European Commission

JRC TECHNICAL REPORTS

Transitional methods for PV modules, inverters and systems in an Ecodesign Framework

DG GROW SI2.764246

JRC Nº 34713-2017

Dunlop, E. D.

Gracia Amillo, A.

Salis, E.

Sample, T.

Taylor, N.

2019

Joint Research Centre

EUR 29513 EN

Contact information
Name: Ewan Dunlop
Address: European Commission, Joint Research Centre, Ispra (VA) Italy
Email: ewan.dunlop@ec.europa.eu

EU Science Hub
https://ec.europa.eu/jrc

JRC114099

EUR 29513 EN

PDF ISBN 978-92-79-98284-2 ISSN 1831-9424 doi:10.2760/496002

Luxembourg: Publications Office of the European Union, 2019

How to cite this report: E.D Dunlop, A. Gracia Amillo, E. Salis, T. Sample, N. Taylor, *Transitional method for PV modules, inverters, components and systems*, EUR 29513 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-79-98284-2, doi:10.2760/496002, JRC114099

Contents

Foreword

This document contains proposal for the establishment of transitional methods (related to calculation and testing aspects) in order to facilitate the potential introduction of requirements in the framework of the Ecodesign Directive, Energy Labelling Regulation, Ecolabel and Green Public Procurement.

1 Introduction

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

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

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

The JRC undertook a detailed study of the situation regarding standardisation for these product groups. The conclusions of this study were presented in a report

"Standards for the assessment of the environmental performance of photovoltaic modules, power conditioning components and photovoltaic systems" EUR 29247 EN

The situation for standards is varied and complex. There are over 100 relevant standards covering aspects of used materials, production, PV modules measurement and safety, power conditioning equipment, PV systems and their components and the design, construction and commissioning cycle. However, not all aspects are covered to the same degree, and where certain aspects essential to the implementation of the above measures are not covered the Commission may choose to specify transitional methods, that are implemented as regulations until suitable standards are adopted.

In the following the situation is summarised for the key areas identified in the standards report. The main chapters of this report then detail the corresponding proposals for transitional methods. The annexes provide information on the additional analyses conducted to support the proposed methods.

PV modules

This group is well covered by existing standards for quality of individual components, production, design qualification and type approval as well as power and energy yield. An overall summary can be found in the JRC report "Standards for the assessment of the environmental performance of photovoltaic modules, power conversion equipment and photovoltaic systems" (Publication EUR 29247 EN). 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 operational service life (OSL) definition is still not fully clarified; however, following the future IEC TS 62994, the IEC/TR 62635 and the guidelines in the ISO 15686 series an agreed method will be achievable. The issues of recyclability, reparability and durability should be covered by the Mandate M/543 pre-norms. PV-specific standards deriving from the horizontal ones will be necessary, although we do not foresee particular problems here.

Power Conditioning Equipment

For the PCE's the standards regarding materials and design are covered. Dedicated standards have been developed for PV inverter performance such as EN 50530, which describes the procedure for determining the "European Efficiency" that is provided in the inverter's datasheet. This parameter could be used in the transitional method for calculating a functional parameter in terms of AC power output for a nominal PV array. Regarding the definition of OSL the situation is similar to that for PV modules and again a transitional method may be required, also taking into account field data.

PV Systems

The situation for PV system reflects a combination of that for PV modules and power conditioning components, as well as factors arising from the system location and design. Aspects on PV system design are the subject of new draft norms, including the full construction cycle while the local situation can have a significant effect on the final energy (and therefore on the material balance). On-site power measurement and verification standards exist. However, there is no actual single standard for the calculation of expected energy yield of a PV system. A transitional method would be required here, based on existing monitoring standards or on the module energy-rating standards but also integrating a model to include the effects of local environment relevant to the specific geophysical position.

Degradation, Operational service lifetime and Circular economy issues.

The generic pre-norms being developed under mandate M/543 are applicable to the PV module, Power conditioning and PV system groups definition. PV-products specific standards deriving from the horizontal ones will have to be necessarily developed. This will be an independent standardisation work, even though collegial knowledge and data already collected in other initiatives might be considered, too. These include for example the PEF guidelines developed for PV.

The degradation of PV modules, components and systems is still subject of debate and scientific investigation. No European or International standard exists at present to define the degradation of photovoltaic (PV) modules, inverters and PV systems and to give an accepted standardised procedure to evaluate it. Therefore, a transitional method that could be used to support the European legislation for PV product categories is needed until the lack of standards is solved. The approaches that were considered for the evaluation of the degradation of PV modules, inverters and PV systems include:

- Prescribed values.
- Experimental determination.
- Estimation method similar to the one in ISO 15686 series for "Buildings and construction assets".

These are not all feasible at present due to the limited amount of validated measured data for some of them. In particular, the latter is considered at present premature and therefore not included in this document. Also, the available accelerated tests, which address some specific failure modes and that could be the base for the second approach, are not considered fully representing all the degradation paths that PV modules and systems could meet when installed outdoors, because several factors influence the degradation of these products.

For these reasons, the approach that is proposed as the default method among those mentioned above is the use of prescribed values, based on long-term experimental data collected on real PV modules and systems that have been mounted outdoors in the last 30-35 years. It has to be mentioned, though, that the majority of these systems have been installed only recently in a wide range of climatic conditions. Therefore, additional monitoring and data collection is needed to strengthen the values.

As a consequence, the transitional method will have to be revised once additional knowledge is available. Moreover, as the PV sector is constantly evolving and improving the existing technologies, the present document gives the possibility to the manufacturer to claim lower values than those prescribed under the condition of presenting robust and assessable measured data to support them.

In addition we present methods for Inverter Efficiency loss effects and PV System Energy yield calculation. Regarding the inverter' performance and its contribution to the final AC energy yield of the PV system, various methodologies have been analysed taking into consideration the available information commonly provided by the manufacturers and the existing standards related the energy rating of PV modules and inverter efficiency. A detailed description of the different methods evaluated is presented in Annex B of the present document.

At present, there are no available standards for the estimation of the expected AC energy yield from a PV system over its lifetime. In this document, a method is proposed taking into consideration real working conditions affecting the PV array DC energy output based on EN IEC standards, as well as the PV system degradation over its assumed service life. Additional considerations are presented so as to model all types of PV systems, including grid-connected, off-grid and BIPV systems.

Finally the topics of disassemblability, dismantlability and remanufacturability are addressed.

2 Prerequisites

It is considered that component products and systems will have achieved pass or conformity to all relevant design qualification, type approval and safety tests as a pre-condition for entering the regulatory framework.

2.1 PV Modules

In case of PV Modules this would be successful completion of the harmonised standard EN IEC 61730 to conform the Low Voltage Directive (LVD) (2014/35/EU). Details on the harmonised standards series are included in Annex A.

Also required are:

- achievement of "pass" of the series of standards EN 61215 for design qualification and type approval test of PV modules (Table 1); and
- PV module energy rating as specified in the series of standards EN 61853 (Table 1).

Table 1 Requirements to be satisfied as prerequisites for PV modules. The table includes also the standards needed for application of the transitional methods proposed in the following sections.

Prerequisite Norm/ Standard/ Regulation	Test Method	Notes
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	Required for crystalline silicon only
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	For cadmium telluride (CdTe) only

Prerequisite Norm/ Standard/ Regulation	**Test Method**	**Notes**
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.	For amorphous silicon (a-Si) only
EN 61215-1; EN 61215-1-4; EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se)2 based photovoltaic (PV) modules Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	For copper indium (gallium) selenide or sulphide based PV (CI(G)Se / CI(G)S) only
EN IEC 61730-1	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction	Mandate M/511 on Directive 2014/35/EU
EN IEC 61730-2	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing	Mandate M/511 on Directive 2014/35/EU
EN 61853-1	Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating	Measurements required for EN IEC 61853-3 calculations
EN 61853-2	Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements	Measurements required for EN IEC 61853-3 calculations

Prerequisite Norm/ Standard/ Regulation	**Test Method**	**Notes**
EN IEC 61853-3	Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules	Required for PV modules and for the application of transitional methods for inverters and for PV system AC energy yield
EN IEC 61853-4	Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles	Pre-defined input for EN IEC 61853-3 calculations

2.1.1 Summary comparison of EN IEC 61730 with EN 61215

Contrary to the general quality assurance approach of the EN 61215 series, the EN IEC 61730 deals with the safety of the PV modules strictly connecting it to the final application for which they will be installed. Indeed, some of the safety tests requirements are of general application, in order to ensure the basic safety of the products from the manufacturing over the installation to the final use. Some other requirements and tests are applicable only to PV modules belonging to specific class for protection against electric shock or to specific characteristics of the PV modules themselves (see Annex I Section 1.2).

As detailed in Annex I, 13 out of 32 (MST) tests required by the EN IEC 61730 are equivalent to tests (MQT) included in the EN 61215 series of standards.

Care must be taken in assuming the exact equivalence of these tests in terms of safety qualification (EN IEC 61730) as compared to design qualification and type approval (EN 61215). Complying with individual tests for design qualification (MQT tests) may lead to an erroneous assumption that compliance with (part of) EN IEC 61730 is also obtained (MST tests). Although the equivalence between those MST tests shared with the MQT tests (listed in section 1.3 of Annex I) can be drawn in terms of test execution and observable result, their inclusion in the overall test sequence for either safety (EN IEC 61730-2) or design qualification (EN 61215-1) is strictly specific to the type of qualification and therefore to the specific series of standards considered. The flow sequence of tests to be followed for safety qualification (Figure 1 in EN IEC 61730-2) is significantly different from the one to be followed for PV modules design qualification and type approval (Figure 1 in EN 61215-1).

From this point of view, equivalence may not be drawn in general and PV modules must undergo both tests sequences as per EN IEC 61730-2 and EN 61215-1 in order to be assessed in terms of their safety besides their performance and some degree of resistance to environmental conditions.

2.2 Inverters

As a minimum prerequisite the relevant European safety standards and the design qualification of BOS (EN 62093) should be applied. In addition, the performance of the EN 50530 is required for the application of the transitional method for inverter energy yield. These standards are listed in Table 2.

Table 2 Requirements to be satisfied as inverters prerequisites and standard needed for the transitional methods application

Relevant Norm/ Standard/ Regulation	**Specific Test Method** **Transitional method parameter**	
EN 62477-1	Safety requirements for power electronic converter systems and equipment - Part 1: General	
EN 62109-1	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements	
EN 62109-2	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters	
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	
EN 62093	Balance-of-system components for photovoltaic systems - Design qualification natural environments.	
EN 62116	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures	
IEC TS 62910	Utility-interconnected photovoltaic inverters - Test procedure for low voltage ride-through measurements	
IEC 61683	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency	Transitional method – AC energy yield
EN 50530	Overall efficiency of grid connected photovoltaic inverters	Transitional method – European Efficiency, AC energy yield
EN IEC 61853-3	Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules	Required for the application of transitional methods for inverter and PV system AC energy yield
EN IEC 61853-4	Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles	Transitional method – AC energy yield

2.3 Systems

For systems, the standards identified as prerequisites for PV modules and PCEs are also applicable. Table 3 contains only the specific additional standards required.

Table 3 Pre-requisite requirements for PV systems and standard needed for the application of transitional methods

Relevant Norm/ Standard/ Regulation	**Specific Test Method** **Transitional method parameter**	
IEC 62548	Photovoltaic (PV) arrays - Design requirements	
HD 60364-7-712	Low-voltage electrical installations - Part 7-712: Requirements for special installations or locations - Photovoltaic (PV) systems	
EN 62124	Photovoltaic (PV) stand-alone systems - Design verification	
IEC TS 62738	Ground-mounted photovoltaic power plants – Design guidelines and recommendations	
EN 62446-1	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection	
IEC 62446-2 (draft)	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 2: Grid connected systems – Maintenance of PV systems	
IEC TS 62446-3	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 3: Photovoltaic modules and plants - Outdoor infrared thermography	
EN 50583-1	Photovoltaics in buildings - Part 1: BIPV modules	
EN 50583-2	Photovoltaics in buildings - Part 2: BIPV systems	

2.4 Other system components

Other system components such as cables and connectors are covered in Table 4

Table 4 Requirements to be satisfied as other components prerequisites and standard needed for the transitional methods application

Relevant Norm/ Standard/ Regulation	**Specific Test Method** **Transitional method parameter**	
EN 62852	Connectors for DC-application in photovoltaic systems - Safety requirements and tests	
EN 62920	Photovoltaic power generating systems - EMC requirements and test methods for power conversion equipment	
EN 61000	Electromagnetic compatibility (EMC)	
EN 61427-2	Secondary cells and batteries for renewable energy storage — General requirements and methods of test. Part 2: on-grid applications	
EN 62509	Battery charge controllers for photovoltaic systems - Performance and functioning.	
prEN 62093 ED 2 (draft)	Power conversion equipment for photovoltaic systems - Design qualification testing	
EN 50618	Electric cables for photovoltaic systems	
IEC 62930	Electric cables for photovoltaic systems with a voltage rating of 1.5 kV DC	
EN 62817	Photovoltaic systems - Design qualification of solar trackers	
IEC 63104 ED1 (draft)	Solar trackers - Safety requirements	
EN 60269-6	Low-voltage fuses - part 6: supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems	
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	
IEC 61643-32	Surge protective devices connected to the DC. side of photovoltaic installations - Selection and application principles	
CLC/prTS 61643-32	Low-voltage surge protective devices - Part 32: Surge protective devices connected to the DC side of photovoltaic installations - Selection and application principles	

3 Degradation and Failure Rates

For the definition and requirements given in this section some assumptions have to be made, as degradation and even more failure rates can depend on the size and on the configuration of the considered PV system. The size of the PV installations is classified (as stated in Task 2 "Market data and trend" of the Preparatory Study for Solar Photovoltaic Modules, Inverters and Systems) in terms of peak power as:

- Residential: up to 10 kW of peak power;
- Commercial: from 10 to 250 kW of peak power;
- Industrial: above 250 kW of peak power;
- Utility-scale: above 1 MW of peak power.

3.1 Definition of degradation rate

The degradation rate τ_{deg} for each PV product category is defined as the annual percentage decrease of the PV product's power output, when compared to the initial value, assuming the decrease to be constant in time and considering the same testing conditions under which the initial value was measured. If P_0 is the initial value of the power output, τ_{deg} can thus be expressed by:

$$\tau_{deg} = \left(\frac{P(t)}{P_0} - 1\right) \cdot \frac{1}{t} \qquad \text{(Eq. 1)}$$

where P is the value of the power output after an amount of years equal to *t*. The degradation rate τ_{deg} is therefore expressed in terms of %/year.

3.2 Failure rate

The failure rate is defined as the percentage of equal/equivalent products that stop functioning per year. Replacement of a product is considered to be due to a failure, either because of irreversible degradation or because of safety issue. For photovoltaic modules, inverters and systems this is usually reported as a linear rate per year during the operation of the system (%/year during operational life). It is accepted that the actual real failures may not follow a linear behaviour but for purposes of material estimation the linear rate is sufficiently accurate.

3.3 PV modules

3.3.1 Prescribed values

The degradation rate values of PV modules shall be distinguished on the basis of the PV technology considered and according to the following list, which is supported by the most recent peer-reviewed literature and international relevant reports [1-3]. The following prescribed values are based on the widest possible observation of market deployed technologies, for innovative materials the degradation should be taken as that of "thin/film and heterojunction PV technologies" unless it is known to be significantly poorer or until sufficient data can be presented to justify change (see section 3.3.2):

— Degradation rate for mono- or polycrystalline Si modules: 0.7 %/year;

— Degradation rate for all *thin-film and silicon heterojunction* PV technologies: 1 %/year.

3.3.2 Validated Measurement Values

When a PV module manufacturer wishes to claim a lower value for the degradation rate compared to those given in 3.3.1, the lower claimed value shall be justified by means of robust experimental data collected from the measurement of field deployed systems.

This data should cover at least 5 (five) consecutive years.

The experimental data shall cover all the climatic profiles that are considered in the calculation of the annual energy yield of PV modules.

The data shall be collected from at least 2 (two) separate geographic locations in each climatic zone.

It should contain open rack ground-mounted, roof-mounted and building added and or building integrated systems (at least 2 of the four options must be included).

The assigned degradation rate shall be the average of all collected degradation rates from above.

The collated report on the observed degradation rates shall be made available upon request of the Authorities responsible for market surveillance for control and verification.

3.3.2.1 Guideline for the data collection

Protocols for data collection and measurement quality shall respect the guidance given in EN 61724-1 and IEC 61724 series.

3.4 Inverters

3.4.1 Prescribed values

No values are available for the degradation rate of inverters, therefore no prescribed values can be given. The inverter is assumed to be either functioning or not.

Typical failure rate is equal to 10% per year.

3.5 PV systems

3.5.1 Prescribed values

The degradation rate values of PV systems shall be distinguished on the basis of the PV technology considered and according to the following list, which is supported by the most recent peer-reviewed literature and international relevant reports [1]:

- Degradation rate for systems with mono- or polycrystalline Si modules: 0.7 %/year;
- Degradation rate for systems with *thin-film and silicon heterojunction* PV technologies: 1 %/year.

3.5.2 Validated Measurement values

When a PV System manufacturer wishes to claim a lower value for the degradation rate compared to those given in 3.5.1 the lower claimed value shall be justified by means of robust experimental data collected from the measurement of field deployed systems.

This data should cover at least 5 (five) consecutive years.

The experimental data shall cover all the climatic profiles that are considered in the calculation of the annual energy yield of PV modules.

The data shall be collected from at least 2 (two) separate geographic locations in each climatic zone.

It should contain open rack ground-mounted, roof-mounted and building added and or building integrated systems (at least 2 of the four options must be included).

The assigned degradation rate shall be the average of all collected degradation rates from above.

The collated report on the observed degradation rates shall be made available to the National Authorities responsible for market surveillance for control and verification.

3.5.2.1 Guideline for the data collection

Protocols for data collection and measurement quality shall respect the guidance given in the EN 61724-1 and IEC 61724 series.

4 Operational Service Lifetime

4.1 Definition of lifetime

Technical lifetime is the total time period during which a product can technically function before it reaches a limiting state that makes it unsuitable to further operation. However, actual operational service lifetime of a product can be influenced by factors such as cost/benefit analysis of replacement and maintenance.

4.2 Lifetime values

The lifetime value of the PV product categories are given according to the following list, which is supported by the most recent peer-reviewed literature and international relevant reports [1-3]:

1. PV modules: **30 years**;
2. Inverters and electronic components: **10 years**;
3. Cabling: **30 years**;
4. PV systems: **30 years**.

NOTE: Although the lifetime of PV systems might be in principle indefinite if an appropriate maintenance is assured, it is reasonable to estimate a value close to the one given for modules with the additional inclusion of replacement of the inverter once or twice in the given lifetime of the system (at least for small installations and to be considered in LCA).

5 Transitional method – Calculation of Inverter Performance Functional Parameter for AC power output from a reference PV system

5.1 Introduction

5.1.1 Definition

The IEC TS 61836 "*Solar photovoltaic energy systems – Terms, definitions and symbols*" defines the inverter as an 'electric energy converter that changes direct electric current to single-phase or poly-phase alternating currents', being 'one of a number of components that is included in the term "power conditioner"'.

In line with this definition, the main function of PV inverters is the conversion of the DC power received from the PV modules array into AC power suitable with the grid requirements or the downstream consumer. In addition to this, the inverter is also responsible of controlling the operating point of the PV array, adjusting it to its Maximum Power Point (MPP tracking) so as to maximize the power output from the PV array.

5.1.2 PV inverter types

The IEC TS 61836 identifies different types of inverters which can be classified according to their features or properties as follows:

- Power output characteristics: current control, high frequency link, voltage control inverter
- Grid interaction: grid-connected, grid-dependent, grid-interactive, non-islanding, stand-alone inverter
- PV array interaction: central, string, module integrated inverter.

As stated in the Task 1 report "*Product scope*" of the "*Preparatory study for solar photovoltaic modules, inverters and systems*" after the stakeholders' consultation, all inverters should be included in the scope of this preparatory study.

5.1.3 Functional unit

The functional unit for PV inverters is defined in Task 1 report "*Product scope*" of the *"Preparatory study for solar photovoltaic modules, inverters and systems"* as "*1 kWh of AC power output from a reference photovoltaic system (incorporating the efficiency of a specific inverter) under predefined climatic and installation conditions as defined for a typical year and for a service life of 10 years*".

Hence, the aim of the present section is to propose a methodology to model the PV inverter performance and its contribution to the estimation of the AC power output or energy yield from a reference PV system as required in the functional unit definition.

5.2 Input data for PV inverter performance model

The proposed methodology accounts for the inverter's DC to AC conversion efficiency as we assume that the PV array connected to it always works at its maximum power point (MPP). Therefore, the MPP tracking efficiency is not considered. The suggested methodology was compared to other modelling approaches as detailed in Annex B. PV inverter modelling.

The proposed methodology requires two main input data as described in the following:

5.2.1 DC energy yield

Following the EN 61853 series of standards *"Photovoltaic (PV) module performance testing and energy rating"* it is possible to estimate the DC energy yield from a reference 1 kWp PV module array over a year (kWh/year). Additionally, following the inverter's functional unit definition, Part 4 of the series of standards entitled "*Standard reference climatic profiles*", contains six datasets that represent the most common climatic conditions that PV systems may encounter worldwide. Out of these six, three are considered representative of the European climate conditions: subtropical arid, temperate continental and temperate coastal, which will be referred to in the present document as Sub, Temp and Coast respectively. More information on the European reference climatic datasets can be found in Annex F.

Therefore, following the EN 61853 series we could obtain the DC energy yield from a reference 1 kWp PV array for the three European representative reference climates: EY_{DC_Sub}, EY_{DC_Temp} and EY_{DC_Coast} expressed in kWh/year per installed kWp.

The final output of the EN IEC 61853-3 standard is not the energy yield but the *Climate Specific Energy Rating* parameter (*CSER*) calculated according to Equation 2.

$$CSER = \frac{EY_{DC}\,(kWh/year)\ \cdot\ G_{ref}\,(W/m^2)}{P_{max}\,(W)\ \cdot\ H_p\,(kWh/m^2 \cdot year)} \qquad \text{(Eq. 2)}$$

Where *EY* is the DC energy output from the PV module under consideration, calculated on hourly basis over a year, G_{ref} is the STC irradiance (1000 Wm^{-2}), P_{max} is the maximum power of the PV module under consideration as stated in the datasheet and measured under STC conditions, and H_p is the yearly irradiation received by the plane of array ($kWh{\cdot}m^{-2}{\cdot}year$).
If instead of considering the performance of one single PV module as described in the EN 61853 series, the performance of a reference 1 kWp PV array is analysed as in the proposed transitional method, the *EY* used in Equation 2 would be the DC energy output from the PV array, while P_{max} would be 1000 W as the installed reference PV array. In both cases, the resulting *CSER* value would be the same.

If EN 61853 series were to be applied by PV manufacturers, they could include in the PV module's datasheet the *CSER* value obtained for that particular PV module for the six reference climatic profiles provided in Part 4 of the Standard. Focusing on the three European reference climates, knowing the corresponding *CSER* values ($CSER_{Sub}$, $CSER_{Temp}$ and $CSER_{Coast}$) and the global irradiation at the reference climatic profiles ($H_{p,Sub}$, $H_{p,Temp}$ and $H_{p,Coast}$), the calculation of the yearly DC energy yield of a 1 kWp array of that particular PV module will be straightforward, according to Equation 3.

$$EY_{DC}\,(kWh/year) = \frac{CSER\ \cdot\ P_{max}\,(W)\ \cdot\ H_p\,(kWh/m^2 \cdot year)}{G_{ref}\,(W/m^2)} \qquad \text{(Eq. 3)}$$

The yearly in-plane irradiation depends on the climatic conditions, while the *CSER* value will depend as well on the PV module under consideration. For the three European reference climatic conditions, the H_p values are shown in Table 5.

If PV manufacturers included the *CSER* parameter in the PV module's datasheet, with the yearly irradiation values of Table 5 and applying Equation 3, it would be possible to easily estimate the yearly DC energy yield from a 1 kWp PV array. Otherwise, it would be necessary to apply the methodology described in the EN IEC 61853-3 standard.

Table 5 Yearly in-plane irradiation (kWh/m^2·year) for the three proposed reference climatic conditions.

Reference climatic condition	Yearly in-plane irradiation, H_p (kWh/m^2·year)
Subtropical arid	2295.452
Temperate continental	1266.003
Temperate coastal	972.934

5.2.2 PV inverter efficiency

The EN 50530 "*Overall efficiency of grid connected photovoltaic inverters*" describes the procedure for calculating the Euroefficiency or European efficiency (η_{EUR}), which is an average weighted efficiency for a full year of power distribution of a middle-Europe climate. Notwithstanding, this value is always reported in the inverter's datasheet, so it is directly available.

5.3 Inverter functional parameter estimation

The first step is the estimation of the AC energy yield (EY_{AC}) from a reference PV system over the period of a year for the different reference climatic conditions considered. The output of the EN IEC 61853-3 provides the DC energy yield for these climatic conditions, so their product by the European efficiency provide an estimate of the AC energy yield, as shown in Equations 4 to 6.

$$EY_{AC\_Sub} \text{ (kWh/year per installed kWp)} = \eta_{EUR} \cdot EY_{DC\_Sub} \quad \text{(Eq. 4)}$$

$$EY_{AC\_Temp} \text{ (kWh/year per installed kWp)} = \eta_{EUR} \cdot EY_{DC\_Temp} \quad \text{(Eq. 5)}$$

$$EY_{AC\_Coast} \text{ (kWh/year per installed kWp)} = \eta_{EUR} \cdot EY_{DC\_Coast} \quad \text{(Eq. 6)}$$

From the yearly AC energy output (EY_{AC}) obtained from 1 kWp PV array for the different reference climates, the inverter functional parameter, $FP_{inverter}$, can be calculated according to Equation 7:

$$FP_{Inverter\_Climate\ N} = \frac{1\ (kWh\ of\ AC) \cdot 1\ (kWp\ PV\ array)}{EY_{AC\_Climate\ N}\ (kWh\ of\ AC/year)} \quad \text{(Eq.7)}$$

Considering the three reference climatic datasets selected for Europe from those included in the EN IEC 61853-4, there will be three different values for the functional parameter for every inverter, one per reference climate ($FP_{inverter\_Sub}$, $FP_{inverter\_Temp}$ and $FP_{inverter\_Coast}$).

5.4 General considerations

5.4.1 Size of the inverter and PV module array

The relative size of the inverter (AC or DC capacity) in relation to the PV module array nominal power depends on the size of the system and should be that so as to maximize the performance of both components. As stated in the Task 2 report "*Market data and trend*" of the "*Preparatory study for solar photovoltaic modules, inverters and systems*" in residential PV systems the size of both components is "closely related", in industrial PV systems the "inverter AC capacity may be less than the module DC power", while for utility scale systems "the inverter AC capacity will tend to be significantly less than the module DC power, with an indicative range for the ratio being 1.2 – 1.4".

In the analysis described in Annex B. PV inverter modelling, two different sizing values have been applied to quantify the impact in the functional parameter estimation: 1.25 more suitable for utility scale systems and 1.1 better suited for small PV systems.

Although it would seem reasonable to define specific sizing ratios for the same categories of PV systems as those used in the Task 2 report (residential, industrial and utility scale), the results obtained show a limited impact of the sizing factor on the AC energy yield and consequently on the inverter's functional parameter value obtained for the five inverters considered in the Annex B analysis. For further information, please check Subsection B3.4 in Annex B.

5.4.2 DC power output

We assume in the proposed methodology, as it is considered in the EN 61853 series of standards, that the PV module array works at its maximum power point.

5.4.3 Efficiency dependency on working conditions: input voltage, power output and temperature

The efficiency of the inverter depends on the working conditions mainly defined by the received DC power from the PV array and the temperature reached by the inverter and its components. As presented in Annex C. PV inverter review, the IEC 62894 "*Photovoltaic inverters – Data sheet and Name plate*" indicate that manufacturers should include in the inverter's datasheet information about the operating efficiency at three different input and eight different output voltages. Normally this information is provided graphically, in what it is known as the efficiency curve. This curve plots the efficiency in the Y axis against the output power, often normalized, in the X axis. As requested by the IEC 62894 standard, three different curves are included, for three different input voltages.

The proposed methodology for the inverter performance estimation uses the Euroefficiency as input data, which is a weighted average value derived from the efficiency values plotted in the efficiency curve. As presented in Annex B, the efficiency curve values were considered in some of the alternative methodologies analysed. However, the additional complexity of these methodologies, the derived accuracy gain compared to the Euroefficiency based method, in addition to the non-guaranteed availability of the efficiency curve values (refer to Annex C. PV inverter review) supports the final proposed methodology based on the Euroefficiency value instead.

Regarding the temperature dependence behaviour of the inverter, as stated in the EN 50530 standard, the measurements of the inverter's efficiency curve values, which are required to calculate the European efficiency are to be performed at an ambient temperature of 25 °C ± 2 °C. However, the efficiency tends to decrease with temperature after certain threshold values as stated by some manufacturers (Annex C). These temperature values refer to ambient temperature. However, the local temperature depends on many factors including the installation conditions and the presence of cooling systems. Besides, a model to relate the temperature of the inverter and its components with the ambient temperature has not been identified. Consequently, and conditioned as well by the heterogeneous information, even sometimes missing information regarding this derating behaviour, provided by manufacturers, the model proposed to simulate the inverter's performance and estimate its functional parameter does not account for this temperature effect in detail. Our proposal is to assume a global derating factor, similarly to how the PV system losses are accounted for in the transitional method proposed for PV systems energy yield estimation. The proposed derating factor ranges from 0.02% to 1.8%, according to the values obtained in the simulations presented in Annex B. Notwithstanding, other methods have been analysed to model the temperature derating effect on the inverter behaviour (Please, see Annex B. PV inverter modelling, subsection B3.3)

5.5 Example of the proposed methodology. Results

Following the analysis described in Annex B PV inverter modelling, the functional parameter for the different inverters considered there as part of a residential PV system for the subtropical arid reference climatic condition are shown in Table 6 as an example. Values are calculated following Equation 7.

Table 6 Functional parameter for the inverters presented in the Annex B. PV inverter modelling. Subtropical arid reference climate.

Inverter	*European efficiency*	EY_{AC_Sub} (kWh of AC/year · installed kWp)	Functional parameter, $FP_{inverter\_Sub}$
1	94.5	1933.689	$5.17 \cdot 10^{-4}$
2	93.6	1844.411	$5.42 \cdot 10^{-4}$
3	93.6	1899.195	$5.27 \cdot 10^{-4}$
4	91.8	1992.532	$5.02 \cdot 10^{-4}$
5	90.9	1996.590	$5.01 \cdot 10^{-4}$

6 Transitional methods – Determination of the Energy Yield of PV systems

6.1 Introduction.

6.1.1 Definition

As stated in the "*Standards for the assessment of the environmental performance of photovoltaic modules, power conditioning components and photovoltaic systems*" report a photovoltaic (PV) system could be defined as a power system designed to supply usable electrical power by means of photovoltaic modules. It consists of an arrangement of several components. The PV modules, which absorb and convert sunlight into electricity, constitute the main one. Other components known collectively as Balance of System (BOS) include switches, wiring, controls, meters and Power Conversion Equipment (PCE). Out of PCEs, the inverter, which changes the electric current from direct (DC) to alternate (AC), is the main element. Other components of the PV system may include mounting structures, solar tracking system or energy storage systems, like batteries.

We assume the PV system include all the elements up the AC output part of the inverter. Therefore, the AC cables which link the inverter to the grid interface or the transformer, if present, are not considered part of the PV system.

6.1.2 PV systems types

PV systems can be classified according to their properties or features as follows:

- Spatial arrangement: centralised, distributed
- Configuration: grid-connected, off-grid system
- End-use: residential, commercial, industrial or utility-scale

This last classification is usually related to the installed capacity of the PV system according to the following ranges as stated in the Task 2 report "*Market data and trend*" of the "*Preparatory study for solar photovoltaic modules, inverters and systems*":

- Residential: up to 10 kW
- Commercial: from 10 to 250 kW
- Industrial: above 250 kW
- Utility-scale: above 1 MW

According to Task 4 "*Technical analysis including end-of-life"* of the "*Preparatory study for solar photovoltaic modules, inverters, and systems",* PV systems can be classified as well in relation to its configuration and maintenance applied in the following three types, which will be used in the transitional method for the definition of the PV systems losses. The three considered PV configurations, from low maintenance requirements to detailed surveillance of its performance, are:

- Configuration A. Default installation
- Configuration B. "A" plus optimised design and yield forecasting
- Configuration C. "B" plus optimised monitoring and maintenance

6.1.3 Functional unit

The functional unit assumed for PV systems is defined in Task 1 report "*Product scope*" of the "*Preparatory study for solar photovoltaic modules, inverters and systems"* of the PV preparatory study as "*1 kWh of AC power output supplied under fixed climatic and* *installation conditions as defined for a typical year (with reference to EN IEC 61853-4) and for a service life of 30 years*".

After analysing the available international standards, it was identified the lack of an agreed methodology to estimate the performance of PV systems as prerequisite for the estimation of their functional unit. Therefore, the aim of the present section is to propose a method to model the performance of PV systems. Due to the wide range of possible configurations, such as grid connected, off-grid systems or BIPV, the proposed methodology is the concatenation of various models that account for the behaviour of the main components of PV systems: PV modules, PCE (inverter) and cables. The methodology accounts for different losses and degradation of the PV system so as to model its performance over the defined service life of 30 years of the functional unit definition.

6.2 PV systems performance model

The proposed model of the performance of a PV system is the concatenation of the performance models for its main components: PV array, inverter and cables, as well as other losses affecting the AC energy output from the PV system.

6.2.1 PV module

The first step in the estimation of the PV system energy yield is the estimation of the PV array DC energy yield (EY_{DC}).

The EN 61853 series of standards "*Photovoltaic (PV) module performance testing and energy rating*" defines a methodology to estimate the performance of PV modules considering real working conditions defined by six datasets representative of the major climatic conditions likely to be encountered by PV installations worldwide. The estimation of the PV energy output takes into consideration various effects, like the irradiance being reflected at the module's surface and therefore not used, the spectral content of the irradiance which results in different PV technologies providing different output under the same irradiance conditions, or the temperature reached by the module that can significantly modify its performance. Taking these effects into consideration enables a more realistic estimation of the energy output of the PV modules than by just considering the power output declared by the manufacturer in the module's datasheet.

The modules are assumed to be installed in a free standing rack, facing the equator with an inclination angle of 20°. No local horizon effects or presence of obstacles are taken into account in the methodology described in this Standard series.

The calculation is based on one year of hourly values as provided in the climatic datasets included in Part 4 of the said standard ("*Standard reference climatic profiles*"). Therefore, the output of the standard is the yearly DC energy output produced by 1 kWp of the PV modules under consideration for the different reference climatic datasets in 8760 hourly values or as their yearly sum. As stated in Section 5.2.1, if PV manufacturers provided the EN IEC 61853-3 output parameter, the *Climate Specific Energy Rating* for the different climatic datasets, the estimation of the yearly DC energy yield of 1 kWp system could be easily obtained. Please refer to Section 5.2.1 for more information.

Regarding energy yield and rating for bifacial modules the present version of the IEC 61853 energy rating standard does not address this. An IEC technical specification on bifacial module power measurement has been published by IEC (IEC TS 60904-1-2:2019 *Photovoltaic devices - Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices*) which can be used to establish peak power. A method for accounting for bifaciality effects may be introduced at a later stage in this transitional method, also taking into account a plausible level of albedo for the residential systems under consideration based on literature results.

6.2.2 Power Conditioning Equipment. Inverter

The functional unit of PV systems requires the estimation of its AC energy output, therefore a conversion from DC PV array output to AC is needed. To that aim, we need to model the inverter's performance, for which the methodology described in Section 5.3 would be applied. Besides the yearly DC energy yield retrieved from the PV array (EY_{DC}, kWh/year per installed kWp), the other required input data is the European efficiency (EN 50530), η_{EUR}, provided at the inverter's datasheet.

6.2.3 PV system losses

There are several losses inside a PV system and for every component in particular. Unless specifically calculated, losses in cables will be accounted for as part of the general system losses, which is a single value for the whole system, η_{system_loss}. In this regard, it may be appropriate to define different system losses according to the size of the system, whether it is residential, commercial, industrial or utility-scale PV system.

However, the proposal to define the η_{system_loss} considers different losses with different values for the three PV system configurations presented in Subsection 6.1.2.

Besides cables losses, other factors are considered which can reduce the estimated energy yield of the PV system such as presence of soiling, dust or partial shading, connectors or losses due to mismatch in the technical characteristics of the PV modules of the same array. All these factors are included in the PV system losses, but their value depends on the PV system configuration. Unless specifically declared by the PV system installer, the proposed methodology includes a set of default values for the different types of losses and PV system configurations, as shown in Table 7.

A detailed description of the proposed method to define the PV system losses is presented in Annex D. PV system losses.

Table 7. PV system losses for the three defined system configuration from section 6.1

Losses	Range (%)	Configuration A (%)	Configuration B (%)	Configuration C (%)
Soiling	2 – 25	5	3.5	2
Shading	0 - 10	5	2.5	0
Mismatch	1.5 - 3	2	1.75	1.5
Connectors	0.3 – 1	0.5	0.4	0.3
Inverter derating	0.1 – 1.8	1	0.55	0.1
DC cabling	1 - 3	2	1.5	1
AC cabling	0.7 - 2	1	0.85	0.7

6.2.4 AC energy yield

Combining the elements described in the previous subsections, the estimation of the annual PV system's AC energy yield (*System* EY_{AC}) can be performed following Equation 8.

$$\textit{System } EY_{AC} \text{ (kWh/year per installed kWp)} = \eta_{EUR} \cdot (1- 0.01 \cdot \eta_{system\_loss}) \cdot EY_{DC} \quad \text{(Eq. 8)}$$

Where η_{EUR} is the European efficiency of the inverter, η_{system_loss} are the system losses expressed in % and EY_{DC} is the DC energy yield from the PV array, expressed in kWh/year per installed kWp as resulted from the EN 61853 methodology.

6.3 PV systems functional parameter estimation

The first step for calculating the functional parameter of any PV system is the estimation of its energy yield over its lifetime, which is considered to be 30 years as stated in the functional parameter definition.

Equation 8 provides an estimate of the PV system AC energy output over a year, which is considered to be the installation year of the system (System EY_{annual_0}). In order to estimate the energy yield over the assumed lifetime (System $EY_{AC\_lifetime}$), Equation 9 is applied.

$$System\ EY_{AC\_lifetime} = System\ EY_{annual\_0} \cdot T_{lifetime} \cdot \left(1 - \tau_{deg} \cdot \frac{T_{lifetime}}{2}\right) \quad \text{(Eq. 9)}$$

Where $T_{lifetime}$ would be the considered service life of the PV system (30 years) and τ_{deg} would be the PV system annual degradation rate, which depends mainly on the PV modules degradation rate, as the other components are mainly subjected to failure, not degradation. The degradation rate is assumed constant over the lifetime of the PV system.

Once the energy yield of 1 kWp PV system is estimated over its lifetime, it is possible to calculate the installed kWp that would be required to obtain 1 kWh of AC power as defined in the functional parameter. This could be estimated according to Equation 10, which considers an average energy yield over the lifetime (EY_{av}) of the considered PV System calculated as $EY_{AC\_lifetime}$ / $T_{lifetime}$.

$$FP_{system\_Climate\_N} = \frac{1\ (kWh\ of\ AC) \cdot 1\ (kWp\ PV\ system)}{EY\ av\ (kWh\ of\ AC/year)} \quad \text{(Eq.10)}$$

Considering the three reference climatic datasets selected for Europe, there will be three different values for the functional parameter for every system, one per reference climate (FP_{system_Sub}, FP_{system_Temp} and $FP_{system\ \_Coast}$).

6.4 General considerations

As mentioned in the introduction, there are many different types of PV systems, which may have different configurations and components, for example in the case of a system including storage.

6.4.1 Installation and Location Specific Energy Yield

For systems with different assumed module installation configurations (orientation and inclination) than those used in the EN 61853 series (20° inclination and equator facing), additional procedures are needed in order to estimate the in-plane effective irradiance as input to the EN IEC 61853-3 methodology.

In the case that policy measures are adopted it is possible to make available a tool or online application which implements all of the formal standard inputs defined here, including the reference standard Climatic data sets and the algorithms defined in the transitional methods in a fixed platform. This would allow stakeholders to input their own specific data sets (according to the components of system) and calculate the specific result. Some flexibility such as change of inclination or orientation may be incorporated (See Annex E for an analysis of the effect of these variables on the *CSER* value). This tool, however, is not a PV modelling or sizing software, but it is only to check conformity with requirements under potential policy measures.

In the case that site specific energy yield is required by the regulations a Geographical defined European wide reference data set must be defined. This differs from the reference climate data sets defined in EN IEC 61853-4 in that it must include also geographic location data. Such a data set may be created for example from the PVGIS online tool.

6.4.2 Building integrated PV systems

For BIPV systems, in addition to the location specific factors such as orientation and inclination, the temperature reached by the modules should be accounted for. This can be done following the EN 61853 methodology, but using different thermal coefficients (u_0 and u_1). At present, the said standard does not define how to obtain these coefficients for BIPV modules, as its scope is based on PV modules installed on a free standing rack.

6.4.3 PV systems with battery storage

Modelling the performance of PV systems with energy storage would require additional models not considered in Subsection 6.3. To be rigorous, it would be necessary to model the battery's working cycles of charge and discharge, the state of charge and the efficiency of the battery which, in turn, depends on other factors such as temperature, longevity, etc. In addition to this, it would be necessary to have consumption profiles which depend on the end user. For an accurate modelling of the performance it would be necessary to perform, at least, hourly calculations so as to model the flow of energy between the different components (PV array, battery, load, inverter and grid). The standard EN IEC 61853-3 used for modelling the DC energy yield already provides hourly values. Regarding the inverter, the method based on the European efficiency could be applied for the hourly calculations, or alternatively an hourly efficiency could be applied. This approach is described in the Annex B. PV inverter modelling as Method 2.

A simplified approach would be to apply a fixed loss factor to reflect the battery's nominal load cycle performance.

6.5 Datasets for Europe

The estimation of the functional unit of the PV system requires using fixed climatic conditions (with reference to EN IEC 61853-4. Three of the six datasets of Part 4 "*Photovoltaic (PV) module performance testing and energy rating – Part 4: Standard reference climatic profiles*" represent the weather conditions PV systems installed in Europe will most likely encounter. These are:

- Subtropical arid
- Temperate coastal
- Temperate continental

To perform more specific analysis for particular PV plants and locations, the same variables contained in the IEC standard datasets could be obtained from tools like PVGIS.

A description of the three reference climatic datasets is presented in Annex F. European reference climatic profiles.

6.6 General overview of the PV System Lifetime AC Energy Yield estimation

Considering the proposed methodologies for the inverter's performance estimation (Section 5), for the quantification of the various PV system losses (Section 6.2.3 and Annex D) and for the PV system's AC energy yield estimation (Section 6.2), the present section provides an overview of the complete methodology that results from the combination of those and provides a methodology to estimate the AC power output produced by a PV system over its lifetime. The methodology, as shown in Figure 1, includes five steps described in the following subsections.

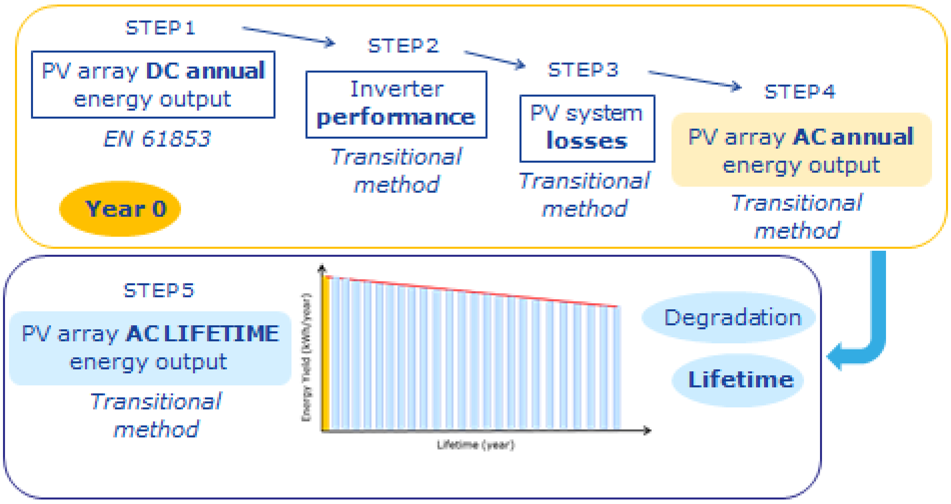


Fig 1. Complete methodology to estimate the lifetime AC energy yield from a PV system.

6.6.1 Step 1. PV array DC annual energy output

The starting point is the estimation of the DC power output from the PV array over a year, which is considered the first year of installation. This step is the only one of the complete calculation chain that is based on existing standards, in particular, on the EN 61853 series of standards "*Photovoltaic (PV) module performance testing and energy rating*".

The outcome of this step, which relates to Part 3 of the aforementioned standard, is the DC power output, either expressed as annual energy output (kWh/kWp installed), or as the 8760 hourly energy output estimates (kW/kWp installed) that sum up to the annual DC energy output. Therefore, the EN 61853 series supports doing the subsequent steps at both yearly and hourly based calculations. Depending on the methodology and assumptions finally applied at each step, the yearly calculations may be accurate enough or it may be that the hourly calculations are required.

6.6.2 Step 2. Inverter performance

As described in Annex B. PV inverter modelling, different methods have been analysed to assess the performance of the PV inverter. Based on the available information provided by manufacturers (See Annex C. PV inverter review), the complexity of the method and the relative accuracy gain derived from considering more complex methods, the proposed methodology is based on the Euroefficiency, which is available in the inverter's datasheet, and the annual DC energy output from Step 1. As a result, the AC power output delivered from the inverter would be calculated on a yearly basis as the product of those two parameters, the Euroefficiency and the annual DC power output.

However, the efficiency of the inverter depends on various factors like its temperature or other working conditions like the input DC power or voltage from the PV array. In order to take into consideration the effect of these working conditions on the inverter's performance an hourly calculation would be more accurate than the yearly proposed methodology so as to model the hourly efficiency. A yearly calculation does not allow a detailed quantification of these effects as these are modelled as derating factors.

Some of the methods analysed in Annex B perform the AC power output calculation based on hourly calculations, considering every hour the DC input voltage and the temperature of the inverter in the AC output estimation. After quantifying these effects and their impact, the yearly calculation is proposed. However, if considered necessary, the hourly calculation of the PV inverter performance could be applied.

6.6.3 Step 3. PV system losses

Up to this point, no losses other than those quantified in the EN 61853 methodology linked to the PV module performance and the DC to AC conversion efficiency of the inverter, have been considered. The former include losses due to the spectral effects (spectral response of the PV module and spectral content of the received irradiance), angle of incidence (irradiance reflected at the module's surface) and the intrinsic performance of the PV module under lower irradiance or high module temperature conditions.

The approach considered to quantify the PV system losses is detailed in Annex D. PV system losses. Basically, three different PV system configurations are considered which would be subjected to the same type of losses. However, the extent of these losses depends on the PV system configuration. The three PV system configurations are:

- Configuration A. Default installation
- Configuration B. "A" plus optimised design and yield forecasting
- Configuration C. "B" plus optimised monitoring and maintenance

It is assumed that the Default installation will be subjected to the typical values of the range assumed for each loss type, while the Optimised monitoring and maintenance configuration is considered affected by the lowest possible system losses.

The PV system losses considered include losses due to the wiring, the connectors, mismatch within the PV modules of the array and presence of soiling and shading. Since the definition of the PV system includes every component up to the AC output of the inverter, either DC or AC wiring losses are applicable, depending on the use of microinverters or regular inverters. If microinverters are used, there will be AC wiring losses, while if regular inverters are used, we will only assume DC wiring losses.

An additional loss is considered linked to the temperature derating of the inverter efficiency. Especially if its performance is calculated as a yearly calculation (Step 2), the temperature effect on its efficiency will be accounted for applying a derating factor as an additional PV system loss.

This, and the other considered losses are applied as derating factors to the AC energy output estimated at Step 2.

6.6.4 Step 4. PV array AC annual energy output

From the AC energy output estimated at Step 2 and the PV system losses defined in Step 3, it is possible to estimate the annual PV array AC energy output. This is done by considering the various losses as derating factors of the AC energy output delivered by the inverter.

The first four steps provide an estimate of the annual AC energy output from the PV system under consideration. The estimation is done assuming a new installation where components have not yet been subjected to degradation. This is the scope of the fifth and last step of the complete methodology.

6.6.5 Step 5. PV array AC lifetime energy output

The AC energy output generated by the PV system over its lifetime is estimated assuming constant over the years both the solar radiation received by the PV array and the PV system losses. These assumptions result in a constant yearly AC output over the PV system lifetime as well, and equal to the value estimated in the Step 4. However, the effect of degradation of the different components must be accounted for. This is done by applying a linear degradation factor which decreases the yearly AC energy output year by year as depicted in Figure 1.

The sum of these "degraded" yearly AC energy output over the time period assumed as lifetime of the PV system provides the estimation of the AC lifetime energy output (AC MWh/kWp), as described by Equation 9.

6.7 Demonstration of PV System Energy Yield Determination and Labelling

An Excel tool has been prepared to demonstrate the calculation of the PV system losses, the lifetime AC energy yield following the method described in section 6.6, together with a proposal for the energy label for residential PV systems (<10 kW). The parameter provisionally proposed for the label is the lifetime AC energy yield normalized to the installed peak power and the area of the installed modules. The units are therefore kWh/kWp.m^2.

Some comments about the demonstration tool

- The calculation is made for a user-defined system at a location in any of the three reference climate zones. The user has to provide relevant details of the proposed PV module and inverters, as well as of the best estimate of actual system losses. Starting from a nominal system size in kW, the actual system size is calculated for the minimum number of physical modules needed i.e. the actual KWp will be slightly higher than the nominal value.
- The user-requested (nominal) DC power of the array is translated into an actual DC power dependent on the precise number of modules used. This latter value, the real DC power determined by the minimum number of modules, is the one used in the calculations.
- The effect of an inclination and/or orientation different to that used in IEC 61853, is accounted for by a correction factor applied to the CSER value.
- Characteristics of the module, including efficiency, area and Pmax are considered.
- For inverters, a) the user should specify if a microinverter is used or not, since this affects the AC or DC loss value to be considered for the system; b) the size (AC power rating) of the inverter is considered only to give a warning to the user when the ratio DC PV array/AC nominal power is above 1.25.
- For the PV system losses, a set of values are provided including default, minimum, typical and average values. The user can decide directly to use the default values (by a Y/N question), which is the worst case scenario, or define their own values, following the recommendations and warning messages that may appear in that section of the tool. For example, if a loss is defined as 0 a warning message will appear, as losses cannot be defined as 0.
- The tool calculates the Performance ratio of the group Module-Inverter and also for the whole PV system, including the PV system losses and the degradation effect.
- For the Lifetime AC Energy yield estimation, degradation, lifetime and climatic data are used. The results are normalized to the installed peak power and the area of the installed modules. And the Energy label is defined according to this variable (kWh/kWp.m^2).

Table 8 shows the AC energy yield calculated for a PV system for the year of installation (Year 0) and over its lifetime as derived from the tool. The results are expressed in kWh, kWh/kWp installed and. The lifetime AC energy yield of the PV system expressed in kWh/kWp·m^2 installed is the variable proposed for the energy labelling classification of the PV system. For the considered example, the obtained classification under the three reference climates is shown in Figure 2.

Table 8. PV system's AC energy yield estimation

	kWh	kWh/kWp	kWh/kWp·m^2
Year 0	5242	1638	98.859
Lifetime	133668	41771	2521

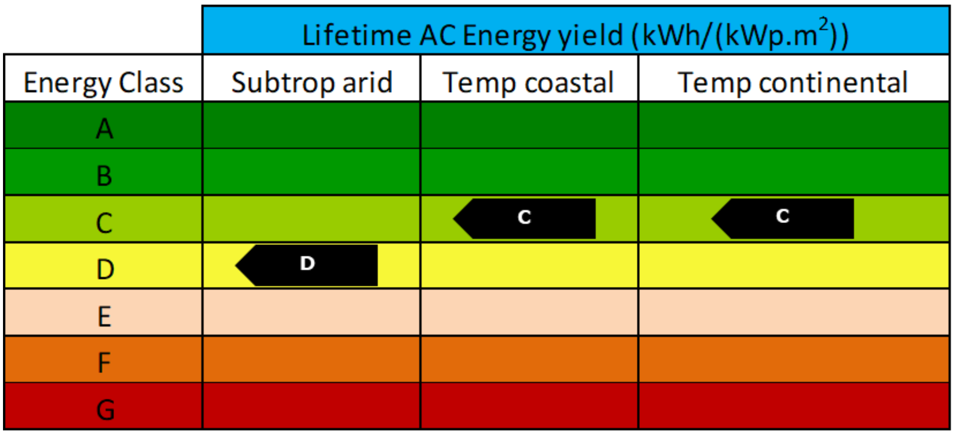


Fig 2. Proposed assigned energy label for the considered PV system based on the lifetime AC energy yield expressed in kWh/kWp·m^2 for the three reference climates.

7 Transitional Method for Dismantlability of PV Modules

The development of standards for Dismantlability of PV Modules, Disassembilability of PV Systems and Remanufacturing of PV systems are being developed under the mandate M/543 horizontal Standards. The definition of these horizontal standards due in 2019 will facilitate the development of dedicated or transitional standards for the PV specific products. PV modules are also within the scope of the series EN 50625 that deals with Collection, logistics & Treatment requirements for WEEE and is being developed under mandate M/518.

8 Transitional Methods for Disassemblability of PV Systems

The development of standards for Dismantlability of PV Modules, Disassembilability of PV Systems and Remanufacturing of PV systems are being developed under the mandate M/543 horizontal Standards. The definition of these horizontal standards due in 2019 will facilitate the development of dedicated or transitional standards for the PV specific products. Components of PV systems are also within the scope of the series EN 50625 that deals with Collection, logistics & Treatment requirements for WEEE and is being developed under mandate M/518.

9 Transitional Methods for Remanufacturing of PV Systems

The development of standards for Dismantlability of PV Modules, Disassemblability of PV Systems and Remanufacturing of PV systems are being developed under the mandate M/543 horizontal standards. The definition of these horizontal standards due in 2019 will facilitate the development of dedicated or transitional standards for the PV specific products. Components of PV systems are also within the scope of the series EN 50625 that deals with Collection, logistics & Treatment requirements for WEEE and is being developed under mandate M/518.

References

[1] Jordan Dirk C, Kurtz Sarah R, VanSant K and Newmiller J 2016 Compendium of photovoltaic degradation rates Prog Photovoltaics Res Appl 24 978-89

[2] International Energy Agency. Köntges M, Kurtz Sarah R, Packard C, Jahn U, Berger K A, Kato K, Friesen T, Liu H and Van Iseghem M 2014 Review on failures of photovoltaic modules

[3] Jordan D and Kurtz Sarah R 2014 Reliability and Geographic Trends of 50,000 Photovoltaic Systems in the USA. In: 29th European Photovoltaic Solar Energy Conference and Exhibition, (Amsterdam) pp 2208-15

Annexes

Annex A. Design and Safety Qualifications of PV modules: EN 61215 and EN IEC 61730 at comparison

A.1 Design qualification (EN 61215) and accelerated tests

A.1.1 The series EN 61215 on PV modules design qualification and type approval

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 was 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*.

A total amount of at least 10 modules is required to run the tests included in the series of standards EN 61215. Table A.1 gives the complete list of tests included in the series EN 61215. It also reports the Module Qualification Test (MQT) code associated to each of them in order to give an immediate reference for the discussion that will be made later on the series EN IEC 61730 (see section A.2).

Table A.1. Coding of tests included in the series EN 61215.

Test code	Test Name	Reference to other standards for test specifications[1]
MQT 01	Visual inspection	-
MQT 02	Maximum power determination	EN 60904; EN 60891
MQT 03	Insulation test	-
MQT 04	Measurement of temperature coefficients	EN 60891
MQT 05	Measurement of nominal module operating temperature (NMOT)	EN 61853-2
MQT 06	Performance at STC and NMOT	EN 60904; EN 60891
MQT 07	Performance at low irradiance	EN 60904; EN 60891
MQT 08	Outdoor exposure test	EN 61853-2
MQT 09	Hot-spot endurance test	-
MQT 10	UV preconditioning test	-
MQT 11	Thermal cycling test	-
MQT 12	Humidity-freeze test	-
MQT 13	Damp heat test	EN 60068-2-78
MQT 14	Robustness of terminations	EN 60068-2-21; EN 62790
MQT 15	Wet leakage current test	-
MQT 16	Static mechanical load test	-
MQT 17	Hail test	-
MQT 18	Bypass diode testing	-
MQT 19	Stabilisation	-

[1] This is given as merely informative reference here. The original test procedure and/or requirements may be different from those actually included in the EN IEC 61215 series. The latter must be referenced for the tests coded in this table.

A.1.2 Additional standards with accelerated tests for design and safety qualification purposes

In addition to those mentioned above, 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. Its present foreseen date of publication is October 2019;
- *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;

Table A.2 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. The series EN IEC 61730, specific on safety qualification of PV modules, is dealt with in more detail in the next section.

Further information on the acceleration factors that have 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[2] (included as well in Table A.2), 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 TC 82 WG 2 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 A.2).

The series EN 62788 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 [A.1]. Assignment of a CPN or other rating methodologies [A.2] 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 and the PV community in general has not yet agreed upon the best approaches for gathering and using the information needed for quantifying overall risk.

[2] "Measurement procedures for materials used in photovoltaic modules"

Table A.2. Quality standards for PV modules and their components, including some safety aspects.

Standard	Specific Test Method	Notes
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
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
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
EN 61215-1; EN 61215-1-4; EN 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se)2 based photovoltaic (PV) modules Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	CIGS
EN 61701	Salt mist corrosion testing of photovoltaic (PV) modules	Based on EN IEC 60068-2-52
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	

Standard	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	
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	Amendment in progress
IEC TS 62916	Photovoltaic modules - Bypass diode electrostatic discharge susceptibility testing	
EN 62979	Photovoltaic modules - Bypass diode - Thermal runaway test	

Standard	Specific Test Method	Notes
prEN 62938 (draft)	Non-uniform snow load testing for photovoltaic (PV) modules	Final stage
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	
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

A.2 The series EN IEC 61730 on PV modules safety

A.2.1 Scope and exclusions

The EN IEC 61730 series of harmonised standards addresses PV modules qualification from the point of view of safety with regard to the persons' as well as to the environmental protection. The series is composed of two parts:

1. *EN IEC 61730-1 Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction*, which gives the fundamental construction requirements to provide safety of PV modules in their operation;
2. *EN IEC 61730-2 Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing*, which describes the individual tests to be run together with their sequence in order to qualify a PV module from the point of view of its safety.

The safety aspects considered in this series of standards address electrical and mechanical topics. Specific requirements for prevention of electrical shock, fire hazards and personal injury due to mechanical and environmental stresses are also considered. Environmental protection from possible danger caused by the PV module presence has to be assured, too.

The EN IEC 61730 series applies to all flat plate PV modules intended to be mounted in open-air climate and as part of a system with maximum DC voltage of 1500 V (i.e. 1.5 kV). It is applicable to all technologies of PV modules, independently from whether they are based on crystalline silicon or on thin-film semiconductor materials. However, for specific applications (see below) additional ISO standards as well as regional or national legislation might be needed in order to encompass all the requirements for PV installation and use in their intended final location. For this reason, a minimum amount of 10 modules is required plus a number of modules for the fire test which varies depending on the local applicable legislation.

The EN IEC 61730 series does not address specific requirements necessary for products made of a PV module combined to a power conversion equipment or some other electronic device (e.g. for monitoring or controlling of the PV module part). Consequently, products like PV modules with integrated (micro-) inverters, converters or other electronic devices capable of disabling the output of the PV module part are not specifically covered by this series of standards.

While complying with EN IEC 61730 assures qualifying the mounting and wiring methods in terms of safety aspects of the PV modules, it does not assess the safety or the suitability of those methods for the specific intended use (e.g. specific application or system configuration) of such modules. These may be ruled by regional or national legislation.

Additional requirements to those set in the EN IEC 61730 series (e.g. ISO standards or other codes) may also be necessary for the following PV modules applications, depending on the local valid regulations:

(a) Marine applications;

(b) Vehicle applications;

(c) Agricultural applications;

(d) Building-attached PV (BAPV);

(e) Building-integrated PV (BIPV);

(f) Applications in locations with a snow or wind load larger than the one tested according to IEC 61730-2;

(g) Applications where the environmental temperature (as measured and documented by meteorological services for the specific location) falls outside the range (-40 ; 40) °C;

(h) Application in locations with explosive or corrosive atmosphere;

(i) Concentrating PV modules (CPV);

(j) PV modules with applied electronics (e.g. with micro-inverters).

A.2.2 EN IEC 61730-1

The EN IEC 61730-1 sets the general frame of the construction constraints for the electrical and mechanical safety of PV modules with regard to persons' and environmental safety. This is addressed in terms of electrical insulation as well as of the mechanical and thermal endurance of the PV module's constituent materials and of the device as a whole. The standard also limits the context of its validity to the allowed application of PV modules on the basis of the classification given in the Table A.3 below and defined in IEC 61140.

The series EN IEC 61730 considers only products of classes II, 0 and III. The strongest requirements are set for class II, which includes electrical products that can come in contact with general public, and class 0, which includes those products that are installed in areas where only trained and specialised personnel can access; nevertheless, class 0 requires the same safety tests as class II. All electric products that by voltage (below 35 V DC) as well as current (below 8 A) limitations (which imply power limitation to 240 W) are considered intrinsically safe fall under Class III. For the latter, some of the tests prescribed in the EN IEC 61730-2 are not compulsory.

A.2.3 EN IEC 61730-2

The EN IEC 61730-2 defines the tests that a PV module has to fulfil in conjunction with compliance to EN IEC 61730-1 in order to be considered safe from an electrical and mechanical point of view. Furthermore, as done in the EN 61215 series, this standard defines the sequence of tests to be followed and the minimum number of samples to be used for each step of the testing sequence in order to qualify a PV module type as safe under the scope of the series EN IEC 61730.

Table A.4 lists all the tests included in the EN IEC 61730-2, sorted by their Module Safety Test (MST) code. The second column reports the test name and the third column gives information relative to other norms or standards on which the test is based. This reference, unless clearly specified with the footnote "Equivalence in test procedure", is given as informative reference only because the actual test requirements in the EN IEC 61730-2 may partly differ from the original one as given in the referenced document.

Almost half of the tests (13 out of 32) included in the EN IEC 61730-2 are based on the series EN 61215, usually mainly from the EN 61215-2 but some specific requirements can also be referred to from the technology-specific parts of EN 61215-1 (see last column of Table A**.** to detect which PV technology can be covered).

Some other tests, mainly related to thermal or mechanical properties of the PV module's constituent materials and features, are based on more general IEC or ISO standards.

A.2.3.1 Fire test (MST 23)

A special case in the MST list is the fire test (MST 23), to be run on a number of samples given in the applicable local legislation. In principle, this test aims at assessing the fire-resistance of a PV module against fire originated from sources outside the PV module itself. This would apply to building environment, too, as PV modules installed on or as part of buildings (building-attached PV and building-integrated PV, respectively) may be subject to flames or strong radiant heat generated in the same or a nearby building.

In practice, PV modules that are installed in buildings also fall under the construction regulations. As building products, PV modules have to comply with safety requirements specific to the construction sector, which is not standardised at European level and therefore is subject of national building codes. The same applies for fundamental fire safety requirements, which are not internationally harmonised. Therefore, until a standardisation is made within the European Union on these aspects, national and (if applicable) local legislation will have to be considered for the test requirements specific to fire test and PV modules as building products. Only in those Member States where no national or local fire code is available, if any, Annex B of the EN IEC 61730-2 can be used as reference for fire test requirements.

Table A.3. Classification of PV modules (from IEC 61140).

Class (IEC 61140)	**Application description**
0	Application in areas with restricted access
I	Special installation measures required (beyond the scope of the EN IEC 61730 series)
II	Application in areas with non-restricted access (i.e. general public access)
III	Basic protection by voltage limitation (i.e. maximum power lower than 240 W with open-circuit voltage lower than 35 V DC and short-circuit current lower than 8 A, when tested at 1000 W/m^2 of solar incident irradiance, 25 °C of module temperature and a spectral content of the incident light equal to the reference spectrum tabulated in EN 60904-3)

Table A.4. Safety tests for PV modules included in the series EN 61730, with either comparison to quality tests required by EN 61215 or reference to external standards, where applicable.

Test code	Test Name	Based on[3]	Notes
MST 01	Visual inspection	MQT 01[4]	Additional safety criteria apply
MST 02	Performance at STC	MQT 06.1[4,5]	After stabilisation as per MQT 19.1[5]
MST 03	Maximum power determination	MQT 02[4,5]	-
MST 04	Insulation thickness test	-	Not applicable to glass layers
MST 05	Durability of markings	IEC 60950-1:2013, 1.7.11[5]	Alternatively, IEC 60335-1:2013, 7.14[5]
MST 06	Sharp edge test	ISO 8124-1	-
MST 07	Bypass diode functionality test	MQT 18.2[4,5]	-
MST 11	Accessibility test	IEC 61032:1997 (for apparatus)	-
MST 12	Cut susceptibility test	ANSI/UL 1703:2015	Not applicable to rigid-rigid bonded PV modules, e.g. glass/glass (in this case see MST 36).
MST 13	Continuity test of equipotential bonding	ANSI/UL 1703:2015	-
MST 14	Impulse voltage test	IEC 60664-1; IEC 60060-1 (for apparatus)	-
MST 16	Insulation test	MQT 03[4,5]	Test levels depend on the PV module class as per Table
MST 17	Wet leakage current test	MQT 15[4,5]	Test voltage depends on joints type (see EN IEC 61730-1)

[3] This is given as merely informative reference here, unless equivalence is explicitly specified in the table by the term EQV. The original test procedure and/or requirements may be different from those actually included in the EN IEC 61730 series. The latter must be referenced for the tests coded in this table.
[4] Refer to **Error! Reference source not found.**
[5] Equivalence in test procedure

Test code	Test Name	Based on[3]	Notes
MST 21	Temperature test	ANSI/UL 1703:2015	-
MST 22	Hot-spot endurance test	MQT 09[4,5]	-
MST 23	Fire test	National/local codes; Annex B of the EN IEC 61730-2 for locations where there is no specific code.	See section 0
MST 24	Ignitability test	ISO 11925-2 (with modification)	If full compliance to ISO 11925-2 is already proven, this can be omitted
MST 25	Bypass diode thermal test	MQT 18[4,5]	Both MQT 18.1 and MQT 18.2 apply
MST 26	Reverse current overload test	ANSI/UL 1703:2015	-
MST 32	Module breakage test	ANSI Z97.1	It does not cover risk of electric shock, only of physical injury due to broken parts. Additional tests due to applicable building codes may have to be considered.
MST 33	Screw connections test	IEC 60598-1	Split according to general (33a) and locking (33b) screw connections
MST 34	Static mechanical load test	MQT 16[4,5]	no need for MQT 15
MST 35	Peel test	ISO 5893; ISO 813	Not applicable to rigid-rigid bonded PV modules, e.g. glass/glass (in this case see MST 36). Test not required if conditions set in Table 3 and Table 4 of EN IEC 61730-1 are met.

Test code	Test Name	Based on[3]	Notes
MST 36	Lap shear strength test	ISO 4587:2003[5]	Not applicable to rigid-flexible or flexible-flexible PV modules (in this case see MST 35). Test not required if conditions set in Table 3 and Table 4 of EN IEC 61730-1 are met.
MST 37	Materials creep test	-	Not required if mechanical mounting means prevent creep at critical external interfaces.
MST 42	Robustness of terminations test	MQT 14[4,5]	no need for MQT 15
MST 51	Thermal cycling test	MQT 11[4,5]	no need for MQT 15
MST 52	Humidity freeze test	MQT 12[4,5]	no need for MQT 15
MST 53	Damp heat test	MQT 13[4,5]	One additional test duration (200 h) is included in one part of the overall MST sequence; no need for MQT 15
MST 54	UV test	MQT 10[4,5]	One additional test dose (4 times the MQT one) is included in one part of the overall MST sequence; no need for MQT 15
MST 55	Cold conditioning	IEC 60068-2-1, Ab	To test applicability of Pollution Degree 1 (see EN IEC 61730-1).
MST 56	Dry heat conditioning	IEC 60068-2-2, Ab	To test applicability of Pollution Degree 1 (see EN IEC 61730-1).

A.3 Comparison of EN IEC 61730 tests with EN 61215 ones

Contrary to the general quality assurance approach of the EN 61215 series, the EN IEC 61730 deals with the safety of the PV modules strictly connecting it to the final application for which they will be installed. Indeed, some of the safety tests requirements are of general application, in order to ensure the basic safety of the products from the manufacturing over the installation to the final use. Some other requirements and tests are applicable only to PV modules belonging to specific class for protection against electric shock or to specific characteristics of the PV modules themselves.

As already previously mentioned, 13 out of 32 tests required by the EN IEC 61730 are in fact equivalent to tests included in the EN 61215 series of standards. They are once more listed below for the reader's convenience:

1. MST 02 ≡ MQT 06.1 (*Performance at STC*)
2. MST 03 ≡ MQT 02 (*Maximum power determination*)
3. MST 07 ≡ MQT 18.2 (*Bypass diode functionality test*)
4. MST 16 ≡ MQT 03 (*Insulation test*)
5. MST 17 ≡ MQT 15 (*Wet leakage current test*)
6. MST 22 ≡ MQT 09 (*Hot-spot endurance test*)
7. MST 25 ≡ MQT 18 (*Bypass diode thermal test*)
8. MST 34 ≡ MQT 16 (*Static mechanical load test*)
9. MST 42 ≡ MQT 14 (*Robustness of terminations test*)
10. MST 51 ≡ MQT 11 (*Thermal cycling test*)
11. MST 52 ≡ MQT 12 (*Humidity freeze test*)
12. MST 53 ≡ MQT 13 (*Damp heat test*)
13. MST 54 ≡ MQT 10 (*UV test*)

The MST 01 (visual inspection test), although based on the MQT 01 and performed in the same way, has some additional criteria for the final evaluation of the result, either connected to safety of the tested PV module or to additional final assessment criteria as per other tests of the same series EN IEC 61730. Therefore, we believe that equivalence of MST 01 and MQT 01 cannot be stated entirely.

For MST 53 Damp Heat, one additional test duration (200 h) is included in one part of the overall MST sequence; no need for MQT 15.

For MST 54 UV test, one additional test dose (4 times the MQT one) is included in one part of the overall MST sequence; no need for MQT 15.

Care must be taken in assuming the exact equivalence of these tests in terms of safety qualification (EN IEC 61730) as compared to design qualification and type approval (EN 61215). Complying with individual tests for design qualification (MQT tests) may lead to an erroneous assumption that compliance with (part of) EN IEC 61730 is also obtained (MST tests). Although the equivalence between the MST and the MQT tests listed above can be drawn in terms of test execution and observable result, their inclusion in the overall test sequence for either safety (EN IEC 61730-2) or design qualification (EN 61215-1) is strictly specific to the type of qualification and therefore to the specific series of standards considered. The flow sequence of tests to be followed for safety qualification (Figure 1 in EN IEC 61730-2) is significantly different from the one to be followed for PV modules design qualification and type approval (Figure 1 in EN 61215-1).

From this point of view, equivalence may not be drawn in general and PV modules must undergo both tests sequences as per EN IEC 61730-2 and EN 61215-1 in order to be assessed in terms of their safety besides their performance and some degree of resistance to environmental conditions.

Annex A - References

[A.1] Moser D, Del Buono M, Jahn U, Herz M, Richter M and De Brabandere K 2017 Identification of technical risks in the photovoltaic value chain and quantification of the economic impact *Prog Photovoltaics Res Appl* **25** 592-604

[A.2] Shrestha S M, Mallineni J K, Yedidi K R, Knisely B, Tatapudi S, Kuitche J and TamizhMani G 2015 Determination of Dominant Failure Modes Using FMECA on the Field Deployed c-Si Modules Under Hot-Dry Desert Climate *IEEE J. Photovoltaics* **5** 174-82

Annex B. PV inverter modelling

In order to define a methodology for the estimation of the inverter's performance inside a PV system and its contribution to the final AC energy yield, we considered different options. Besides, the estimated AC energy yield is necessary for the estimation of the inverter's functional unit as described in Section 5.3.

The different methodologies analysed are based on two sets of standards. Firstly, most of the estimation procedures considered are in line with the one described in the recently completed series of standards EN 61853, which defines a method for the estimation of the hourly DC energy yield of a standardised 1 kWp PV module over a year.

Secondly, the considered methodologies use the efficiency values measured on the inverter under consideration according to IEC 61683 and EN 50530.

B.1. PV inverter efficiency

There are two international standards whose scope is the quantification of the DC to AC conversion efficiency and the MPP tracking efficiency of PV inverters.

B.1.1. IEC 61683

The standard IEC 61683 "*Photovoltaic systems – Power conditioners – Procedure for measuring efficiency*" whose second edition is currently under development, describes the guidelines for measuring the efficiency of power conditioners used both in stand-alone and utility-interactive PV systems. The scope of this standard does not cover maximum power tracking accuracy.

The efficiency is calculated from direct measurements of input and output power at different levels of the rated power as specified in Table B1.

Table B1. Rated power conditions under which measure the inverter efficiency. The applied testing conditions depend on the type of inverter.

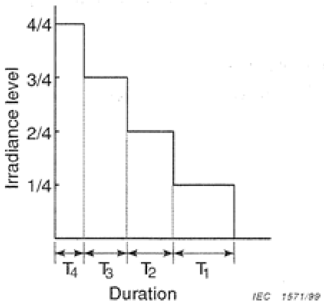
Total load, % of rated VA	5	10	25	50	75	100	120
Grid-connected		✓	✓	✓	✓	✓	✓
Stand-alone	✓	✓	✓	✓	✓	✓	✓

These measurements are to be performed at three input voltages: minimum rated input voltage, the inverter's nominal voltage or the average of its rated input range and at 90% of the inverter's maximum input voltage.

Measurements are to be performed at an ambient temperature of 25 °C ± 2 °C.

The results shall be presented in tabulated or in graphical form. Most manufacturers provide the efficiency measured at one of those voltage levels in graphical form. The complete measurements in tabulated form are not normally available.

This standard also describes a weighted average energy efficiency whose weighting coefficients depend on the type of inverter. For utility-interactive inverters, the weighting coefficients are derived from the regional irradiance duration (Figure B1a), while for stand-alone ones, the coefficients are defined according to the load duration curve (Figure B1b).



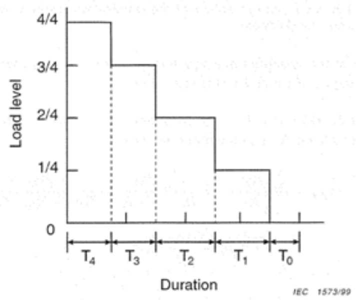


Figure B1a. Example of irradiance duration curve

Figure B1b. Example of load duration curve

(Figures extracted from IEC 61683 standard)

B.1.2. EN 50530

The EN 50530 "*Overall efficiency of grid connected photovoltaic inverters*" describes the procedure for measuring the accuracy of both static and dynamic MPP tracking. The static efficiency describes the accuracy of the inverter to regulate on the maximum power point on a given static characteristic curve of a PV generator. While the dynamic efficiency accounts for the performance of the inverter under variable irradiation intensity conditions which require the transition to different operation points.

The overall efficiency of the inverter (η_t) is calculated from the conversion efficiency obtained from the IEC 61683 (η_{conv}) and the static MPPT efficiency ($\eta_{MPPT\ stat}$), as shown in Equation B1, where P_{DC} is the actual DC power of the inverter under test, which depends on the MPP power provided by the PV generator.

$$P_{AC} = \eta_t \cdot P_{DC} = \eta_{conv} \cdot \eta_{MPPT\ stat} \cdot P_{MPP} \qquad \text{(Eq. B1)}$$

The static MPPT efficiency is measured at different levels of DC rated power, similarly to IEC 61683. New measuring conditions are added regarding the IEC standard as indicated in Table B2. Differently from the IEC 61683, the scope of the EN 50530 standard only covers grid-connected inverters.

Table B2. Rated power conditions under which measure the inverter static efficiency.

MPP power normalized to rated DC power	5	10	20	25	30	50	75	100
Grid-connected	✓	✓	✓	✓	✓	✓	✓	✓

For the static MPPT efficiency, measurements are to be performed at AC nominal grid voltage, and shall be repeated three times at three different levels of DC voltage (maximum MPP voltage, rated DC input voltage and minimum MPP voltage).

The dynamic MPPT efficiency, which is reported separately, is determined applying a test sequence of fluctuating irradiance intensities as defined in the Annex B of the EN 50530 standard.

All measurements have to be made at the same reference ambient condition as that applied in the IEC 61683.

The results are to be documented in the measuring report.

The EN 50530 standard also defines two weighted efficiencies: the Euroefficiency or European efficiency (Equation B2) whose weighting coefficients account for a full year of power distribution of a middle-Europe climate, and the CEC efficiency (California Energy Commission) defined for locations with higher radiation profiles and whose weighting factors consider, for example, less likely that the inverter would work at its maximum efficiency (η 100%) as shown in Equation B3.

$$\text{European efficiency} = 0.03 \cdot \eta\, 5\% + 0.06 \cdot \eta\, 10\% + 0.13 \cdot \eta\, 20\% + 0.1 \cdot \eta\, 30\% + 0.48 \cdot \eta\, 50\% + 0.2 \cdot \eta\, 100\% \quad \text{(Eq. B2)}$$

$$\text{CEC Efficiency} = 0.04 \cdot \eta\, 10\% + 0.05 \cdot \eta\, 20\% + 0.12 \cdot \eta\, 30\% + 0.21 \cdot \eta\, 50\% + 0.53 \cdot \eta\, 75\% + 0.05 \cdot \eta\, 100\% \quad \text{(Eq. B3)}$$

Manufacturers provide the European efficiency at the inverter's datasheet, along with the maximum efficiency.

B.2. Considered estimation methodologies

Taking into account the commonly available data regarding the inverter's efficiency and the inverter's functional unit definition linked to the AC energy output from a reference PV system over one year considering reference climatic conditions, we defined different models for the estimation of the inverter's AC energy output.

The applicability of the different considered methodologies depends on the information provided by the manufacturers regarding the various input data used by the said methodologies. As explained in Annex C. PV inverter review, some of the methodologies presented here cannot be applied to all inverters reviewed. In these cases, either that specific methodology is rejected for not being applicable for all inverters, or manufacturers are requested to provide more information than the one currently declared in either the datasheet or other additional technical documentation.

Four different methodologies have been considered as described in the following:

B.2.1. European efficiency (Method 1)

Considering that the European efficiency is present at all inverter's datasheet, the first proposed methodology uses this value to estimate the AC energy output from a reference PV system.

Following the EN 61853 methodology, it is possible to estimate the yearly DC energy output retrieved from a 1 kWp PV module array, expressed in kWh/year per installed kWp. Using the datasets included in Part 4 of the said Standard series that represent European conditions (Subtropical coastal, Temperate continental and Temperate coastal), the DC energy output value could be calculated for these predefined reference climatic conditions (EY_{DC_Sub}, EY_{DC_Temp} and EY_{DC_Coast} (kWh/year per installed kWp).

Using these two inputs, a very simple estimation of the yearly AC energy output could be obtained by multiplying the DC energy output derived from the EN 61853 methodology (kWh/year per installed kWp) by the European efficiency (η_{EUR}) of the inverter under consideration (Equation B4). The result would be expressed in kWh/year as well, but of AC energy.

$$EY_{AC\_Climate} \text{ (kWh/year per kWp)} = \eta_{EUR} \cdot EY_{DC\_Climate} \text{ (kWh/year per kWp)} \quad \text{(Eq. B4)}$$

B.2.2. Climate Zone (Methods 2, 3 and 4)

As part of the approach for determining the PV system performance within the scope of the Ecodesign preparatory study, it is proposed to refer the simulations to three distinct climatic zones. These are defined in EN IEC 61853-4, which provides a series of 8760 hourly values of the relevant environmental parameters, while the procedure for calculating the corresponding DC energy output (kWh) from a reference 1 kWp PV is presented in EN IEC 61853-3.

In opposition to the first methodology that uses the inverter's European efficiency value for the calculations at all climatic zones, the other proposed methodologies apply different efficiency values depending on the working conditions of the inverter under the various climatic conditions. The efficiency values are obtained from linear interpolation on the efficiency values measured following IEC 61683 and EN 50530 standards at different rated power (5%, 10%, 20%, 25%, etc.) and are used to calculate the energy output accordingly for the three climate reference datasets.

The yearly DC energy output (kWh/year) obtained with the models described in the EN IEC 61853-3 and used in Method 1, is in fact the sum of the 8760 hourly values in a year of DC energy output (kWh) estimated for every reference climatic dataset. Considering these hourly values, it is possible to define for every hour the working conditions of the inverter regarding its rated power and with these calculate the corresponding efficiency for every hour.

Depending on how the climate specific inverter efficiencies are treated, we have considered three new methods.

B.2.2.1. Method 2: hourly efficiency

Using as input the hourly values of DC energy output ($EY_{DC,h}$) and inverter efficiency (η_h), their product would provide an estimate the AC energy output for every hour. Their sum will be a more realistic estimate of the yearly AC energy output (Equation B5) compared to using the single European efficiency value.

$$EY_{AC} \text{ (kWh/year per kWp)} = \sum_{h=1}^{8760} \eta_h \cdot EY_{DC,h} \text{ (kWh/ kWp)} \qquad \text{(Eq. B5)}$$

Where η_h would be the inverter's efficiency for hour *h* obtained by interpolation of the efficiency values derived from IEC 61683 and EN 50530 standards, which range between 6 and 8 values. The working conditions of the inverter at every hour, required to perform the interpolation, is defined by the ratio of the DC power received from the PV array and the inverter's nominal power.

In opposition to the European efficiency value which is always provided in the inverter's datasheet, these efficiency values measured at different rated power working conditions (IEC 61683 and EN 50530) are not always available in the inverter's datasheet. And when they are, they are normally provided in graphical format as an efficiency curve which makes it more difficult to estimate the hourly efficiency values. If the rated efficiency values are provided in tabulated form (following Table B1 and B2 structure) or defined from the efficiency curve, we propose a simple linear interpolation to calculate the η_h values.

In case the DC power delivered from the PV array is higher than the recommended maximum power for the inverter, we assume the inverter continues working at its maximum power during that period (clipping).

B.2.2.2. Method 3: weighted efficiency based on in-plane irradiance

The weighted annual conversion inverter efficiency, internationally adopted as Euroefficiency or European efficiency in the EN 50530 standard was originally defined by Hotopp in the 1990s [B1, B2]. It was defined based on averaged hourly irradiance data measured for a single reference year at the location of Trier in Germany. The weighting factors shown in Equation B2 (0.03, 0.06, 0.13, etc.) were obtained by analysing the distribution of irradiance levels over the considered year, normalized to the STC irradiance (1000 Wm^{-2}). The authors found that, for example, the number of hours during the period of a year that the received irradiance is 50% of the STC one represented 20% of the time.

Considering the in-plane irradiance hourly values provided in the reference climatic datasets of EN IEC 61853-4, it would be possible to define new weighting factors for the three reference climatic datasets following Hotopp's procedure based on irradiance values ($f_{\_I5}$, $f_{\_I10}$, $f_{\_I20}$, etc.) and with those obtain an average weighted inverter efficiency adjusted to the reference irradiance yearly profiles, following Equation B6.

$$\eta_{Irrad\ climate} = f_{\_I5} \cdot \eta\,5\% + f_{\_I10} \cdot \eta\,10\% + f_{\_I20} \cdot \eta\,20\% + f_{\_I30} \cdot \eta\,30\% + f_{\_I50} \cdot \eta\,50\% + f_{\_I100} \cdot \eta\,100\% \qquad \text{(Eq. B6)}$$

Following Hotopp methodology, the weighted factors ($f_{\_I5}$, $f_{\_I10}$, $f_{\_I20}$, *etc.*) are calculated from the number of hours when the received irradiance is between the following ranges:

$f_{\_I5}$ is defined counting the hours the in-plane irradiance divided by the STC irradiance is between the interval (0% to 7.5%) over a year. Similarly,

$f_{\_I10}$ considers the range [7.5% to 15%)

$f_{\_I20}$ considers the range [15% to 25%)

$f_{\_I30}$ considers the range [25% to 40%)

$f_{\_I50}$ considers the range [40% to 75%)

$f_{\_I100}$ considers the range ≥ 75%

The estimation of the yearly AC energy output is then obtained by multiplying the DC energy output derived from the EN 61853 methodology (kWh/year per kWp installed) by the climate specific aggregate efficiency of the inverter under consideration for a particular reference climate ($\eta_{Irrad\_climate}$) as shown in Equation B7:

$$EY_{AC\_climate}\ \text{(kWh/year per kWp)} = \eta_{Irrad\_climate} \cdot EY_{DC\_climate}\ \text{(kWh/year per kWp)} \qquad \text{(Eq.B7)}$$

Where $\eta_{Irrad\_climate}$ would be the inverter's weighted efficiency obtained considering the hourly in-plane irradiance values of the reference climatic conditions under consideration, and $EY_{DC\_climate}$ would be the DC energy output from a reference 1 kWp PV array under the same climatic conditions. This latter value is common with Method 1, but instead of using the European efficiency, this third Method applies an efficiency adjusted to the irradiance profiles of every climatic condition ($\eta_{Irrad\_climate}$).

B.2.2.3. Method 4: weighted efficiency based on rated power

In Method 3 the weighting factors ($f_{\_I5}$, $f_{\_I10}$, $f_{\_I20}$ *etc.*) are calculated based on the irradiance profile at the different reference climatic profiles, while the efficiency values (η 5%, η 10%, η 20%, *etc.*) are measured according to IEC 61683 and EN 50530 standards submitting the inverter to different rated power. Since not all the received irradiance is effectively transformed to DC energy by the PV module array, Method 4 proposed here would define the weighting factors considering the number of hours the inverter works at different working conditions (received DC power), which are better related to the conditions in which the inverter's efficiency are measured.

From the hourly irradiance values of the reference climatic datasets, the DC energy output from a reference PV module array can be estimated. With these it is possible to define the inverter's working conditions and knowing the frequency distribution of these working conditions over a year, it is possible to define the percentage of hours within a year that the inverter works at different power levels. From these a single aggregate efficiency parameter, similar to the European efficiency, can be calculated. The new weighted average efficiencies for each of the three climate reference zones are calculated as shown in Equation B8.

$$\eta_{Rated\ Power\_climate} = f_{\_RP5} \cdot \eta\,5\% + f_{\_RP10} \cdot \eta\,10\% + f_{\_RP20} \cdot \eta\,20\% + f_{\_RP30} \cdot \eta\,30\% + f_{\_RP50} \cdot \eta\,50\% + f_{\_RP100} \cdot \eta\,100\% \qquad \text{(Eq. B8)}$$

In order to apply this fourth methodology, we could maintain the rated power levels used in the European efficiency calculation, as shown in Equation B2 (5%, 10%. 20%, 30%, 50% and 100%) or define different ones like those used in the CEC efficiency. In addition to this, the method on how to quantify the hours during which the inverter works at these discrete levels has to be defined. In this regard, we propose using the levels and ranges considered in the European efficiency definition, which are also applied in Method 3 described above. Therefore, it is necessary to quantify the hours assigned to each level (5%, 10%. 20%, 30%, 50% and 100%) considering the same intervals as defined in Method 3 but linked to the rated power received by the inverter from the PV array. For example, the weighting factor $f_{\_RP5}$ would be the number of hours during the year, for a particular reference climatic region, that the DC power provided to the inverter by the PV array is between 0% and 7.5% of its rated power.

Similarly to Equation B7, the estimation of the yearly AC energy output is then obtained by multiplying the DC energy output derived from the EN 61853 series methodology (kWh/year per installed kWp) by the climate specific aggregate efficiency obtained considering the rated power provided to the inverter under consideration (Equation B9).

$$EY_{AC\_climate} \text{ (kWh/year} \cdot \text{kWp)} = \eta_{Rated\ Power\_climate} \cdot EY_{DC\_climate} \text{ (kWh/year} \cdot \text{kWp)} \qquad \text{(Eq. B9)}$$

Where $\eta_{Rated\ Power\_\ climate}$ would be the inverter's weighted efficiency for the reference climatic conditions under consideration defined using the rated power to which the inverter is submitted every hour.

B.3. Results

B.3.1. Input data

● From the EN IEC 61853-4 reference climatic datasets representative of the European climatic conditions, we have used the hourly in-plane irradiance values (required in Method 3) and the ambient temperature, T_{amb}, (used in Methods T1 and T2 which are described in Subsection B3.3).

● Following the procedure described in EN IEC 61853-3, we calculated, for every climate, the hourly DC energy output from 1 kWp PV array of crystalline silicon modules. These are assumed mounted in a free standing rack, with an inclination angle of 20° and facing the equator. The yearly sum of the hourly DC energy output at every climatic condition is the yearly energy yield EY_{DC_Sub}, EY_{DC_Temp} and EY_{DC_Coast} (kWh/year per installed kWp) used in Methods 1, 3 and 4. The hourly DC energy yield values are also needed for Methods 2 and 4.

● We considered seventeen different inverters, including microinverters, string and central inverters from various manufacturers reviewed in Annex C. The selection is based on the available information provided by the manufacturer. For practical reasons, we will only present here the results for five of these inverters: one microinverter (module integrated inverter), three string inverter and one central inverter, whose characteristics are presented in Table B3.

In order to optimize the PV array-Inverter pair, for every inverter, due to their different nominal power, a different size of PV array needs to be applied so as to maintain the sizing ratio between the two elements. We have used two different size ratios, 1.25 for central inverters and 1.1 to micro and string inverters, in order to consider two different PV systems sizes, utility scale and residential respectively. The installed PV array peak power in every case is defined in Table B3.

Table B3. AC nominal power (W) and European efficiency of the five considered inverters, and the installed PV array peak power applied to every inverter derived from the applied size ratio.

Inverter	AC nominal power, $P_{ac,r}$ (W)	η_{EUR}	Size ratio	Installed PV array (kWp)
1	230	95.3	1.1	0.253
2	1200	90.9	1.1	1.32
3	2750	93.6	1.1	3.025
4	75000	98.2	1.1	82.50
5	1000000	98.4	1.25	1250

As a result, for every inverter there is a different PV system, denoted Syst, with a different installed PV array, based on the size ratio applied between both components. The PV system containing the inverter 1 is denoted Syst 1, the system including the inverter 2 is Syst 2, etc.

B.3.2. Estimated AC energy output

The four methodologies described in the previous subsections have been applied considering the climatological data from the three European reference climates.

Table B4 contains the yearly DC energy output from the PV array connected to every inverter and the estimated AC energy yield delivered from the inverter, considering the four methods described in Section B2, for the Subtropical arid reference climate.

Table B4. Yearly DC energy output from the PV array of the five different PV systems, and their AC energy output estimated by the four methodologies (kWh/year). Subtropical arid reference climate.

Subtropical arid	Syst 1	Syst 2	Syst 3	Syst 4	Syst 5
EY_{DC_Sub} (kWh/year)	513.35	2678.35	6137.89	167397	2536318
Method 1. EY_{AC_Sub} (kWh/year)	489.22	2434.62	5745.06	164383.9	2495737
Method 2. EY_{AC_Sub} (kWh/year)	490.42	2434.37	5769.90	164122.9	2506063
Method 3. EY_{AC_Sub} (kWh/year)	489.71	2420.41	5729.08	164089	2497700
Method 4. EY_{AC_Sub} (kWh/year)	489.42	2414.36	5715.76	164037.5	2497368

In order to compare the performance of the inverters in the different systems, the results are normalised to the installed PV peak power, so as to reference all energy yield estimation to 1 kWp of installed peak power, as required by the inverter's functional unit definition. Results are shown in Table B5.

Table B5. Yearly DC energy output from the PV array at the five different PV systems, and AC energy output estimated by the four methodologies normalized to 1 kWp PV array (kWh/year per installed kWp). Subtropical arid reference climate.

Subtropical arid	Syst 1	Syst 2	Syst 3	Syst 4	Syst 5
EY_{DC_Sub} (kWh/year·kWp)	2029.05	2029.05	2029.05	2029.05	2029.05
Method 1. EY_{AC_Sub} (kWh/year·kWp)	1933.69	1844.41	1899.20	1992.53	1996.59
Method 2. EY_{AC_Sub} (kWh/year·kWp)	1938.43	1844.22	1907.41	1989.37	2004.85
Method 3. EY_{AC_Sub} (kWh/year·kWp)	1935.60	1833.64	1893.91	1988.96	1998.16
Method 4. EY_{AC_Sub} (kWh/year·kWp)	1934.45	1829.06	1889.51	1988.33	1997.89

Considering the results from Method 1 as reference values, Table B6 shows the difference, in percentage, between the AC energy yield estimated by Method 1 and the other 3.

Table B6. Difference (%) in the AC energy output from Methods 2 to 4 with regard to Method 1 estimates. Subtropical arid reference climate.

Subtropical arid	Syst 1	Syst 2	Syst 3	Syst 4	Syst 5
Method 1. EY_{AC_Sub} (kWh/year·kWp)	1933.69	1844.41	1899.20	1992.53	1996.59
Method 2. Vs. Method 1 (%)	0.245	-0.010	0.432	-0.159	0.414
Method 3. Vs. Method 1 (%)	0.099	-0.584	-0.278	-0.179	0.079
Method 4. Vs. Method 1 (%)	0.040	-0.832	-0.510	-0.211	0.065

The difference in all cases is below 1%. For both the microinverter (Syst 1) and the central inverter (Syst 5) Method 1 provides lower values than the other three methods, with differences below 0.1% for Methods 3 and 4 compared to Method 1. Differences are higher for the string inverters, for which Method 1 tends to provide higher values than the other methods.

Differences between Method 1 results and the other three methods tend to increase in the other two reference climatic datasets, as shown in Tables B7 and B8 that contain respectively the differences obtained in the Temperate continental and Temperate coastal climates. Especially for two of the string inverters Method 1 results in AC energy yields about 2% higher than Methods 3 and 4 which apply a new weighted average efficiency defined according to the frequency distribution of in-plane irradiance and working conditions over the year of the reference climatic datasets.

Table B7. Difference (%) in the AC energy output from Methods 2 to 4 with regard to Method 1 estimates. Temperate continental reference climate.

Temperate continental	Syst 1	Syst 2	Syst 3	Syst 4	Syst 5
Method 1. EY_{AC_Temp} (kWh/year·kWp)	1123.56	1071.69	1103.52	1157.75	1160.11
Method 2. Vs. Method 1 (%)	0.244	0.064	0.267	-0.077	0.331
Method 3. Vs. Method 1 (%)	-0.071	-1.185	-1.128	-0.155	-0.324
Method 4. Vs. Method 1 (%)	-0.110	-1.354	-1.246	-0.189	-0.235

Table B8. Difference (%) in the AC energy output from Methods 2 to 4 with regard to Method 1 estimates. Temperate coastal reference climate.

Temperate coastal	Syst 1	Syst 2	Syst 3	Syst 4	Syst 5
Method 1. EY_{AC_Coast} (kWh/year·kWp)	854.36	814.92	839.12	880.36	882.15
Method 2. Vs. Method 1 (%)	0.168	-0.206	-0.126	-0.063	0.165
Method 3. Vs. Method 1 (%)	-0.275	-1.991	-1.962	-0.216	-0.689
Method 4. Vs. Method 1 (%)	-0.320	-2.180	-2.115	-0.250	-0.536

Methods 3 and 4 calculate a new average weighted efficiency for every reference climate which compare to the European efficiency of the five inverters as shown in Table B9.

Table B9. New average weighted efficiency values obtained by Methods 3 and 4, for the five considered inverters at the three climatic regions.

		Method 3. In-plane irradiance based			Method 4. DC rated power based		
Inverter	η_{EUR}	η_{Irrad_Sub}	η_{Irrad_Temp}	η_{Irrad_Coast}	η_{RP_Sub}	η_{RP_Temp}	η_{RP_Coast}
1	95.3	95.4	95.2	95.0	95.3	95.2	95.0
2	90.9	90.4	89.8	89.1	90.1	89.7	88.9
3	93.6	93.3	92.5	91.8	93.1	92.4	91.6
4	98.2	98.0	98.0	98.0	98.0	98.0	98.0
5	98.4	98.5	98.1	97.7	98.5	98.2	97.9

The new average weighted efficiencies (η_{Irrad} and $\eta_{Rated\ Power}$) for the Subtropical arid reference dataset are similar to the Euroefficiency values, especially when the new weighting factors are defined according to the irradiance distribution (η_{Irrad}). For the other two reference climates, the new efficiencies are lower than the Euroefficiency, meaning that the working conditions of the inverters under those climatic conditions would make them work more frequently at lower efficiency ranges than those assumed by the Euroefficiency (Eq. B2).

B.3.3. Temperature derating effect

According to the IEC 61683 and EN 50530 standards, the inverter's efficiency measurements are to be performed at an ambient temperature of 25 °C ± 2 °C. However, the temperature of the inverter and its components is likely to be different under real working conditions.

Due to the lack of models to relate ambient and inverter temperature, we have performed a simple analysis considering the temperature of the inverter equal to the ambient temperature, assuming an active cooling system that maintains this balance. Considering the information on temperature derating provided by the manufacturers, it is possible to identify the hours, within the three reference climatic datasets, that the ambient temperature exceeds the declared temperature threshold above which the performance of the inverters starts to decrease. Depending on the inverter, this derating effect may have various intensities at different temperature ranges. As described in Annex C. PV inverter review, central inverters often present two or three declared AC power outputs depending on the temperature. Using these values, it is possible to calculate the derating effect for the different temperature ranges (χ_{der}). Using these derating factors (assumed linear) and the hourly ambient temperature values of the reference climate datasets, it is possible to reduce the inverter efficiency accordingly (Equation B10).

$$Derated\ \eta = \eta \cdot (1 + \chi_{der})^{\Delta T} \qquad \text{(Eq. B10)}$$

Where η is the inverter's efficiency, χ_{der} is the derating effect calculated from the information provided by the manufacturers, and ΔT is the difference between the hourly ambient temperature value and the derating temperature threshold value.

Table B10 shows, for the five inverters used as example, the minimum temperature threshold declared by the manufacturers above which derating occurs, and the number of hours within the year when the ambient temperature is above that threshold for the three reference climates. According to the manufacturer, the inverter 5, central inverter, would have two derating factors, one applicable from 25°C to 40 °C, and a second one above 40 °C. No information on temperature derating is provided for the microinverter (Inverter 1).

Table B10. Temperature threshold above which derating occurs and number of hours within the reference year when the ambient temperature is above that threshold for the three reference climatic datasets and the five considered inverters.

		Number of hours within the year with T_{amb} above the temperature threshold		
Inverter	Temperature threshold (°C)	Subtropical arid	Temperate continental	Temperate coastal
1	No info	-	-	-
2	38	96	0	0
3	33	701	0	0
4	44	0	0	0
5	25	2914	91	0

For this temperature derating analysis, we have only considered two methods, based on Methods 1 and 2 described above. The new methods are denoted T1 and T2. In Method T1, for every hour whose ambient temperature is above the derating temperature, the Euroefficiency value is reduced according to the corresponding derating factor. Similarly, Method T2 applies the same derating factor to the hourly efficiency values estimated interpolating the efficiency curve values, according to the DC energy output delivered by the PV array. These hourly efficiency values were used in Method 2. Therefore, the η used in Equation B10 is the Euroefficiency in Method T1 and the hourly efficiency value obtained from interpolation of the efficiency curve values in Method T2.

The ambient temperate at the Temperate coastal reference climate never exceeds the derating threshold temperatures so, according to the model considered, the inverters' performance would not be affected by temperature derating. Regarding the Temperate continental climate only inverter 5 would be affected by derating. The difference, in percentage, between the estimated AC power output from Methods T1 and T2 and the corresponding calculations without considering derating (Method 1 and 2, respectively) is 0.041% decrease in power prediction when derating is quantified. Table B11 shows the temperature derating effect in the AC energy output estimation for the Subtropical arid reference climate. The values shown are the difference, in percentage, between the energy outputs from Methods T1 and T2, in comparison to Methods 1 and 2, respectively.

Table B11. Variation, in percentage, in the estimated AC energy output when temperature derating is considered in Methods 1 (Euroefficiency) and 2 (hourly interpolated efficiency values) under the Subtropical arid reference climatic conditions.

Inverter	AC power output variation Methods 1 and T1 (%)	AC power output variation Methods 2 and T2 (%)
2	-0.0219	-0.0220
3	-0.3826	-0.3830
4	0	0
5	-1.7947	-1.7950

Except from the fifth inverter whose declared performance decreases above 25 °C, the temperature derating effect according to the methodology and assumptions applied here does not significantly reduce the AC energy output for the other inverters analysed. No results are shown for Inverter 1 (microinverter) since no information on temperature derating was available.

B.3.4. PV array- Inverter sizing ratio effect

The results shown so far had applied in the calculations a sizing ratio between PV array and inverter for micro and string inverters of 1.1, while 1.25 was considered for the central inverter simulation. In order to study the effect of the sizing ratio in the AC energy output estimation, the calculations have been repeated using 1.25 sizing ratio for the small inverters and 1.1 for the central inverter.

Once the results of AC energy output are normalized to 1 kWp PV array DC energy output, the results from Methods 1 and 3 are independent on the sizing ratio, since the DC/AC conversion factor is independent of the working conditions of the inverters. Method 1 applies the European efficiency, while Method 3 uses a weighted average efficiency which depends only on the irradiance profile. On the contrary, Methods 2 and 4 account for the hourly working conditions of the inverter, so the sizing ratio has an effect on the AC output. However, as shown in Table B12, the effect is small.

Table B12. Difference (%) between the AC energy output from 1 kWp PV array estimated with Method 2 considering a sizing ratio of 1.1 for small inverters and 1.25 for central inverters, compared to applying the inverse sizing ratios, for the five different inverters at the three European reference climates.

	Inverter 1	Inverter 2	Inverter 3	Inverter 4	Inverter 5
Subtropical arid	-0.044	-0.236	-0.080	-0.073	0.019
Temperate continental	-0.017	-0.113	0.017	-0.052	-0.029
Temperate coastal	0.022	0.059	0.143	-0.021	-0.074

Since the AC energy yield is used in the transitional parameter calculation, the sizing ratio will also have a limited impact on its value.

B.3.5. Selected methodology

Considering the different results, especially between Method 1, which uses readily available data such as the European efficiency and Method 2, which may be considered the most accurate methodology for doing hourly calculations, we propose applying Method 1 for the estimation of the inverter performance. Method 2 requires data that is not always provided by the inverter's manufacturer and needs to perform more complex calculations than Method 1.

Methods 3 and 4, although provide similar results to the other two, still require a further step in the calculations to obtain the new average weighted efficiency. And, as it is the case of Method 2, they require further input data that it is not always available.

On the contrary, Method 1 uses the European efficiency and the yearly DC energy output from the PV array calculated according to the EN 61853 methodology. If in the future PV manufacturers included in the PV module's datasheet the *Climate Specific Energy Rating* values derived from their PV module at the different reference climatic regions, the yearly DC energy yield could be easily calculated from the said *CSER* values, as explained in Section 5.2.1, Equation 3.

In addition to the four different methods applied to estimate the AC energy output from the inverter, the effect of the sizing ratio between PV array and inverter and the temperature effect on the inverter's efficiency have been analysed. As shown in Table B12, the sizing ratio only affects the estimates from Methods 2 and 4, which account for the hourly working conditions of the inverter dependent on the received DC power from the PV array. Two different sizing ratios have been applied and differences in the AC estimates are below 0.25%.

Regarding the temperature derating of the inverter's efficiency, the analysis carried out considers a series of assumptions due to the lack of detailed information. At present, there is not a model that relates the ambient temperature to the temperature reached by the inverter under real working conditions. And the information provided by the manufacturers is heterogeneous and insufficient to perform a detailed analysis. Notwithstanding, the model considered to account for the temperature derating resulted in a decreased AC energy output due to temperature that ranges from 0.02% to 1.8% for inverters whose derating temperature threshold is declared as 25 °C, which is often exceeded in the Subtropical arid reference climate. However, due to the lack of accurate information, our proposal to account for this effect in the simulations is to include this effect as a derating factor similarly as how the PV systems losses are accounted for in the AC energy yield estimation from PV systems.

Annex B - References

[B.1] R. Hotopp; „Private Photovoltaik-Stromerzeugungsanlagen im Netzparallelbetrieb“, 2. Auflage, RWE Energie AG, Essen, 1991.

[B.2] Auf den Spuren von „Euro-Eta“, Photon, Juni 2004, S. 62 – 65

Annex C. PV inverter review

As stated in the Task 1 report "*Product scope*" of the "*Preparatory study for solar photovoltaic modules, inverters and systems*" after the stakeholders' consultation, it was concluded that all inverters should be included in the scope of this preparatory study. Therefore, the transitional method for the evaluation of the functional parameter should also cover all types of inverters, from microinverters, to string and central inverters.

The objective of this Annex is to present the results of a review study performed on the relevant information to the transitional method for inverters that are available at the inverters' datasheet and other information provided by the manufacturers. In most cases, the information required is only available on the Manual of the inverter or other additional documentation and not on the datasheet. Besides, the information provided is not common to all manufacturers and it also depends on the type of inverter (micro, string or central).

The various methodologies considered for the estimation of the inverter's functional parameter and the AC power output depend on the available information (Annex B PV inverter modelling). Depending on the information provided by a particular manufacturer or type of inverter, some of the considered methods cannot be applied. However, it would be convenient that the methodology proposed in the transitional method could be applicable to all inverters. Therefore, it should be based on information provided by all manufacturers for all types of inverters. Otherwise, it would be necessary to request manufacturers to provide more detailed and homogeneous information than the one currently available.

Nine different manufacturers have been reviewed, including those that represent more than half of the market share of solar inverters. Most brands produce string and central inverters, while microinverters are only available from four of the nine considered manufacturers. A total of almost 140 datasheets have been analysed considering the different manufacturers and the various produced types of inverters available.

C.1. PV inverter datasheet

The IEC 62894 "*Photovoltaic inverters – Data sheet and Name plate*" defines the minimum required information that manufacturers should include in the inverter datasheet, at the time that it allows additional information to be included as well. This information is commonly presented by manufacturers in two sections: technical and general data. The technical data section is often distributed in Input DC and Output AC containing information about electrical parameters like voltage and current; Efficiency normally expressed as Maximum efficiency, Euroefficiency and CEC efficiency' and Protective devices related information. The general data section normally contains information about dimensions, weight, noise emission, cooling method, communication protocols and applicable standards.

According to the IEC standard, the manufacturer should provide information about the operating performance of the inverter. The operating efficiency, for example, should be specified in tabular form for three input voltages and eight output voltages, and a graphical representation is optional. Notwithstanding, the graphical representation is more frequently available in the datasheet than the tabulated values, which when available, are provided separately in additional documentation different to the datasheet.

The IEC standard also specifies that when self-protection routines are implemented into the inverter, the possible derived derating shall be described in tabular or graphical form over the entire permitted operation range.

However, whilst the efficiency dependence on the operating conditions (input power or voltage) is commonly available either graphically or tabulated, the derating of the efficiency with temperature is hardly ever described in detail. Most manufacturers, especially for central inverters, provide the AC power output at two or three different temperatures. The highest of these is defined, by some manufacturers, as threshold temperature above which derating occurs. Nevertheless, according to the AC output power values provided at other temperatures, some power decrease already occurs at lower temperatures. For example, for big central inverters it is common to find the AC power output described in the datasheet as follows: AC power at 25 °C 1100 kVA, at 40 °C 1000 kVA and at 50 °C 900 kVA, which already indicates some extent of derating with temperature. In the same datasheet the operation temperature range is defined to be between -25 °C to 62 °C. Smaller central inverters tend to have the AC output power declared at two different temperatures, 35 °C and 45 °C, for example, and the derating is specifically described to occur only above 45 °C. On the contrary, string inverters have a single AC power value declared in the datasheet, which is also the case of the microinverters analysed. Besides, none of the four microinverters manufacturers provides any information about the temperature derating of these devices.

When declared, the derating is referred to the ambient temperature, but it has not been possible to find in any documentation provided by the reviewed manufacturers or in any available standard, a model or mathematical expression that relates ambient and inverter temperature. On the contrary, the EN IEC 61853-3 "*Photovoltaic (PV) module performance testing and energy rating – Energy rating of PV modules*", describes a model to estimate the temperature reached by a free standing PV module using the ambient temperature, wind speed and in-plane irradiance as main inputs. However, an equivalent model to estimate the temperature of the inverter and its components has not been found. Besides, this working temperature will depend, to a great extent, on the installation and operating conditions that, as declared in the IEC 62894 standard, could vary between unprotected in the open, protected in the open, air-conditioned in interiors and without air-condition in interiors. Even though the datasheet contains information about the cooling method used (ranging from convection, natural flow and natural cooling for small inverters, to fan, forced ventilation, or other active systems used in bigger inverters), nothing is mentioned about the targeted temperature for the inverter operating conditions or about the temperature range that these cooling systems maintain. According to the information provided in the datasheets, the presence of an active cooling system does not prevent temperature derating above a certain temperature. But no information is provided about the working patterns of the active cooling system.

This lack of information, combined with the heterogeneous information provided about the derating of the AC power output dependent on temperature, makes it difficult to get an estimate of the temperature reached by the inverter under working conditions. In addition to this, not all manufacturers provide the same information and with the same detail. For example, only four of the nine reviewed manufacturers provide graphical information about the temperature derating and this information is not even provided to all models of inverters. Even though big inverters have a declared decreased AC power output with temperature (AC power output defined at two or three temperature levels), only 20% of the reviewed inverters explicitly declare the threshold above which derating occurs. And as previously mentioned, this contradicts somehow the decreased AC output power declared in the same datasheet at increasing temperature values. While three manufacturers do not provide any type of information related to derating, four provide graphical representation of the derating effect, but not for all models of inverters. According to these graphs, a linear derating does not always occur, even though is the most common behaviour observed in the reviewed information. Therefore, if modelled, the temperature derating could be assumed linear, with a slope defined from the AC power output and temperature values provided in the datasheets or additional documentation.

In opposition to the temperature derating, the efficiency of the inverter is always declared in the datasheet. Either the Euroefficiency or the CEC efficiency, depending on the targeted market, is provided. These are calculated according to the standard EN 50530 "*Overall efficiency of grid connected photovoltaic inverters*". Besides these weighted efficiencies, the datasheets tend to include, in graphical form, the efficiency at different input and output voltages as stipulated in the IEC 62894 standard. If not provided in the datasheet, these values, commonly denoted efficiency curve, are normally available at the additional information provided by the manufacturers like the Manual or other technical information sheets. Two out of the nine manufacturers do not provide any graphical information of the efficiency values at different working conditions. And of the other seven manufacturers, only one provides this kind of information for all types of inverters. Most manufacturers only provide the efficiency curve for some devices, not for all models. The efficiency values in tabulated form are even scarcer, being available for only some devices from two manufacturers. Besides, in these cases, this information is not normally provided in the datasheet but in additional information like the Manual of the inverter. In fact, only one of the reviewed manufacturers includes the tabulated values in the datasheet.

C.2. Input data for the transitional methods

After the review analysis carried out on several inverters and manufacturers, we can conclude that if a single methodology is to be proposed to simulate the performance of the inverter and calculate the functional parameter of the inverter with the information currently available, these estimation models should be based on the Euroefficiency or CEC efficiency, depending on the market.

Since information on the efficiency dependence on temperature and working conditions (input power or voltage) is not always available, a unique methodology that accounted for these two effects should model them as single derating factors reducing to some extent the AC power output estimated from the product of the DC power input delivered by the PV array and the Euroefficiency, a weighted average efficiency.

If the efficiency curve or the tabulated values were always provided by the manufacturer, it would be possible to apply a corrected efficiency at every simulation step, like hourly calculations. At every hour of the simulation it would be possible to estimate the efficiency of the inverter depending on the DC power received from the PV array.

Similarly, with the currently available information about the derated performance with temperature, simulating the inverter performance under real working conditions is not possible. As a result, for the estimation of the inverter performance and for its functional parameter calculation, the temperature derating is proposed to be accounted for using a derating factor along with the PV system losses, like soiling, shading or wiring losses, in order to decrease to a certain extent the AC power output from the inverter and PV system. More information on this proposed methodology can be found in Section 5 and Annex B.

Annex D. PV system losses

There are several losses that affect the performance of a PV system reducing the AC energy output finally delivered by the system. These losses can be classified in two different types. They can be directly linked to the different components, like wiring losses or the inverter's DC to AC conversion efficiency, or they can derive from the installation and maintenance of the PV system, being therefore independent of the PV system components. Poor maintenance or an incorrect installation (non-optimal orientation or presence of shades, for example) can significantly reduce the performance of a PV system regardless of the quality and efficiency of its components. That is why the proposed method to account for the PV system's losses is based on the PV system configuration, more than on its components, whose intrinsic performance is already considered in the corresponding model used within the complete methodology applied to estimate the AC energy output of the PV system. As explained in Subsection 6.6, the final AC energy output from the PV system is estimated in various steps that represent the performance of its main components: the PV array (DC energy output) and the inverter (AC energy output). These two elements are modelled in the first two steps, in which the losses due to their intrinsic characteristics are already considered. In a subsequent step, the PV system losses are considered and included in the AC energy yield estimation from the complete PV system.

The three different PV systems configurations that will be considered to define the range of the various losses are:

- Default installation
- Optimised design and yield forecasting
- Optimised monitoring and maintenance

We assume that they are all subjected to the same losses but the value of these losses depends on the PV system configuration. We consider that the Default installation will be affected by the typical losses reported in the scientific bibliography, while the Optimised monitoring and maintenance PV system will be affected by the lowest values of every PV system losses. So, unless declared differently by the PV installer, we propose a range of values for every type of PV system loss to be used in the simulations. The lowest value would be applied to the Optimised monitoring and maintenance system, the typical value will be used for the Default installation, while for the Optimised design and yield forecasting configuration the average of the two aforementioned values will be applicable.

By the combination of the various losses, it is possible to estimate η_{system_loss}, a single variable which is used in the proposed methodology to estimate the AC annual energy yield from the PV system (Equation 8). An example on how to define η_{system_loss}, is shown in the present Annex. A tool to perform this calculation could be developed if needed.

To easily quantify the impact of the various losses in the PV system's performance, in this Annex we will use the Performance Ratio (*PR*), which is the ratio of the energy yield delivered by the PV system and the energy yield from the same system if losses were not considered. Therefore, a value of PR equal to 1 would correspond to an ideal PV system without losses.

D.1. Losses in the PV array

As mentioned in the introduction, there are losses which are intrinsic to the PV system components and others that are not directly linked to their quality or efficiency but depend on the installation, maintenance and operation activities.

Regarding the PV array, the method used to estimate the DC energy output from the array, defined in the EN IEC 61853-3 standard ("*Photovoltaic (PV) module performance testing and energy rating – Part 3: Energy rating of PV modules*") takes into consideration and quantifies three types of losses derived from the intrinsic characteristics of the PV module. These are:

- Angle of incidence. Part of the received irradiance is reflected on the surface of the module. Different coatings or surface texture could minimize this kind of loss, which also depends on the installation conditions and the solar coordinates. These two factors are predefined in the reference climatic datasets of Part 4 of the same standard (EN IEC 61853-4 "Part 4 "*Standard reference climatic profiles*") which contains the solar coordinates for a specific location in every reference climate.
- Spectral effects. Due to the photovoltaic active material of the PV modules, not all wavelengths of the incoming irradiance are actively used to produce electricity. The methodology used to estimate the DC energy output accounts for this spectral effect.
- PV module behaviour at conditions different from the Standard Test Conditions used to measure the declared P_{max} provided in the datasheet. The conversion efficiency of the modules depends on the module temperature and also on the received irradiance. These two effects are also accounted for in the methodology used to estimate the DC energy output.

Besides these three effects that directly depend on the PV module characteristics, there are other losses affecting the DC energy output from the PV array, which depends on the installation conditions, like for example:

- Soiling whose impact could be minimized by a good maintenance.
- Presence of shades which are very much site dependent.
- Mismatch within the array. The PV array should be composed of modules of similar electrical characteristics since modules of lower quality could decrease the performance of the complete array.
- Diodes and connectors which are part of the PV array.

These losses, not directly linked to the PV module will be considered within the PV system losses so as to estimate the η_{system_loss} used to calculate the final annual AC energy yield.

D.2. Losses in the inverter

Similarly to the PV array, the performance of the inverter depends both on its own characteristics but also on the installation conditions which affects the temperature reached by the inverter.

The methodology proposed to model the performance of the inverter (see Section 5), is based on the Euroefficiency which accounts for the DC to AC conversion efficiency. However, this value is obtained under specific conditions which may differ from real working conditions derived from the installation and operation of the inverter. While the Euroefficiency is measured at ambient temperature of 25 °C, the temperature reached by the inverter may change significantly under real working conditions.

As described in Annex B. PV inverter modelling, the performance of the inverter decreases with temperature and most manufacturers declare some extent of derating. After reviewing several inverters and analysing various approaches to account for the derating effect on the inverter's performance, we propose to model this effect as a derating factor along with other PV system losses. As a result, the η_{system_loss}, will be calculated considering the inverter temperature derating which is not considered in the estimation of the AC energy output from the inverter. This, according to the proposed methodology, depends only on the Euroefficiency and the DC energy yield delivered by the PV array.

D.3. Losses in the PV system

As described in previous subsections, within the PV system losses we include some linked to the PV array and to the inverter. In addition to this, we should account for other losses like those from the wiring system. For this study, the PV system is considered to include every element of the photovoltaic installation up to the AC output side of the inverter. Any other element after this point, like transformers for the grid connection are not considered part of the PV system. Therefore, with this definition, there should not be AC wiring losses, only DC wiring losses. However, if microinverters (module integrated inverters) are used, the output of the PV array will be in AC. So in this case, AC cables losses should be included as well.

If the PV system had an energy storage system, we should model the performance and efficiency of the battery system. Following the proposal to perform the simulations of the PV system performance on yearly basis, it is not possible to model accurately the flow of energy between the different components (PV array, battery, inverter, load or grid) neither the state of charge of the battery, for which hourly or even shorter time period simulations would be required. In addition to this, information about the loads connected to the PV system would be needed as well. As a result, the battery system will be included in the estimation of the annual AC energy yield of the PV system as a new derating factor within the PV system losses.

Even though it is out of the scope of this study, if the PV system under analysis were mounted on a solar tracking system, the losses due to this component should also be included. If specific PV systems were to be validated with the proposed methodology, like building integrated systems, for example, it would be necessary to account for new types of losses, like that from the sun tracking system or others specific to the system under consideration. However, following the reference PV system considered in the present study composed of a free standing PV array, inverter and cables, the proposed list of PV system losses would be the following:

- Soiling or dust
- Shading
- PV array mismatch
- Diodes and connectors
- Inverter temperature derating
- Wiring DC or AC

We consider no losses due to grid availability or long repair times.

After reviewing various scientific publications [D.1-D.5], we propose the values shown in Table D1 for the different losses. We assume that the PV systems classified as Default installation will be subjected to the typical values, while the Optimised monitoring and maintenance system are simulated considering the lowest values of the different losses. For the third PV system configuration, Optimised design and yield forecasting the value of the PV system losses will be the average of the typical and lowest value, which is also indicated in Table D1.

Table D1. PV system losses: typical value, and range with the minimum and maximum values.

Losses	Range (%)	Typical (%)	Minimum (%)	Average Typ-Min (%)
Soiling	2 – 25	5	2	3.5
Shading	0 - 10	5	0	2.5
Mismatch	1.5 - 3	2	1.5	1.75
Connectors	0.3 – 1	0.5	0.3	0.4
Inverter derating	0.1 – 1.8	1	0.1	0.55
DC cabling	1 - 3	2	1	1.5
AC cabling	0.7 - 2	1	0.7	0.85

The degradation of the different components can also represent a reduction over time of the AC energy output. In the proposed methodology, the degradation is not considered among the PV system losses, but it is accounted for in a subsequent step when the AC energy yield is estimated over the complete lifetime of the PV system (See Subsections 6.3 and 6.6).

D.4. Example of PV system losses calculation

For the present example, we consider a PV system composed of a 5 kWp PV array of crystalline silicon modules and an inverter with a Euroefficiency of 96%. The aim of this example is to evaluate the performance ratio of this PV system at the three European reference climates (Annex F).

Table D2. Performance Ratio (*PR*) after considering the losses intrinsic to the PV module and the inverter, for each reference climate.

	EN IEC 61853-3 PV module performance			Inverter Losses (%)	PR with Module + Inverter Losses
Reference climates	AOI (%)	λ (%)	Irrad & Temp (%)		
Temperate coastal	-3.9	1.8	-3.2	-4	0.909
Temperate continental	-3.1	1.3	-6.1	-4	0.885
Subtropical arid	-2.7	0.4	-8.7	-4	0.856

The estimation of the DC energy output, following the EN 61853 methodology, accounts for the angle of incidence losses (AOI) and those derived from the behaviour of the modules under low irradiance levels and high temperatures (Irrad & Temp). The spectral effects (λ) can, like in this example, represent a gain, not a loss due to the spectral response of the considered PV module and the spectral content of the irradiance at the sites representative of the three reference climates.

From an ideal performance ratio of 1, the losses linked to the PV module and inverter already represent a reduction that varies, for this example, from 9% in the Temperate coastal climate to 14% in the Subtropical arid location where modules are more affected by the temperatures reached by the modules.

Assuming no other losses but those in Table D1, the PV system losses (η_{system_loss}) for the three system configurations are shown in Table D3.

Table D3. PV system losses for the three different system configurations.

PV system configuration	Losses	PV system losses (%)
Default installation	Typical	14.62
Optimised design and yield forecasting	Average	9.81
Optimised monitoring and maintenance	Minimum	4.82

From the losses reported in Table D1, the η_{system_loss} shown in Table D3 are calculated according to Equation D1.

$$\eta_{system\ loss} = 100 \cdot \left(1 - \left[\left(1-\eta_{soiling}\right)\cdot\left(1-\eta_{shades}\right)\cdot\left(1-\eta_{mismatch}\right)\cdot\left(1-\eta_{connect}\right)\cdot \cdot\left(1-\eta_{DC\ wiring}\right)\cdot\left(1-\eta_{inverter}\right)\right)\right) \quad \text{(Eq. D1)}$$

Since microinverters are not used in this example only DC wiring losses are considered. To be used in Equation D1, the different losses need to be expressed in decimal format. A 5% losses due to soiling would be quantified in Eq. D1 as 0.05.

Once the η_{system_loss} is calculated, it is possible to estimate the AC annual energy yield of the PV system according to Equation 8 shown in Subsection 6.2.4. Subsequently, as described in Subsection 6.3 the AC energy yield delivered by the PV system over its lifetime can be estimated (Eq. 9), when degradation is considered.

Following with the example, Table D4 shows, for the considered PV system and three possible PV system configurations, the final performance ratio for the three reference climates.

Table D4. Final Performance Ratio for the PV system used in the example, for the three different PV system configurations, and for the three reference climates.

	PR with Module & Inverter Losses	PV system Performance Ratio		
Reference climates		Default	Opt. design & forecasting	Opt. monitoring & maintenance
Temperate coastal	0.909	0.776	0.820	0.865
Temperate continental	0.885	0.756	0.798	0.842
Subtropical arid	0.856	0.731	0.772	0.815

Compared to an ideal PV system with no losses (*PR* equal to 1), the PV system used in this example, results in *PR* which goes from 0.731 in the warmest climate and least maintained PV system configuration, to 0.865 for the best monitored PV system configuration and coldest climate, where the PV modules used in this example perform best.

According to Task 4 "*Technical analysis including end-of-life*" of the "*Preparatory study for solar photovoltaic modules, inverters, and systems",* the three PV system configurations could be represented by *PR* of 0.75, 0.80 and 0.85 respectively. According to this, if the PV system evaluated in the example had been classified as Default installation due to the operation and maintenance actions performed on it, it would not reach the *PR* of 0.75 for that configuration in a subtropical arid location. The PV installer in that case, should try to reduce the PV system losses or improve the quality of the components, in order to increase the final *PR*. In a temperate coastal location whose climatic conditions are more favourable to the PV array performance, even a default installation would reach the threshold of 0.75 of the *PR*. Under this kind of climatic conditions, an optimal maintained PV system could reach a *PR* of 0.865, like shown in the example.

The final *PR* values obtained in the present example are in line with reported performance ratio of real monitored PV systems [D.4, D.6]. For example, [D.4] collected performance data of almost 100 PV systems installed in Germany between 1994 and 2010. The *PR* of new systems is clearly higher than those measured on the PV systems installed in the 1990s. While the *PR* of those is normally between 0.6 and 0.8, the *PR* of the PV systems installed in 2010 tends to vary between 0.7 and 0.9.

Further research work could be aimed to propose a 'normalisation' of the Final Performance Ratio (of a certain PV system) against the reference climatic area (e.g. considering irradiance and temperature aspects). This would make the Final Performance Ratio independent from the specific reference climatic area, allowing comparability.

D.5. Performance ratio: various effects

Following the reference PV array installation used in the series of standards EN 61853, which considers the PV array installed in a free standing rack facing the equator with an inclination angle of 20°, the PV system considered in the example presented in Section D4 is assumed installed following the same settings. This configuration has an impact on, not only the broadband and spectral in-plane irradiation but also on the diffuse/beam composition of the said irradiation. The free rack installation allows the wind to cool down the PV modules which, in turn, increases the efficiency of most PV technologies.

In the present section, we will present the effect of changing some of the assumptions considered in the default installation used in series of standards EN 61853, and in the example above, on the Performance Ratio [D.7].

Figure D1 shows the relative difference between the *PR* values of the PV array only, when the c-Si modules are inclined 40° or 20°. The inclination angle has an impact on the three effects presented in Table D2. Higher latitudes benefit from higher inclination angles in winter months when the solar elevation is low, that results in higher *PR* values using an inclination angle of 40°. However, the absolute value of the difference is low, below 0.5% in most areas.

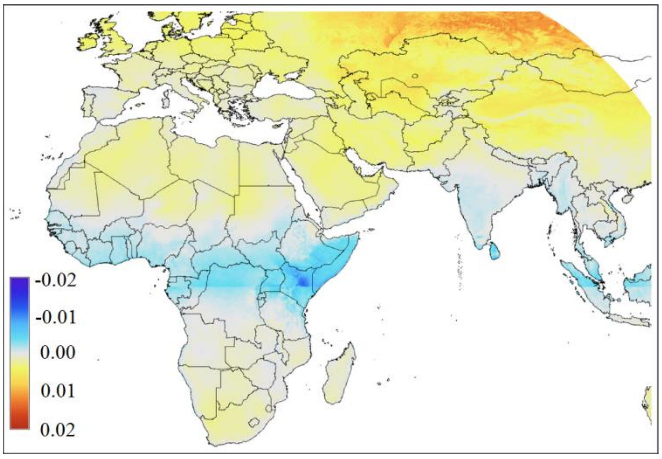


Fig D1. Relative difference between the c-Si PV array performance ratio when modules are inclined 20° or 40°.

Table D5 shows the performance ratio of a c-Si array for the reference sites used for the three European reference climates when modules are assumed inclined 20° or installed with the optimal inclination angle for each site.

Table D5. Performance ratio for a c-Si PV array installed with an inclination angle of 20° or with the optimal angle for each location.

Reference climates	20° inclination angle	Optimal inclination angle
Temperate coastal	0.923	0.930
Temperate continental	0.916	0.921
Subtropical arid	0.887	0.890

As shown in Table D5, considering the optimal inclination angle does not improve significantly the performance ratio of the PV module. The maximum gain is observed in the Temperate coastal location with a 0.76% increment.

The wind can increase the performance of the PV modules as their temperature is reduced. Figure D2 shows the relative difference in the *PR* of a c-Si module with or without considering the wind effects. This could serve as example of the losses in the *PR* that could be expected in building integrated PV system where the wind effect cannot be considered.

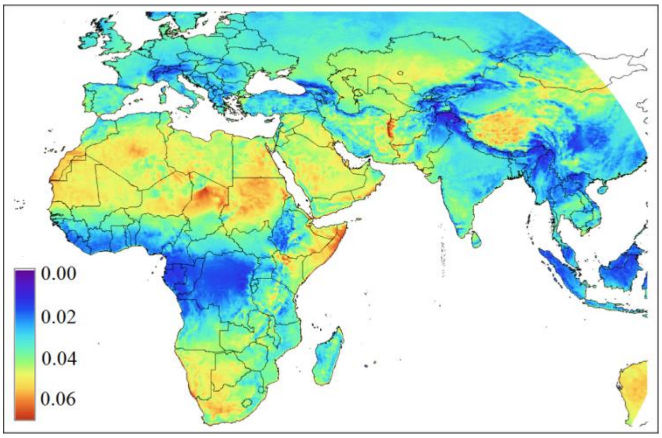


Fig D2. Relative difference between the c-Si performance ratio with and without considering the wind effect.

The reduction of the PV module temperature by the wind can result in *PR* increment of up to 6% in the extreme cases as shown in Fig D2.

Annex D - References

[D.1] B. Marion et al. Performance parameters for grid-connected PV systems. 31st IEEE Photovoltaic Specialists Conference. 2005. Doi: 10.1109/PVSC.2005.1488451.

[D.2] A. Bianchini et al. Performance analysis and economic assessment of different photovoltaic technologies based on experimental measurements. Renewable Energy (2016) 85, 1-11.

[D.3] S. Ekici and M. Ali Kopru. Investigation of PV system cable losses. International Journal of Renewable Energy Research (2017) 7(2), 807-815.

[D.4] N.H. Reich et al. Performance ratio revisited: is PR>90% realistic? Progress in Photovoltaics: research and applications (2012) 20, 717-726.

[D.5] A. Woyte et al. Analytical monitoring of grid-connected photovoltaic systems. Good practices for monitoring and performance analysis. IEA PVPS Task 13, Substask 2. Report IEA-PVPS T13-03:2014. ISBN 978-3-906042-18-3.

[D.6] U. Jahn and N. Wolfgang. Operational performance of grid-connected PV systems on buildings in Germany. Progress in Photovoltaics: research and applications (2004) 12, 441-448.

[D.7] T Huld and A.M Gracia Amillo. Estimating PV module performance over large geographical regions: the role of irradiance, air temperature, wind speed and solar spectrum. Energies (2015) 8, 5159-5181.

Annex E. *CSER* dependence on orientation and inclination

The methodology proposed for the estimation the energy yield derived from a PV system assumes the PV modules installed facing the equator with an inclination angle of 20°, according to the configuration applied in the EN 61853 series. However, as indicated in subsection 6.4.1 "*Installation and Location Specific Energy Yield*", PV systems may be installed according to other configurations. In order to consider these in the energy yield estimation, additional models or correction factors should be included.

The first step in the estimation of PV system's lifetime AC energy yield (See Section 6) is the evaluation of the DC annual energy output. This is done following the EN IEC 61853-3 methodology, which assumes the installation previously mentioned of inclination and orientation (azimuth) of the PV modules, using the reference climatic datasets of hourly values. However, if PV manufacturers included in the datasheet of the PV modules the *CSER* (*Climate Specific Energy Rating*) value, the yearly DC energy output could be easily obtained applying Equation 3.

However, the *CSER* are derived considering the modules inclined 20° and facing the equator, while it may be that the analysed PV system is installed following other configuration. Therefore, the *CSER* calculated with the EN 61853 methodology may not be directly applicable to that PV system. The aim of the present Annex is to quantify the effect of considering different installation settings (inclination and orientation) in the *CSER* values.

To do so, the *CSER* has been calculated for 1 kWp PV array of crystalline silicon modules located at the three European reference climatic regions considering different inclination and orientation angles, besides the EN 61853 installation configuration. The inclination angle has been evaluated from 0° (horizontal plane) to 90° (vertical plane) in steps of 5°. Regarding the orientation angle or azimuth of the PV array, which is assumed due to the equator by the EN 61853, in this Annex it has been evaluated from north (-180°) to east (-90°), south (0°), west (90°) and back to north (180°), at 30° steps. As a result, a total of 247 installation configurations have been analysed.

The *CSER* for each setting (inclination and orientation combination) has been normalized to the *CSER* value for the EN 61853 installation condition (inclination of 20° and orientation of 0°), in order to evaluate the effect of the inclination and orientation on the *CSER*. These normalized *CSER* values could be used to "correct" the declared *CSER* value obtained following the EN 61853 methodology, in order to consider other configurations of the PV system when evaluating the DC annual energy yield.

The obtained normalized *CSER* values are shown in the figures E1 to E3, showing the results for the Subtropical arid, Temperate continental and Temperate coastal reference climatic regions, respectively.

For deviations up to 90° from the equator (-90° east and 90° west), the effect on the *CSER* with regard to the EN 61853 results is in general below the -2%, regardless of the inclination angle. Depending on the reference climate, which affect the ratio of direct and diffuse irradiance, the *CSER* for vertical surfaces oriented towards north can be up to 18% lower than the value obtained for the EN 61853 configuration.

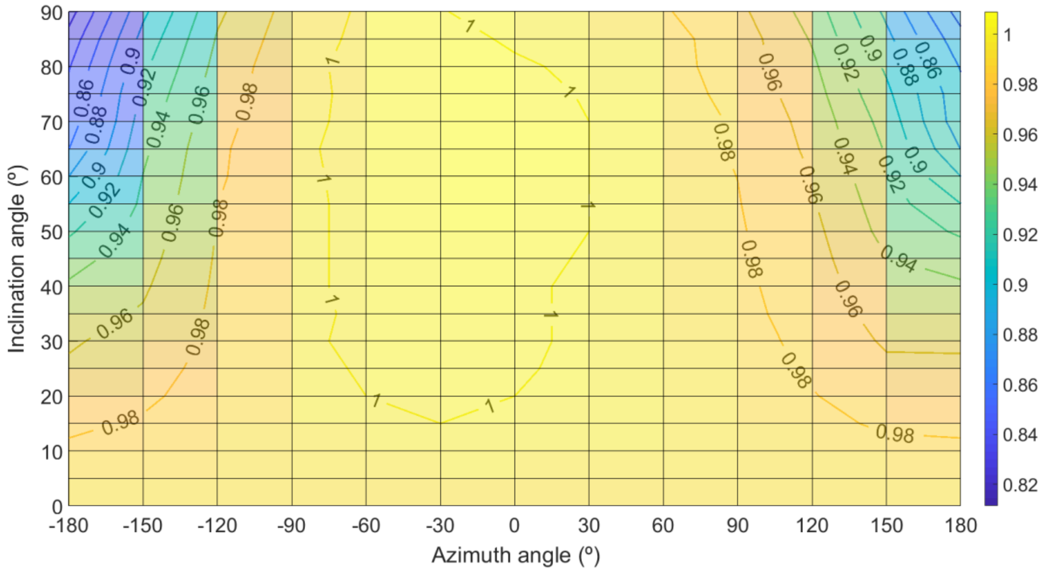


Figure E1. *CSER* normalized to the EN 61853 configuration for the Subtropical arid European climatic profile.

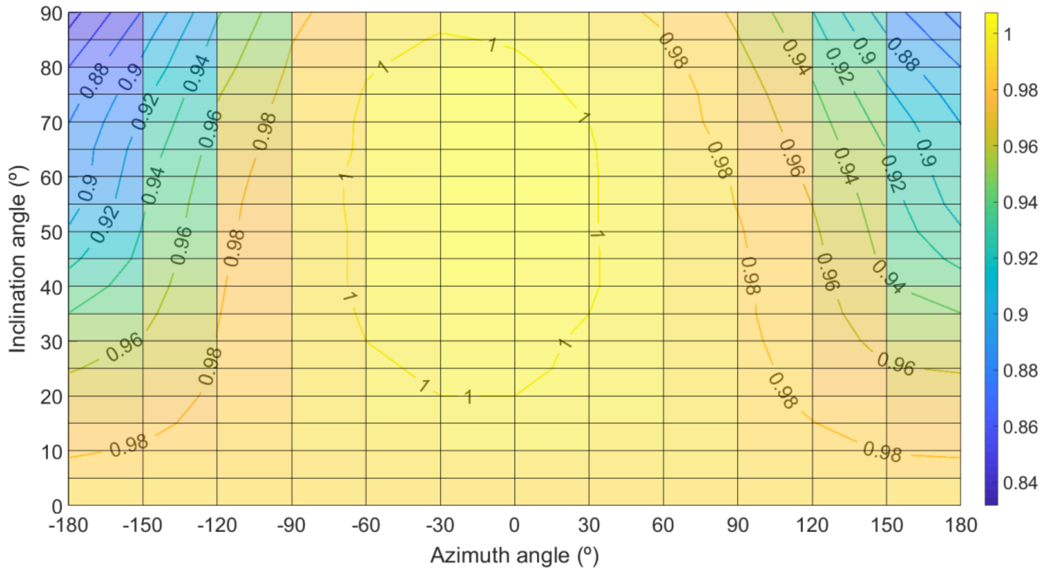


Figure E2. *CSER* normalized to the EN 61853 configuration for the Temperate continental European climatic profile.

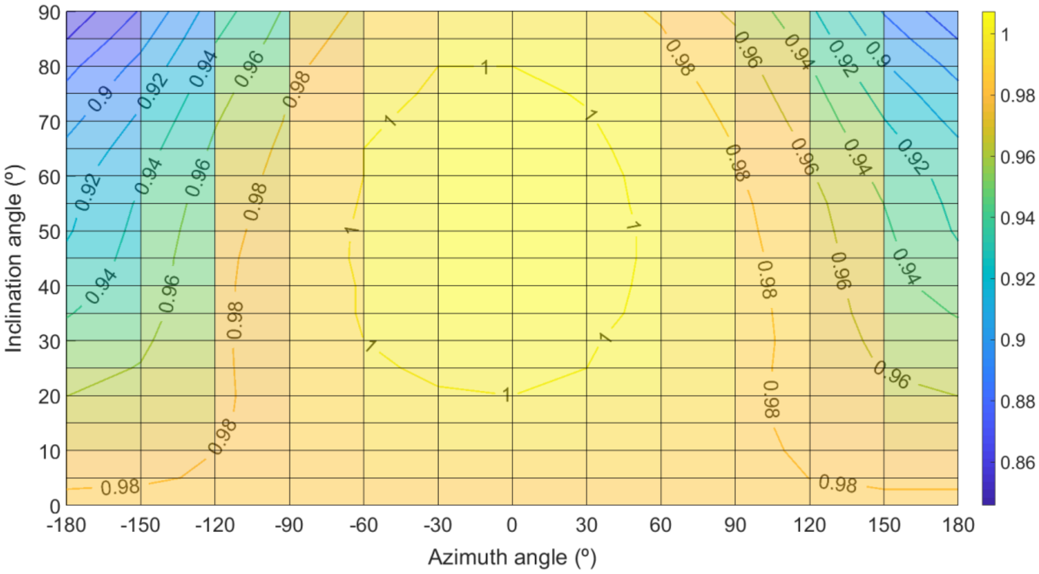


Figure E3. *CSER* normalized to the EN 61853 configuration for the Temperate coastal European climatic profile.

Annex F. European reference climatic profiles for PV

The EN IEC 61853-4 "*Photovoltaic (PV) module performance testing and energy rating – Part 4: Standard reference climatic profiles*" tabulates the standards reference climatic profiles used for calculating energy rating. Six climatic profiles are used to define the climatic conditions that PV systems will most likely by subjected to when installed worldwide. Out of these six, three are considered representative of the European climatic conditions:

- Subtropical arid
- Temperate continental
- Temperate coastal

The climatic datasets included in Part 4 contain hourly values over one full year, listed as days one through 365, of the following parameters:

- Year
- Month
- Day
- Hour (local solar time)
- Ambient temperature (T_{amb}, °C)
- Wind speed at module height (v, m/s)
- Sun elevation (°)
- Sun incidence angle (to the normal of module) (°)
- Global horizontal irradiance (Gh, W/m^2)
- Direct horizontal irradiance (Bh, W/m^2)
- Global in-plane irradiance (G, W/m^2)
- Direct in-plane irradiance (B, W/m^2)
- Spectrally resolved global in-plane irradiance (W/m^2) integrated for a set of discrete bands ($G(\lambda)$,W/m^2)

Modules are assumed to be installed in a fixed open-rack, facing the equator with an inclination angle of 20°.

Figure F1 shows the geographical distribution of the EN IEC 61853-4 reference climatic profiles assumed representative of the European weather conditions. Figure F2 shows the distribution of the three reference climates in the 1348 NUTS 3 European regions as defined in the current NUTS 2016 classification. According to the average available solar resource of the region, this is assigned one of the three European weather conditions. This may result in regions that in Figure 1 are under two or more climatic conditions, when represented by its average irradiation value, are represented only by one of those initial reference climates. As a result, the transition between reference climates in Figure 2 is not progressive as in Figure 1, as it depends on the NUTS 2 regions distribution. Being based on an accepted existing classification, Figure F2 is certainly better fit (than Figure F1) for potential use for regulatory purposes. In order to 'smoothen' the transition from one reference climate to another, it could be necessary to modify Figure F2 by introducing a 'granularity' at the municipality level, at least in specific areas.

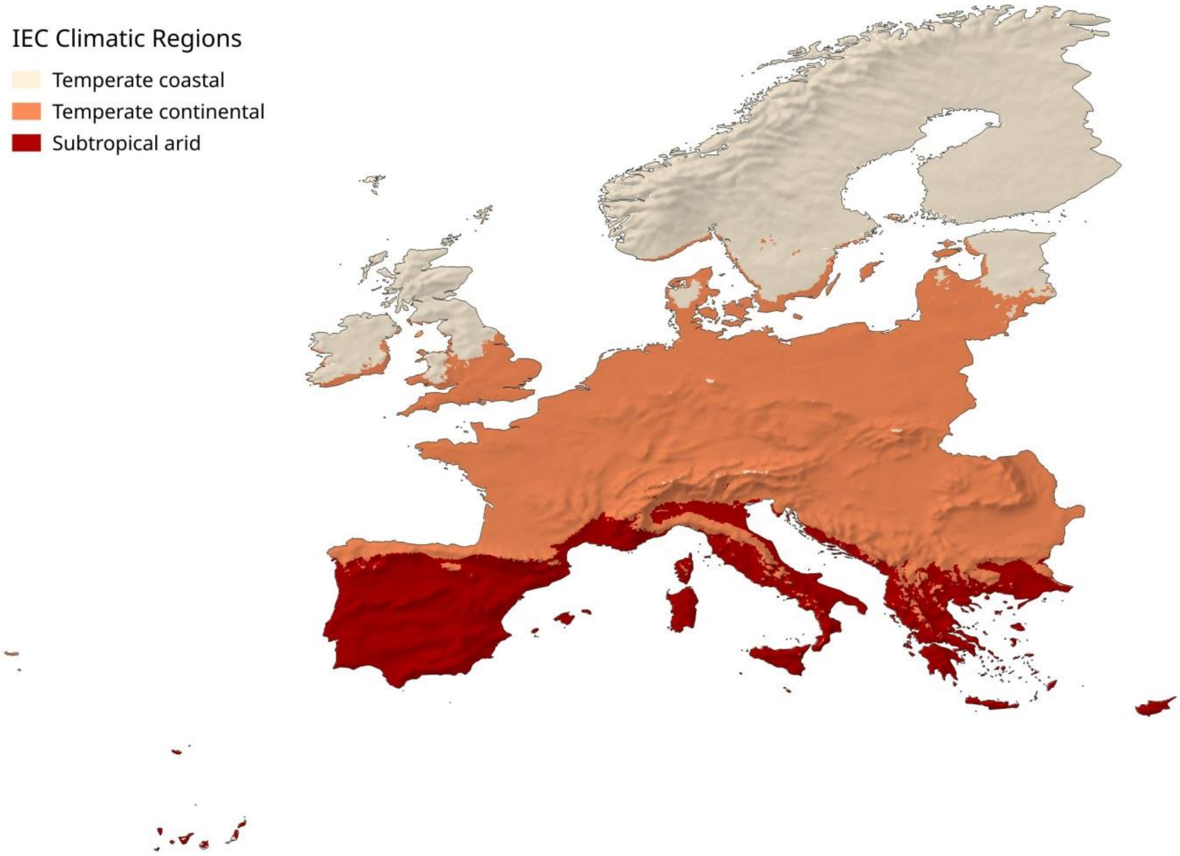


Figure F1. Geographical distribution of the EN IEC 61853-4 climatic profiles representative of the PV European climatic conditions.

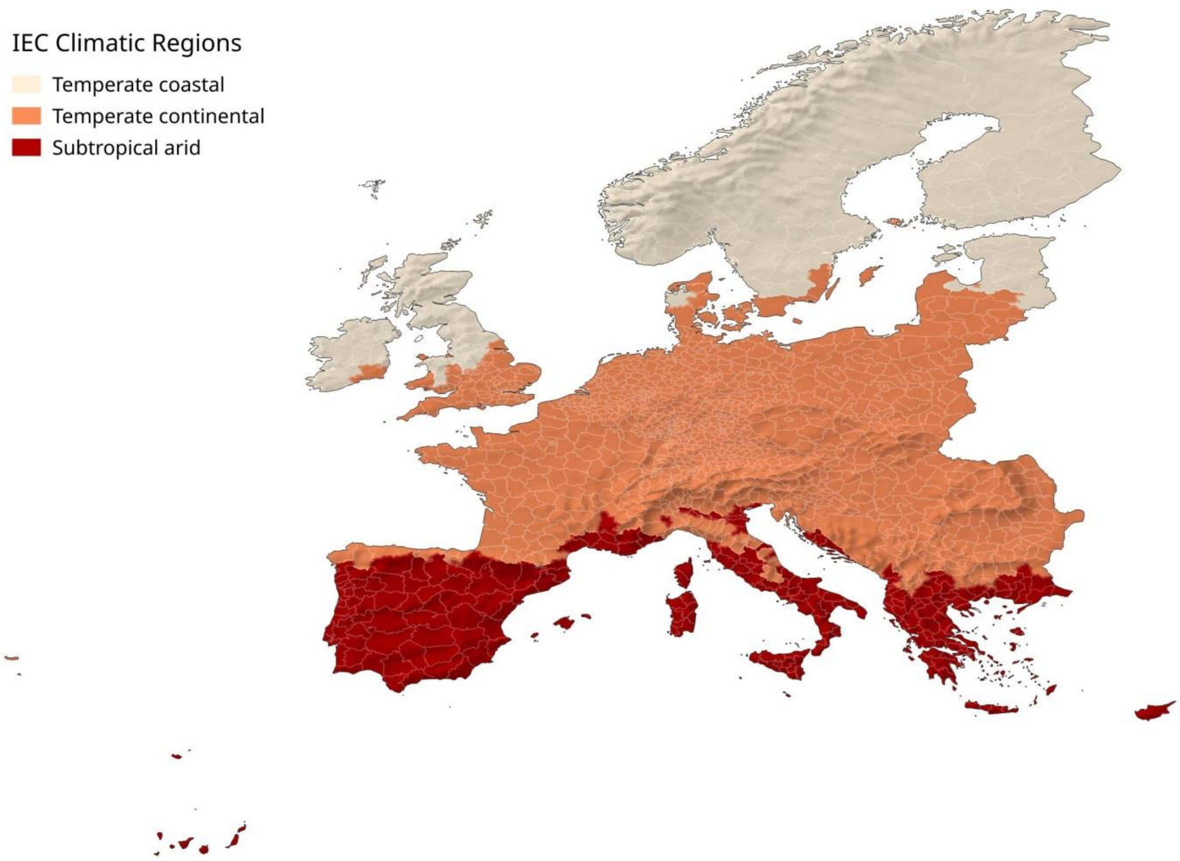


Figure F2. Geographical distribution of the EN IEC 61853-4 climatic profiles representative of the PV European climatic conditions in the 1348 NUTS 3 European regions.

KJ-NA-29513-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

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

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi: 10.2760/496002

ISBN 978-92-79-98284-2