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Contents

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 CO_2 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. The preparatory study 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[1]) 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[2] 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 available 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] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010R0066&rid=10
[2] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0400:FIN:EN:PDF

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[3] 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 product 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 by-pass diodes), intended to generate direct-current (DC) power under non-concentrated sunlight. For the purpose of this report, only non-concentrating PV modules are considered due to their dominant market share. The structural (load carrying) element of a module can either be the top layer (superstrate) or the back layer (substrate) with or without a metal frame.
2. Power conversion equipment, 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, main of which are PV modules to absorb and convert sunlight into electricity, an inverter to change 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 life cycle (e.g. production, design, use, end of life) are considered in the context of the Circular Economy and Materials Efficiency.

[3] Unless specifically stated otherwise, the applicable edition of the cited standard is the latest published edition, including amendments.

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 (CI(G)S), 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 thin-film sub-technology remains in the novel and emerging categories. Also, as the market share of multi-junction thin-film PV technologies (where two or more photoactive layers are assembled together to form a single monolithic PV cell) is currently minor, standards specifically related to them are not included in this report.

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 PV 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 the substrate or superstrate of the PV module. 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 (Gallium) Sulphides and Selenides, overall generally referred to as CIS and CIGS depending on whether gallium is not or is included in the composition. Amorphous silicon (a-Si) was the first commercially successful thin-film PV technology. However, since its energy conversion efficiency at reference conditions 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 formal 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 Agreement[4] 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 (i.e. of IEC origin) 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[5];
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.

[4] 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

[5] Some standards reported in this document are examples of this common numbering.

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 within a prescribed period 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 steps[6]:

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.

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

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

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 edition 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 edition 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 110 documents[7], which have laid the foundation for the strong increase of trade for PV products. IEC TC 82 currently[7] has 52 Member States (41 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: Bahrain, Iran, Israel, Oman, Saudi Arabia

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

[7] Information updated to 30 November 2018.

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.

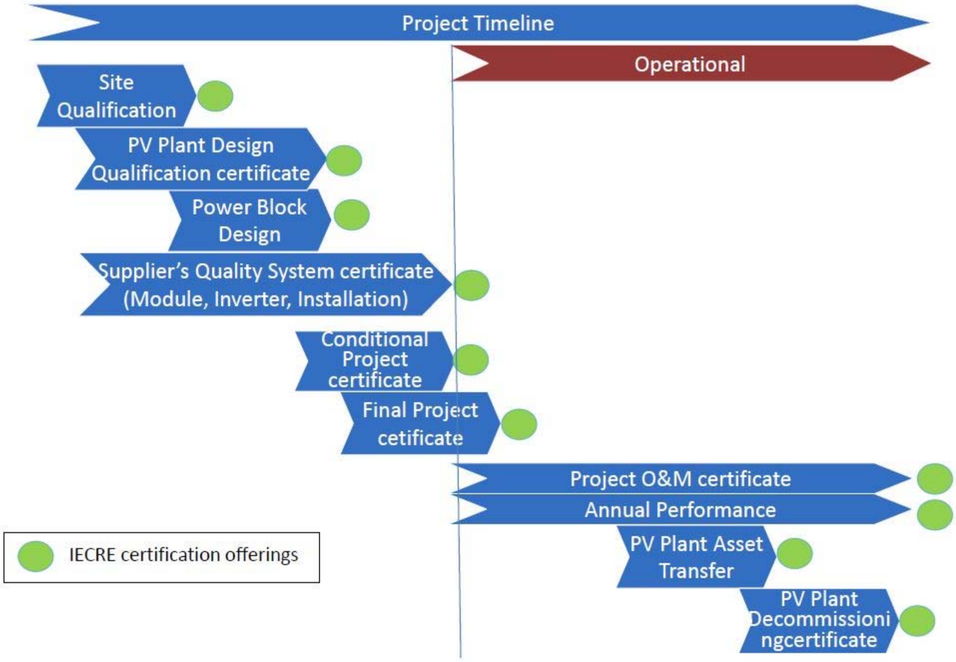
While IECRE utilises standards developed by IEC TC82, the operating documents in IECRE do draw on relevant standards in TC 56 (Dependability) which are useful.

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 stakeholders the confidence that PV power plants conform International Standards for PV equipment (where existing) and will safely perform as promised based on meaningful, transparent and effective third-party reviews. At the same time it also aims at reducing cost by facilitating mutual recognition of relevant certificates. In ultimate analysis, the IECRE certification process aims at achieving more reliable, consistent, safe and cost effective PV plant projects. It represents a step beyond individual standards, in that while IEC writes technical standards, IEC does not define how these are used.

The IECRE 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.



Source: IEC TC82, 2017

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 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 conversion equipment 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 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 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 defined by the Technical Specification CLC/TS 61836 and further 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 ;
4. Module Energy Yield DC; the DC energy produced by a single PV module following the method of calculation described in EN IEC 61853-3 for one or all of the Standard Reference Climatic Profiles tabulated in EN 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 Service Life (see section 4.1.2)
7. Module's 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 evaluated at STC.

The popular 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. However, efficiency on its own does not directly evaluate 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 and evaluation of module conversion efficiency.

The functional unit integrating several of the above functional parameters could be defined as:

"The 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 30 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 standard EN 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 Standard Reference Climatic conditions for PV application are defined in the standard EN 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 for PV with three of these six data sets (or define three data sets specifically for Europe), which are defined in EN IEC 61853-4 as subtropical arid, temperate continental and temperate coastal.

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

1. To use those data sets already included in the EN 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 European already included in the EN 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 EN 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 EN 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 EN 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 correctly perform the methods in the EN 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 or complementary 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 IEC 61730. The latter is now a harmonised standard.

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
	EN IEC 61853-3	Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules	Describes the calculation of PV module energy rating values
	EN IEC 61853-4	Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles	Climate datasets for Europe can be selected from the available six standard reference climatic datasets that cover the entire world
Module Energy Yield AC	-	-	A way of converting the DC energy yield to an equivalent AC Yield
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
	EN IEC 61853-3	Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules	Describes the calculation of PV module energy rating values

Parameter	Relevant Norm / Standard / Regulation	Specific Test Method	Notes
	EN IEC 61853-4	Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles	Climate datasets for Europe can be selected from the available six standard reference climatic 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 likely included in the IEC 60904-1 currently under revision
Module Degradation Rates	-	-	This is expanded under section 4.1.1
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

Parameter	Relevant Norm / Standard / Regulation	Specific Test Method	PV technology
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
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

Parameter	**Relevant Norm / Standard / Regulation**	**Specific Test Method**	**PV technology**
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 60904-13	Photovoltaic devices - Part 13: Electroluminescence of photovoltaic modules	All SJ
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	

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	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	

Relevant Norm / Standard / Regulation	Specific Test Method	Notes
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	
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	

Relevant Norm / Standard / Regulation	Specific Test Method	Notes
IEC TS 63140 (draft)	Photovoltaic (PV) modules – Partial shade endurance testing for monolithically integrated products	
IEC TS 62994 (draft)	Environmental health and safety (EH&S) risk assessment of the PV module through the life cycle - General principles and definitions of terms	Publication foreseen for end 2018
IEC 62759-1	Transportation testing of photovoltaic (PV) modules – Part 1: Transportation and shipping of PV modules stacks	

3.2.2 Power Conversion Equipment

The product category of power conversion 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 DC into AC inverters, but also other instruments to modify the voltage or frequency like DC-DC 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 as the most important PCE for most solar PV installations, there are several parameters that could be considered as the main functional one.

In accordance with the standard IEC 62894 "Photovoltaic Inverters - Data Sheet and Name Plate" or the equivalent EN 50524 "Data sheet and name plate for photovoltaic inverters" (currently under revision with the new draft title "Data sheet 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, but rather at an efficiency that depends on the input power level. Accounting for this, the "European Efficiency" is a parameter that corresponds to an operating efficiency averaged over one 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. These may have working pattern that is different from that of inverters used in stand-alone PV installations.

$$\text{European Efficiency} = 0.03*Eff5\% + 0.06*Eff10\% + 0.13*Eff20\% + 0.1*Eff30\% + 0.48*Eff50\% + 0.2*Eff100\% \quad \text{(Eq. 1)}$$

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 (a factor of 0.05 for Eff100% in Equation 2 compared to 0.2 in Equation 1).

$$\text{CEC Efficiency} = 0.04*Eff10\% + 0.05*Eff20\% + 0.12*Eff30\% + 0.21*Eff50\% + 0.53*Eff75\% + 0.05*Eff100\% \quad \text{(Eq. 2)}$$

The efficiency could in fact be an adequate primary functional parameter for the whole category, 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 only, 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 parameter, 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 over one year of the AC power output from the DC power output of the reference modules and for predefined climatic conditions.

A further elaboration of this approach is to include an assumed inverter's service life of 10 to 15 years depending on the size of the inverter (residential PV system or large PV plant). Such a definition is based on a report [2] by the International Energy Agency (IEA) and on EN 61724. However, in order to estimate the inverter efficiency defined in this way, 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, but that could be used as secondary 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.

The functional unit integrating several of the above functional parameters could be defined as:

"The 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 prEN 50524	Photovoltaic Inverters - Data Sheet and Name Plate Data Sheet and Name Plate for Photovoltaic Inverters Data sheet 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 For the prEN document, the data sheet information is a technical description separate from 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	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 CENELEC, 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 Spanish royal decree RD 1699/2011, which regulates the connection of low-voltage generating plants to the Spanish distribution network. Similar regulations exist in other Member States 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 non-site-specific as much as possible, so that LVRT characteristics measured at one test site can also be considered valid at other sites. The IEC TS 62910 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 numerical simulation and model validation of utility-interconnected PV inverter.

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 stabilised 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 CENELEC 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 EN 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, 4.1.3, 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
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
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 series EN 60068	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 sodium-chloride salt can degrade the performance of parts manufactured using metallic and/or non-metallic materials

Parameter	Standard	Title	Description
Power conversion equipment testing	EN 62093 ED 1	Balance-of-system components for photovoltaic systems - Design qualification natural environments.	Under M/089. 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
Power conversion equipment testing	prEN 62093 ED 2 (draft)	Power conversion equipment for photovoltaic systems - Design qualification testing	In progress at IEC and set for parallel vote at CENELEC. Revised ED 2 of the IEC 62093 ED 1
Bi-directional power converters	EN IEC 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	

Parameter	Standard	Title	Description
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 (draft)	Overall efficiency of grid connected photovoltaic inverters	In progress (currently under translation of the FDIS before publication)
Power conversion equipment	IEC TS 63106-1 (draft)	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 (draft)	Basic requirements for simulator used for testing of photovoltaic power conversion equipment - Part 2 DC power simulator	In progress
Power conversion equipment	IEC TS 63156 (draft)	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 (draft)	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 rechargeable 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 battery 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 durability value for a reference temperature of 20 °C, even though normal working temperature could be significantly higher depending on the actual installation location, thus 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 for the definition of the functional parameter for batteries. However, we consider that the capacity in Ah or Wh is more suitable as primary functional parameter. It is often referenced as C10 or C100 Ah, i.e. the capacity value 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 (a new edition is under revision at IEC and will follow the parallel vote at CENELEC)
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 60896-11	Stationary lead-acid batteries - Part 11: Vented types - General requirements and methods of tests	Applicable to lead-acid cells and batteries which are designed for service in fixed locations (i.e. not habitually to be moved from place to place) and which are permanently connected to the load and to the DC power supply. This part 11 of the standard is applicable to vented types only. This first edition of EN 60896-11 cancels and replaces EN 60896-1 (first edition) published in 1987 and its amendments 1 (1988) and 2 (1990), and constitutes a technical revision.
Batteries	EN 60896-21	Stationary lead-acid batteries - Part 21: Valve regulated types - Methods of test	This part of EN 60896 applies to all stationary lead-acid cells and monobloc batteries of the valve regulated type for float charge applications (i.e. permanently connected to a load and to a DC power supply), in a static location (i.e. not generally intended to be moved from place to place) and incorporated into stationary equipment or installed in battery rooms for use in telecom, uninterruptible power supply (UPS), utility switching, emergency power or similar applications.
Batteries	EN 60896-22	Stationary lead-acid batteries - Part 22: Valve regulated types - Requirements	This part of EN 60896 applies to all stationary lead-acid cells and monobloc batteries of the valve regulated type for float charge applications (i.e. permanently connected to a load and to a DC power supply), in a static location (i.e. not generally intended to be moved from place to place) and incorporated into stationary equipment or installed in battery rooms for use in telecom, uninterruptible power supply (UPS), utility switching, emergency power or similar applications.

Parameter	**Standard**	**Title**	**Description**
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	EN IEC 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
Electrical energy storage systems	IEC TS 62933-3-1	Electrical energy storage (EES) systems - Part 3-1: Planning and performance assessment of electrical energy storage systems - General specification	Applicable to EES systems designed for grid-connected indoor or outdoor installation and operation. It considers: - necessary functions and capabilities of EES systems; - test items and performance assessment methods for EES systems; - requirements for monitoring and acquisition of EES system operating parameters; - exchange of system information and control capabilities required.
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

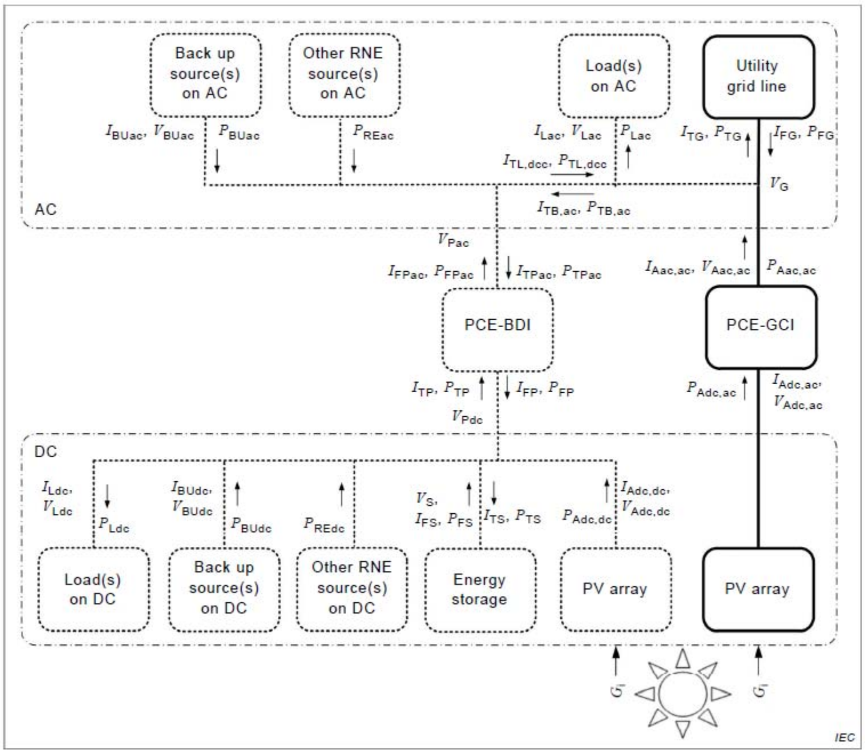
Parameter	Standard	Title	Description
Batteries	IEC TS 62933-5-1	Electrical energy storage systems Part 5-1: Safety considerations for grid-integrated EES systems - General specification	IEC TS 62933-5-1 specifies safety considerations (e.g. hazards identification, risk assessment, risk mitigation) applicable 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
Batteries	prEN 62902	Secondary batteries: Marking symbols for identification of their chemistry	Equivalent draft IEC 62902 is close to end of publication process.
Batteries	prEN 62932-1	Flow battery systems for stationary applications - Part 1: Terminology	Equivalent draft IEC 62932-1 is close to end of publication process.
Batteries	prEN 62932-2-1	Flow battery systems for stationary applications - Part 2-1: performance general requirements and test methods	Equivalent draft IEC 62932-2-1 is close to end of publication process.
Batteries	prEN 62932-2-2	Flow battery systems for stationary applications - Part 2-2: safety requirements	Equivalent draft IEC 62932-2-2 is close to end of publication process.

3.2.3 PV Systems

PV systems vary widely in terms of possible configurations and functions. The main component 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, solar-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 of the PV system is shown schematically in Figure 3. In this report the focus is on a simplified configuration consisting of one PV module array and one PCE 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 ()



Key

RNE renewable energy

PCE power conditioning equipment

BDI bi-directional inverter

GCI grid-connected inverter

Bold lines denote simple grid-connected system without local loads, energy storage, or auxiliary sources.

Source: 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 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, 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. Table 7 lists the standards that could be used to give some basis to the proposed functional parameters discussed hereafter.

System Power Output: EN 61724-1 defines the system nominal or rated DC power (labelled Wp) as the arithmetic sum of the STC power values of the installed PV modules (see section 3.2.1). The AC rated power of the PV system is determined in EN 61724-1 as the smaller value between the sum of the array DC power and the sum of the inverter maximum power ratings.

System Energy Output/Yield: They would be the system's AC energy output, E_o, which is typically calculated as the system power output delivered for a one-year reference period[8], and the system's energy yield, which is defined as the system's energy output normalised to the system's rated DC power as defined above.

There is currently no dedicated standard for calculating the expected[9] 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 the PV module energy yield as per EN 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, etc.).

The environmental data can be a Standard Reference Climatic Profile (from EN IEC 61853-4 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 (although not complete for PV application), 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 Clause 6.2 describes a method for calculating the annual electrical energy output of PV system, $E_{el;pv;out}$:

$$E_{el;pv;out} = E_{sol}.P_{pk}.\frac{f_{perf}}{I_{ref}} \quad \text{(Eq. 3)}$$

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

[8] 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).

[9] 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.

factor and I_{ref} is the reference solar irradiance equal to 1000 W/m^2. The method can also be used with hourly or monthly time steps to arrive at a value for annual energy output. 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. Also, we notice that the detail of the environmental data sets considered and to be provided by the Member States is not adequate for the proper calculation of a PV system energy output or yield. Therefore, the application of this method to PV system reliable energy output predictions would in any case require the use of more detailed information, similar to those included in the Reference Climatic Profiles of the EN IEC 61853-4.

System performance ratio: EN 61724-1 applies the definition

$$PR = \frac{Y_f}{Y_{ref}} \quad \text{(Eq. 4)}$$

where

- Y_f is the final energy yield of the system, 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 PV system already 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. The EN 61724-1 defines the system efficiency as:

$$\eta_f = \frac{E_{out}}{H_i . A_a} = \eta_{A,0} \; x \; PR$$

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 PV system energy yield. This would logically be based on the approach for the Module Energy Yield DC (EN IEC 61853-3) with additional input of system-level considerations.

3.2.3.2 Supporting Standards

Table 8 summarises the main standards that can support the *a posteriori* measurement of the functional parameters defined in the previous section, in particular the series IEC 61724. 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 the ones mentioned in previous sections specifically 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 series HD 60364 regarding low-voltage installations apply to PV systems, including those with storage elements (HD 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 EN 61727 and the EN 62446-1 define the conditions and requirements that they must comply with when connected to the grid.

The functional unit integrating several of the above functional parameters could be defined as:

"*The PV System functional unit is 1 kWh of AC power output supplied under fixed climatic conditions for 1 year (with reference to EN IEC 61853-4) and assuming a service life of 30 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.[10]

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	Photovoltaic system Performance – Part 1: Monitoring	Generic definition in EN 61724-1, but the expected final Energy Yield is required

[10] 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 EN 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
PV arrays	IEC 62548	Photovoltaic (PV) arrays - Design requirements	Defines the design requirements for photovoltaic (PV) arrays including DC array wiring, electrical protection devices, switching and earthing provisions. The scope includes all parts of the PV array up to but not including energy storage devices, power conversion equipment or loads.
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: - this new version is focused on small PV generators up to 100 kWp; - it provides case studies

Parameter	Standard	Title	Description
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
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

Parameter	**Standard**	**Title**	**Description**
Low voltage installations	HD 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
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

Parameter	Standard	Title	Description
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	EN 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	IEC TS 62738	Ground-mounted photovoltaic power plants – Design guidelines and recommendations	Sets out general guidelines and recommendations for the design and installation of ground-mounted photovoltaic (PV) power plants. A PV power plant is defined within this document as a grid-connected, ground-mounted system comprising multiple PV arrays and interconnected directly to a utility's medium voltage or high voltage grid.
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
Grid-connected system	IEC 62446-2 (draft)	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 2: Grid connected systems – Maintenance of PV systems	In progress
Grid-connected system	IEC TS 62446-3	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 3: Photovoltaic modules and plants - Outdoor infrared thermography	
PV systems	IEC TS 63049	Terrestrial photovoltaic (PV) systems – Guidelines for effective quality assurance and PV systems installation, operation and maintenance.	Provides the minimum activities deemed necessary to implement an effective quality assurance program for the managing and reducing of risk in the installation and operation of photovoltaic (PV) systems. This document defines requirements for certifying that an entity has and uses a quality assurance program to prevent, or reduce errors and learns from any new errors in installation, operation and maintenance of a PV system.
Utility interface	EN 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

Parameter	Standard	Title	Description
Power conversion equipment testing	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
Power conversion equipment testing	prEN 62093 ED 2 (draft)	Power conversion equipment for photovoltaic systems - Design qualification testing	In progress at IEC TC82 and set for parallel vote at CENELEC. Revised ED 2 of the IEC 62093 ED 1 (to which the EN 62093 is equivalent)
Cables	EN 50618	Electric cables for photovoltaic systems	Applies to low smoke halogen-free, flexible, single-core power cables with cross-linked insulation and sheath. In particular for use at the direct current (DC) side of photovoltaic systems, with a nominal DC voltage of 1.5 kV between conductors and between conductor and earth. The cables are suitable to be used with Class II equipment. The cables are designed to operate at a normal maximum conductor temperature of 90 °C, but for a maximum of 20 000 hours a max. conductor temperature of 120 °C at a max. ambient temperature of 90 °C is permitted. NOTE The expected period of use under normal usage conditions as specified in this standard is at least 25 years.

Parameter	Standard	Title	Description
Cables	IEC 62930	Electric cables for photovoltaic systems with a voltage rating of 1.5 kV DC	Applies to single-core cross-linked insulated power cables with cross-linked sheath. These cables are for use at the direct current (DC) side of photovoltaic systems, with a rated DC voltage up to 1,5 kV between conductors and between conductor and earth. This document includes halogen free low smoke cables and cables that can contain halogens. The cables are suitable to be used with Class II equipment as defined in IEC 61140. The cables are designed to operate at a normal continuous maximum conductor temperature of 90°C. The permissible period of use at a maximum conductor temperature of 120 °C is limited to 20000 h.
Cables	IEC 62125	Environmental considerations specific to insulated electrical power and control cables	In progress
Cables	CLC/TR 62125	Environmental statement specific to TC 20 - Electric cables	A technical report intended to give assistance to standard-writers of IEC Technical Committee 20, to take into account the relevant environmental aspects as far as they are specific to electric cables in normal use. It also assists them to keep in mind a clear methodology when considering these aspects and when checking possible interaction of the normative requirements with the environment. Also, these guidelines assist standard-writers to avoid too simple or too stringent requirements that might not achieve a favourable global result.

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 (draft)	Solar trackers - Safety requirements	In progress

Parameter	Standard	Title	Description
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 (under revision as EN IEC standard)
Monitoring PV systems	EN 60870 series	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	IEC 61643-31	Low-voltage surge protective devices – part 31: surge protective devices connected to the DC side of photovoltaic installations – requirements and test methods	In the track to become an EN standard under the Frankfurt agreement.
Installation, safety requirements, protection	IEC 61643-32	Surge protective devices connected to the d.c. side of photovoltaic installations - Selection and application principles	
Installation, safety requirements, protection	CLC/prTS 61643-32	Low-voltage surge protective devices - Part 32: Surge protective devices connected to the d.c. side of photovoltaic installations - Selection and application principles	The IEC equivalent standard will become a TS under CENELEC

Parameter	Standard	Title	Description
Safety connectors	EN 62852	Connectors for DC-application in photovoltaic systems - Safety requirements and tests	Amendment in progress. 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 (still in draft) IEC 63092-1 (for BIPV modules) and IEC 63092-2 (for BIPV systems), currently scheduled to be published between late 2019 and beginning 2020. 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 also 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 discussed in the latter standard 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 yet (e.g. system performance factors and degradation effects).

There are specific documents related to safety in building installations like the technical report CLC/TR 50670 "External fire exposure to roofs in combination with photovoltaic (PV) arrays - Test method(s)".

The same definition of the functional unit for generic PV systems (see 3.2.3.2 on page 37) can be applied to BIPV, too. However, it might be necessary to select climatic profiles and/or environmental conditions more appropriate to the BIPV local environment (e.g. higher temperatures compared to open-rack ground-mounted 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 50583-2 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
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 will[11]:

"*…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 materials[12]. 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 PV[13], 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.

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[11] 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"

[12] 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"

[13] 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 the ones indicated in the (still draft) 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 (with reference to initial power) "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 (μc-Si) technologies, although not as plentiful, exhibit degradation around 1 %/year and resemble thin-film products more closely than x-Si" [3]. Jordan et al. underline the difficulty to assign individual rates to different thin-film technologies due to low number of cases reported compared to crystalline silicon based materials. Clearly, when looking at single PV systems there are cases of very low degradation rates (some silicon plants are reported as low as 0.2%), but such data is well below the statistical mean. Interpretation is also complicated due to other factors, for example substantial module replacement and clear initial underrating of the PV system's power among others. Collation of multiple data sources allows for the inclusion not only of the widest set of climatic condition, but also of systems with various states of maintenance/repair. As and when individual cases of lower degradation are collated, they will contribute to make the setting of individual degradation rates for specific materials possible.

4.1.1.2 Power conversion equipment

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 applies 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 EN 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 second edition IEC 62093 "*Power conversion equipment for photovoltaic systems - Design qualification testing*", which is still in draft at the IEC TC82 and will follow the Frankfurt agreement approach, 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 specifically 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 [11]. 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

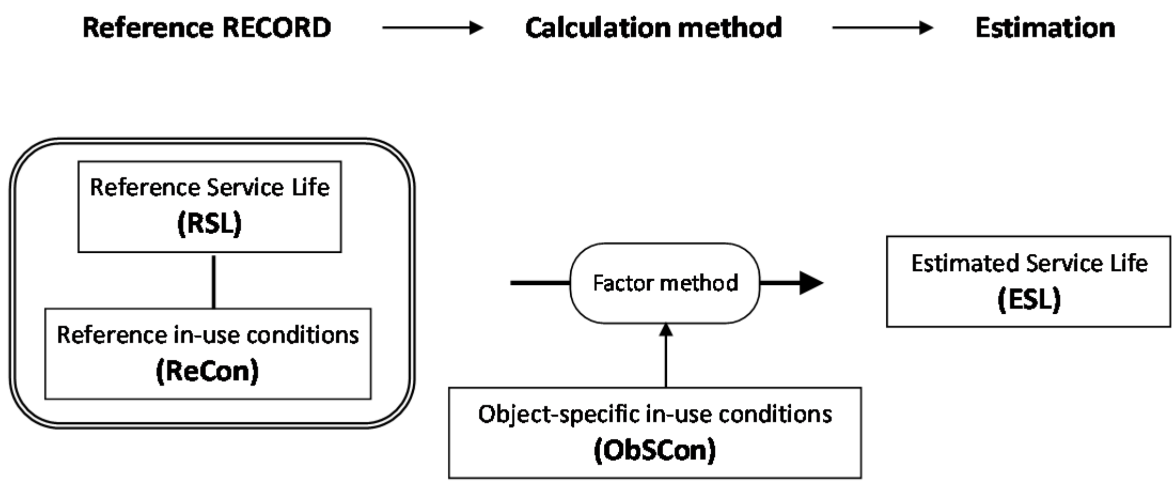
In the case of BIPV systems, the degradation is expected to be even more pronounced than in ventilated open mounting structure. This is mainly due to the higher temperatures reached by the PV modules and components because of the poor air circulation around them. Some of the standards included in section 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 reference climatic year with the operational service life definition combined with the annual linear system degradation rates. This would give an expected energy delivery in KWh (or MWh) for the actual PV systems considering the system’s OSL and 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*”. The latter 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). The 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 entireness 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 categories[14] 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 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 European and IEC standards regarding PV module design qualification and testing (see section 4.2), which 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

An approach to be considered alternative or from which to integrate the previous one could be based on reliability prediction models, which use reliability block diagrams (RBDs) to perform data analysis in terms of energy output. These RBDs are dealt with by the EN 61078. As in the previous approach, also here several parameters influencing the OSL and ESL, like for example degradation as well as outage losses or replacement/ repair costs, could be accounted for through specific factors.

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

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 conversion equipment) 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.

A report jointly written by the International Renewable Energy Agency (IRENA) and the IEA [12] addresses the end-of-life management of PV modules and therefore of PV systems, too. It could be useful for the lifecycle considerations included in other Tasks of the PV preparatory study.

4.2 Quality standards for modules, power-conversion equipment 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 standards 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 and approved as EN 61215 series), 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;
- *IEC TS 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;
- *IEC TS 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);
- *IEC TS 62804-1-1 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1-1: Crystalline silicon – Delamination* (draft), 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);
- *EN 62852 Connectors for DC-application in photovoltaic systems - Safety requirements and tests*;
- *IEC TS 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;

- *EN 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;
- *prEN 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 TS 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 TS 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 a new work item approved at IEC TC82 WG2 to prepare a new technical specification on extended testing, IEC TS 63209 "*Extended-stress testing of photovoltaic modules for risk analysis*" , 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 (EN 61215 for measurements and EN 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 EN 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: (i) as quality check of the incoming material/component or of the PV module production process itself and (ii) as feedback from the production to the design and engineering stage within the overall quality system of the manufacturer.

Additionally, the standards series EN 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 [13]. Assignment of a CPN or other rating methodologies [14] relies on being able to link knowledge about the components and system with the anticipated outcomes. Another possible approach would be the use of RBDs as dealt with by EN 61078. 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;	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	
	EN 61701	Salt mist corrosion testing of photovoltaic (PV) modules	Based on EN IEC 60068-2-52
	EN 62716	Photovoltaic (PV) modules - Ammonia corrosion testing	
	IEC TS 62782	Photovoltaic (PV) modules - Cyclic (dynamic) mechanical load testing	
	IEC TS 62804-1 (draft)	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon	
	IEC TS 62804-1-1 (draft)	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1-1: Crystalline silicon - Delamination	
	IEC TS 62804-2 (draft)	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 2: Thin-film	
	EN 62852	Connectors for DC-application in photovoltaic systems - Safety requirements and tests	Amend ment in progress
	IEC TS 62916	Photovoltaic modules - Bypass diode electrostatic discharge susceptibility testing	
	EN 62979	Photovoltaic modules - Bypass diode - Thermal runaway test	
	prEN 62938 (draft)	Non-uniform snow load testing for photovoltaic (PV) modules	

Parameter	**Relevant Norm / Standard / Regulation**	**Specific Test Method**	**Notes**
	IEC TS 63126 (draft)	Guidelines for qualifying PV modules, components and materials for operation at higher temperatures	
	IEC TS 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	
	EN 61078	Reliability block diagrams	

4.2.2 Power Conversion Equipment

Standardisation documents like the draft technical specification IEC TS 63157 "*Guidelines for effective quality assurance of power conversion equipment for photovoltaic systems*", the 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 IEC 62548 "*Photovoltaic (PV) arrays - Design requirements*" 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 it excludes the energy storage devices, the power conversion equipment and the loads. The IEC TS 62738 "*Grounded-mounted photovoltaic power plants – Design guidelines and recommendations*" provides the general guidelines for the design and installation of ground-mounted PV plants. The AC power plant described in the document comprises multiple PV arrays and is directly interconnected to a utility's medium or high voltage grid. The safety and design requirements are referenced to those in the IEC 62548.

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 grid-connected PV 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. While the draft IEC 62446-2 "*Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 2: Grid connected systems – Maintenance of PV systems*" presents the best practices for PV plant maintenance, IEC TS 63049 "Terrestrial *photovoltaic (PV) systems – Guidelines for effective quality assurance in PV systems installation, operation and maintenance*" describes the minimum activities necessary to implement an effective quality assurance program for managing and reducing the risk in the installation and operation of PV systems.

Another possible approach, to be adjusted for PV systems, would be the use of RBDs as dealt with by EN 61078. More quality standards for the PV system might however be necessary.

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

The WEEE Directive[15] requires the establishment at Member State level of schemes to ensure the separate collection and "proper treatment" of Electrical and Electronic Equipment (EEE). An overall collection rate for EEE is stipulated to rise from 45% in 2016 to 85% in 2019. From 2019, the minimum collection rate to be achieved annually shall be 65% of the average weight of EEE placed on the market in the three preceding years in the Member State concerned, or alternatively 85% of WEEE generated on the territory of that Member State.

Since the 15th August 2018 the scope of EEE was 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

[15] *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)"

EEE category 4(b) "*Large equipment*". Since the 15th August 2018 the minimum applicable targets that shall be achieved for EEE of category 4 are an 85% recovery rate and an 80% rate shall be prepared for re-use and recycling.

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*" and which includes "*small equipment with integrated photovoltaic panels*". The new EEE category applies since 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 inverters[16]:

> *"…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 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 data[17]. The adopted default disposal rate 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 if it 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 specification[18].

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, depending on their configuration and scale:

- Batteries,
- Printed-circuit boards with a surface greater than 10 cm^2,
- Plastics containing brominated flame retardants,
- Chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluoro-carbons (HFC), hydrocarbons (HC),
- External electric cables,

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

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

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

- 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 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, to our knowledge the draft IEC TS 62994 (close to publication) is the only standardisation document being developed specifically in relation to life cycle assessment (LCA) 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, 12, 15] and that partially contributed to the development of the above-mentioned draft 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 materials[12], the IEC TR 62635 and the EN 15804. The IEC TR 62635 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 PV preparatory 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, recyclability rate 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 product[19] should be considered in the specific delivered EPD. This CEN 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 and, where relevant, additional environmental information. For specific and building-specific details see the standard.

Specifically to the PV preparatory 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 subclause 5.2.2 for developing a FU). It is a unit of measure used to:
  (a) Quantify the performance of the product strictly connected to the function it has to deliver;
  (b) Provide the reference by which material's flows are normalised through each stage of the product's LCA (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);

[19] 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.

(b) Mass: [kg]

(c) Length: [m]

(d) Area: [m^2]

(e) Volume: [m^3]

(f) All others have to be converted to this list, with few exceptions including 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 three 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 by-pass diodes), intended to generate DC power under non-concentrated sunlight. In the PV preparatory study (Task 1) 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 30 years.
- Power Conversion Equipment
    - Power conversion equipment, 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 PV 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. A PV system 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 Directive[20]. In the PV preparatory study the proposed functional unit is 1 kWh of AC power output supplied under fixed climatic conditions for 1 year (with reference to EN IEC 61853-4) and assuming a service life of 30 years.

5.2 Standards

5.2.1 General overview

The situation for standards is varied and complex. There are about 120 relevant standards covering aspects on used materials, production, PV modules measurement and safety, power conversion equipment, PV systems and their components including their 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.

[20] *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 may 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 Conversion Equipment
  - For the PCEs the standards regarding materials and design are covered. Dedicated standards are available for PV inverter performance such as EN 50530. This would allow to calculate one single value (for each Reference Climatic Profile, if deemed necessary), which is named "European efficiency", for the inverter functional parameter efficiency or to develop a transitional method for calculating a functional parameter in terms of AC power output at different operating conditions 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 conversion equipment, 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). Standards exist for *a posteriori* on-site power measurement and verification of PV systems. 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 not only on existing monitoring standards or on the module energy-rating standards, but also integrating a model to include as much as reasonably possible the main effects of local environment relevant to the specific geophysical position.
- Degradation, operational service lifetime and circular economy issues.
  - The horizontal standards on sustainability aspects being developed under mandate M/543 are applicable to the PV module, power conversion equipment and PV system categories. However, PV-products specific standards springing from the horizontal ones will have to be developed if the legislation development will require them, considering also the PEF guidelines developed for PV.

5.2.2 Compulsory harmonised standards

Among all those listed in this report, only two harmonised standards series on the low-voltage directive and on the safety of PV products already exist. All other standards or norms are EN, IEC or ISO documents that are generally not harmonised as per the definition given in 3.1. This will need to be addressed in the future, if necessary.

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 conversion equipment

- Calculation of the inverter performance based on a (standardised) reference PV system, consistently with the definition of its functional unit (see end of 3.2.2.1);

— PV Systems

- System energy yield calculation: a transitional method is required.

For all product categories, the definition of a transitional method for quantifying degradation and/or durability must be addressed. In addition, a methodology for defining 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 considering the functional parameters identified per each PV 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 assessment of:

1. Energy Yield of PV systems;
2. Degradation and lifetime of PV modules and systems;
3. Durability and lifetime of inverters for PV;
4. Performance of inverters included in a reference system and under reference conditions;
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 within the current preparatory study. Items 5, 6 and 7 require first the publication of the horizontal standards under EC mandate M/543, publication that is not expected to occur within the time frame of the present PV preparatory study.

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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
EES	Electrical Energy Storage Systems
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
IEA	International Energy Agency
IEC	International Electrotechnical Commission

IECRE	IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications
IRENA	International Renewable Energy Agency
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
RBDs	Reliability Block Diagrams
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

List of figures

Annexes

Annex 1. Energy rating study related to the Ecodesign project

A.1 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/m^2; 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.

A.2 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.

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

E_{tot} is the total energy output (kWh) over the time period analysed, which is normally one year, and H_{tot} is the total in-plane irradiation received at the module's surface (kWh/m^2).

A.3 Energy rating calculation

The procedure followed and described here has been included in the new standard EN IEC 61853-3: *Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules*.

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 power values for the PV module measured at different levels of in-plane irradiance and temperature. Considering the hourly values of effective in-plane irradiance at the specific 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 the location/climate considered and on intrinsic properties of the PV technology analysed. The irradiance is calculated considering two effects. On the one hand, the increased front-surface reflectivity for shallow angles of the incident irradiance reduces the irradiance potentially absorbed by the module; on the other hand, the spectral responsivity of the PV module's active material determines the irradiance that can be effectively absorbed and converted 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 as well as 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 hourly data of ambient temperature and wind speed; in addition, it requires in-plane irradiance data integrated in different spectral bands to apply the spectral effects calculations. The standard EN IEC 61853-4 (*Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles*) provides full standard data sets for 6 climatic reference conditions.

Regarding the specific PV technology under analysis on a case base, the procedure applied requires the spectral responsivity and the PV-technology dependent thermal coefficients used to estimate the temperature of the module, in addition to the above-mentioned matrix of PV power output measured at controlled conditions of irradiance and temperature.

A.4 Practical Examples of PV Module Energy rating

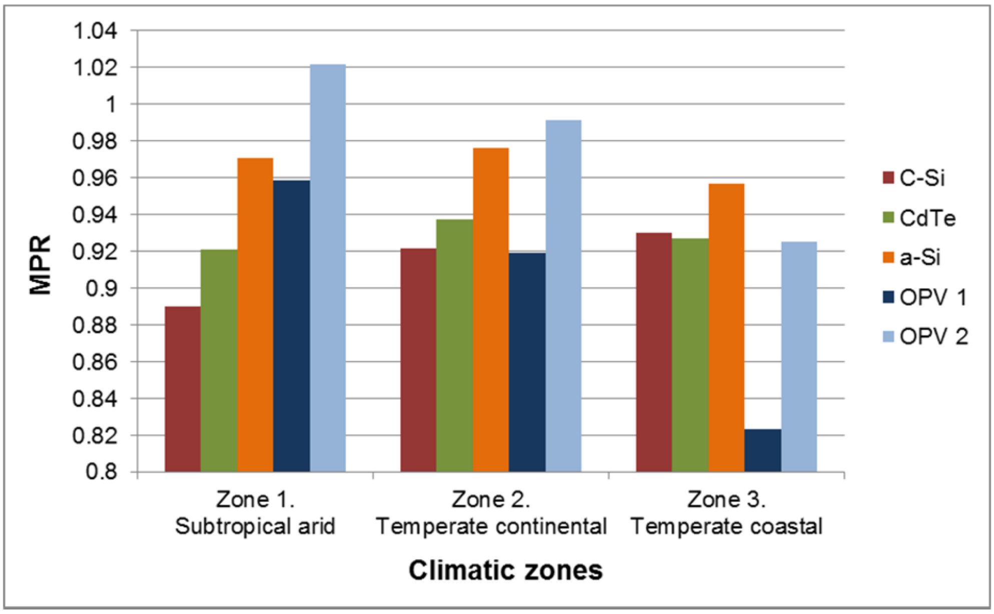
The energy-rating study presented here has been performed at three European locations with distinct climatic conditions, which can be related to three of the six climatic reference profiles included in the standard EN IEC 61853-4. The six reference climates of the EN IEC standard cover the most common weather conditions observed on 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 and that are significant for the PV application (i.e. with (spectral) irradiance and temperature as main contributing agents). For technical and computational reasons, a choice of a real location for each European climate profile had to be done. Therefore, the three European representative climates have been located in South Spain –to describe a subtropical arid 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 European weather conditions for PV, the other three reference climate profiles included in the aforementioned EN IEC standard are tropical humid, subtropical coastal and high elevation (>3000 m). 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 either numerous enough or likely to be used for PV systems deployment in order to require a representative European climate profile for this energy-rating analysis.

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

Even though the current PV market is dominated by c-Si 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 PV technologies.

The MPR values obtained for the three climatic zones 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 the PV technology under examination would achieve with respect to an ideal climate where the environmental conditions were always equal to STC. For example, the MPR result achieved by c-Si in the three zones compared to a-Si or even to organic PV OPV says that c-Si is in fact more affected than the others by the deviations of the actual 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 current 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 currently artificial assumption of the same lifetime 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.

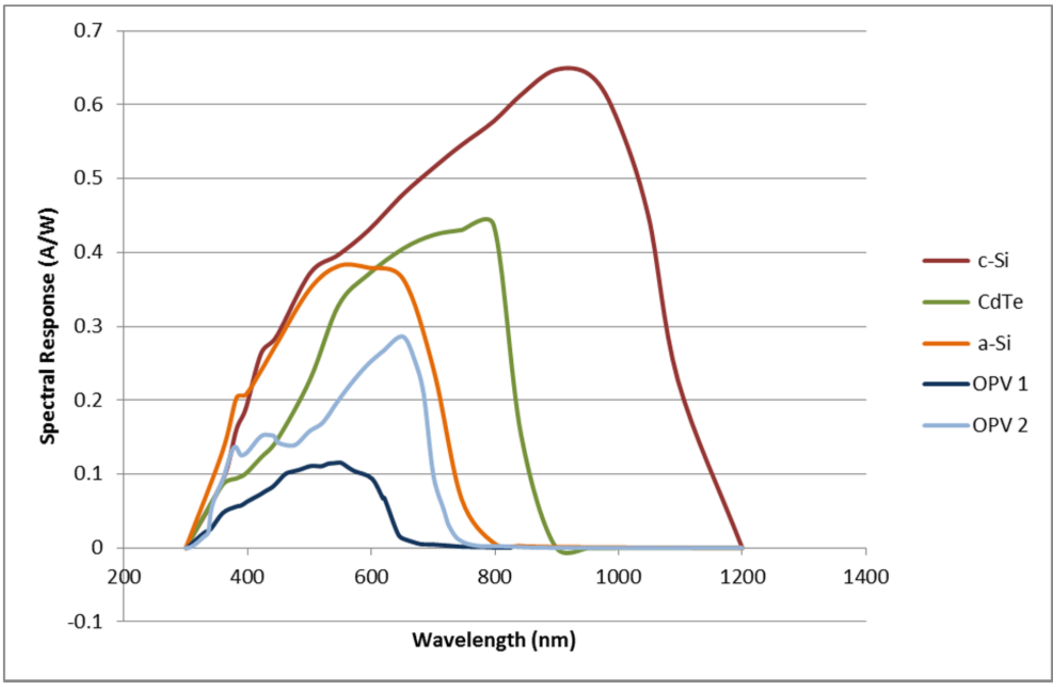


As evident in Figure A1, depending on the location and technology the obtained MPR values are generally below the performance level that would be expected (MPR=1) from considering the devices always at STC. This reflects the fact that the modules temperature often differs from the reference 25 °C, being 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 an inverse correlation is usually 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 quite unusual for PV technologies, i.e. its measured maximum power increased with temperature. This contributed to generate for this device the MPR value above 1 reached at the subtropical arid 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). It has to be highlighted once more, though, that this statement does not consider the degradation of the device.

The spectral effects could also contribute to these high MPR values compared to c-Si, especially for the OPV devices, as generally technologies with narrow spectral responsivity would obtain higher spectral gain. The spectral responsivity of the devices mentioned above 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 each 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 [A2]. However, with the new methodology presented here for MPR estimation and considering the six world reference climatic profiles included in the new standard EN 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 constant STC. 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 emerging PV technology under all climatic profiles. However, due to the assumptions made and to the necessary technical boundaries currently present in the energy-rating approach, this result does not imply that a real OPV system will provide more energy than the other major PV technologies. Indeed, factors that still highly affect the absolute energy performance of OPV devices, like their high degradation rate and low P_{max}, were ignored here. Therefore, considering the overall current status of this emerging technology, OPV cannot be considered for the moment an appropriate option for large-scale PV deployment, but possibly it would better suit niche applications.

A.5 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 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 locations or climatic zones used in the present study are equivalent to those included in the standard EN IEC 61853-4, which could therefore be the source of those to be used in the development of the PV product policy tools. The datasets 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- by 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 through this procedure could help in the decision whether to consider one or more climatic profiles to describe Europe for PV product policy purposes. The results shown here, especially for the c-Si technology support the choice of multiple regions or climatic profiles. The variability in the MPR values obtained at the different climates for CdTe or a-Si is not as significant as for the c-Si, but we would still support the proposal to choose multiple climatic regions.

— the procedures included in the EN 61853 series could also be used to produce realistic energy-yield values for a given module technology under the reference climatic profiles.

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