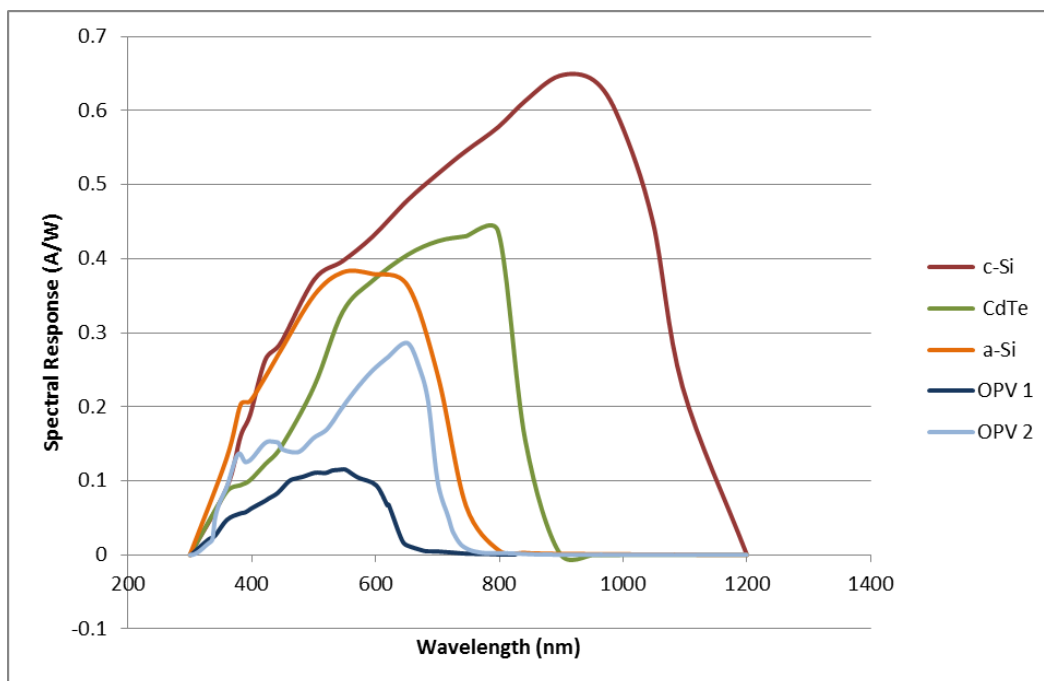


Figure A2. Spectral responsivity data representative of the considered technologies, as measured on actual devices at the European Solar Test Installation (ESTI) of the European Commission.

However, regardless of the specific MPR values obtained for every technology and climatic zone, the main outcome of these results relevant for the Ecodesign project is the variability observed among the three different locations analysed, which depends on the considered technology. While the c-Si energy-rating performance varies 4.5% between the best and worst location, the CdTe and a-Si technologies are less sensitive with a variation of 1.7 and 1.9% respectively between the best location and the one where they showed the poorest energy-rating performance. This variability can be up to 16% for the OPV devices due to their poor energy-rating performance under low irradiance conditions (very low MPR values in Scotland, temperate coastal). A similar variation of the MPR values obtained by c-Si and CdTe technologies through Europe has been reported in [A1, A2]. Even though the methodology applied there to calculate the MPR values is not exactly the same as the one presented in this document, the observed trend here is also

reported in those two scientific papers. In fact, four different regions with MPR values similar to those reported here were identified in Europe. However, with the new methodology presented here for MPR estimation and considering the six world reference climatic zones proposed in the new draft standard IEC 61853-4, we have considered for this study only three different regions in Europe.

We must bear in mind that the MPR gives an idea of how a PV technology performs under actual working conditions (one year of hourly data) in comparison to what would be expected under permanent STC conditions. The relative deviations from STC in terms of module temperature, total in-plane irradiance and sunlight spectral composition for the climatic zones considered, seem to favour OPV more than other technologies as shown by the higher MPR values obtained by this new technology in all climates. However, due to the made assumptions and necessary technical boundaries present at the present development of the energy-rating approach, this result does not guarantee at present that in a real PV system, the OPV technology will provide more power output than the other technologies. Indeed, factors that still highly affect the absolute performance of OPV devices, like their degradation rate and lower absolute power output, have not been considered here. Therefore, considering the overall current status of this emerging technology, OPV would not be an appropriate option for large-scale PV deployment, but possibly it would better suit niche applications.

Conclusions

The energy rating study presented here could contribute to the Ecodesign project in the following aspects:

- to define a parameter to easily compare the electrical performance of different PV modules in order to help customers choose the best option (module type or even module technology) for their location. In ultimate analysis, the MPR is a better and more suitable parameter than just P_{STC} to assess the annual relative performance of a PV module technology under specific climatic conditions in comparison to the STC reference, which is currently the only information used to compare different PV modules and technologies. A combination of both aspects would be very positive for a complete and appropriate assessment of PV deployment. For the c-Si technology the deviation from the performance at STC can be up to 12%, while for some OPV it could be up to 18%. However, the OPV technology was included in this study just as an example of an emerging new technology.
- the datasets related to the location or climatic zone used in the present study have been proposed to be included in the standard IEC 61853-4 and could therefore be extracted from there to be used in product policy. They include data of broadband and spectral irradiance, ambient temperature and wind speed. However, the required input data specific for the PV module should be provided by other sources, like the manufacturer itself or -even better- independent laboratories. These module-specific data include its spectral responsivity, either the coefficients to estimate the temperature of the module or measured data to retrieve these coefficients, and the power matrix measurements.
- the MPR values obtained could help in the decision whether to consider one or more climatic regions inside Europe for product policy purposes. The results shown here, especially for the c-Si technology support the consideration of more than one region or climate. The variability in the MPR values obtained at the different climates for the CdTe or a-Si is not as significant as for the c-Si, but we would still support the consideration of different regions.
- the IEC 61853 procedures could also be used to produce realistic energy yield values for a given module technology in the reference climatic conditions.

References

- [A1] Huld, T., Dunlop, E., Beyer, H.G., Gottschalg, R. Data sets for energy rating of photovoltaic modules. *Solar Energy* 93, 267-279 (2013).
- [A2] Huld, T., Salis, E., Pozza, A., Herrmann, W., Müllejans, H. Photovoltaic energy rating data sets for Europe. *Solar Energy* 133, 349-362 (2016).

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: <http://europa.eu/contact>

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
- at the following standard number: +32 22999696, or
- by electronic mail via: <http://europa.eu/contact>

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: <http://europa.eu>

EU publications

You can download or order free and priced EU publications from EU Bookshop at: <http://bookshop.europa.eu>. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see <http://europa.eu/contact>).

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.



EU Science Hub
ec.europa.eu/jrc



@EU_ScienceHub



EU Science Hub - Joint Research Centre



Joint Research Centre



EU Science Hub



Publications Office

doi:10.2760/89830

ISBN 978-92-79-86608-1