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Preparatory study for solar photovoltaic modules, inverters and systems

*(Draft) Task 1 report:
Product scope*

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Task 1: Scope, standardisation and legislation

The aim of Task 1 is to analyse the scope, definitions, standards and assessment methods and other legislation of relevance to the product group and to assess their suitability for classifying and defining products for the purposes of analysing Ecodesign and Energy Label requirements, and in turn to analyse the suitability of using this product scope for the EU Ecolabel and Green Public Procurement.

1.1. Product Scope and Definition

The following sections first provide a brief introduction to photovoltaics, and then an analysis of existing definitions of photovoltaic modules, inverters and systems, as used for example in European statistics, EU legislation, standards and other voluntary initiatives such as ecolabels; together with stakeholder feedback on the suitability of existing scope and definitions for each of the policy instruments in question.

1.1.1. Basic introduction to photovoltaic technology

The solar photovoltaic effect was discovered in 1839 as an off shoot from photochemical experiments. The first silicon photovoltaic cell was created in the 1950's and this technology has been constantly refined since then. At a fundamental level the process is founded on the ability of a semiconductor to convert light into electrical energy.

The photovoltaic effect when a semiconductor material absorbs light and positive and negative electrons are released. These are then extracted from the semiconductor as electric current. Most PV cells are made from metallurgical grade silicon. The effect takes place in a solar cell which is usually very small and fragile. The electricity generated by a single cell is very small, but when connected together in the form of a solar panel, this output is greatly increased. The cells are also protected by being sealed in a weather proof module consisting of a glass front, aluminium frame and protective cover.

The first uses of the more familiar PV module form factor were in the US space program, which required a lightweight and compact energy source for its satellites. This ensured that further research took place on the photovoltaic effect and how to produce more efficient solar panels.

There are different types of solar cells and these are formed into different types of solar panels. The first type is a *crystalline* silicon solar cell; the other type is *amorphous*. *Crystalline* cells are cut from a solid ingot of silicon whereas *amorphous* (also known as *thin film*) is made by depositing a silicon compound on to a glass. Crystalline PV cells are more efficient in their conversion of light to electricity because of their contiguous crystalline structure but usually this comes at a higher cost. One of the main activities in the PV industry is to increase the level of efficiency of cells, in relation to their cost.

There are two types of crystalline cell: the monocrystalline and the polycrystalline. Monocrystalline is the more efficient of the two, but has been traditionally more expensive because it requires ingots that are grown using special processes and that are made of silicon with a higher purity. The first modules manufactured relied on the use of cells made from reject monocrystalline wafers from the semi-conductor industry (see Figure 1).



Figure 1 Early example of monocrystalline cells in a module Source: Green Building Advisor (2018)

Thin films do not have the same level of performance as crystalline PV cells and despite being substantially less expensive, have not had the same market penetration either. The development of thin film has been detrimentally affected by the constant reduction in the cost of crystalline panels.

Whatever the technology, the electrical current that is created in the PV cell and subsequently extracted as a current, is direct current (DC) not the alternating current (AC) of the type produced by the alternating magnetic generators in power stations or wind turbines on which the normal mains supply in the EU operates.

Solar power systems

Solar cells made into modules to optimise the electricity generated, normally form part of a system. There are two types of systems: those connected to the grid and stand-alone systems or off grid. The latter use the power created on site, and normally include an electricity storage arrangement. In many EU countries however almost all systems are connected to the grid. They can be mounted on a building or they can be free standing. When in a building, the following components are usually present (see Figure 2):

- The solar panels or module array: the combination of solar cells in a weatherproof package
- The racking: this is the equipment that attaches the solar panels onto the roof of the building.
- Cabling: to transport the current generated from the module array to the inverter
- The inverter: this unit(s) converts the DC current from the modules to AC current that can be used in the building or transferred to the grid
- Junction box(es): this is the terminus of the DC wiring from each module
- The meters: in order to measure the amount of electricity generated. It is usually a legal requirement to claim subsidies such as a feed in tariff.

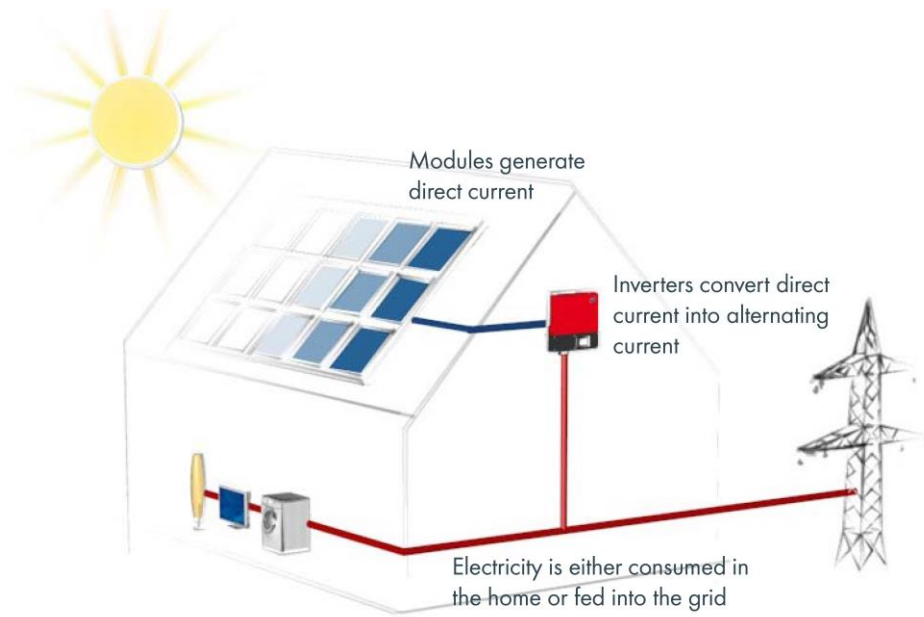


Figure 2. Basic installation of a domestic solar photovoltaic system. Source: SMA (2018)

The sun's energy

The impact of the sun's rays on earth is called irradiance. Levels of irradiance differ depending on the location. Attention therefore has to be paid to the level of irradiance available for a solar project as this will influence the electricity yield. Figure 3 reproduces the map of EU levels of irradiance. This shows that the Southern latitude (e.g. Spain and Italy) are the best places for solar power, where the average irradiance is 2000-2200 kWh/m²yr. This level makes the energy payback times (EPBT) – the amount of time it takes to generate more energy than it took to make the system – are shorter. However, the greatest interest in installing solar PV has, to date, been in central EU. Germany, France and Italy have been the pioneers in the deployment of solar energy.

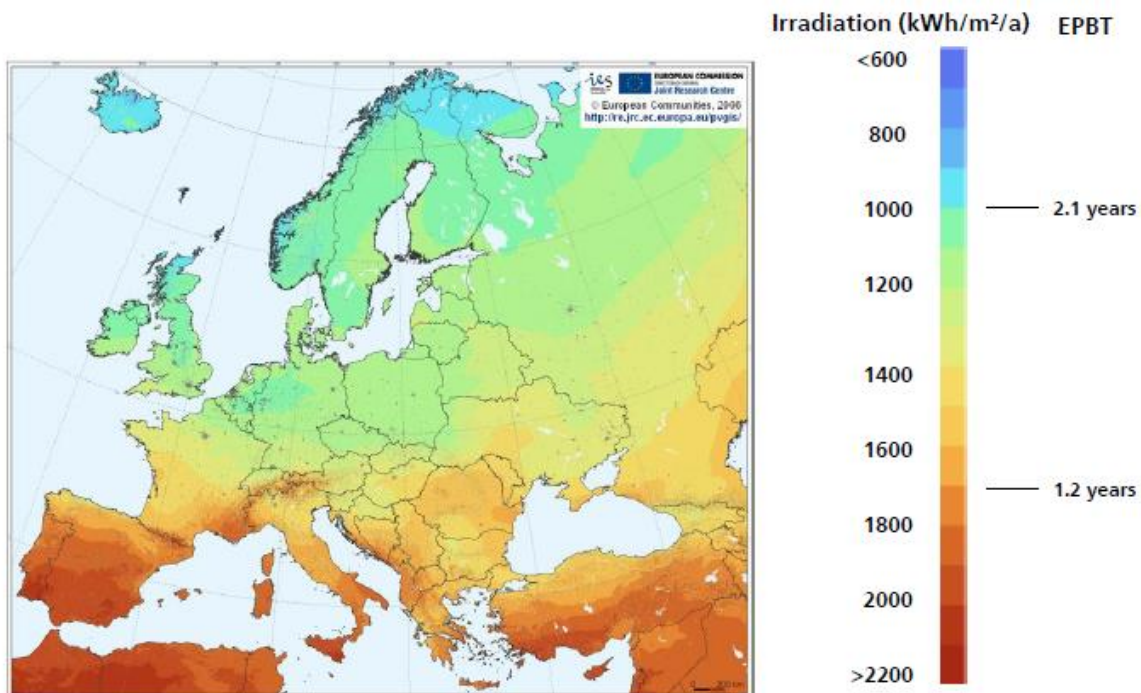


Figure 3. EU irradiation and solar electricity potential

1.1.2. Product scope and definition for Ecodesign and Energy labelling

The following section provides an overview of existing definitions of photovoltaics modules, inverters and systems, using as its starting point the following categorisations:

- PRODCOM codes and activities;
- Definitions and categorisations for the purpose of CE marking requirements;
- Definitions and categorisations according to EN, IEC and ISO standards;
- Other product specific definitions and categories e.g. labels, Product Category Rules;

The product scope and definition is analysed within the frame of the Ecodesign and Energy label Directives, in turn for each of the three sub-products that are a focus for the Preparatory Study. A proposal of scope, definition and functional unit for modules, inverters and systems is shown in section 1.4. Conclusions and recommendations.

1.1.2.1. Definitions found in Eurostat PRODCOM codes

The EU's industrial production statistics are compiled in the PRODCOM (PRODUCTION COMMUNAUTAIRE) survey and also in the EUROPROD database, which includes external trade statistics. The economic activities surveyed by PRODCOM are classified according to the Statistical Classification of Economic Activity (NACE). The statistics for production under each economic activity are in turn reported by each Member State according to Statistical Classification of Products by Activity (CPA) codes. The link between the NACE and CPA codes is illustrated in Figure 4.

The main indicators of the production sold during the calendar year are collected and published both in monetary units (EUR) and physical units of production (kg, m², number of items, etc.). Data is provided, where available at Member State level, for:

- the physical volume of production sold during the survey period,
- the value of production sold during the survey period,
- the physical volume of actual production during the survey period, including any production which is incorporated into the manufacture of other products from the same undertaking.

These statistics provide an outlook on the volume of imports, as well as enabling the actual and apparent production to be estimated based on the balance of EU sales and trade.

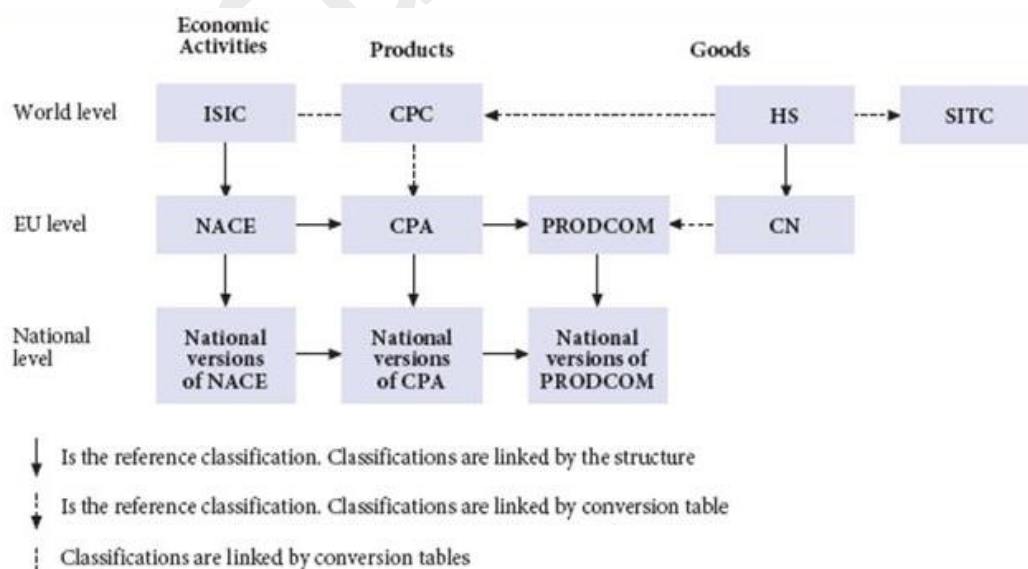


Figure 4. Overview of the revised EU system of integrated statistical classifications. Source: Eurostat (2017)

Table 1 presents the divisions and classes of potential relevance to the product group, identified using the NACE and CPA Revision 2 classifications¹. Potentially relevant CPA activities span four broad types:

- Module and system sub-components e.g. wafers, junction boxes, transformers.
- Solar photovoltaic modules, which could be reported as 'other' electrical equipment.
- Renewable electricity generation, of which solar photovoltaic is a reported component.
- Electrical solar energy installations.

It can be seen that the only specific references to solar photovoltaics are made under Section C ('photovoltaic cells'), which refers to the cell component of a module, and Section F ('electric solar energy collectors'), which relates to electrical installations. CPA code 26.11.40 aggregates a range of semiconductor devices, including Light Emitting Diodes (LEDs). The supply and consumption of solar photovoltaic electricity is reported in terajoules for each Member State as a component of Eurostat's energy database².

With the exception of solar photovoltaic electricity generation, it is not possible to identify specific disaggregated production or trade data related to solar photovoltaic modules or system components produced for solar photovoltaic end-use applications. This lack of specific photovoltaic manufacturing and installation codes appears to have been reflected in the Product Environmental Footprint Category Rules (PEFCR) pilot on solar photovoltaic electricity generation's choice of reference CPA code 35.11.10 Production of electricity (photovoltaic).

¹ Obtained from the Eurostat RAMON (Reference and Management of Nomenclatures) metadata, accessed in November 2017, <http://ec.europa.eu/eurostat/ramon/nomenclatures>

² Eurostat, *Energy from renewable sources*, <http://ec.europa.eu/eurostat/web/energy/data/shares>

Table 1. NACE economic activities and Classifications of Products by Activity (CPA) codes of potential relevance to the product group

Section	Division	Class	Sub-class	Activities (CPA code)
C Manufacturing	26. Manufacture of computer, electronic and optical products	26.1 Manufacture of electronic components and boards	26.11 Manufacture of electronic components	26.11.10 – Manufacture of dice or wafers, semi-conductor, finished or semi-finished
				26.11.22 – Photosensitive semiconductor devices; solar cells, photo-diodes, photo-transistors, etc.
				26.11.40 – Parts of diodes, transistors and similar semiconductor devices, photosensitive semiconductor devices and photovoltaic cells, light-emitting diodes and mounted piezo-electric crystals
	27. Manufacture of electrical equipment	27.1 Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	27.11 Manufacture of electric motors, generators and transformers	27.11.01/02 – Electrical apparatus for switching or protecting electrical circuits
				27.11.04 – Electrical transformers
		27.2 Manufacture of batteries and accumulators	27.20 Manufacture of batteries and accumulators	27.20.10 – the manufacture of non-rechargeable and rechargeable batteries
				27.33 Wiring devices
27.90 Manufacture of other electrical equipment				27.90.10 – miscellaneous electrical equipment other than motors, generators and transformers, batteries and accumulators, wires and wiring devices, lighting equipment or domestic appliances.
D Electricity, gas, steam and air conditioning	35. Electricity, gas, steam and air conditioning supply	35.1 Electric power generation, transmission and distribution	35.11 Production of electricity	35.11.10 – Electricity (solar photovoltaic)
			35.14 Trade of electricity	35.14.10 – Sale of electricity to the user – Activities of electric power brokers that arrange the sale of electricity via power distribution systems operated by others – Operation of electricity and transmission capacity exchanges for electric power
F Construction	43. Specialist construction activities	43.2 Electrical, plumbing and other construction installation works	43.21 Electrical installation	43.21.10 – Electrical installation works of other electrical equipment, including electric solar energy collectors and baseboard heaters of buildings

1.1.2.2. CE marking conformity requirements

There are currently no CE marking conformity requirements nor related European harmonised testing standards established at EU level that relate specifically to solar photovoltaic modules or inverters³. There are, however, relevant generic CE marking requirements that establish market entry requirements for:

- Construction products in accordance with Regulation (EU) No 305/2011⁴,
- Electromagnetic compatibility in accordance Directive 2014/30/EU⁵,
- Low voltage electrical equipment in accordance with Directive 2014/35/EU⁶, and
- Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS) in accordance with the recast Directive 2011/65/EU⁷.

These set requirements that solar photovoltaic modules, inverters and other components of photovoltaic systems must be in conformity with in order to be placed on the EU market. They also set requirements that AC and DC power supply systems must be in conformity with.

The certification of conformity requires modules and inverters to pass several electrical and mechanical tests in line with CE quality and safety rules, including co-operability/ compatibility tests involving the assessment of the electromagnetic interference of the solar products which may not exceed certain levels as this could otherwise lead to operation and performance impacts on other nearby electronics.

The Construction Products Regulation requires all products that are covered by a harmonised standard to provide a Declaration of Performance (DoP) in support of CE marking. Products therefore need to pass equivalent tests for building materials that they may substitute e.g. roof tiles. These Declarations are intended to relate to what are referred to in the Construction Products Regulation (EU) No 305/2011 as the 'Basic requirements for construction works'. These requirements are explained further in section 1.3.1.4.1.

As can be seen, these CE marking requirements provide only generic categories or classes related to, for example, types of construction product or electrical equipment voltages. These may, however, be useful in setting cut-off thresholds for the purpose of the types of product to be analysed and their related market segments.

Even though the self-certification for the CE Mark greatly facilitates solar product production, export to and consumption in the EEA, manufacturers however are bound to the conformity self-assessments. Therefore, identified non-compliant manufacturers knowingly producing non-conforming solar products and self-issuing the CE mark face severe penalties and sanctions.

1.1.2.3. Photovoltaic module definitions

A photovoltaic module forms a fundamental part of a solar photovoltaic system, being the primary component that converts solar irradiation into DC electricity. The modules installed as part of a system must be

³ DG GROWTH, *Manufacturers and product groups*, https://ec.europa.eu/growth/single-market/ce-marking/manufacturers_en

⁴ DG GROWTH, *Construction*, https://ec.europa.eu/growth/sectors/construction_en

⁵ DG GROWTH, *Electromagnetic compatibility (EMC) standards*, https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/electromagnetic-compatibility_en

⁶ DG GROWTH, *The Low Voltage Directive*, http://ec.europa.eu/growth/sectors/electrical-engineering/lvd-directive_en

⁷ DG Environment, *Restriction of Hazardous Substances in Electrical and Electronic Equipment* http://ec.europa.eu/environment/waste/rohs_eee/legis_en.htm

interconnected in order to form an array, the DC electrical output from which is then supplied to the Balance of System components of a system for conversion into AC current.

1.1.2.3.1. Standardised product category definitions for photovoltaic modules

The International Electrotechnical Commission (IEC) defines photovoltaic panels or modules as a complete and environmentally protected assembly of interconnected PV cells. (IEC 61836:2016, 3.1.48.7)

"Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 365 Watts (W). The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 W module will have twice the area of a 16% efficient 230 W module".

Photovoltaic module is frequently used as general term to refer to for both panels (framed modules) and laminates (unframed module).

1.1.2.3.2. Other non-standardised product category definitions

The Underwriters Laboratories' 1703 Standard for Flat-Plate Photovoltaic Modules and Panels is the industry standard for baseline safety and performance and the gateway to the marketplace. It is the basis for the IEC 61730 document, which is the international safety standard, and defines PV modules as:

"...the smallest environmentally protected, essentially planar assembly of solar cells and ancillary parts, such as interconnects and terminals, intended to generate DC power under unconcentrated sunlight. The structural (load-carrying) member of a module can either be the top layer (superstrate), or the back layer (substrate), in which:

- a) The superstrate is the transparent material forming the top (light-facing) outer surface of the module. If load-carrying, this constitutes a structural superstrate.*
- b) The substrate is the material forming the back outer surface of a module. If load-carrying, this constitutes a structural substrate "*

The latter definition for PV modules covers:

- flat-plate photovoltaic modules and panels intended for installation on or integral with buildings, or to be freestanding (that is, not attached to buildings), in accordance with the National Electrical Code, NFPA 70, and Model Building Codes.
- These requirements cover modules and panels intended for use in systems with a maximum system voltage of 1000 V or less.
- These requirements also cover components intended to provide electrical connection to and mounting facilities for flat-plate photovoltaic modules and panels.

UL 1703 does not cover however the following elements in the definition of PV module:

- a. Equipment intended to accept the electrical output from the array, such as power conditioning units (inverters) and batteries;
- b. Any tracking mechanism;
- c. Cell assemblies intended to operate under concentrated sunlight;
- d. Optical concentrators; or
- e. Combination photovoltaic-thermal modules or panels.

Another definition is provided by the Product Environmental Footprint Category Rule (PEFCR) for a PV module:

“...of 48, 60 or 72 photovoltaic cells (156 x 156 mm crystalline technology), or a semiconductor layer (thin film technology), a substrate and a cover material (glass, plastic films), the connections (used for the interconnection of the cells), the cabling (used for the interconnection of the modules) and the frame (in case of panels).”

The product scope definition in the context of the PEF Initiative for, the term “photovoltaic module” is used as general term for panels (framed modules) and laminates (unframed module). The scope of the PEFCR is the production of DC electricity with photovoltaic modules. Mounting is considered as part of the product. Not considered in the product scope are balance of system components such as inverter and AC cabling (connection to the grid).

According to IEA technology roadmap, *the basic building block of a PV system is the PV cell, which is a semiconductor device that converts solar energy into direct-current (DC) electricity. PV cells are interconnected to form a PV module, typically up to 50-200 Watts (W).*

Table 2 gathers the main features or concepts used in the definitions of photovoltaic modules that have been analysed. The most complete definition is the one provided by PEF, followed by the Underwriters Laboratories. None of the definitions mention explicitly building integration products, which are reviewed separately in the next section.

Table 2. Categorisation of solar photovoltaic module definitions according to IEA, IEC, UL and PEF

Categorisation	IEA	IEC	UL	PEF
Size (m ²)				✓
Power output (kWp)	✓	✓		
Number of cells (e.g. 48, 60, 72)				✓
Structure load bearing form (substrate or superstrate)			✓	✓
Framed or unframed	✓			✓
Building integration products (e.g. façade panels, sloped and flat roofs, brise soleil, louveres, glass-glass laminates and roof tiles)				
Environmental protection features (e.g. isolation from weathering)			✓	✓
Components of a module (e.g. encapsulants, interconnections, junction box)			✓	✓

1.1.2.3.3. Building integration of photovoltaic cells or modules

A high level of solar photovoltaic deployment will suppose a greater level of integration of photovoltaic technology into buildings and their fabric. The CENELEC makes a distinction in EN 50583-1:2016 between Building Attached PV (BAPV) modules and Building Integrated PV (BIPV) modules. It defines BAPV as:

'photovoltaic modules [that] are considered to be building-attached, if the PV modules are mounted on a building envelope and do not fulfil the [BIPV] criteria for building integration'

Moreover it defines BIPV modules as:

'photovoltaic modules [that] are considered to be building-integrated, if the PV modules form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011. Thus the BIPV module is a prerequisite for the integrity of the building's functionality.'

Further clarification is then provided on the functional overlap between a BIPV module and a construction product:

If the integrated PV module is dismantled (in the case of structurally bonded modules, dismantling includes the adjacent construction product), the PV module would have to be replaced by an appropriate construction product. The building's functions in the context of BIPV are one or more of the following:

- *mechanical rigidity or structural integrity*
- *primary weather impact protection: rain, snow, wind, hail*
- *energy economy, such as shading, daylighting, thermal insulation*
- *fire protection*
- *noise protection*
- *separation between indoor and outdoor environments*
- *security, shelter or safety*

Inherent electro-technical properties of PV such as antenna function, power generation and electromagnetic shielding etc. alone do not qualify PV modules as to be building-integrated.'

In the case of BIPV, photovoltaic cells are required to be integrated into form factors that are equivalent to the construction products they will replace. The IEA PVPS makes reference to modules that are '*specialised products for building integrated PV systems*' and states that these may be at larger sizes than their reference rating range of 50 W to 350 W. They also make reference to the different mounting structures that may be used for BIPV, including facades, sloped and flat roofs, glass-glass laminates and roof tiles.

The potential for a range of different form factors suggests that a broader and more flexible definition of 'module' may be required if Building Integrated PV (BIPV) products are to be considered within the scope. This is also because cells, rather than modules, are commonly the starting point for the design of a building integration PV product.

1.1.2.3.4. Summary of the results from the first stakeholder questionnaire

In this section the scope related questions asked in the first stakeholder questionnaire of December 2018 are reprised and the responses briefly summarised in order to identify the main findings.

Q1.1 Could the photovoltaic module scope and definition provided below be appropriate for use in this study?

The product category scope corresponds to the production of photovoltaic modules used in photovoltaic power systems for electricity generation.

A photovoltaic module is defined as being a panel (framed module) or a laminate (unframed module). A photovoltaic module basically consists of 48, 60 or 72 photovoltaic cells (crystalline technology), or a semiconductor layer (thin film technology), a substrate and a cover material (glass, plastic films), the connections (used for the interconnection of the cells), the cabling (used for the interconnection of the modules) and the frame (in case of panels).

Adapted from: Product Environmental Footprint Category Rules definition of scope, 2014

The stakeholders were asked to react to a proposed definition and scope for the modules. Three options were given as seen in Figure 5. Of the 39 respondents a slim majority (51%) considered the scope and definition to need amending.

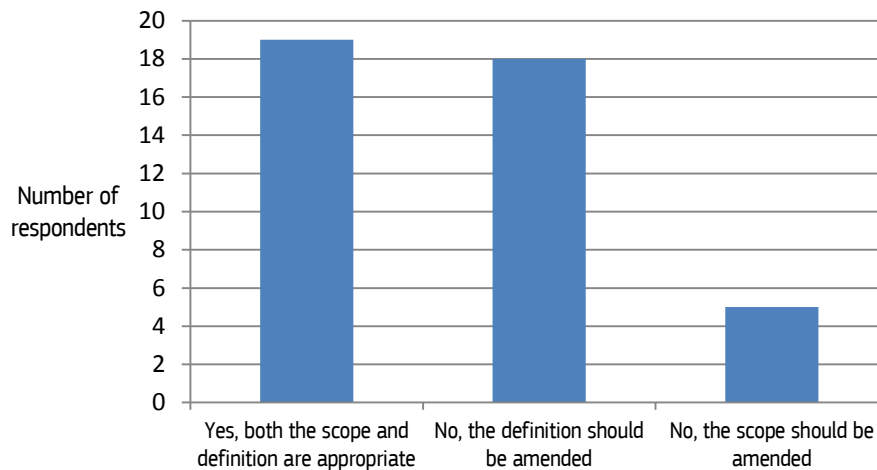


Figure 5 Agreement on the proposed scope and definition

In terms of the product definition, of the respondents that were in favour to amend it, 78% recommended to leave out the number of cells. Encapsulants and junction boxes were mentioned as needing be explicitly included in the definition by 2 respondents. A complete definition was proposed as follows by 6 of the respondents:

A photovoltaic module is defined as being a panel (framed module) or a laminate (unframed module). A photovoltaic module basically consists of photovoltaic cells (crystalline technology), or a semiconductor layer (thin film technology), a substrate and a cover material (glass, plastic films), the connections (used for the interconnection of the cells), the cabling (used for the interconnection of the modules) and the frame (in case of panels).

Specific reference was also made by 8 respondents to the IEC 61836 standard.

Q1.2. Of the aspects listed below, which should be taken into account in determining the scope and definition of modules to be analysed?

The majority (64%) of respondents chose 'as many as required' as their preference. Of these respondents, 47% were from 'contractors and supply chain' and 23% from 'performance and standards'.

It can be seen in Figure the aspects selected by 50% or more of the respondents were *size (m²)*, *power output (kWp)*, *building integration products and intended end-use*. *Number of cells* and *structural load bearing form* were considered the least relevant.

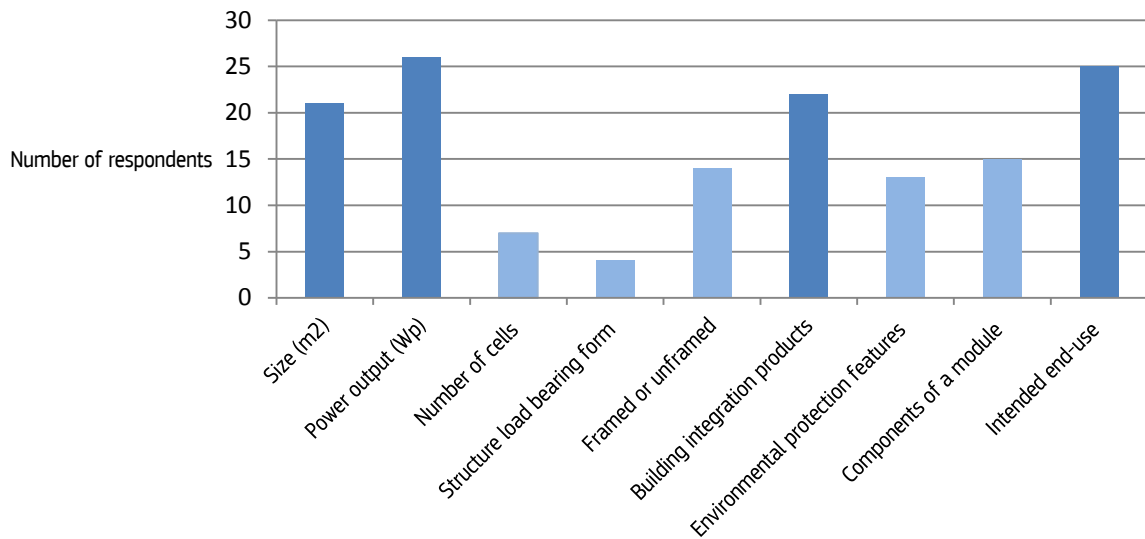


Figure 6 Aspects selected by respondents that should be taken into account in determining the scope and definition of inverters

In terms of comments on the listed aspects, many related to the *intended end use* and *framed or unframed* aspects:

- Intended end use: seven stakeholders consider that only the “intended end-use” is an aspect relevant in determining the scope and definition of modules to be analysed. They believe the scope should be limited to the production of terrestrial photovoltaic modules used in photovoltaic power systems with the sole purpose to generate electricity from solar light for public, commercial, industrial, rural and residential applications. PV modules in mobile applications, such as electric vehicles, watches, calculators, power banks and other gadgets should be excluded. Hence the integration into a consumer product should not be included into the scope. (Remark: tracker applications should not be excluded on these grounds.)
- Framed or unframed: one respondent stated that as long as only the PV modules and not the whole PV systems are regulated via Ecodesign, the module frames should be excluded from the Regulation/Evaluation, as otherwise the market could be distorted towards unframed PV modules without an overall positive effect as the material would be put into more rigid mounting structures.

Respondents also mentioned other aspects that were not listed but that could be taken into consideration, such as:

- Active area of modules, weight or semiconductor materials, photovoltaic cell nature/type/ technology
- Energy yield (kWh/kWp): one respondent considered it important to have a broad scope and definition which should not be limited through a priori lock-in / lock-out decisions. Since the most important factor (in terms of environmental and socio-economic performance) is the life-time energy production of a PV module. It was suggested to consider the aspect of energy yield (for a given number of standardised installations and insulation conditions) measured as kWh/kWp.

Q1.3 Should any form of threshold for the inclusion/exclusion of products in the scope be used? If so, based on which of the following aspects?

Among the respondents to this question the majority (15 out of 20) were in favour of considering a power output cut off for modules below 50W , so that they are not in the scope of the preparatory study. This is in line with the replies for the previous question where respondents recommended leaving out of the scope the applications of modules intended for mobile use or gadgets as watches and calculators. However 5 respondents noted that the cut off should be perhaps lower than 50W proposed.

There were however 11 stakeholders that argued that thresholds for inclusion/exclusion of products in the scope was not in line with a technology-neutral, innovation-friendly approach of a preparatory study, since the innovation cycles in the industry are very short and new technology concepts can emerge within 3 to 5 years. Some of the reasons given were that:

- since there is no standard *form factor* in the industry, a restriction by size is not viable.
- considering the potential broad range of *power outputs* between small form factor solar tiles (10 – 30 W) and large form factor utility scale PV modules (> 400W).
- there are fundamental technological differences in device architectures which could lead to a wide variety of *cell numbers* (i.e. solar tiles with 1 to 2 cells vs. utility scale thin film modules with more than 300 cells).

The overall results are presented in Figure 7.

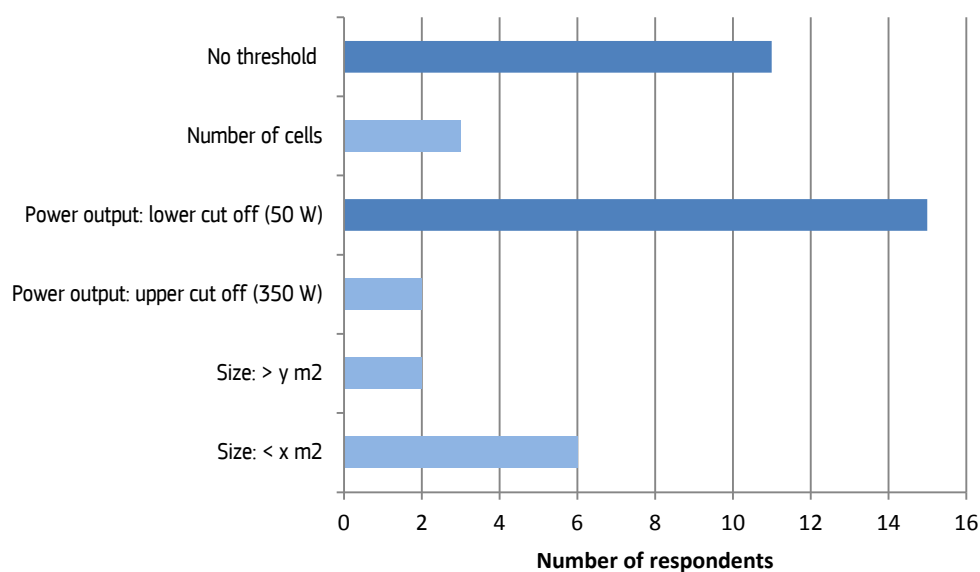


Figure 7 Options selected by respondents for inclusion or exclusion from the scope of photovoltaic modules

Q1.4. Should Building Integrated Photovoltaic (BIPV) products, as defined below, be included within the module scope?

'Photovoltaic modules are considered to be building-integrated, if the PV modules form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011. Thus the BIPV module is a prerequisite for the integrity of the building's functionality. If the integrated PV module is dismantled (in the case of structurally bonded modules, dismantling includes the adjacent construction product), the PV module would have to be replaced by an appropriate construction product.'

Definition taken from EN 50583-1:2016

The majority of respondents supported the inclusion of BIPV products in the scope (73%). One respondent answered it would probably be better to consider BIPV products as part of a 'system', since it is a multifunctional element, not only producing electricity (Figure 8).

There were however also a significant share of respondents (19%) that considered that BIPV products should not be included within the module scope. The reasons given were that BIPV products represent a very specific category of products, notably in terms of:

- Market size: BIPV products approximately account for only 5 GW of installed capacity worldwide.
- Type of market: BIPV products correspond to a construction product. This market is therefore very distinct from PV modules markets which correspond exclusively to electricity generation function.
- Functionality: Adding PV functionality to a construction product improves the LCA of the corresponding construction product.
- Product characteristics: BIPV products combine electricity generation in addition to functions related to any traditional building envelope: weather impact protection, energy economy, fire and noise protection, and architectural and aesthetics considerations.
- Technologies involved: Several different technologies have various levels of development and correspond to different levels of efficiency usually linked to their level of ability to be easily integrated in buildings.

Overall BIPV were to be considered a distinct product group besides PV. A combined trade association response highlighted the following issues to take into account:

- Setting up minimum performance requirements for products that still correspond to a niche market would risk impeding the development of innovative products and technologies that could have reached higher efficiency in the future.
- Energy labelling measures showcasing the benefits that such products have in comparison with traditional construction products / building envelopes, may be a driver for market uptake of the products.

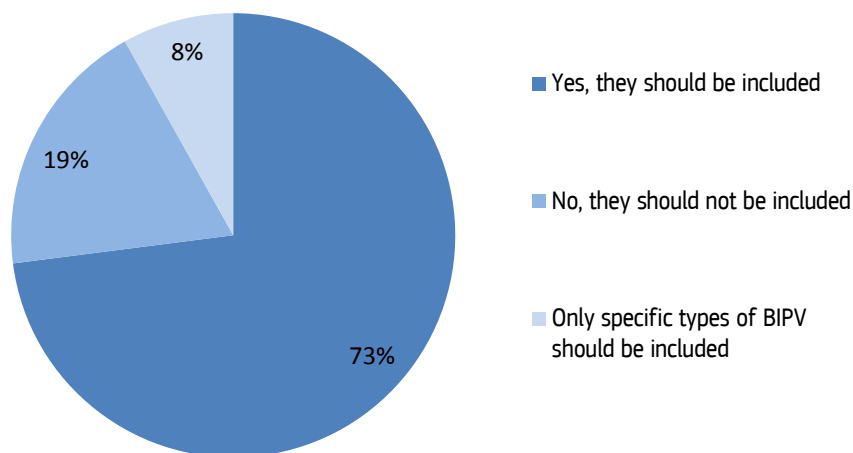


Figure 8 Should Building Integrated Photovoltaic (BIPV) products, as defined, be included within the module scope?

1.1.2.4. Inverters for photovoltaic applications definitions

An inverter is a power conditioning device used in electrical systems to convert DC voltage and DC current into AC voltage and AC current. They are directly connected to the photovoltaic (PV) array (on the DC side) and, where grid-connected, to the electrical grid (on the AC side), and convert the DC energy produced by the array into the AC energy required by the grid or end-user.

1.1.2.4.1. Standardised product category definitions

There are many interrelated definitions of inverters provided within IEC standards series that are of relevance to solar photovoltaics. The simplest definition is:

'[an] electric energy converter that changes direct electric current to single-phase or polyphase alternating currents' (IEC 61836:2016)

The IEC also note in relation to the above provided definition that an inverter is:

'...one of a number of components that is included in the term "power conditioner"'

This definition is complemented by fifteen sub-definitions, which mainly make reference to the different ways in which electricity is conditioned and distributed. To aid an understanding of the different definitions they have been sorted into three broad categories:

- Power conditioning characteristics: Inverters that can be distinguished by the aspect of power supply that they are specified to condition.
- Grid configuration: Inverters that can be distinguished according to how they interact as a component of the interface with the electricity distribution grid.
- Module configuration: Inverters that can be distinguished based on their intended configuration as part of a module array.

The fifteen sub-definitions are presented under these three categories in Table 3.

Table 3. Categorisation of the IEC inverter definitions. Source: IEC (2016)

Categorisation	IEC term used	IEC definition(s) used
Power conditioning characteristics	Current control	Inverter with an output electric current having a specified sine waveform produced by pulse-width modulated (PWM) control or other similar control system.
	Current stiff	Inverter with an essentially smooth DC input electric current.
	High frequency link	Inverter with a high frequency transformer for electrical isolation between the inverter's input and output circuits.
	Utility frequency link	Inverter with a utility frequency transformer for electrical isolation at the inverter output.
	Transformerless	Inverter without any isolation transformer.
	Voltage control	Inverter with an output voltage having a specified sine waveform produced by pulse-width modulated (PWM) control, etc.
	Voltage stiff	Inverter having an essentially smooth DC input voltage.
Grid configuration characteristics	Grid-connected	Inverter that is able to operate in parallel with the distribution or transmission system of an electrical utility.
	Grid-interactive	A grid-connected inverter that is able to operate in both stand-alone and parallel modes.
	Utility interactive	Inverter used in parallel with the distribution or transmission system of an electrical utility to supply common loads and that may deliver electricity to that distribution or transmission system.
	Non-islanding	Inverter that ceases to energize an electricity distribution system that is out of the normal operating specifications for voltage and/or frequency.
	Stand-alone	Inverter that supplies a load not connected to the distribution or transmission system of an electrical utility (also known as a 'battery-powered' inverter).
Module configuration	Module	Inverter that is integrated to the output of a single PV module. It is usually attached to the rear of a module.
	String	Inverter that is designed to operate with a single PV string. The AC output can be connected in parallel to the output of other string inverters.

As can be seen from Table 3 inverters are designed to operate in conjunction with different module configurations. Here, the IEC standard 62093 provides a useful common reference point. The standard refers to Power Conversion Equipment (PCE) in the context of design qualification testing for photovoltaic systems with a maximum circuit voltage of 1500 V DC and connections to systems not exceeding 1000 V AC. The standard groups PCEs into three broad categories based on their size and installation target:

- Category 1: Module-level power electronics (MLPE) – specified to operate at a PV module base level interfacing up to four modules.
- Category 2: String-level power electronics – designed to interface multiple series or parallel connected modules and specified for wall, ceiling or rack mounting.
- Category 3: Large-scale power electronics – also designed to interface multiple series or parallel connected modules, but due to its complexity, size and weight is housed in a free standing electrical enclosure.

(IEC 62093:2017)

The first two categories were already addressed within the general IEC sub-definitions, although Category 1 varies in that it includes for an interface with up to four modules as opposed to only module in the case of an 'AC photovoltaic module'. The latter category 3 is more akin to a standalone substation transformer, being more likely to be used for ground mounted systems such as utility scale solar farms.

1.1.2.4.2. Other non-standardised product category definitions

The U.S. EPA carried out a scoping in 2013 to inform the potential to expand Energy Star to cover inverters. The scoping report provides a further set of definitions⁸, but which closely reflect those of IEC 62093, with a focus on the conditioning of grid compatible AC power:

- Central inverter: They are used for installations from 100 kW upwards and, in most cases, are designed for outdoor installation.
- String inverter: In string technology, the photovoltaic generator is subdivided into individual module surfaces and each of these individual "strings" has its own string inverter allocated to it.
- Multi-String inverter: An inverter which, to a large extent, combines the advantages of several string inverters (separate MPP control of individual strings) and a central inverter (low output-related costs).
- Micro-inverter: A micro-inverter is a device that takes the DC output of a single solar module and converts it into grid-compliant AC power.

The scoping report also introduces the concept of smart inverters, providing the following definition:

'inverters [are] capable of receiving and responding to grid signals in order to help keep the power grid stable, by for example, disconnecting from the grid in a controlled manner to prevent a sudden change in load when numerous inverters disconnect at once.'

This definition reflects new developments in the market that have introduced inverters that have the potential for a dynamic interaction with the electricity distribution grid.

⁸ https://www.energystar.gov/sites/default/files/asset/document/Solar_PV_Inverters_Scoping_Report.pdf

1.1.2.4.3. Summary of the results from the first stakeholder questionnaire

In this section the scope related questions asked in the first stakeholder questionnaire of December 2018 are reprised and the responses briefly summarised in order to identify the main findings.

Q2.1 Could the inverter scope and definition provided below be appropriate for use in this study?

The International Electrotechnical Committee (IEC) defines an inverter as '[an] electric energy converter that changes direct electric current to single-phase or polyphase alternating currents' (IEC 61836:2016) The IEC identifies a range of different types of inverters that are used to convert the power output from a solar photovoltaic array. The scope of these inverters can be categorised according to their distinguishing features/properties:

- Power conditioning characteristics: The aspect of power supply that the inverters are specified to condition *e.g. current control, voltage control.*
- Grid configuration: How the inverters interact as a component of the interface with the electricity distribution grid *e.g. grid connected, grid interactive.*
- Module configuration: An inverters intended configuration as part of a module array *e.g. central, string, module integrated.*

Adapted from: IEC 61836:2016

Of the 14 respondents to this question all responded positively that 'Yes, both the scope and definition are appropriate'. Only one additional comment was made that 'European network codes already set certain criteria for inverters, therefore it is important to avoid any overlaps.'

Q2.2 Of the aspects listed below, which do you think should be taken into account in determining the scope and definition of inverters to be analysed? (respondents were invited to choose from a list of nine aspects)

It can be seen in *Figure 9* that the three most selected aspects were capacity, power output and intended configuration. In contrast, digitalisation was selected by less than half of the respondents.

Only limited additional comments were made. Two respondents considered that digitalisation is an important future feature. In relation to digitalisation, it was noted by one stakeholder that Maximum Power Point Tracking (MPPT) should be dealt with separately. One respondent pointed out that intended configuration should address the presence of a grid connection or not. Integration with embedded storage was mentioned by one respondent.

It is notable that, with the exception of digitalisation, each aspect was selected by at least 9 respondents, equating to nearly two thirds of the respondents to the inverter part of the questionnaire. This suggests that each of these aspects is of relevance to a specific electrical configuration.

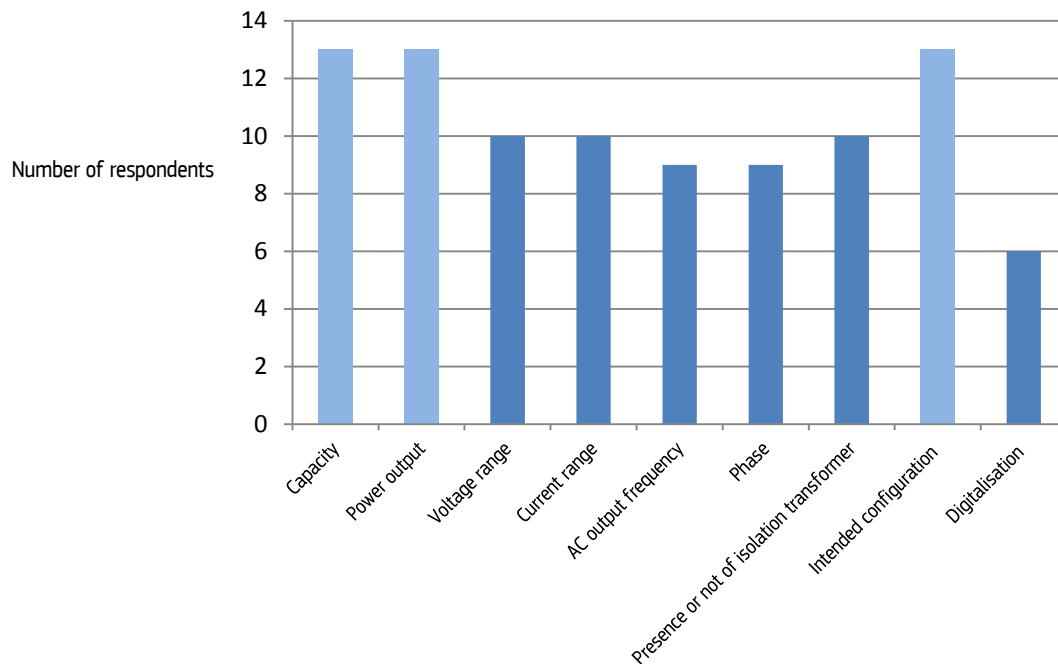


Figure 9 Aspects selected by respondents that should be taken into account in determining the scope and definition of inverters

Q2.3 Would the three categories of Power Conversion Equipment as defined by IEC 62093:2017 be a useful component of the scope and definition?

The IEC 62093 standard refers to Power Conversion Equipment (PCE) with a maximum circuit voltage of 1500 V DC and connections to systems not exceeding 1000 V AC. Such equipment may include, but is not limited to, grid-tied and off-grid DC-to-AC inverters, DC-to-DC converters and battery charge converters. The IEC standard groups PCEs into three broad categories based on their size and installation target:

Category 1: Module-level power electronics (MLPE) – specified to operate at a PV module base level interfacing up to four modules.

Category 2: String-level power electronics – designed to interface multiple series or parallel connected modules and specified for wall, roof, ceiling or rack mounting.

Category 3: Large-scale power electronics – also designed to interface multiple series or parallel connected modules, but due to its complexity, size and weight is housed in a free-standing electrical enclosure.

Of the 17 respondents to this question 13 responded positively that the three categories would be 'a useful component of the scope and definition'. Four respondents noted the need for some amendments. These included the observation by two respondents that 'Category 1 may include both micro-inverters and DC optimisers'. In this respect 'it must be made clear that a DC optimiser does not qualify as an "inverter" but requires an additional string-level device of category 2'. It was also noted by two respondents that DC-to-DC converters used in storage configurations (battery charge converters) should also be included.

Q2.4 Should any sizes or types of inverter be excluded from the scope? If so, based on which of the following parameters should this be based?

Of the 16 respondents to this question all responded that 'all inverters should be included'.

1.1.2.5. Solar photovoltaic system definitions

A solar photovoltaic system is a broad term that could potentially encompass all types or form of installation in the market, including systems that may supply electronic products. Identification of the target market niches, system scales and end-uses for systems that may be of relevance to the four policy instruments being analysed is therefore of importance in order to refine the scope and definition.

Looking at the possible types of photovoltaic systems, the IEA identify a range of possible configurations that exist in the market. The main distinguishing features are whether the end-user is domestic or non-domestic, and whether the system is grid connected or not. The IEA establishes the classification presented in the Table 4.

Table 4. The six broad types of solar photovoltaic systems identified by the IEA

Off-grid domestic	Grid-connected distributed
<ul style="list-style-type: none"> • Basic electrification: lighting, refrigeration and other low power loads • Off grid networks of households/ villages • Typically up to 5 kW 	<ul style="list-style-type: none"> • Grid-connected customer or directly to the electricity network • Size from kW to MW scale
Off-grid non-domestic	Grid-connected centralized
<ul style="list-style-type: none"> • Precious electricity: Telecommunications, water pumping, vaccine refrigeration and navigational aids. • Cost competitive 	<ul style="list-style-type: none"> • Centralized power stations • Typically MW scale • Ground-mounted
Pico systems	Hybrid systems
<ul style="list-style-type: none"> • Essential electrification: lighting, phone charging and powering a radio or a small computer • Off grid in • Developing countries • PV+ battery + charge controller 	<ul style="list-style-type: none"> • Mini grids: PV + diesel generator • Reliable and cost-effective power source: Mitigate fuel price increases, offer high service quality • Telecom base stations and rural electrification.

Source: IEA, Trends 2016 in photovoltaic applications

Careful consideration of the scope and definition for systems will allow for a better consideration of the environmental and economic implications of aspects such as component selection, installation arrangements and the ongoing operation and maintenance of such systems as are relevant.

System scope definitions used in the market identify a range of possible components that can fall within the scope of a 'system'. A non-exhaustive list of the primary components could include the following:

- Module array
- Power conditioning equipment, including inverters
- Energy storage
- Mounting structures
- System monitoring and (charge) control
- Cables and connectors
- Metering and data transmission
- Transformers

As will be explored in further subsequent sections, these components include a number of sub-systems that are associated with definitions in their own right.

1.1.2.5.1. Standardised product category definitions

For the purpose of the IEC standards series a simple overarching definition of a photovoltaic system is provided as starting point:

'[an] assembly of components that produce and supply electricity by the conversion of solar energy.'

The IEA PVPS programme provides an extended definition which introduces system level concepts relating to how the electricity generated is conditioned and distributed. Their definition includes different potential elements of a system, which may consist of:

'...one or several PV modules, connected to either an electricity network (grid connected PV) or to a series of loads (off-grid). It comprises various electrical devices aiming at adapting the electricity output of the module(s) to the standards of the network or the load: inverters, charge controllers or batteries.'

This definition has some overlaps with the concepts of a solar photovoltaic 'array', which the IEA defines as:

'[a] mechanical and electrical assembly of photovoltaic modules, photovoltaic panels, or photovoltaic sub-arrays and its support structure...it includes all components up to the DC input terminals of the inverter or other power conversion equipment or DC loads.'

And linked to this definition of an 'array' is that of an 'assembly', which the IEA defines as:

'PV components that are installed outdoors and remote from its loads, including modules, support structure, foundation, wiring, tracking apparatus, and thermal control (where specified), and including junction boxes, charge controllers and inverters depending on the assemblies installed configuration.'

The IEA note that the components of an assembly are those parts of a system considered to be those installed in the external environment, as opposed to those that may be installed inside a building.

The simple IEC definition introduced at the beginning of this section is complemented by sixteen sub-definitions, which as well as making reference to the different ways in which electricity is conditioned and distributed, introduce a number of additional system level concepts. To aid an understanding of the different system concepts introduced by the IEC they have been sorted into four broad categories:

- Spatial arrangement: Systems that can be distinguished by the spatial relationship between the different component arrays.
- Electricity end-use: Systems that can be distinguished based on the primary end use that the electricity generated is earmarked for.
- Grid configuration: Systems that can be distinguished according to how they physically interface with the electricity distribution grid.
- Electrical configuration: Systems that can be distinguished based on their modes of operation.

The sixteen system definitions are presented under these four categories in Table 5.

Other types of photovoltaic systems that are not addressed in Table 5 are those where a photovoltaic cell or module form 'part of another device for which it produces electricity where the photovoltaic cell [or module] provides the energy needed to make the electronic product function' (NSF 2017). Examples include street lights with integrated solar modules which charge a battery.

Table 5. Categorisation of IEC solar photovoltaic system definitions

Categorisation	IEC term used	IEC definition(s) used
Spatial arrangement	Centralised	Grid connected PV system that generates bulk electricity.
	Dispersed	Multiple dispersed PV generators or PC systems operating as if they were a single PV generator or system.
	Distributed generation	PV system that is also a distributed generation system
Electricity end-use	Domestic	PV system that electrifies household loads. It may be grid connected or standalone.
	Non-domestic	PV system used for a purpose that is not a domestic purpose. It may be grid connected or standalone.
	Off-grid village	Standalone PV system electrifying a village.
Type of grid configuration	Grid backed-up	PV system that switches over to a utility electricity source when the PV output is less than load requirements.
	Grid-connected	Functions only in a grid connected mode of operation.
	Off-grid standalone	Functions only in an off-grid, standalone mode of operation
	Hybrid	A multi-source PV system operating in parallel with other electricity generators
Type of electrical configuration	Isolated	PV system that only functions in an isolated mode of operation.
	Utility interactive	Functions in an isolated mode or in a parallel mode of operation.

Source: IEC (2016)

1.1.2.5.2. Sub-system definitions of potential relevance

Beyond the concept of a solar photovoltaic 'array', which the IEC defines as comprising the modules, their support structures and all DC cabling up until the input terminals of the inverters, two other important sub-systems are defined in relevant solar photovoltaic standards – Balance of System (BOS) and Power Conversion Equipment (PCE). These two sub-systems describe the power conversion and conditioning equipment that handle the DC electricity generated by the module, so are important in defining relevant components and system configurations for different types of photovoltaic systems.

Balance of System (BOS)

For the purpose of the IEC standards series the Balance of System (BOS) is defined as:

'parts of a PV system other than the PV array field, including switches, controls, meters, power conditioning equipment, PV array support structure, and electricity storage components, if any.'

The IEA makes a further distinction between typical BOS components associated with roof top and ground mounted applications. Ground mounted systems, also sometimes referred to as utility scale systems, require medium voltage grid connections (including transformers), concrete pad foundations and cleaning systems. They may also include tracking equipment as an option to improve performance.

Power Conversion Equipment (PCE)

Also sometimes also referred to as power conditioning, for the purpose of the IEC standards series Power Conversion Equipment (PCE) forms a sub-system of the Balance of System (BOS) and is defined as:

'Electrical devices converting one form of electrical power to another form of electrical power with respect to voltage, current frequency, phase and the number of phases. The definition of PCE covers all active and passive circuitry components and all mechanical components required for operation.'

The term therefore refers exclusively to electrical equipment. PCE equipment is then further sub-divided into three categories of PCE as reported in section 1.1.2.5.1, reflecting different inverter sizes and configurations. Further sub-divisions recognise environmental conditions to which the PCE may be exposed to during its lifetime.

1.1.2.5.3. Summary of the results from the first stakeholder questionnaire

In this section the scope related questions asked in the first stakeholder questionnaire of December 2018 are reprised and the responses briefly summarised in order to identify the main findings.

Q3.1 Could the photovoltaic system scope and definition provided below be appropriate for use in this study?

The International Electrotechnical Committee (IEC) defines a photovoltaic system as: '[an] assembly of components that produce and supply electricity based on photovoltaic conversion of solar energy. [This] could also include the following sub-systems: power conditioning, storage, system monitoring and control, and utility grid interface.' (IEC 61836:2016)

The IEC identifies within their scope a range of different system concepts which vary according to how a system is configured, and how the electricity generated is converted and distributed. These can be categorised according to the following distinguishing features/properties:

- Spatial arrangement: Based on the spatial relationship between the different component arrays (e.g. centralised, distributed).
- Electricity end-use: Based on the primary end use that the electricity generated is earmarked for (e.g. domestic, non-domestic).
- Grid configuration: Based on the type of physical interface with the electricity distribution grid (e.g. grid connected, off-grid, hybrid).
- Electrical configuration: Based on the systems modes of operation (e.g. isolated, utility interactive).

16 out of the 24 respondents to this question indicated that '*yes, the scope and definition are appropriate*'.

Of the 8 respondents that considered that an amendment was necessary 3 considered that the scope should be amended. The inclusion of '*interconnections (cabling) between sub-systems, as well as transformers*' and '*the size of the PV system*' were proposed. Reference was also made to '*PV on buildings*' and '*PV farms*'.

6 respondents considered that the definition should be amended. Proposals included more reference to market segmentation ranging from '*individual, residential, tertiary installations to huge utility plants*', encompassing '*different system sizes (micro, residential, commercial, utility scale)*' and with a distinction made between ground mounted PV, BAPV and BIPV. Two respondents considered that '*energy storage facilities (mainly batteries) should not be considered as part of a PV system*' as they are '*clearly an optional component*' and '*do not contribute to the renewable energy generation*'.

Q3.2 Of the aspects listed below, which do you think should be taken into account in order to determine the scope and definition of the types of photovoltaic systems to be analysed?

It can be seen in Figure the aspects selected by 50% or more of the respondents were *module array, power conditioning, tracking systems, spatial configuration, roof or ground mounted, and grid configuration*. It is notable that each aspect was selected by at least 8 respondents, equating to one third of the respondents to the system part of the questionnaire. This suggests that each one is of relevance to a specific system configuration.

In terms of 'any other aspect to the photovoltaic system scope and definition', limited further suggestions were made. One respondent considered that the presence or not of storage should be noted. Three respondents reflected a trade association proposal to differentiate between:

- residential, commercial and utility-scale installations (installation size)
- central, string and microinverters
- ground-mounted vs rooftop installations
- systems with and without storage
- PV systems with tracker (1-2 axes) and without tracker.

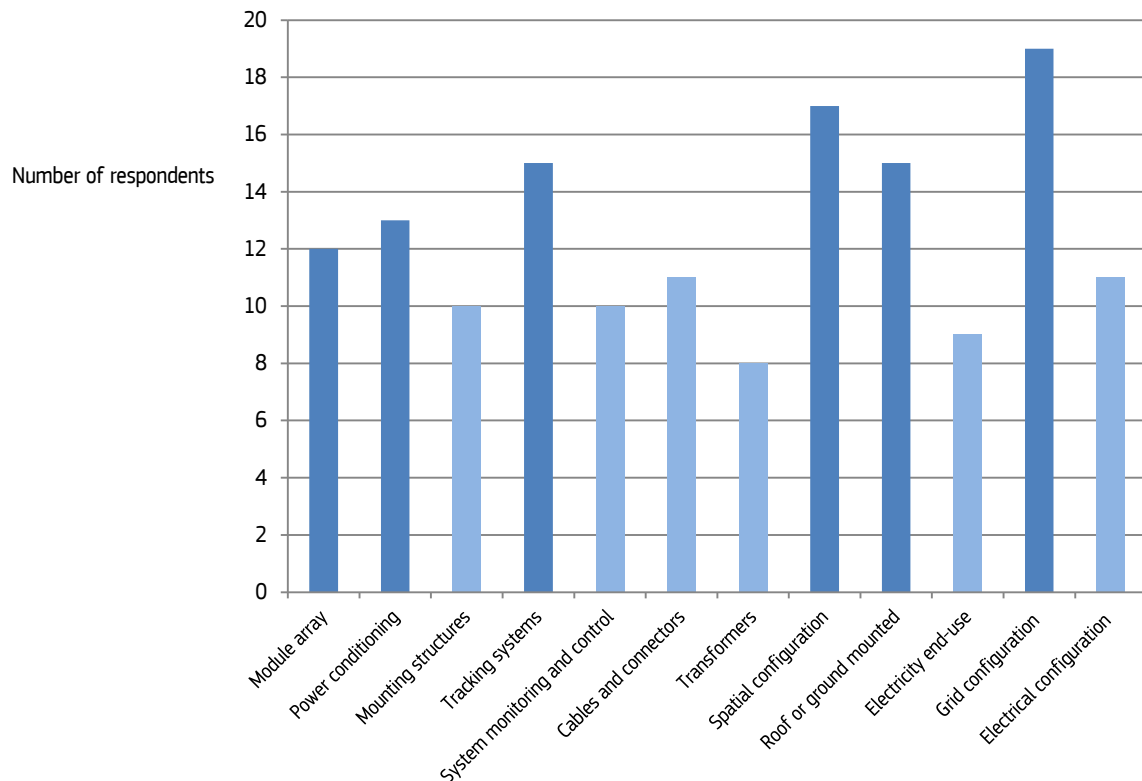


Figure 10 Aspects selected by respondents that should be taken into account in determining the scope and definition of photovoltaic systems

Q3.3 Should any size or type of system be excluded from the scope? If so, based on which of the following aspects?

Of the 24 respondents to this question, 11 considered that all systems sizes and types should be within scope. As can be seen in Figure the main scope exclusion selected by respondents related to 'specific electricity end-uses'. The questionnaire cited examples as including buildings, street lighting, street furniture and vehicles. Of those that selected this exclusion, one respondent considered that 'specific end-uses such as street lighting and urban furniture' were not relevant. Another respondent elaborated further, identifying 'electric vehicles, watches, calculators, power banks and other gadgets'.

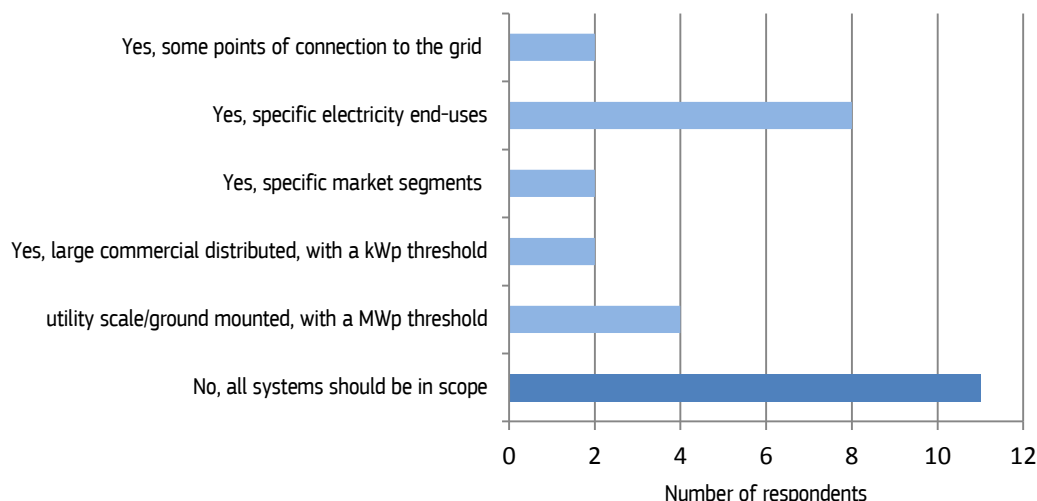


Figure 11 Options selected by respondents for inclusion or exclusion from the scope of different photovoltaic systems

1.1.2.6. Definition of the functional unit and product performance parameters

A review of the commonly used functional units for photovoltaics is made in the following section. At the end of this Task 1, in section 1.4, a first proposal for the solar photovoltaic products functional unit, definition and scope will be presented.

1.1.2.6.1. The primary product performance parameter (functional unit)

In order to carry out meaningful modelling of the life cycle of a product it is important to define the function being provided, and then linked to that a common reference unit of comparison between different products designs or systems – a functional unit of performance. The terms functional unit and reference flow are defined extensively in Life Cycle Assessment (LCA) literature. The ISO 14040⁹ defines them as following:

Functional unit: quantified performance of a product system for use as a reference unit

Reference unit: measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit

IEA PVPS Task 12¹⁰ highlights the importance of taking into account following fundamental parameters that influence performance along the lifetime of PV systems:

- Life expectancy: life expectancy based on manufacturers guarantee or period of time before the incidence of product or system failures become unacceptable.
- Irradiation: the irradiation collected by modules depends on their location and orientation
- Performance ratio: the performance ratio (PR) (also called derate factor) describes the difference between the modules' (DC) rated performance (the product of irradiation and module rated efficiency) and the actual (AC) electricity generation, taking into account a number of variables.

⁹ ISO 14040:2006 series. Environmental management -- Life cycle assessment -- Principles and framework <https://www.iso.org/standard/37456.html>

¹⁰ IEA Task devoted to PV Environmental, Health And Safety (E, H & S) Activities. <http://iea-pvps.org/index.php?id=56#c87>

- Degradation: the level of degradation of a module's efficiency over time.

An additional concept which might differ from the life expectancy is the service lifetime considered either at system or component level. The ISO 15686 'Building and constructed assets – service-life planning' series defines it as:

'the period of time after installation during which a component or an assembled system meets or exceeds the technical performance and functional requirements laid down by the end user'.

The functional unit in an LCA for the analysis of Energy related Products describes the unit of end product to which the energy requirements will be related. The IEA and CEN define it as:

'... the quantified performance of a product system for use as a reference unit' (ISO 2006a, Clause 3.20).

Related to this definition they also define the reference flow as:

'a measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit' (ISO 2006a, Clause 3.29).'

The best choice for the functional unit will depend on the objectives of the study. Extensively used in literature, functional units in the context of this study are:

- 1 kWh of electricity produced by the PV system;
- 1 Wp of module power or 1 Wac of inverter power;
- 1 m² of module area;
- 1 m² of cell area;
- 1 module or inverter

Of course the kWh and to a lesser extent the Wp are the most functional of these units because they are directly related to the end-user service. The disadvantage of the kWh or Wp units is that this choice introduces extra parameters, namely irradiation, PV system performance and module efficiency, which have no or little relation to the energy consumption during module production.

It is obvious that most energy requirements for module production, like energy for material consumption and energy for processing are in the first place area-dependent. Very often the efficiency of a module and thus its power rating may be enhanced by a subtle change in the production process without a significant increase in the production stage energy consumption. An area related unit will be therefore be the most convenient functional unit when the objective is to compare different modules or different energy technologies. The choice between *module area* or *cell area* is less important, although for crystalline silicon technology the unit of cell area has some advantages.

The *module* is considered an inconvenient level to consider the functional unit because modules do not have a standard size or power rating.

A comprehensive analysis of functional unit definitions used in the context of LCA evaluation is presented below. The evaluation is with reference to the following sources:

1. the European Commission's PEF LCA method solar photovoltaic pilot¹¹

¹¹ Wade et al. (2017) The Product Environmental Footprint (PEF) of photovoltaic modules—Lessons learned from the environmental footprint pilot phase on the way to a single market for green products in the European Union <https://onlinelibrary.wiley.com/doi/abs/10.1002/pip.2956>

2. IEA Life cycle Assessment (LCA) recommendations¹²
3. ADEME life cycle environmental impact evaluation guidance (France)¹³
4. CRE solar photovoltaic tender requirements (France)¹⁴

The European Commission's PEF LCA method solar photovoltaic pilot

The PEF solar photovoltaic pilot chose to use a unit of analysis in line with ISO 14044:

1 kWh (kilo Watt hour) of DC electricity generated by a photovoltaic module.

The reference flow is the photovoltaic module, measured in kWp (Kilowatt peak), the maximum power output of a module.

The functional unit is then defined according to the following four criteria listed in the PEF Guide.

- The function(s) / service(s) provided ("what"):

DC electrical energy measured in kWh (provided power times unit of time) at the outlet of the DC connector attached to the junction box of the PV module

- The magnitude of the function or service ("how much")

1 kWh of DC electrical energy

- The expected level of quality ("how well")

DC electrical energy at the photovoltaic module at a given voltage level.

- The amount of service provided over the lifetime ("how long")

DC electrical energy generated by the photovoltaic module during the service life of 30 years

IEA Life Cycle Assessment (LCA) recommendations

IEA PVPS Task 12, in the last Methodological guidelines on LCA for PV electricity recommends the following functional unit definition:

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

Alternatively, the reference flows "m²" or "kW_p (rated power)" may be used. However, these reference flows are not considered suitable for comparisons of PV technologies.

¹² IEA PVPS Task 12, Methodology Guidelines on Life-Cycle Assessment of Photovoltaic Electricity, LCA Report IEA-PVPS T12-03:2011, http://www.iea-pvps.org/fileadmin/dam/public/report/technical/rep12_11.pdf

¹³ Methodological framework for assessing the environmental impacts of photovoltaic systems using the life cycle assessment method of the French Environment and Energy Management Agency (ADEME), <http://conferences.chalmers.se/index.php/LCM/LCM2013/paper/viewFile/523/124>

¹⁴ <http://www.cre.fr/documents/appels-d-offres/appele-d-offres-portant-sur-la-realisation-et-l-exploitation-d-installations-de-production-d-electricite-a-partir-de-l-energie-solaire-d-une-puissance-superieure-a-250-kwc3/cahier-des-charges-publie-le-8-avril-2015>

"One m² of module is used for quantifying the environmental impacts when PV forms part of a building, or of supporting structures (excluding PV modules and inverters). One square metre is not suited for comparisons of PV technologies because of differences in module and inverter efficiencies and performance ratios.

kW_p (rated power, DC) is used for quantifying the environmental impacts of electrical parts, including inverter, transformer, wire, grid connection, and grounding devices. The kW_p may also serve as the reference flow in quantifying the environmental impacts of an individual module technology. However, the comparisons of module technologies shall not be based on nominal power (kW_p) figures because the amount of kWh fed to the grid may differ between the systems analysed."

The location, the module technology used, the voltage level, and whether and how the transmission and distribution losses are accounted for, shall be specified. AC electricity may differ in dispatchability and intermittency. Electricity production with one technology hardly meets all the demand at all times; thus, mixtures of power generating technologies are typically deployed. Aspects of dispatchability or intermittency of AC electricity produced with different technologies shall not be addressed on technology level but on the level of grid mixes provided by utilities (see also Carbajales-Dale et al. 2015).

ADEME life cycle environmental impact evaluation guidance (France)

For ADEME (the French environment agency), the basic function of the PV installations analysed using an LCA methodological framework is electricity production. It is therefore:

1 kWh generated by a photovoltaic system during its lifespan and either exported to the grid (distribution or transmission) or consumed.

Consumed energy in this context means energy consumed on-site by electric appliances, when operating within a contractual arrangement to sell any surplus capacity to the grid. This useable consumed energy does not include losses through the internal electricity network nor any consumption by ancillary functions of the photovoltaic installation (e.g. monitoring).

To carry out the environmental analysis of the technological process characterised by this functional unit it is necessary to estimate the PV systems potential output. This estimate should take into account the technical characteristics of the installation being studied (i.e. module yield, electricity losses, PV system lifespan, etc.) as well as the irradiation at the PV system location.

The environmental impacts of the PV system can be calculated either by using the system's nominal power or the effective surface area of the PV field related to the kWh (the functional unit in the framework).

CRE solar photovoltaic tender requirements (France)

CRE (Commission de régulation de l'énergie) defines the functional unit of the simplified carbon footprint analysis as: *1kW_p of PV modules without frame*.

The respective reference flows of included materials in this functional unit are as described as follows:

- Modules in m² modules. This value is the module area needed to make 1 kW_p whether for crystalline modules or thin film.
- Polysilicon in kg. This value is reduced to the mass of silicon contained in 1 kW_p equivalent of module.
- Ingots in kg silicon. This value is reduced to the mass of silicon contained in 1 kW_p equivalent of module.
- Wafers in number of wafers. This amount is reduced to the number of wafers needed to make 1 kW_p equivalent of module. Losses and breakages are neglected. (The reference value contribution is based on the actual size and the actual thickness of wafers - wafer reference size: 156 x 156 mm, thickness 190 microns).

- Cells in number of cells. This value is the number of cells required to make 1 kWp equivalent of module. Losses and breakages are neglected. The contribution may be reduced to the actual cell size (reference wafer 156 x 156 mm).
- Glass in kg. This value is the mass of glass needed to make 1 kWp so reduced to the surface and the thickness of glass (reference density of 2700 kg/m³).
- Tempered glass in kg. This value is the mass of tempered glass to make 1 kWp (so returned to the surface and thickness of the tempered glass, reference density 2700 kg / m³).
- EVA/PET/PVF in kg. This value is the mass of EVA/PET/PVF needed to make 1 kWp equivalent of module (so reduced to the surface and the thickness of the material, reference density 963 or 1400 kg/m³).

Further specifications laid down are as follows:

- The calculations are based on the electricity mix of the country regardless of the actually electricity supply contract.
- Savings linked to the recycling of the complete module at the end of life cannot be considered in the carbon footprint calculation.
- Process inefficiencies are neglected. (e.g. breakage and yield loss).

1.1.2.6.2. Secondary product performance parameters

Secondary product performance characteristics are also possible to define based on additional functional performance characteristics required of the products. An initial identification has been made of the most important secondary characteristics related to interactions between the components of an installed PV system and:

- the electricity network to which a system is connected;
- a host building onto which a system may be installed or integrated; or
- users who may wish to maximise self-consumption of the electricity generated by a system.

These three possible forms of functional interaction are each briefly reviewed below and are then analysed in greater technical detail in the Task 3 report of this study:

Electricity network interactions

Interactions take place between the electricity distribution network to which a system is connected, and how components and parameters of the power supplied are managed – for example:

Power management in order to provide control functions such as the generation of reactive power, where beneficial to the system operator or as required by AC distribution network operators.

Host building interactions

Both functional overlaps and performance interactions may arise between a PV system and the host building onto which it may be installed or integrated within the external envelope or façade systems – for example:

- Window replacement provided by glass-glass laminates. The PV glass laminate pane will need to substitute like for like a high performance glass pane's functional characteristics.
- Weather proofing and façade substrate stabilisation or replacement provided by PV integrated into a rain screen cladding system, curtain wall or roofing. The PV cladding solution will need to substitute like for like the conventional construction product's functional characteristics.

- Shading that may be provided by cells or modules integrated into a brise soleil façade or patio shading system. The PV solution will substitute the expected shading characteristics of a metal fin, lamina or louvre.

It is also to be discussed whether potential trade-offs in the PV system performance as a result of integration should be accounted for in the evaluation e.g. higher operating temperatures due to the thermal absorption by building elements or constraints on the back ventilation of modules due to building fabric integration.

User interactions

Interactions may take place between a PV system the electrical systems of the host building and its users. In particular this may be influenced by users who may wish to maximise the self-consumption of the electricity generated, either by instantaneous load matching or by achieving a time shift of several hours between generation and final supply through the use of energy storage – for example:

- Demand-side management: Smart metering and data loggers that enable information about the electricity generated by a system to be consulted by a consumer and/or to be used as part of a smart control system linking appliances and systems within a home or office. In this case the consumer is likely to be interested in the 'smart readiness' of the digital systems.
- Electricity storage: Battery storage in order to supply electricity demands that occur when there is no solar insolation. In this case the consumer is likely to be interested in the characteristics of the battery system, the proportion of the electricity generated that can be stored and also the life cycle performance characteristics of the battery cells.

Thermal storage system components such as heat pump/thermal accumulator combinations are considered outside the scope of the study, because they would suppose remodelling to take into account an additional affected energy system *i.e. a domestic hot water system*. The same would apply to an interface with a grid ready car battery storage system, which would suppose remodelling to take into account displaced vehicle fuel systems.

1.1.3. Product scope for the EU Ecolabel

In this section an initial analysis of the scope, definition and criteria areas of existing ecolabel criteria at EU and international level. Initial feedback gathered from stakeholder questionnaire on the suitability and practicability of using the Ecodesign and/or EU Ecolabel product scope is also analysed.

1.1.3.1. Existing Ecolabel criteria sets at EU and international level

The Global Ecolabelling Network (GEN) identifies the following organisations as having developed ecolabel criteria sets with some relation to the photovoltaic product group at international level:

- TÜV Rheinland: The private body is considering the establishment of criteria for photovoltaic modules under its Green Product Mark ecolabel¹⁵. These are likely to be adopted from EPEAT, the ecolabel scheme of the US Green Electronics Council (GEC).
- Japan Environment Association (JEA): Criteria have only been developed for consumer products incorporating photovoltaic cells¹⁶.
- Korea Environmental Industry & Technology Institute: Criteria have only been developed for consumer products incorporating photovoltaic cells¹⁷.

¹⁵ TÜV Rheinland, *Green Product Mark*, <https://www.tuv.com/world/en/green-product-mark.html>

¹⁶ Japanese Environment Association, *Product categories (certification criteria)*, <https://www.ecomark.jp/english/nintei.html>

- Singapore Environment Council: Criteria have only been developed for consumer products incorporating photovoltaic cells¹⁸.

In addition to those initiatives listed by the GEN there are three further ecolabelling initiatives that may be of significance to this study:

- The German national ecolabel the Blue Angel. The ecolabel has since 2012 maintained a criteria set for inverters, but of potentially broader relevance to this study are their successive attempts to introduce criteria for both systems and modules.
- As referred to by TÜV Rheinland, module criteria are under development by private US organisation NSF International with the support of the US Green Electronics Council (GEC).
- The private US non-profit organisation Cradle to Cradle Products Innovation Institute, which has established a certification for the inherent sustainability of products and their component materials.

Each one of these initiatives is examined in turn in the following sections.

1.1.3.1.1. Blue Angel criteria for photovoltaic modules, inverters and systems (Germany)

The Blue Angel is an ecolabel established at national level by the German government in 1978. It is a pioneer in the development of product performance criteria for a broad range of consumer products. A criteria set for inverters was published in 2012. Several attempts have been made to develop criteria for modules and also systems. The criteria areas that were identified and the main issues encountered that prevented adoption of the criteria are briefly explained in this section.

Photovoltaic inverters product group (RAL-UZ 163)

The 2012 Blue Angel criteria for inverters apply to string and multi-string inverters with up to an output power of 13.8 kVA that are designed for use in grid-connected PV power systems. They identify maximising inverter efficiency as part of a photovoltaic system and engaging in network management to support grid stability as key challenges that the criteria seek to address. The eight technical criteria areas are listed in Table 6. Excluded from the product group are inverters integrated into a module (micro-inverters) and inverters designed for use in stand-alone systems. The criteria are all pass or fail. There are currently no licenses awarded.

Table 6. Blue Angel photovoltaic inverters criteria overview (Germany). Source: RAL (2012)

Criteria area	Criteria	Requirement
1. Energy efficiency	Overall efficiency	Overall European weighted efficiency calculated according to EN 50530 of 95%
	No-load loss	No-load loss not exceeding 0.5 watts
2. Reactive power capability	Reactive power capability	In accordance with Guideline VDE-AR-N 4105
3. Longevity	Warranty	Free-of-charge warranty of at least 5 years Extended option of up to 20 years at extra charge
	Service	Defective systems repaired or replaced within a maximum of 48 hours

¹⁷ Korea Environmental Industry & Technology Institute, *Certification criteria*, <https://www.ecomark.jp/english/nintei.html>

¹⁸ Singapore Environment Council, *Singapore Green Labelling Scheme directory*, <https://www.sglsec.org.sg/sgl-directory.php>

4. Material requirements	General requirements for plastics	Shall not contain REACH Candidate list substances Shall not contain substance with specific CLP hazard classifications (see the criteria document listing which includes some exemptions)
	Additional requirements for plastics used in housings and housing parts	Halogenated polymers shall not be permitted Halogenated organic compounds may not be used as additives or added to parts (with exemptions)
	Additional requirements for plastics used in Printed Circuit Boards	PBBs, PBDEs, TBBPA or chlorinated paraffins may not be added to the carrier material of the printed circuit boards.
	Requirements for electronic components	Shall not contain lead, mercury, cadmium or hexavalent chromium. Lead-containing solder shall not be used.
5. Recycling and disposal	Recyclability	Shall be designed to allow for easy disassembly for recycling by a specialist firm using ordinary tools.
	Product take-back	Free take back of the product Routing to reuse, recycling or professional disposal
6. Safety	Safety requirements	Meets minimum requirements according to EN 62109 (CE marking) Certificate of non-objection to integrated electronic load break switch Product literature to integrate product into protection systems
7. Electromagnetic capability	Compatibility requirements	Conformity with EN 61000-6-1/6-3 (CE marking)
8. Noise emissions	Maximum level	Maximum sound power level of 55 dB(A)

Criteria development for modules and systems

The Blue Angel has made previous attempts to develop criteria sets for systems (2002 and 2008) and modules (2013)¹⁹. Neither of these criteria sets were adopted, in both cases due to problems reaching agreement on the assessment of energy yield and the restriction of hazardous substances.

The system criteria were to have included a requirement to simulate the performance of a system. However, agreement could not be reached on how to ensure comparability between the results whilst allowing designers a choice of calculation methods and software tools. They were also to have included a criteria on batteries, with cadmium content and the warranty a focus of attention.

The module criteria were to have included requirements relating to module quality (with reference to IEC 61215 and IEC 61646), the Energy Payback Time (EPBT) of the product, the marking of components for recycling purposes and a requirement for RoHS compliance which would have excluded certain PV-technologies containing lead or cadmium. Similarly to systems, agreement could not be reached on how to measure performance, with exemplars from the German market, such as PV Test and the Photon Module test, having been studied at the time. It was considered in the end that the development of a test protocol to measure energy performance fell outside the scope of the criteria study.

¹⁹ Communication with Elke Kreowski, German UBA (2018)

1.1.3.1.2. NSF/ANSI 457 Sustainability Leadership Standard for Photovoltaic Modules (USA)

The US organisation NSF International, with the support of the Green Electronics Council (GEC), has been leading since 2015 a process to develop environmental criteria for photovoltaic modules. The starting point for the criteria set has been the US Silicon Valley Toxics Coalition's (SVTC) 'Solar Scorecard' and the aim has been to develop a criteria set that addresses the full life cycle of a module. The final criteria set will become ANSI standard 457 and will be qualified to become an EPEAT standard as part of the global ecolabelling scheme for IT products²⁰. Given the global success of the EPEAT standards for ICT equipment, this new standard therefore has potentially wider significance than just within the USA.

In terms of the product scope and definition used within the proposed criteria, the final 2017 release version of the NSF/ANSI 457 standard defines a solar photovoltaic module as being for:

'installation on, or integral with buildings, or to be primarily used as components of free-standing power-generation systems...'

It defines a module as including, but not being limited to the following components:

- photovoltaic cells that generate electric power using solar energy
- interconnects (materials that conduct electricity between cells)
- encapsulant (insulating material enclosing the cells and cell interconnects)
- superstrate (material forming primary light-facing outer surface) and substrate (material forming back outer surface) (e.g., glass, plastic films)
- wires used to interconnect photovoltaic modules and connect junction boxes to the balance of system equipment
- frame or integrated mounting mechanism, if present

Moreover, the product definition then establishes the following exclusions:

- balance of system equipment, such as cabling and mounting structures, equipment intended to accept the electrical output from the array, such as power conditioning units (inverters) and batteries, unless they are contained in the photovoltaic module
- a photovoltaic cell that is a part of another device for which it produces the electricity, such as consumer or industrial electronic products (e.g. calculators, lights, textile) where the photovoltaic cell primarily provides the energy needed to make the electronic product function
- mobile photovoltaic cell where the inverter is so integrated with the photovoltaic cell that the solar cell requires disassembly before recovery

The standard contains product performance criteria and corporate performance metrics and consists of seven performance categories, which are identified together with the required criteria under each category, in Table 7. Like all EPEAT standards three levels of performance can be achieved – bronze, silver and gold. The bronze level is intended to reflect the performance of the top third of the market. Few products are currently anticipated to meet the gold level. The criteria set includes both environmental and social criteria. The criteria documentation contain an extensive set of normative references, which include IEC standards, European legislation (e.g. REACH,

²⁰ NSF International. *Joint Committee on Sustainability Leadership Standard for Photovoltaic Modules – NSF/ANSI 457*, October 2017, https://standards.nsf.org/apps/group_public/workgroup.php?wg_abbrev=sls_sust_photovoltaic

CLP and RoHS). Reference is also made to industry and NGO initiatives, such as those relating to the development of sources of conflict-free minerals.

Table 7. NSF/ANSI 457 Sustainability Leadership Standard for Photovoltaic Modules required criteria overview
Source: NSF International (2017)

Criteria area	Required criteria	Requirements for conformity
1. Management of substances	List of declarable substances	<ul style="list-style-type: none"> – Listing of IEC 62474 declarable substance groups – Processes to manage, maintain, update the listing
	List of declarable substances used in manufacturing	– List of substances from the ECHA database present in the product
	Disclosure of substances on the EU REACH Regulation Candidate List of Substances of Very High Concern	– List of substances from the Candidate List of SVHCs present in the product above 0.1%
	Avoidance or reduction of high Global Warming Potential (GWP) gas emissions resulting from photovoltaic module manufacturing	<ul style="list-style-type: none"> – Ensure that high GWP gases are not used or emitted – That abatement systems are installed, operated and maintained
2. Preferable materials use	Declaration of recycled content in product	– Declaration of the minimum % by weight of recycled content in the product (by component)
3. Life cycle assessment	Conducting life cycle assessment	– Conduct an LCA in accordance with ISO 14040/14044, EU PEF Guide or IEA PVPS Task 12 guidelines
4. Energy efficiency & water use	Water inventory	– Manufacturing in facilities that compile an inventory of water use and wastewater effluent
5. End of life management & design for recycling	Product take-back service and processing requirements (corporate)	– Provision of a product take-back service in conformance with the requirements
6. Product packaging	Elimination of substances of concern in product packaging	– Product packaging shall not contain lead, mercury, cadmium or hexavalent chromium in total >100ppm
	Elimination of chlorine in processing packaging materials	– Paper based materials shall not be bleached with chlorine compounds
	Enhancing recyclability of packaging materials	<ul style="list-style-type: none"> – Non-reusable packaging components $\geq 25g$ shall be separable by material type without the use of tools – All plastics $\geq 25g$ shall be clearly marked with their material type according to ISO 11469/1043
7. Corporate responsibility	Environmental Management System (EMS) certification (corporate)	– The product(s) shall be manufactured in facilities certified to either ISO 14001 or EMAS
	Manufacturer conformance with occupational health and safety performance (corporate)	– Manufacturers' operations covered by their EMS shall conform to OHSAS 18001
	Reporting on Key Performance Indicators (corporate)	– Annual public disclosure of information according to 10 Key Performance Indicators (KPIs)
	Commitment to environmental and social responsibility (corporate)	– A commitment to continuous improvement in their operations and their suppliers
	Public disclosure of use of conflict minerals in products (corporate)	– Declaration of whether products contain conflict minerals

1.1.3.1.3. Cradle to Cradle certification (USA)

The Cradle to Cradle programme is a third party verified labelling scheme that aims to determine the extent to which the design and material composition of a product are able to facilitate future recycling. Two major solar PV module manufacturers are currently listed as having products certified according to the US Cradle to Cradle scheme – Solar Power and Jinko Solar²¹. The programme's criteria are grouped according to the following attributes²²:

- Material health: Use of materials that are safe for human health and the environment through all use phases
- Material reutilisation: Product and system design for material reutilisation, such as recycling or composting
- Renewable energy and carbon management: Use of renewable energy in production
- Water stewardship: Efficient use of water, and maintenance of water quality at production sites
- Social fairness: Company strategies for social responsibility.

Certification is in four tiers of attainment - Basic, Silver, Gold, and Platinum levels. The certification program applies to materials, sub-assemblies and finished products.

Table 8. Cradle to Cradle certification 'basic' level criteria overview (USA). Source: Cradle to Cradle Institute (2016)

Attribute	Standard requirements (basic level)
1. Material health	<ul style="list-style-type: none"> - No Banned List chemicals are present above thresholds. - Materials defined as biological or technical nutrients. - 100% "characterized" (i.e., all generic materials listed).
2. Material reutilisation	<ul style="list-style-type: none"> - Defined the appropriate cycle (i.e., technical or biological) for the product.
3. Renewable energy and carbon management	<ul style="list-style-type: none"> - Purchased electricity and direct on-site emissions associated with the final manufacturing stage of the product are quantified.
4. Water stewardship	<ul style="list-style-type: none"> - The manufacturer has not received a significant violation of their discharge permit related to their product within the last two years. - Local- and business-specific water-related issues are characterized (e.g., the manufacturer will determine if water scarcity is an issue and/or if sensitive ecosystems are at risk due to direct operations). - A statement of water stewardship intentions describing what action is being taken for mitigating identified problems and concerns is provided.
5. Social fairness	<ul style="list-style-type: none"> - A streamlined self-audit is conducted to assess protection of fundamental human rights. - Management procedures aiming to address any identified issues have been provided.

²¹ Cradle to Cradle certified product registry, Listed under 'building supply and materials>electrical'
<https://www.c2ccertified.org/products/registry>

²² Cradle to cradle products innovation institute (2016) *Cradle to cradle certified – product standard, version 3.1.*

1.1.3.2. Summary of the results from the first stakeholder questionnaire

1.1.3.2.1. Modules

Q1.8 Do you think that the scope of the study should be broadened or restricted for the specific purpose of the EU Ecolabel?

35 out of the 39 respondents to this question (90%) indicated that the Ecolabel product scope should reflect that used for Ecodesign and Energy Labelling. Those that felt that the scope and definition should be different cited the potential to '*focus more on recyclability and Life cycle than power efficiency*' as well as '*material use, their toxicity for workers and their depletion*'.

Q1.9 Are you aware of any relevant certification schemes or labels for the environmental performance of photovoltaic modules?

In terms of relevant certification schemes or labels, those cited were:

- NSF/ANSI 457 Sustainability Leadership standard (10 respondents),
- Cradle to cradle (C2C) certification, noted as having been achieved by Sunpower (5 respondents),
- the French photovoltaic national call for tenders (4 respondents),
- the French Ecopassport scheme (4 respondents),
- the French E+C labelling (2 respondents).
- the Ecolabel initiative, piloted by CEA-INES and CERTISOLIS, with the support of Fraunhofer ISE and ENEA. (1 respondent)
- Clean Production Evaluation Index System for PV Cells in China (1 respondent),
- The Silicon Valley Toxics Coalition in the USA (1 respondent),
- 'Climate Savers' Partnership between WWF and Yingli Solar (1 respondent),
- The 'Solar Commitment' voluntary scheme in the USA (1 respondent).

One respondent highlighted that a set of Member State national ecolabel criteria had not been developed further because '*the difference in environmental performance between products was too small*' and that it '*could cause confusion for customers*' which would not be desirable given the overall environmental gain from solar electricity production.

1.1.3.2.2. Inverters

Q2.8 Do you think that the scope of the study should be adapted for the specific purpose of the EU Ecolabel?

12 out of the 14 respondents to this question (86%) indicated that the Ecolabel product scope should reflect that used for Ecodesign and Energy Labelling. The two respondents who felt that the scope should be adapted considered that Ecodesign and Energy Labelling have different scopes – '*efficiency (energy labelling) is [not always] proportional to a lower environmental impact*'.

Q2.9 Are you aware of any relevant certification schemes or labels for the environmental performance of photovoltaic inverters?

In terms of relevant certification schemes and labels, the only one mentioned was the German Blue Angel (1 respondent).

1.1.3.2.3. Systems

Q3.11 Do you think that the scope of the study should be broadened or restricted for the specific purpose of the EU Ecolabel?

Of the 20 respondents to this question all indicated that the Ecolabel product scope should reflect that used for Ecodesign and Energy Labelling.

Q3.12 Are you aware of any relevant schemes or labels for the environmental performance of photovoltaic systems? In terms of relevant certification schemes and labels, those mentioned were:

- the French photovoltaic national call for tenders (4 respondents),
- The German renewable energy law (EEG) which sets a requirement for the type of land to be used for PV projects (3 respondents)
- IEC Renewable Energy conformity assessment scheme for systems (1 respondent)

Under Q3.9 relating to 'existing initiatives or criteria sets used to benchmark or promote an improved quality of installation for solar photovoltaic system' the following were also identified:

- DNV GL (private) certification for power plants, originating from Norway (1 respondent)
- The 'GRTU approved' quality, efficiency and safety inspection scheme for installed PV systems in Malta (1 respondent)
- The Quest scheme in Belgium for installation quality (1 respondent)
- VDE (and Fraunhofer ISE) Technical Bankability certification for PV power plants (1 respondent)

The mandatory schemes for certification of installers resulting from art 14 of the Renewable Energy Directive were highlighted.

1.1.4. Product scope for Green Public Procurement (GPP) criteria

In this section an initial analysis of the scope, definition and criteria areas of existing Green Public Procurement (criteria) used in the EU is made. Initial feedback gathered from stakeholder questionnaire on the suitability and practicability of using the Ecodesign and/or EU Ecolabel product scope is also analysed.

1.1.4.1. Existing GPP criteria sets used in the EU

A EU GPP criteria set for the solar photovoltaic product group does not currently exist. A criteria set for electricity was published in 2012 by DG Environment²³. The criteria document states part of EU GPP approach shall be to 'increase the share of electricity from renewable energy sources'. No specific criteria or references to solar photovoltaic technology could be found in the current criteria document. A review of European Commission surveys of Member State GPP criteria²⁴ and collaborative EU projects such as PRIMES and GPP 2020 did not reveal any national criteria sets to be currently in use²⁵.

²³ DG Environment (2012) *EU GPP criteria for electricity*, <http://ec.europa.eu/environment/gpp/pdf/criteria/electricity.pdf>

²⁴ DG Environment, *Studies*, http://ec.europa.eu/environment/gpp/studies_en.htm

²⁵ DG Environment, *GPP Ongoing projects*, http://ec.europa.eu/environment/gpp/projects_en.htm

1.1.4.2. Summary of the results from the first stakeholder questionnaire

1.1.4.2.1. Modules

Q1.11 Should the same scope as set out for the whole study also be used for public procurement purposes?

Of the 24 respondents to this question 23 indicated that the Green Public Procurement (GPP) product scope should reflect that used for Ecodesign and Energy Labelling.

Q1.12 Are you aware of any existing initiatives or criteria sets used in public procurement for the environmental performance of modules?

In terms of existing initiatives or criteria sets, those mentioned were:

- the French photovoltaic system national call for tenders, which contain 'a carbon criterion for modules and some additional environmental criteria' (6 respondents),
- NSF/ANSI 457 Sustainability Leadership standard (1 respondent),
- The German renewable energy law (EEG) which sets a requirement for the type of land to be used for PV projects (1 respondents)
- US EPA GPP webinar entitled 'Improving Solar PV Results through Collaborative Procurement' which covered the Renewable Energy Procurement (REP) Project in California (1 respondent)

Amongst the references to the French national call 'a "simplified carbon evaluation" based on specific emission factors considering material or component manufacturing process' was referred to. One respondent noted that:

'the lower the value is, the better the evaluation for the tender is. The purpose of these steps is to bring manufacturers to modify their environmental practices by proposing a gradual improvement throughout the periods and calls for tender.'

In relation to the NSF/ANSI 475 standard it was noted by the respondent that 'since the EPEAT ecolabel is widely recognized globally and within the EU when it comes to GPP, the [standard] could offer a lot of synergies to the GPP process.'

1.1.4.2.2. Inverters

Q2.11 Should the same scope as set out for the whole study also be used for public procurement purposes?

All 14 respondents to this question indicated that the Green Public Procurement (GPP) product scope should reflect that used for Ecodesign and Energy Labelling.

Q2.12 Are you aware of any existing initiatives or criteria sets used in public procurement for the environmental performance of inverters?

No initiatives were put forward and it was noted by one respondent that *'there are very few public tenders specifically for inverters'*.

1.1.4.2.3. Systems

Q2.11 Should the same scope as set out for the whole study also be used for public procurement purposes?

Of the 14 respondents to this question 13 indicated that the Green Public Procurement (GPP) product scope should reflect that used for Ecodesign and Energy Labelling.

Q2.12 Are you aware of any existing initiatives or criteria sets used in public procurement for the environmental performance of inverters?

In terms of existing initiatives or criteria sets, those mentioned were:

- the French photovoltaic system national call for tenders (2 respondents),
- The German renewable energy law (EEG) which sets a requirement for the type of land to be used for PV projects (2 respondents)
- US Department of Energy solar procurement guide for Federal Agencies (1 respondent)

Consultation draft

1.2. Measurement and test standards

This section represents a summary version of the accompanying draft JRC Technical Report ‘Standards for the assessment of the environmental performance of photovoltaic modules, power conditioning components and photovoltaic systems’, which forms an Annex of this Preparatory Study. It makes the following analysis of standards that are specific for solar photovoltaic modules, inverters and systems:

- Identification and description relevant standards,
- Comparative analysis of existing standards and their functional parameters,
- New standards under development.

For each sub-product an overview of the identified relevant performance parameters and their supporting standards, when available, is presented – namely: individual PV modules (see 1.2.2), power conditioning and storage components with a focus on inverters and batteries (see 1.2.3), and PV systems including stand-alone building-added (BaPV) and Building Integrated (BIPV) systems (see 1.2.4 and 1.2.5).

Generic standards that address aspects of environmental performance and which are applicable to solar photovoltaics, such as those establishing methods for Life Cycle Assessment (LCA) and the assessment of material efficiency and circularity aspects such as repairability and disassemblability, are addressed further in the Annex report.

1.2.1. Organisational structure of standardisation

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

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

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

1.2.2. PV Module standards

1.2.2.1. Functional parameters and related standards

The following functional parameters currently have a basis in standardisation and can be considered essential as a starting point for supporting the Preparatory Study:

- a. **PV module maximum power (P_{max})** according to the EN 60904-1 and reported at specific reference conditions, named Standard Test Conditions (STC) and defined by the Technical Specification CLC/TS;

- b. **Module Energy Conversion Efficiency**, as described in the new edition of the EN 60904-1 under revision;
- c. **Module Performance Ratio (MPR)** calculated according to the series of standards EN 61853 partly still in preparation at the IEC (drafts IEC 61853-3 and IEC 61853-4);
- d. **Module Energy Yield DC**; the DC energy produced by a single PV module following the method of calculation described in the draft IEC 61853-3 for one or all of the Standard Reference Climatic Profiles tabulated in the draft IEC 61853-4, with measurements of PV module power according to EN 61853-1 and corrections for temperature, spectrum and angle-of-incidence losses as described in EN 61853-2;
- e. **Module Energy Yield AC**, derived from Module Energy Yield DC by suitable losses factors (to be defined);
- f. **Module Annual Degradation Rate**.

The PV module maximum power P_{max} is a first measure to compare the performance of different PV modules and is normally defined at STC.

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

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

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

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

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

This represents the module energy yield, instead, and is based on the measurement of the electrical power delivered by a PV module under several conditions of irradiance and temperature, which better represent the real conditions met in the field. Such a set of power measurements at varying irradiance and temperature defines the power matrix (or performance surface) of the PV module and is subject of the standard EN 61853-1. The power matrix is then used as input to the MPR calculation according to the draft standard IEC 61853-3 together with other parameters defined and required by the standard EN 61853-2.

The MPR calculation is performed considering the climatic conditions that represent the typical location at which the PV module will be installed. A set of six Reference Climatic conditions are defined in the draft standard IEC 61853-4, which covers the most common climatic conditions observed in the world. As far as the European continent is concerned, it is possible to cover the variety of the European climatic regions with three of these six data sets (or define three data sets specifically for Europe), which can be described as subtropical, temperate continental and temperate coastal.

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

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

These solutions are also discussed in the Task 3 report of this Preparatory Study, in relation to the modelling of 'direct' impacts according to a system expansion approach.

1.2.2.2. Product quality standards

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

The current series EN 61215 consists of two main Parts:

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

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

- *EN 61215-1-1 Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules;*
- *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;*
- *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;*
- *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 tests 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 quantitative correspondence between the stressor as applied in the laboratory and the degradation achieved in the field due to exposure to specific environmental conditions, are not yet available, as they indeed depend on climatic

conditions to which the PV module is exposed as well as on the specific design of the PV module and the actual installation.

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

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

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

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

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

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

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 as quality check of the incoming material/component or of the PV module production process itself and as feedback from the production to the design and engineering stage within the overall quality system of the manufacturer.

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

An evolution in the standardisation process might be anticipated, whereby there could be a move from "pass-fail" qualification testing to more sophisticated analyses, which instead provide more quantitative assessment of risks

specific to a particular location, or type of location, and thus enable more quantitative assessments to be made 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 problem²⁶. Assignment of a CPN or other rating methodologies²⁷ relies on being able to link knowledge about the components and system with the anticipated outcomes. The industry has not yet agreed upon the best approaches for gathering and using the information needed for quantifying overall risk.

1.2.2.3. Lifetime, failure modes and performance degradation

The lifetime of a PV module is not precisely defined yet in any international standard or other official document. Some suggestions or common practices are available, which are reported in both this section and in section 1.2.2.2.

In particular the subject of degradation of PV modules is still subject to debate within the PV community and all the standardisation bodies. The available standards, published or in draft as first edition, dealing with degradation issues are tabulated in the main standards report.

The lack of extended standardisation work on this topic is due mainly to the fact that, although some tests for qualification were developed to set some pass/fail criteria according to which to discard the most probable failing modules, new and different failure modes of PV modules appear in the field over time. Also, alternative materials or different environment (climatic) conditions are explored. The previous IEC 61215 (now IEC 61215 series) standard has demonstrated its value for rapidly uncovering well-known failure mechanisms. However, it is insufficient for assessing long-term risks, for evaluating newer or less common materials and designs, or for establishing field performance degradation²⁸.

The issue of failure modes and performance degradation for PV modules (and therefore systems) must still be considered as belonging to the learning curve of the PV scientific community. As a consequence, the operational service life of PV modules may have to be defined by the co-legislators instead, according to best criteria still to be determined. This opens the possibility for wider involvement of the PV community in a feedback process that could be the basis for building a European dataset of failure modes; these could then be used as input to new and improved standardisation activities, e.g., for the prEN 45552 work.

Today's rapidly changing PV technology requires many companies to launch new versions of their products every few months while requiring warranties that are decades long (typically 80% of power after 25 years). In the absence of a standardised method to determine the durability of PV modules, one can use compiled field data, in order to obtain educated (scientifically observed) estimates for degradation rates for different technologies.

²⁶ 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

²⁷ 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

²⁸ Kurtz S et al. 2017 *Qualification Testing versus Quantitative Reliability Testing of PV – Gaining Confidence in a Rapidly Changing Technology*. In: 33rd European Photovoltaic Solar Energy Conference and Exhibition, (Amsterdam) pp 1302 - 11

1.2.3. Inverters and other power conversion and conditioning components

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

1.2.3.1. Functional Parameters and related standards

With a focus on inverters as being the most important PCE for most solar PV installations, there are several parameters that could be considered as the main functional unit.

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

In addition to these parameters, for commercial purposes, PV manufacturers tend to classify different inverters by the recommended PV array power range (i.e. input power to the inverter), by the maximum efficiency or by the “European efficiency”. Inverters and power converters in general do not constantly operate at their maximum efficiency possible, but rather at an efficiency that depends on the input power level. The “European Efficiency” is a parameter that corresponds to an operating efficiency averaged over a year of operation in a middle-European climate. This parameter, defined in Annex D of the standard EN 50530, is at present referenced by most manufacturers. The California Energy Commission (CEC) proposed other weighting factors, which are also included in the above-mentioned EN 50530. The CEC efficiency considers, for example, less likely that the real working conditions of the inverter would make it work at its maximum efficiency, contrary to the European Efficiency definition.

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

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

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

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

A further elaboration of this approach is to include an assumed service life of 10 to 15 years depending on the size of the inverter (residential PV system or large PV plant). Such a parameter is derived from IEA report references, together with EN 61724. However, in order to estimate such parameter several assumptions should be

adopted so as to model both PV array power output and inverter performance including the effects of degradation.

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

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

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

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

1.2.3.2. Lifetime, reliability and failure modes

Various reports conclude that the inverter is the element of the PV system which is responsible for the highest number of operation and maintenance events with the subsequent cost burden and loss of power production. In order to reduce these impacts, some standards are being developed in order to improve the inverter's reliability from quality and testing points of view. In parallel, industry already applies various accelerated tests so as to detect infant failures that would result in premature failure and degradation of the inverter. Some examples are given in Hacke et al (2018)²⁹.

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

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

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

1.2.3.3. Complementary Standards

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

²⁹ Hacke P, Lokanath S, Williams P, Vasan A, Sochor P, TamizhMani G, Shinohara H and Kurtz S 2018 *A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols* Renewable and Sustainable Energy Reviews 82 1097-112

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

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

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

Other standards related to safety or grid-connection requirements have been adopted at EN and IEC level simultaneously, while in some cases they exist solely at IEC level.

Although not directly related to their technical performance, but however possibly applicable to durability, degradation and lifetime analyses, the IEC standard series 60068 constitutes a set of documents containing information on environmental testing procedures for electrical, electro-mechanical and electronic equipment and devices. Some of these testing may be applicable to PCEs for testing degradation due to corrosion or failure due shock, vibration or deposition of dust and sand. The IEC standard 60529 provides test methods and ratings of casing ingress protection from, for example, water and sand.

1.2.3.4. Batteries

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

Battery performance is subject to degradation over time, expressed in terms of the number of charge and discharge cycles after which a battery will maintain a notional level of capacity, usually 80%. IEC EN 61960 is the reference standard for the measurement of battery cycle endurance. It specifies both a standard endurance in cycles test at 0.2 It A and an accelerated endurance in cycles test routine based on increased charge of 0.5 It A within the tolerance of the battery.

1.2.4. PV Systems

1.2.4.1. Functional Parameters and related standards

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

- System Power Output;

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

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

System Power output: EN 61724-1 defines the system nominal or rated DC power (labelled P_p) as the arithmetic sum of the power values at STC of the installed PV modules (see section **Error! Reference source not found.**). The AC rated power on the other hand is determined in EN 61724-1 as the lesser of the sum of the array DC power and the sum of the inverter maximum power ratings.

System Energy output/yield: They relate to AC power output, E_o , typically for a one-year reference period³⁰, and energy yield, which is the energy output normalised by the rated DC power as defined above.

There is currently no dedicated standard for calculating the expected³¹ energy output for PV systems. IEC TS 61724-3 provides a framework for a generic model that would combine a set of fixed parameters describing a PV system with environmental parameters, but it also explicitly notes that the definition of the model itself is outside its scope. Nonetheless, some concepts and parameters can be useful in the present context.

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

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

The environmental data can be a Standard Reference Climatic profile (as discussed in section 1.2.2.1 or a location specific dataset, such as the Typical Meteorological Year (TMY) data foreseen under the Energy Performance of Buildings Directive, and compliant with the INSPIRE Directive. In the latter case, the resulting energy output value will be specific to a given system configuration and the assumed location/environment.

EN 15316-4-3 standard “Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies” provides a simple methodology to estimate the energy yield of building integrated PV system, but it is in principle applicable to any kind of PV system.

System performance ratio: EN 61724-1 applies the definition

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

Where:

Y_f is final energy yield, defined as net energy output E_o normalised by the DC rated power, P_p .

³⁰ It is also possible to consider the energy output over the service life, including any progressive degradation of the performance of the components (see section 3.2.5).

³¹ In IEC terminology “expected” indicates an ex-ante design calculation using an appropriate system model and historical or reference environment input, “predicted” refers to the theoretical output for given environmental conditions, and “actual” refers to measured values.

Y_{ref} is the reference energy yield, defined as the in-plane irradiation for the reference period normalised by the reference irradiance $G_{i,ref}$. The latter corresponds to the irradiance condition used to define the nominal DC power, P_0 .

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

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

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

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

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

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

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

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

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

1.2.4.2. System design, installation and maintenance standards

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

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

It should be noted that additional quality standards for the PV system may be necessary to consider.

1.2.4.3. Lifetime, failure modes and performance degradation

To the knowledge of the research team there are no standards currently available for modelling the performance degradation rates of PV systems, and even though there are publications on fault detection and the monitoring of PV systems^{32 33 34}, there are no clear degradation rates for PV systems as there are for PV modules.

Degradation in performance may derive from the modules, wiring, the inverter's maximum power-point tracking system or even other factors, like soiling or presence of shadows. The combined impact of these possible effects is difficult to model and are referred to in the EN 61724 standards series as derate factors with respect to a systems nameplate DC power rating. Even if the performance and power output of a PV system had been monitored over long periods of time, the source of the performance degradation would be difficult to clearly identify. In addition to this, the measurement uncertainty is not negligible in these cases, making the performance degradation rate difficult to measure and quantify.

1.2.4.4. Supporting Standards

There exist several standards that could be applied for the PV systems analysis as a whole, like the standard EN 61724-1. Those standards that relate to single components behaviour could also be used, e.g., those mentioned previously in the sections on PV modules and PCEs which were linked to their power performance and efficiency.

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

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

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

1.2.5. Building-Integrated PV Modules or Systems

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

1.2.5.1. Supporting standards

At present, only the series EN 50583 (2016) addresses specifically the building-integration of PV modules (EN 50583-1) and systems (EN 50583-2). An IEC project team is now further developing the EN concepts in two

³² Madeti S R and Singh S N 2017 *A comprehensive study on different types of faults and detection techniques for solar photovoltaic system* Sol. Energy 158 161-85

³³ Villarini M, Cesarotti V, Alfonsi L and Introna V 2017 *Optimization of photovoltaic maintenance plan by means of a FMEA approach based on real data* Energy Conversion and Management 152 1-12

³⁴ Triki-Lahiani A, Bennani-Ben Abdelghani A and Slama-Belkhodja I 2018 *Fault detection and monitoring systems for photovoltaic installations: A review* Renewable and Sustainable Energy Reviews 82 2680-92

standards IEC 63092-1 (for BIPV modules) and IEC 63092-2 (for BIPV systems), currently scheduled to be published in 2019.

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

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

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

1.2.5.2. Lifetime and performance degradation

In the case of BIPV systems, the level of degradation is expected to be even more pronounced than in a ventilated open mounting structure. This is mainly due to the higher temperatures reached by the PV modules and components because of the reduced air circulation around them. Some of the standards included in section 1.2.1 address these issues.

1.2.5.3. Functional parameters

With reference to a combined energy parameter for cells or modules integrated into a building fabric the already proposed definition for modules could be used as a starting point:

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

However, this would require a reflection regarding the higher ambient temperatures that are reached in BIPV installations.

1.3. Existing legislation

1.3.1. Legislation and agreements at European Union level

In this section European Union legislation and agreements of relevance to the product scope are briefly described and analysed for their potential implications. To aid an understanding of how they may influence the EU solar photovoltaic market – both in terms of technical performance and deployment potential – they have been grouped under the following broad themes:

- Energy Union and reshaping of the EU electricity market
- Driving the market for renewable electricity generation
- Driving the market for building renovation and near zero energy buildings
- Improving information on construction product performance
- Improving material efficiency and creating a Circular Economy
- Product policy and consumer information

In some cases legislation has been highlighted that is still under discussion, in which case a level of uncertainty must be accepted in relation to the final implications.

1.3.1.1. Energy Union and reshaping of the EU electricity market

1.3.1.1.1. The role of citizens in the 'Energy Transition'

In 2015 the Commission set out under the title of 'Energy Union' a new strategy for '*more secure, affordable and sustainable energy*' in the EU. This strategy is of relevance to solar photovoltaics because it has a central focus on the role of citizens, including the potential of renewable energy and in particular self-generation. To illustrate this, the Energy Union Framework Strategy of 2015 set out a vision of an Energy Union with:

'... citizens at its core, where citizens take ownership of the energy transition, benefit from new technologies to reduce their bills, participate actively in the market, and where vulnerable consumers are protected.'

This vision informed a green paper published in 2015 which in turn led in 2016 to a proposal for a new Directive that will lay down new common rules that will empower citizens. This proposal formed part of the 'Clean energy transition' Package of measures that was presented by the Commission in 2016.

1.3.1.1.2. Proposed new common rules for the EU electricity market

In 2016 proposals were put forward for a new Directive which would lay down new common rules for the functioning of the EU's internal electricity market. Its proposed provisions would include guaranteeing consumers rights to the self-consumption of electricity and the establishment of legal frameworks for 'local energy communities' to engage in generation, distribution and supply. The proposed Article 15 on 'Active consumers' states that:

1. Member States shall ensure that final customers:

(a) are entitled to generate, store, consume and sell self-generated electricity in all organised markets either individually or through aggregators without being subject to disproportionately burdensome procedures and charges that are not cost reflective;

(b) are subject to cost reflective, transparent and non-discriminatory network charges, accounting separately for the electricity fed into the grid and the electricity consumed from the grid, in line with Article 59.

Article 16 would additionally require that non-discriminatory legal frameworks are laid down for local energy communities. In addition, Article 31 makes general provision for a Member State to require distribution system operators, when dispatching generating installations, to give priority to generating installations using renewable energy sources.

1.3.1.2. Driving the market for renewable electricity generation

1.3.1.2.1. The Renewable Energy Directive (2009)

The Renewable Energy Directive 2009/28/EC recast the general regulatory framework for increasing the share of renewable energy in the EU. A number of specific articles are of potential relevance to this study. These include a number of references to renewables in the context of buildings and the establishment of installer certification schemes in Member States.

Article 4 states that *'Member States shall, in their building regulations and codes or by other means with equivalent effect, where appropriate, require the use of minimum levels of energy from renewable sources in new buildings and in existing buildings that are subject to major renovation'*. Moreover, Article 13 states that Member States shall also that new public buildings and existing buildings subject to major renovation *'fulfill an exemplary role'* and that this obligation may be fulfilled by either:

- complying with standards for zero energy housing, or
- by providing that the roofs of public or mixed private-public buildings are used by third parties for installations that produce energy from renewable sources.

Article 14 is of relevance to photovoltaic system installations as it requires Member States make available certification schemes or equivalent qualification schemes for installers. Criteria intended to ensure consistent establishment of schemes and associated requirements are then laid down in Annex IV of the Directive, although there is some evidence of inconsistent implementation by Member States³⁵. Annex IV states that *'accredited training programmes should be offered to installers with work experience, who have undergone, or are undergoing, the following types of training'* and that in the case of a solar photovoltaic installer:

'training as a plumber or electrician and have plumbing, electrical and roofing skills, including knowledge of soldering pipe joints, gluing pipe joints, sealing fittings, testing for plumbing leaks, ability to connect wiring, familiar with basic roof materials, flashing and sealing methods as a prerequisite' or 'a vocational training scheme to provide an installer with adequate skills corresponding to a three years education in the skills referred to in point (a), (b) or (c) including both classroom and workplace learning'.

Moreover, the installer shall demonstrate the following 'key competencies':

- (i) the ability to work safely using the required tools and equipment and implementing safety codes and standards and identify plumbing, electrical and other hazards associated with solar installations;
- (ii) the ability to identify systems and their components specific to active and passive systems, including the mechanical design, and determine the components' location and system layout and configuration;
- (iii) the ability to determine the required installation area, orientation and tilt for the solar photovoltaic and solar water heater, taking account of shading, solar access, structural integrity, the appropriateness of the installation

³⁵ T. Tsoutsos et al, *Training and certification of PV installers in Europe - A transnational need for PV industry's competitive growth*, Energy Policy 55(2013)593-601

for the building or the climate and identify different installation methods suitable for roof types and the balance of system equipment required for the installation; and

(iv) for solar photovoltaic systems in particular, the ability to adapt the electrical design, including determining design currents, selecting appropriate conductor types and ratings for each electrical circuit, determining appropriate size, ratings and locations for all associated equipment and subsystems and selecting an appropriate interconnection point.

1.3.1.2.2. Recasting of the Renewables Directive

Proposals were put forward in 2016 for a further recast of the Renewables Directive to better reflect the new priorities under the Energy Union strategy. These proposals formed part of the 'Clean energy transition' Package of measures that was presented by the Commission in 2016.

The proposals include a policy option to focus on '*empowering citizens to self-consume and store renewable electricity*'. This option is preferred because it:

- maximises consumer's empowerment and their potential participation,
- mitigates grid deployment costs and grid costs distributional issues, and
- enhances the contribution of rooftop solar PV to the renewable energy target.

A number of proposed modifications and new Articles are of potential relevance to the scale and type of solar photovoltaic systems that may be promoted as a result:

- Article 15 includes a new calculation methodology (anchored on the Energy Performance of Buildings Directive) of minimum levels of energy from renewable sources in new and existing buildings that are subject to renovation.
- Article 17 introduces a simple notification to Distribution System Operators for small scale projects and a specific provision on accelerating permit granting process for repowering existing renewable plants;
- Article 21 empowers consumers by enabling them to self-consume without undue restrictions, being remunerated for the electricity they feed into the grid.
- Article 22 sets forth new provisions on energy communities to empower them to participate in the market.

1.3.1.2.3. Network code requirements for grid connection

A new network code for the grid connection of power generators was adopted in 2016. Regulation (EU) 2016/631 includes the intention to support the integration of renewable electricity sources, however increasing grid penetration of distributed renewable generation means that the potential impacts on the overall stability, reliability, and efficiency of grids require addressing. Bruendlinger (2016) highlights the case of Germany where the simultaneous tripping of several gigawatts of distributed wind or solar capacity could lead to an undersupply that could not be compensated by reserves³⁶. The new code is applicable to all new generators >0.8 kW, and adopts a proportional approach with smaller generators of up to 1MW having to meet basic requirements to ensure system stability (type A generators) and with larger generators of >1MW having to fulfil an extended

³⁶ Bruendlinger, R (2016) *Review and Assessment of Latest Grid Code Developments in Europe and Selected International Markets with Respect to High Penetration PV*, Austrian Institute of Technology, Paper presented at the 6th Solar Integration Workshop.

responsibility (type B,C and D generators) – see the summary in Table 9. The code is supported by standards developed by CENELEC TC8X.

Table 9 Overview of system aspects and requirements addressed by the European network codes

System aspect	Requirement	Generator type		
		A	B	C/D
Frequency stability	Operating frequency ranges	x	x	x
	RoCoF withstand capability	x	x	x
	Limited Frequency Sensitive Mode – overfrequency	x	x	x
	Constant active power output regardless of changes in frequency	x	x	x
	Limitation of power reduction at under frequency	x	x	x
	Automatic connection	x	x	x
	Remote on/off	x	x	
	Active power reduction remote control		x	
	Additional requirements relating to frequency control			x
	Provision of synthetic inertia			x
Robustness of power generating modules	Fault ride-through		x	x
	Post-fault active power recovery		x	x
System restoration	Co-ordinate reconnection		x	x
General system management	Control schemes and settings		x	x
	Electrical protection and control schemes and settings		x	x
	Priority ranking of protection and control		x	x
	Information exchange		x	x
	Additional requirements to monitoring			x
Voltage stability	Reactive power capability		x	x
	Fast reacting reactive power injection		x	x
	Additional requirements for reactive power capability and control modes			x

Source: Bruendlinger (2016)

1.3.1.3. Driving the market for building renovation and near zero energy buildings

1.3.1.3.1. Energy Performance of Buildings Directive (2010)

The construction and refurbishment of buildings in such a way as they reduce energy use and CO₂ emissions is a central environmental policy objective for Europe. The recast *Energy Performance of Buildings Directive 2010/31/EU (EPBD)*³⁷ requires Member States to prepare national plans to ensure that all new buildings are ‘nearly zero energy’ by 2020. This is defined in Article 2(2) of the EPBD as:

³⁷ Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

'...a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources,'

Annex I of the Directive lays down a common framework for calculation of a buildings energy performance. The reference to renewable energy within the definition of Nearly Zero Energy Buildings (NZEB) is of relevance to solar photovoltaic systems. Moreover, the Commission Recommendation (EU) 2016/1318 of 29 July 2016 on nearly zero-energy buildings noted that solar PV has been one of the most frequently applied technologies in order to fulfil Member States' NZEB requirements³⁸.

The recast EPBD states that reporting on the energy performance of a building shall include *'an energy performance indicator and a numeric indicator of primary energy use'* and that the methodology should take into account European (EPB) standards. Within the frame of CEN Mandate M/480 the EN standards providing a harmonised calculation method have been comprehensively updated by the CEN ISO/TR 52000 series. This series is intended to support harmonisation of the National Calculation Methodologies (NCMs) for assessment of the overall energy use of a building.

The contribution of solar photovoltaics is calculated within the Technical Building System calculation module M11 *'Electricity production'*. This module supports calculation of the delivered energy and exported energy from a solar photovoltaic system installed on or integrated into a building. The EN ISO 52000 series and the calculation method provided in EN 15316-4-3 are discussed further in section 1.2 of this Task report.

1.3.1.3.2. Proposed further amendment of the Energy Performance of Buildings Directive (2017)

A proposal for a further amendment of the EPBD formed part of the 'Clean energy transition' package of measures that was presented by the Commission in 2016. Agreement was reached in December 2017 on the content of this further amendment³⁹. It is proposed as including a stronger focus on the renovation and decarbonisation of the existing building stock. Also proposed is the introduction of a 'smartness indicator' intended to:

'...enhance the ability of occupants and the building itself to react to comfort or operational requirements, take part in demand response and contribute to the optimum, smooth and safe operation of the various energy systems and district infrastructures to which the building is connected.'

In particular it is understood that it would measure a buildings' capacity to use new technologies and electronic systems to optimise operation and interact with the grid.

1.3.1.4. Improving information on construction product performance

1.3.1.4.1. The Construction Products Regulation (2011)

The Construction Products Regulation (EU) No 305/2011 seeks to ensure that reliable information on the environmental performance of products is provided in the EU market. It lays down in Annex I a set of seven *'basic requirements for construction works'* stating that:

³⁸ <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016H1318&from=EN>

³⁹ Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/31/EU on the energy performance of buildings, COM(2016) 765 final, Brussels, 30.11.2016

'Construction works as a whole and in their separate parts must be fit for their intended use, taking into account in particular the health and safety of persons involved throughout the life cycle of the works. Subject to normal maintenance, construction works must satisfy these basic requirements for construction works for an economically reasonable working life.'

To this end, the regulation seeks to harmonise Declarations of Performance for the essential characteristics of building products, and hence any associated CE marking requirements, under each of these seven 'basic requirements for construction works'. The main instrument for achieving this is through the application of new and existing harmonised European standards. The seven requirements are described in Table 10

Table 10. Basic requirements for construction works according to the Construction Products Regulation (EU) No 305/2011

<p>1. Mechanical resistance and stability</p>	<p>The construction works must be designed and built in such a way that the loadings that are liable to act on them during their constructions and use will not lead to any of the following:</p> <ul style="list-style-type: none"> (a) collapse of the whole or part of the work; (b) major deformations to an inadmissible degree; (c) damage to other parts of the construction works or to fittings or installed equipment as a result of major deformation of the load-bearing construction; (d) damage by an event to an extent disproportionate to the original cause.
<p>2. Safety in case of fire</p>	<p>The construction works must be designed and built in such a way that in the event of an outbreak of fire:</p> <ul style="list-style-type: none"> (a) the load-bearing capacity of the construction can be assumed for a specific period of time; (b) the generation and spread of fire and smoke within the construction works are limited; (c) the spread of fire to neighbouring construction works is limited; (d) occupants can leave the construction works or be rescued by other means; (e) the safety of rescue teams is taken into consideration.
<p>3. Hygiene, health and the environment</p>	<p>The construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of workers, occupants or neighbours, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate during their construction, use and demolition, in particular as a result of any of the following:</p> <ul style="list-style-type: none"> (a) the giving-off of toxic gas; (b) the emissions of dangerous substances, volatile organic compounds (VOC), greenhouse gases or dangerous particles into indoor or outdoor air; (c) the emission of dangerous radiation; (d) the release of dangerous substances into ground water, marine waters, surface waters or soil; (e) the release of dangerous substances into drinking water or substances which have an otherwise negative impact on drinking water; (f) faulty discharge of waste water, emission of flue gases or faulty disposal of solid or liquid waste; (g) dampness in parts of the construction works or on surfaces within the construction works. <p>EN 4.4.2011 Official Journal of the European Union L 88/33</p>

4. Safety and accessibility in use	The construction works must be designed and built in such a way that they do not present unacceptable risks of accidents or damage in service or in operation such as slipping, falling, collision, burns, electrocution, injury from explosion and burglaries. In particular, construction works must be designed and built taking into consideration accessibility and use for disabled persons.
5. Protection against noise	The construction works must be designed and built in such a way that noise perceived by the occupants or people nearby is kept to a level that will not threaten their health and will allow them to sleep, rest and work in satisfactory conditions.
6. Energy economy and heat retention	The construction works and their heating, cooling, lighting and ventilation installations must be designed and built in such a way that the amount of energy they require in use shall be low, when account is taken of the occupants and of the climatic conditions of the location. Construction works must also be energy-efficient, using as little energy as possible during their construction and dismantling.
7. Sustainable use of natural resources	The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following: (a) reuse or recyclability of the construction works, their materials and parts after demolition; (b) durability of the construction works; (c) use of environmentally compatible raw and secondary materials in the construction works. EN L 88/34 Official Journal of the European Union 4.4.2011

Source: European Commission (2011)

With the advent of the European single market for construction products, there was a concern that national Environmental Product Declaration (EPD) schemes and building level assessment schemes based on LCA principles would represent a barrier to trade across Europe. As a result, two standards were developed and published by CEN/TC 350:

- EN 15978 (2011) This standard deals with the aggregation of the information at the building level, describing the rules for applying EPDs in a building assessment. The identification of boundary conditions and the setting up of scenarios are major parts of the standard.
- EN 15804 (2012) This standard provides the Product Category Rules for construction products and services, with the aim to ensure that EPDs for construction products are derived, verified and presented in a harmonised way.

These standards provide a harmonised set of environmental and resource use indicators for use in the assessment and reporting of performance as well as a modular schematic of the life cycle stages (see . EN 15804 in particular is assuming an increasing important in the EU as the sector moves towards greater use of life cycle assessment, with an accompanying need for data on the performance of individual building products. The major building assessment schemes that are currently used in the EU, together with Member State governments such as France and the Netherlands, are actively aligning EPDs and building assessment methods with the EN series.

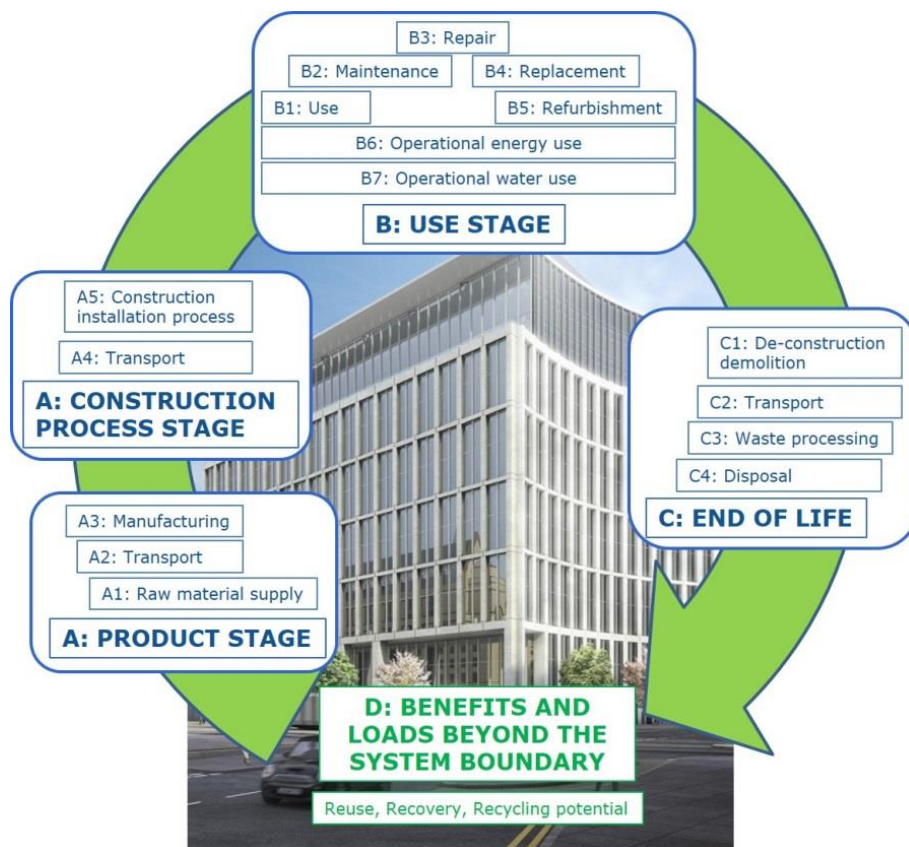


Figure 12 Modular schematic of building life cycle stages

Source: Based on CEN (2011)

During the recent development of the common EU framework of building environmental performance indicators by the JRC for DG Environment it was identified that life cycle information for energy technologies such as solar photovoltaics is limited in its availability to building designers. It is anticipated that with the onset of the EU framework, now referred to by the Commission as Level(s), there will be increasing demand for this type of life cycle data at product level.

1.3.1.4.2. Piloting of the Product Environmental Footprint (PEF) method

The pilot phase of the European Commission's Product Environmental Footprint (PEF) method for Life Cycle Assessment (LCA) ran during 2014 -2017. It tested the technical basis for establishing Product Environmental Footprint Product Category Rules (PEFCRs) for a series of products⁴⁰. The pilot included a number of building related products, one of which was solar photovoltaic modules.

The PEF method has as its basis a more extensive set of environmental and resource use indicators than the EN standards series described in section 1.3.1.4.1. The potential influence of the PEF on future standards and category rules for building product environmental assessment will, to a great extent, depend on deliberations by the Commission on the way forward following this pilot, which are ongoing at the time of writing.

⁴⁰ European Commission, *The Environmental Footprint pilots*, DG Environment, http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

1.3.1.5. Improving material efficiency and creating a Circular Economy

The Roadmap to a Resource-Efficient Europe COM(2011) 571 highlighted the need for a more sustainable and productive use of natural resources⁴¹. There have subsequently been a number of related policy initiatives that have aimed to drive a transformation in how materials are obtained and used. Two initiatives of particular relevance to solar photovoltaics are briefly reviewed in this section.

In addition to a focus on processes upstream of producers, European waste legislation has extended producer responsibility for the take back and subsequent handling, treatment and/or disposal of solar photovoltaics. The implications are briefly summarised in this section.

1.3.1.5.1. Battery directive

Directive 2006/66/EC regulates the manufacture and disposal of batteries in the European Union with the aim of improving the environmental performance of batteries and accumulators. The directive, apart from restating the content limits of cadmium and prohibiting mercury in all batteries, it no longer restricts the lead content of batteries. The Directive aims to prevent batteries from being incinerated or dumped in landfills.

The Battery directive was amended in 2013 to ensure that batteries and accumulators can be easily removed from the electrical or electronic equipment they are attached. This means that it should be possible to remove them without delay or difficulty and at a reasonable cost, where needed using the instructions provided.

Batteries and accumulators used in electrical and electronic equipment (EEE) fall within the scope of the Batteries Directive unless there are specific provisions in the WEEE Directive. When they are in waste electrical and electronic equipment (WEEE) can be collected on the basis of the WEEE Directive. However, after collection, they must be removed from the appliance (electronic equipment) in accordance with Article 8(2) and Annex VII of the Battery Directive (as well as Article 3 (l)) of the WEEE Directive and they count towards the collection targets laid down in the Batteries Directive. These batteries and accumulators must be recycled as required by the Batteries Directive.

1.3.1.5.2. The Raw Materials Initiative

The Commission is implementing the Raw Materials Initiative⁴², which sets out a strategy for tackling the issue of access to raw materials in the EU. This strategy has three pillars which aim to ensure:

1. Fair and sustainable supply of raw materials from global markets: The EU has committed to pursue a Raw Materials Diplomacy reaching out to third countries through strategic partnerships and policy dialogues.
2. Sustainable supply of raw materials within the EU: The EU is dependent on the imports of many raw materials. To facilitate the sustainable supply of raw materials from European deposits, the European Commission aims to secure the right legal and regulatory conditions.
3. Resource efficiency and supply of 'secondary raw materials' through recycling: Production using recycled materials contributes to the supply of raw materials and is often much less energy intensive than manufacturing goods from primary materials. Recycling can thus improve supply conditions and reduce production costs and GHG emissions.

⁴¹ COM (2011) 571 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *Roadmap to a Resource Efficient Europe*

⁴² COM(2011)25 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *Tackling the challenges in commodity markets and on raw materials*

Related initiatives include the assessment of the criticality of raw materials and a package of measures to tackle the sourcing of certain minerals sourced from areas of conflict.

Critical Raw Materials are described by the European Commission as '*raw materials of high importance to the economy of the EU and whose supply is associated with high risk*'. Their criticality is assessed according to two main parameters - economic importance (EI) and supply risk (SR). A list of raw materials assessed as being critical is revised every three years to reflect changes in the market. The third revision of the list was published in 2017 and the materials listed as CRMs are identified with red/yellow points in Figure 13. Of broad relevance to the solar photovoltaic product group the following CRMs can be provisionally identified - cobalt, borate, indium, gallium, silicon metal and tantalum.

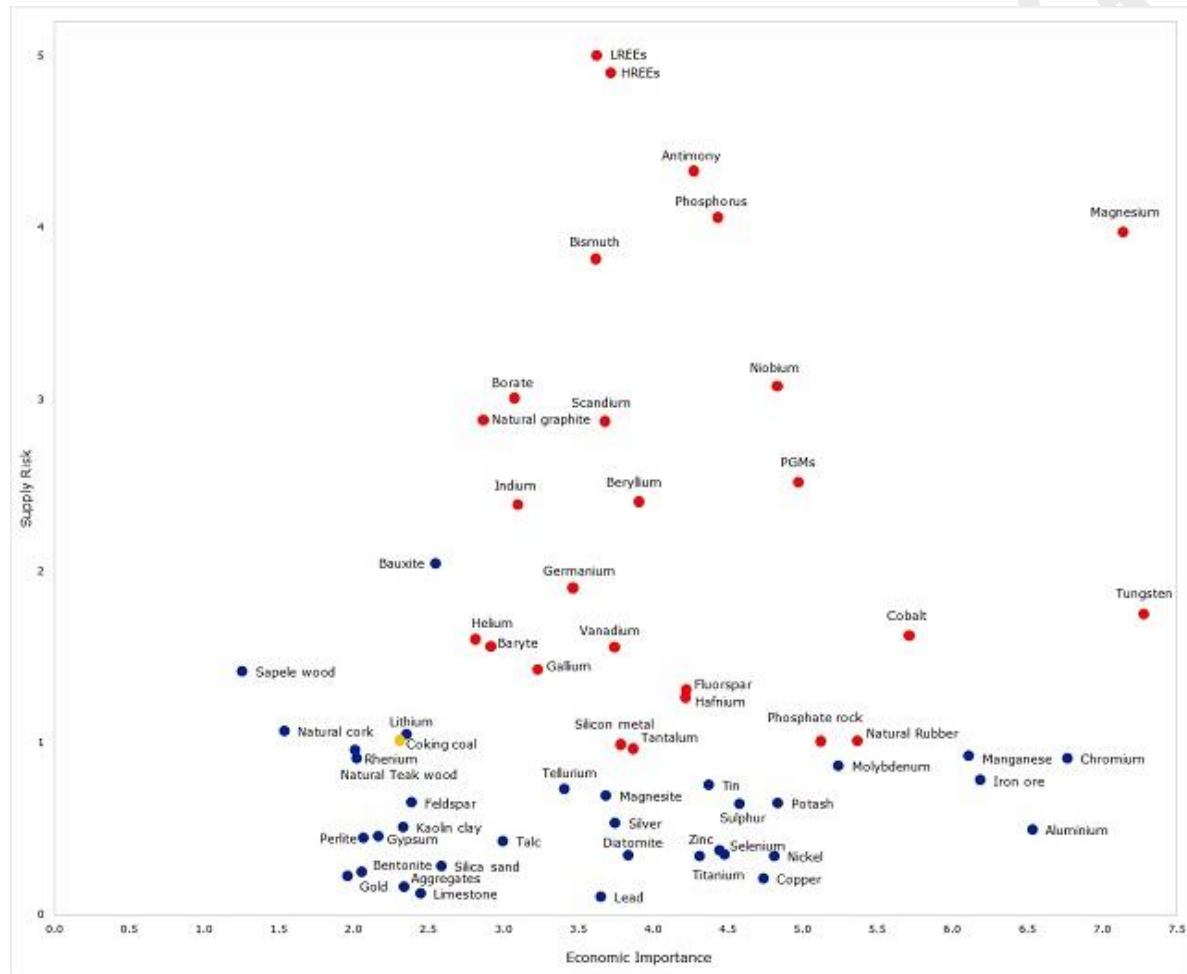


Figure 13 The 2017 list of Critical Raw Materials (in red) to the EU

(HREEs = Heavy Rare Earth Elements, LREEs = Light Rare Earth Elements, PGMs = Platinum Group Metals)

Source: European Commission (2018)

1.3.1.5.3. The recast Waste Electrical Equipment (WEEE) Directive (2012)

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

Annexes I - IV of the Directive specifically identifies solar photovoltaic 'panels' (modules) under EEE category 4(b). No specific collection rate for modules is specified, instead an overall collection rate for EEE is stipulated which

shall rise from 45% in 2016 to 85% in 2019. From the 15th August 2018 for EEE category 4 products an 85% recovery rate and an 80% re-use and recycling rate shall be achieved.

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

In terms of whether inverters fall within the general scope of the Directive the Commission clarified in 2014 in response to a Frequently Asked Question that inverters⁴³:

'...fall[s] under the definition of EEE given in Article 3(1)(a) and thus fall[s] within the scope of the Directive. An example of an inverter that falls within the scope of the Directive is one used in a photovoltaic installation. However, an inverter does not fall within the scope of the Directive in the following cases:

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

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

To support data collection and tracking the Commission published in 2017 a new WEEE Calculation Tool which compiles stock Placed on the Market (POM) and waste data⁴⁴. The default disposal rate used is based on a product lifespan that is determined using a Weibull distribution. 'Photovoltaic panels (including inverters)' are assigned UNU (United Nations University) code 0002 and preliminary data can be obtained that has been pre-loaded in the individual Member State calculator spreadsheets. The data obtained for this category should, however, be treated with caution because the inclusion or not of system components such as inverters is not clear from the metadata specification⁴⁵.

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

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

⁴³ Frequently Asked Questions on Directive 2012/19/EU on Waste Electrical and Electronic Equipment (WEEE), April 2014.

⁴⁴ DG Environment, *Statistical data – WEEE calculation tools*, http://ec.europa.eu/environment/waste/weee/data_en.htm

⁴⁵ ProSum, 0002 Basic metadata catalogue - photovoltaic Panels (incl. inverters), <http://prosum.geology.cz/records/5a0ee62e-9fc0-46ae-8e18-6cda0a010854>

Verification of proper treatment and depollution is supported by the EN 50625 series which, informed by the approach developed by the EU LIFE funded WEEElabex project ⁴⁶ which ran during 2009-2012, defines WEEE collection logistics and treatment requirements. Annex A of EN 50625-1 identifies specific components of equipment that shall be removed for depollution purposes. Parts 2-4 and 3-5 focussing on treatment requirements and a specification for depollution for 'photovoltaic panels' are under development.

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

1.3.1.5.4. An EU action plan for the Circular Economy (2015)

A Circular Economy package was published in late 2015. The Package contains measures to address the whole materials cycle, from production and consumption through to waste management and the use of recycled (secondary) raw materials, with the aim of contributing to 'closing the loop' of product lifecycles through greater recycling and re-use.

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

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

And that it will also:

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

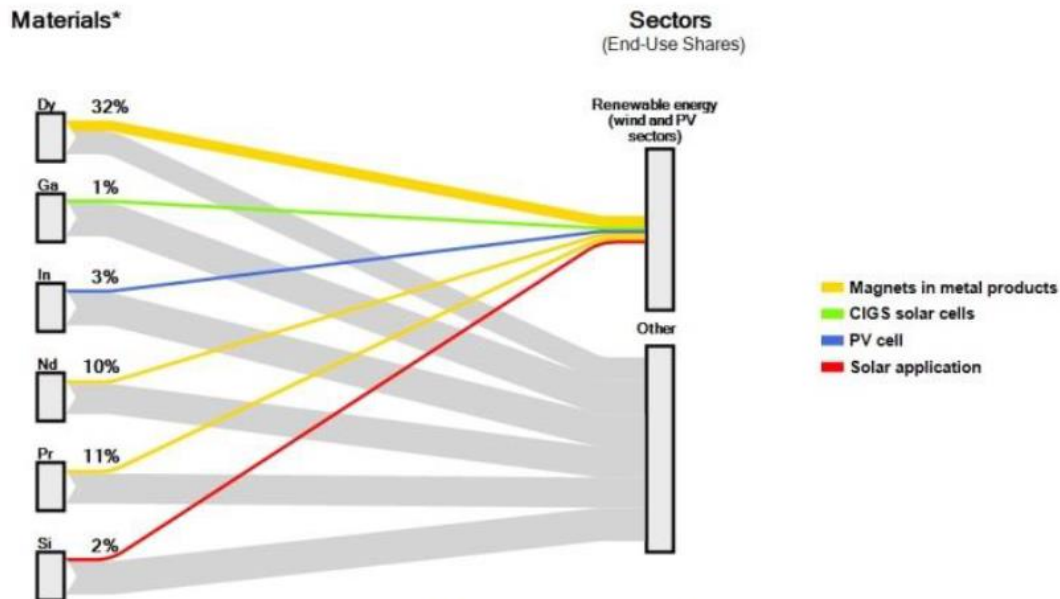
The need for an efficient use and recycling of Critical Raw Materials was highlighted within the action plan.

1.3.1.5.5. Critical Raw Materials and circular economy report (2018)

Solar photovoltaics receive specific attention in a Commission Staff Working Document on CRMs published early 2018 which analyses the link between CRM management and circular economy objectives. The CRMs indium, gallium and silicon metal are identified in the report as being of particular relevance. A high potential (95%) for economically feasible recycling is identified. Figure 14 illustrates the proportion of material flows that are estimated to be associated with these CRMs.

The lag time before large amounts of solar PV waste are generated is discussed and based on likely future waste arising forward projections of the EU CRM demand are made.

⁴⁶ WEEElabex, <http://www.weeelabex.org/>



* Only a subset of all CRMs used in renewable energy sector is included.

Figure 14 Share of CRMs used in wind and solar PV cell production

Source: European Commission (2018)

1.3.1.6. Product policy and consumer information

1.3.1.6.1. Climate dependant Ecodesign and Energy labelling requirements

Two product group lots that have been developed under the Ecodesign Working Plan for 2009-2011 are of potential relevance to solar photovoltaics. This is because calculations made in support of the performance requirements and/or the information requirements must, in addition to being based on average test conditions, also reflect two other distinct European climate zones. The lots and associated sub-products of potential relevance are:

- Reversible and heating-only air conditioners under Lot 10^{47 48}
- Heat pump water heaters and solar water heaters provided as part of a package 'offered to the end-user containing one or more water heaters and one or more solar devices' under Lot 2^{49 50}

⁴⁷ Commission regulation (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans OJ L 72, 10.3.2012

⁴⁸ Commission Delegated Regulation (EU) No 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of European Parliament and of the Council with regard to energy labelling of air conditioners OJ L 178, 6.7.2011

⁴⁹ Commission Regulation (EU) No 814/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water heaters and hot water storage tanks OJ L 239, 6.9.2013

⁵⁰ Commission Delegated Regulation (EU) No 812/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device OJ L 239, 6.9.2013

In both cases an approach has been adopted to Ecodesign information requirements and Energy Labelling that is, in part, based on the communication of performance under pre-defined conditions in three different geographical locations in Europe.

In the case of reversible and heating-only air conditioners three designated European heating seasons representing average, cooler and warmer conditions are specified. In the context of these two Lots these three conditions are defined as *'the temperatures and global solar irradiance conditions characteristic for the cities of Strasbourg, Helsinki and Athens, respectively'*. Manufacturers placing products on the EU market shall present:

- the cooling energy efficiency class and the *Seasonal Energy Efficiency Ratio (SEER)* under average climate conditions.
- the heating mode energy efficiency class and the related *Seasonal Coefficient of Performance (SCoP)* for each of the three designated European heating seasons (see Figure 15).

For the purposes of measurement and calculation the heating seasons, together with reference design conditions, are defined in Annex VII of the Ecodesign implementing Regulation No 206/2012 and of the Energy Labelling delegated Regulation No 626/2011.

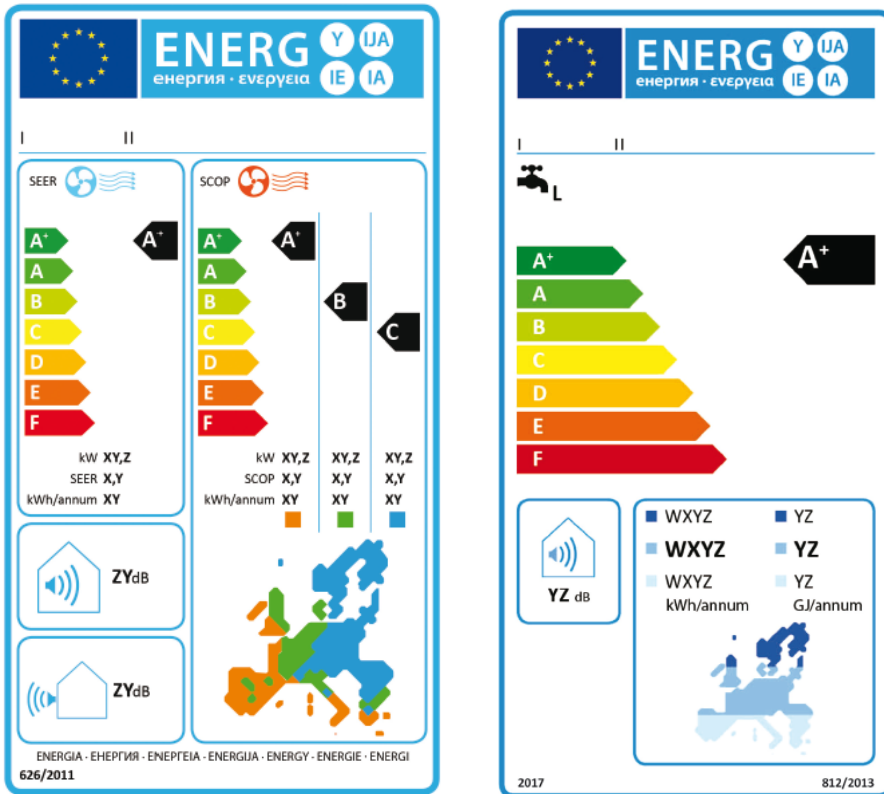
In the case of heat pump water heaters and solar water heaters, three geographically defined zones representing average, cooler and warmer conditions are specified. For the purpose of product testing the Ecodesign minimum requirements specify only the average conditions. For energy labelling purposes manufacturers placing products on the EU market shall present:

- foremost on the label the energy efficiency class based on the performance under *average climate conditions*.
- Inset on the label electricity and fuel consumption estimates for the *three European climate conditions* (see Figure 15).

For the purposes of measurement and calculation the climate conditions are defined in Annex III of the Ecodesign implementing Regulation No 814/2013 and of Annex VII of the Energy Labelling delegated Regulation No 812/2013.⁵¹

Dealers of packages shall ensure that the labelling for each component - which may include a solar water heater, a water heater and/or a hot water storage tank - is displayed at the point of sale. Moreover an additional step is specified that provides the purchaser of a package with an assessment of the water heating efficiency class for a combination of components. The calculation method is specified in an information fiche in Annex IV of the delegated Regulation, but it is important to note that it includes a disclaimer for possible losses in performance due to *'factors such as heat loss in the distribution system and the dimensioning of the products in relation to building size and characteristics'*.

⁵¹ Note that the recent EL framework regulation (2017/1369) will lead to a rescaling from A to G, which neither for air conditioners nor for solar heaters has happened yet - and in the latter case is planned for 2025. Moreover, what it is meant to be shown here is an example of how a differentiation of climatic zones has been dealt in the energy label.



a. Reversible air conditioners:
three heating seasons

b. Solar water heaters:
three temperature zones

Figure 15 European climate zones used by the air conditioner and solar water heaters labelling schemes.

Note that the recent EL framework regulation (2017/1369) will lead to a rescaling from A to G, which neither for air conditioners nor solar heaters has happened yet and in the latter case is planned for 2025.

Source: European Commission (2018)

Dealers of water heater packages shall ensure that the labelling for each component - which may include a solar water heater, a water heater and/or a hot water storage tank - is displayed at the point of sale. Moreover an additional step is specified that provides the purchaser of a package with an assessment of the water heating efficiency class for a combination of components.

The calculation method for the water heater package consumer information fiche is provided in section 4 of Annex IV of the delegated Regulation. It is important to note, however, that it includes a disclaimer for possible losses in performance due to 'factors such as heat loss in the distribution system and the dimensioning of the products in relation to building size and characteristics'. This means in practice that it does not provide information on the efficiency of the system as a whole.

1.3.1.6.2. Ecodesign requirements that address battery performance

Batteries on products have been object of Ecodesign regulations of other product categories. In the ecodesign regulation for computers EU 617/2013, specific requirements for batteries included to give information on the minimum number of loading cycles and battery replacement issues (e.g. in the case the battery was not accessible it has to be stated in the external packaging).

For the revision of this regulation an analysis of material efficiency aspects of personal computers product group has been made in 2018 by JRC⁵². Battery durability aspects were looked at, since the lifetime of batteries could be extended by up to 50% by preventing the battery remaining at full load when the notebook is in grid operation. The study concludes that implementing a preinstalled functionality on notebooks would make possible to optimise the state of charge (SoC) of the battery. Information to users in that regard is seen as a valuable measure.

A focus on the content of CRMs (especially cobalt in batteries) is also made in this JRC report. To improve the material efficiency during the recycling, the identification of the chemistry type of batteries in computers is necessary for an efficient and sorting.

1.3.1.6.3. Preparatory study on smart appliances

The lot 33 preparatory study on smart appliances has a wide scope⁵³. This study is not analysing all communication-enabled appliances, but the appliances that support *Demand Side Flexibility*. Those smart appliances that are relevant for the present solar preparatory study are:

- Home energy management systems: they are systems using the same language/semantics that the smart home appliances to exchange information. They are also referred to as energy boxes. Some appliances at home are considered to have flexibility potential to store electricity coming for example from solar photovoltaics (smart radiators or electric water heaters).
- Residential energy storage system: they mainly work for storing cheaper (renewable) electric energy to avoid buying expensive electricity at a later period. Distinctions are made between different implementations, such as:
 - residential energy storage systems combined with a separate PV installation,
 - fully integrated residential energy storage systems with PV, or
 - electric vehicles to home, where the vehicles will be used as (mobile) Battery Storage Systems

In the Follow up study for lot 33, chargers for electric cars have been included. Smart charging involves the intelligent charging of the batteries in electric vehicles: charging them in a way that avoids excessive and costly spikes in power demand and also – in the years to come – using the batteries of the cars as storage to deliver valuable services to the electricity system, as well as maximising local integration of renewable energy sources (RES). Standards in grid interconnection for battery electric cars are currently being developed by JRC.

1.3.2. Legislation and requirements at Member State level

Intervention to improve market conditions for solar photovoltaics at Member State level has historically played an important role in the support of growth in the deployment of the technology. Legislation designed to improve the market conditions and incentivise investment has been pivotal in the growth of the European market and the policy instruments used continue to evolve in response to policy priorities.

In this section an overview of legislation and agreements for thirteen selected Member States is provided. The Member States have been selected based on the significance of their solar photovoltaic markets, in terms of

⁵² Tecchio, Ardente et al. Analysis of material efficiency aspects of personal computers product group, JRC 2018.

⁵³ Ecodesign Preparatory study on Smart Appliances (Lot 33) MEErP Tasks 1-6, http://www.eco-smartappliances.eu/Documents/Ecodesign%20Preparatory%20Study%20on%20Smart%20Appliances%20_Tasks%201%20to%206.pdf

combination of historical, present and projected market penetration. The Member States that have been selected are identified in Table 11.

Table 11 Clustering of the Member States analysed based on their market evolution and penetration

Pioneers (pre 2008)	High market penetration – Germany
	Medium market penetration – Austria – Netherlands – Denmark – Spain
Late starters (post 2008)	High market penetration – Italy – United Kingdom
	Medium market penetration – Belgium – Czech Republic – France – Greece
	Low market penetration – Bulgaria – Romania
Key to electricity market penetration levels High = >5.0% Medium = 1.0 – 5.0% Low = <1.0%	

The Member State overviews have been developed based on the JRC's 'PV Status Report' (2016), the IEA-PVPS publications 'Trends 2016' and 'Review and analysis of PV self-consumption policies', the Horizon 2020 funded PV Financing initiative database⁵⁴ and consultation of Member State legislation. For each Member State the most important instruments are then characterised and briefly analysed for their relevance to the study. Qualification requirements for equipment, systems and installers in order to receive subsidies and contracts are also identified, where relevant.

1.3.2.1. Pioneers, high market penetration

1.3.2.1.1. Germany

PV system support: The main price support instrument driving growth of the market has been the Renewable Energy Sources Act (Erneuerbare Energien Gesetz EEG) introduced in 2000. This piece of legislation introduced a feed-in tariff with 20 year contracts. This mechanism is credited with creating Europe's largest solar PV market. The tariffs are adjusted in function of growth in the market and reductions in system costs. The tariffs are currently weighted to provide greater support to residential building and sound barrier mounted systems of <10kWp and <40kWp respectively. Since 2016 only systems <100 kWp have been eligible for the feed-in tariff.

⁵⁴ PV Financing, Database, Accessed in March 2018, <http://database.pv-financing.eu/database.html>

Utility scale system support: Since 2015 new systems must win in an auction of new capacity by the Federal electricity network agency. The first auction called on 500 MW of new capacity. The auction follows the 'market integration model' which provides a feed-in premium on top of the market electricity prices.

Self-consumption support: Systems <10 kWp are exempt from a 40% levy on electricity. The feed-in tariff rates are now below those for consumer electricity, providing an incentive for self-consumption. A maximum of 90% of the electricity generated is eligible for price support, thereby incentivising self-consumption.

Product environmental criteria: The federal ecolabel scheme the Blue Angel has had since 2012 a set of environmental criteria for inverters. A number of attempts have been made to establish criteria sets for both solar PV modules and solar PV systems, but consensus could not be reached in both cases (see section 1.1.3).

Grid integration support: The high numbers of installations in some areas has driven the introduction of new regulations in 2015. These have focussed on frequency disconnection settings for inverters in order to avoid a 'cascade' disconnection in the case of frequency deviations and the peak shaving of the maximum power output for systems <30 kWp at 70% for systems not remotely controlled by the grid operator.

Electricity storage support: A market support programme was introduced in 2013 and targets storage that is installed in conjunction with systems of <30 kWp. A 30% rebate is complemented by low interest loans available from the Kreditanstalt für Wiederaufbau (KfW)⁵⁵. Loans are subject to a cap on the capacity of the storage relative to the nominal rating of the accompanying PV system. Funding is only provided for products that meet technical quality requirements. Furthermore, systems must reduce pressure on the local grid by reducing peak load exports of the electricity generated.

Table 12 Germany: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017

2016	2017E	2018E	2019E	2020E
41111	43111	45411	47911	50611

1.3.2.2. Pioneers, medium market penetration

1.3.2.2.1. Austria

PV system support: The most important national policy instrument is the Ökostrom-Einspeisetarifverordnung 2012 (Eco-Electricity Act) which establishes a feed-in tariff with 13 year contracts for renewable electricity. Only PV systems >5kWp are currently supported and ground mounted systems of >200 kWp are no longer supported. The tariff is adjusted annually and is currently capped at a level that constrains growth. Federal investment support programmes also support PV system installations up to 30 kWp but have limited funds available. In addition, five provinces are reported as having their own PV support programmes.

BIPV support: Building integrated systems of a size up to 5 kWp currently receive an upfront investment subsidy on a kWp basis.

Self-consumption support: Self-consumption is legal unless the system owner is in receipt of a feed-in tariff. Self-consumed electricity is exempt from tax up to an annual threshold of 25,000 kWh electricity generation.

⁵⁵ kfW Bank, KfW and Federal Environment Ministry launch programme to promote use of energy storage in solar PV installations, 18th April 2013, https://www.kfw.de/KfW-Group/Newsroom/Aktuelles/Pressemitteilungen/Pressemitteilungen-Details_107136.html

Electricity storage support: Six Federal States are reported to have subsidy programmes supporting electricity storage. The subsidies range from 200-500 €/kWh storage.

Table 13 Austria: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017

2016	2017E	2018E	2019E	2020E
1077	1277	1577	1977	2577

1.3.2.2.2. Netherlands

PV system support: The main price support instrument has been a net metering scheme that was introduced in 2011. This has targeted residential systems of up to 15 kWp and a cap of 5,000 kWh/yr electricity generation. This arrangement is to be retained until 2020. New systems with a capacity ≥ 15 kWp may benefit from the SDE+ auction process. Contracts for subsidy of the difference between the cost price and the market price of electricity are allocated for periods of 8, 12 or 15 years. Three bands of capacity are supported < 1 MWp and ≥ 1 MWp. A maximum number of 950 full load hours is specified and systems must have a large scale grid connection.

Self-consumption support: A net-metering scheme was initiated in 2011 with modifications in 2014. Below 15 kWp excess electricity that is not consumed on site is remunerated with a lower feed-in tariff rate. Self-consumption is permitted above 15 kWp but not incentivised. High electricity prices further incentivise self-consumption.

Table 14 Netherlands: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017

2016	2017E	2018E	2019E	2020E
1911	3099	4091	5391	6591

1.3.2.2.3. Denmark

PV system support: A feed-in tariff introduced in 2012 was suspended in 2016 due to an oversubscription of the scheme and a total cap on installed capacity of 800 MW was imposed until 2020. The results has been a significant decline in the annual installed capacity, particularly at the smaller end of the market.

Utility scale system support: Since 2015 new systems must compete in a competitive auction of new capacity based on electricity price bids for 20 years contracts. This auction process is open to bids from Germany and signals the first use of a provision within the Renewables Directive that allows for cross border auctions.

BIPV support: There are currently no support mechanisms but BIPV is promoted by the building codes for new and refurbished Near Zero Energy Buildings.

Self-consumption support: Self-consumption is legal but the original system of annual net metering compensation was modified in 2012 to allow for compensation for one hour daily only. Where the hourly threshold is exceeded a price below market value is paid. A system size limitation of 6 kW exists in order to access this net metering arrangements with a preferential electricity tariff. Time of Use tariffs are available as an incentive for self-consumption.

Table 15 Denmark: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017

2016	2017E	2018E	2019E	2020E
862	1002	1152	1332	1530

1.3.2.2.4. Spain

PV system support: A feed-in tariff scheme was first introduced in 2004 but it was not until a further revision of this scheme in 2007 that there was a rapid expansion of the market. A moratorium and a 500 MW cap on support was introduced in 2008 because the scheme was oversubscribed, contributing to an existing electricity market budget deficit. The scheme was subsequently stopped in 2012 and replaced by an auction process for investment subsidy based on system size instead of the electricity generated. It now seems that investors frustrated with the subsidy regime but recognising the good investment fundamentals in Spain are moving to prepare utility scale system proposals without subsidy, with a pipeline of up to 29 GW claimed to be under approval, as of April 2018⁵⁶.

Self-consumption support: A new regulatory framework for self-consumption was introduced in 2015. Two types of self-consumers are defined in the legislation, with the framework being different in each case:

- Type 1 self-consumers are defined as those with systems of up to 100 kW and which use all of the electricity generated on site. The consumer and the owner of the system must be the same entity. No compensation is permitted for electricity export to the grid. Type 1 systems of a size up to 10 kW which impede the export of electricity are exempted from grid connection and access studies.
- Type 2 self-consumers are defined as those that export surplus electricity at the wholesale electricity market rate or via an aggregator. The installation of net metering is required. Grid charges are applied to all electricity generated. An additional 'grid backup toll' is applied to surplus electricity exported from systems with a capacity > 10 kW.

Where the system size is less than the contracted electricity supply capacity of the consumer then a system can be connected at the same point of supply and according to a simpler procedure. Self-consumption by several end-consumers or communities of consumers is not currently permitted. Battery storage is permitted but the electricity is still subject to grid tariffs.

BAPV/BIPV support: The building regulations include a requirement for new and major renovations of commercial buildings to install photovoltaic systems with a minimum capacity of 6.25 kW⁵⁷. A calculation must be made to determine the capacity that shall be installed. The calculation is based on the buildings floor area and additional co-efficients related to the building use and the climate zone.

⁵⁶ PV-Tech, Economics not tenders driving Spain's solar resurgence, 23rd April 2018, <https://www.pv-tech.org/news/economics-not-tenders-driving-spains-solar-resurgence>

⁵⁷ El Código Técnico de Edificación (2013) *Sección HE 5: Contribución fotovoltaica mínima de energía eléctrica*, Documento Básico de Ahorro de Energía

Table 16. Spain: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017

2016	2017E	2018E	2019E	2020E
5491	5571	5721	5971	6271

1.3.2.3. Late starters, high market penetration

1.3.2.3.1. Italy

PV system support: Following the end of successive legislation that mandated a feed-in tariff there now only exists an investment tax credit. The tax credit is available for residential systems of up to 20 kW. Financial support under the Conto Energia was subject to specific quality and performance requirements which may be of relevance to this study (see the box below).

Self-consumption support: Self-consumption is supported for all system sizes under the 'Scambio Sul Posto' system. For systems below 500 kW real-time self-consumption based on a net metering arrangement apply. In the case of self-consumption, the avoided grid costs are compensated for, either fully or partially (systems >20kW). Above 500 kW real-time self-consumption is supported. A combination of grid electricity market prices ('energy quota') and a grid service quota apply ('grid quota') are applied. Multiple systems can be connected to a single customer by private distribution cables.

Product and system qualification requirements

Conto Energia feed-in tariff 2005-2016 (Italy)

In order to receive the feed-in tariff for solar photovoltaic installations made available under successive Energy Bills between 2005 and 2016, systems as well as their component modules and inverters, were required to comply with a series of standards and requirements laid down in legislation.

Before owners of systems could be in receipt of the feed-in-tariff, the Performance Ratio (PR) of systems had to be tested in accordance with EN 61724. The PR achieved had to be greater than 0.78 in the case of systems with inverter ratings <20kW and greater than 0.80 in the case of systems with inverter ratings >20 kW. The system performance was to be tested under minimum light conditions of 600 W/m².

In addition, a series of requirements are stipulated for modules which comprise the following product quality standards:

- IEC standards
 - IEC 61215 for crystalline modules
 - IEC 61646 for thin film modules
- A warranty for 10 years against manufacturing defects
- Adherence of the manufacturer to a system or a consortium that will ensure the recycling of the modules at the end of life
- Confirmation of the execution of periodic factory inspections and product verifications in support of compliance with the above technical standards (IEC 61215/61646/62108)

In addition inverters shall be certified to be in compliance with EN 45011.

Electricity storage support: Tax credit measures are foreseen, but have not been brought forward yet due to the low number of installations.

Table 17 Italy: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017

2016	2017E	2018E	2019E	2020E
18983	19418	19940	20575	21275

1.3.2.3.2. United Kingdom

PV system support: The feed-in tariff previously used to support systems of up to 5 MW was closed in 2016, resulting in a substantial fall in the installed capacity. A new scheme started in 2017 and has restricted the number of installations in specified capacity bands. The support is split into two tariffs – a generation tariff (applicable to all electricity generated) and an export tariff (applicable to all electricity exported). The export tariff is only available to systems below 30 kWp. The tariffs are adjusted on a quarterly basis and in accordance with the subscription rate for each capacity band. Larger systems can be supported under Contracts for Difference capacity auction rounds, whereby bids are selected based on the lowest prices tendered, but to date only one round has taken place in 2015.

An important feature of the subsidy regime in the UK is that those in receipt of price support must ensure that quality requirements for PV systems and their components laid down by the Microgeneration Certification Scheme are met. More details are provided in the box below.

Self-consumption support: Self-consumption is supported by a generation tariff which applies to up to 50% of the electricity generated which is not consumed on site. For systems below 30 kWp the differential between the retail price of electricity and the export tariff is an incentive to self-consumption.

Product and system qualification requirements

Microgeneration Certification Scheme (UK)

Photovoltaic modules that will be used in systems in receipt of feed-in tariff support must be selected from a pre-approved list that is maintained under the Microgeneration Certification Scheme (MCS). Systems are also subject to checking in accordance with the guidance and requirements under the MCS scheme.

The module pre-approval scheme provides independent third party assessment of compliance with the standards EN 61215 (crystalline modules) and EN 61646 (thin film modules). Tolerances applying to the module maximum power rating are also laid down as follows:

- tolerances as declared on the data sheet and label shall be either a value either side of zero (e.g. +/- 5%) or a value relative to zero (e.g. 0% to +3%)
- tolerance brackets above zero are not permitted (e.g. +5% to +10%).
- a variation of more than 10% between the upper and lower figures is not permitted.

Building Integrated PV products are the subject of separate MCS requirements. The scheme uses the concept of a BIPV product family in order to facilitate the approval process via test samples. The main standards tested are the same as for modules, but more detailed instructions are provided on how to test material or product samples e.g. the number of cells, the glass or coating type. In addition, the following are specified:

- a measurement of the deflection of the sample,

- application of relevant glazing quality standards from a listing,
- consideration of imposed, static and live loads that the product may be exposed to in the field, and
- application of factory methods to achieve correct lamination in accordance with EN ISO 12543.

All manufacturers shall operate a certified documented factory quality control system, in accordance with specific MCS 'Generic Factory Production Control Requirements'.

System supply, design, installation, commissioning and handover are subject to requirements. These include the professional competence of the contractor carrying out the installation, the extent to which they have followed MCS installation technical guidance and that an estimate of annual energy performance has been made in accordance with the MCS methodology.

Products and installers must be accredited under the Microgeneration Certification Scheme (MCS) to be eligible for payments under the FITs scheme.

Table 18 UK: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017

2016	2017E	2018E	2019E	2020E
11547	12397	13047	13722	14722

1.3.2.4. Late starters, medium market penetration

1.3.2.4.1. Belgium

PV system support: A system of green certificates has been chosen by each of the three regions. Owners of systems are entitled to an allocation of green certificates per MWh generated which in turn have a market value. Since 2015 an electricity price subsidy scheme called Quali watt has been operated in Wallonia. The first 3 kW of up to 10 kW systems is eligible for a subsidy. Quality requirements are laid down in the contract to receive the subsidy (see the box below).

Product and system qualification requirements

Quali watt feed-in tariff (Belgium)

In order to receive the electricity subsidy available under the Quali watt programme the following quality related requirements must be fulfilled:

- a copy of the certificate of competence for the installer of the solar photovoltaic systems issued by the RESCERT body;
- a copy of a Factory Inspection Certificate (FIC) which identifies the site of the photovoltaic modules used were produced;
- evidence that photovoltaic modules used are certified according to:
 - IEC 61215 for crystalline modules
 - IEC 61646 for thin film modules
 - IEC 61730 when panels are integrated or superimposed on a building.

- The certifications must be carried out by an accredited testing laboratory according to ISO 17025 by BELAC or another national accreditation body enjoying mutual recognition with BELAC.

Source: CWaPE (2017)

Self-consumption support: Net metering is supported for residential systems of up to 5 kW (Brussels) and 10 kW (Flanders and Wallonia). The electricity generated by a system must not exceed the consumers annual demand. Capacity based grid utilisation fees apply in Flanders. Time of Use electricity tariffs are also available.

Table 19 Belgium: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017.

2016	2017E	2018E	2019E	2020E
3423	3623	3873	4073	4283

1.3.2.4.2. Czech Republic

PV system support: A feed-in tariff was introduced in 2009 which led to a boom in installations through to 2014/15. The capacity installed mainly consists of utility scale systems (86%). The confidence of investors was damaged by the retroactive reduction in tariffs and the application of a 10% tax from 2014. Feed-in tariff support for PV systems was withdrawn completely in 2014.

A new 'Green Savings' programme running from 2015-2021 provides investment subsidy for new system installations on residential roofs of up to 10 kW. Systems may be installed in conjunction with electricity and hot water storage.

Table 20 Czech Republic: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017.

2016	2017E	2018E	2019E	2020E
2078	2088	2103	2123	2148

1.3.2.4.3. France

PV system support: Following the Paris COP21 in 2015 the government decided to give a new impetus to market development. National targets for installation are set through to 2023 under the Energy Transition for Green Growth Act (2015). Market support is provided by a combination of feed-in tariffs and capacity auctions to drive down market prices. Feed-in tariffs are available for all sizes of systems but those below 100 kWp are favoured by the pricing structure. The tariffs are adjusted in function of growth in the market and reductions in system costs. A calendar for tenders for new capacity with the combined aim of contracting 4.350 MW between 2016 and 2019 was published in 2015. The tender process targets systems of greater than 100 kWp.

Green procurement requirements: Calls for tender for Power Purchase Agreements let under the national scheme are run by the Commission de régulation de l'énergie (CRE). The calls are notable for each containing an award criteria that rewards modules with a lower estimated production stage CO₂ emissions. The most recent calls for tender include a specific award threshold expressed in kg eq CO₂/kWp. To ensure comparability the boundaries and calculation method are laid down in the tender documentation (see Section 1.1.2.6 for more details). Moreover the call for tender also stipulates that owners shall make provision for the recycling of system components upon replacement or dismantling.

BIPV support: Building integrated systems up to 100 kWp currently receive a 10% increase in the feed-in tariff rate. Purchasers of BIPV systems shall be provided with a 10 year warranty for the performance of the integrated system and a guarantee that the installation works comply with current building regulations. In order to provide such a warranty insurers will expect the main components to comply with French product quality standards. For solar photovoltaics the national Technical Assessments (ATecs) are understood to be an important reference point (see the box below).

Product and system qualification requirements

BAPV and BIPV product warranties (France)

National Technical Assessments (ATecs) of innovative construction products are made by CSTB. The ATec GS21 'Photovoltaic systems' evaluation was developed in 2008 to provide assurance to insurers of solar photovoltaic systems.

GS21 has as a pre-requisite the conformity of modules with the performance standards EN 61215 (crystalline modules) and EN 61646 (thin film modules). Non-standard modules with no rear protection such as those specified for façades, glass roofs or shading applications must then be subjected to additional durability, strength and safety tests. Where PV modules are intended as like for like replacements for building systems (e.g. glass products, waterproof membranes, etc.), they must be tested to demonstrate equivalent minimum performances and behaviour as described in National or European standards.

Moreover, GS21 also makes reference to a number of system components. In the '*construction data form*' submitted to CRE for a solar PV system the following information and certifications of conformity (as relevant to this study) shall be provided:

- A calculation note on the mechanical resistance of the component parts of the mounting system (fixing clips, rails, screws, etc.) and on the climatic loads that may be applied to the modules.
- Justifications based on test results of the waterproofing of the main system components.
- Justifications based on test results of the resistance and durability of the component parts and their materials according to their ageing under environmental conditions (e.g. temperature, UV, humidity).
- Junction boxes according to EN 50548, which covers a range of environmental protection aspects, including water ingress and ambient temperature range, as well as resistance to ageing and corrosion.
- Classification of fire cables according to national standard NF C 32-070 which contains the need for reporting on halogen content in conformance with IEC 60754-1.

Source: CSTB (2008) CC FAT (2017)

Self-consumption support: Market electricity prices are currently low relative to the feed-in tariffs available, thereby dis-incentivising self-consumption. This is particularly the case for building integrated systems, which are eligible for a feed-in tariff approximately double the value of rooftop (building added) systems. A new law on self-consumption of renewable energy was introduced in 2016. This law applies to systems of less than 100 kWp and establishes a new network usage tariff together with tax exemptions for self-consumed electricity and a reduction in, and in some case the elimination, of network connection costs. Those choosing to maximise self-consumption can opt to receive investment support but in exchange receive a lower remuneration compared to the feed-in tariff for any electricity sold to the grid.

Table 21. France: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017.

2016	2017E	2018E	2019E	2020E
7134	8134	9734	11394	13220

1.3.2.4.4. Greece

PV system support: A feed-in tariff scheme was introduced in 2009 but the rapid increase in system deployment was curtailed in 2013, with a particular impact on systems larger than 100 kW. This reduction in support was in part called for by electricity network operators in order to maintain normal grid operation.

Table 22. Greece: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017.

2016	2017E	2018E	2019E	2020E
2611	2641	2731	2950	3250

1.3.2.5. Late starters, low market penetration

1.3.2.5.1. Bulgaria

PV system support: A feed-in tariff was introduced in 2011 which led to a boom in installations during 2011/12, prompting concerns about grid stability. Retroactive reductions in tariffs and the application of new grid access charges have since depressed the market. Feed-in tariff support for PV systems was withdrawn completely in 2014. During the daytime renewable energy plant are also requested by the grid operator to limit their output to between 40% and 60% of their capacity. Significant administrative barriers exist to the installation, commissioning and grid connection of a system.

Table 23. Bulgaria: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017.

2016	2017E	2018E	2019E	2020E
1024	1025	1026	1031	1046

1.3.2.5.2. Romania

PV system support: A Renewable Portfolio Standard (RPS) based price support for systems was introduced in 2011 and led to rapid market growth. The majority of systems are of a multi MW utility scale. A reduction in the number of green certificates issued was imposed in the period 2014-2017 in order to sustain market prices.

In 2017 a new source of investment support for residential systems - the Green Economy Financing facility (GEFF) - was introduced by the European Bank for Reconstruction and Development (EBRD)⁵⁸. Modules that form part of a financed system must be selected from a pre-approved 'GEFF technology selector' list. The products in this list must meet a requirement to demonstrate an efficiency of at least $\geq 14\%$. Module and battery combinations also figure in the list.

Self-consumption support: A new law supporting net metering for systems up to 100 kW will come into force in 2018⁵⁹.

Table 24. Romania: historical and projected cumulative installed capacity (MW). E by the year stands for estimated in a medium scenario. Source: Solar Power Europe, 2017.

2016	2017E	2018E	2019E	2020E
1372	1459	1599	1749	1899

1.3.3. Third country legislation and requirements

China is globally the country with the largest photovoltaic capacity installed (25% in 2016⁶⁰). It continues to lead growth followed by Japan and the United States. The cumulative installed capacity of solar power in Japan reached almost 43 GW in 2016, with a 2,5 times growth projected up to reaching 100 GW in 2030. US occupies the third place in capacity installed though in 2016 has overtaken Japan in installed power p.a. This can be seen in Figure 16

In this section an overview of legislation and agreements for third countries outside the EU zone is provided. The countries have been selected based on the significance of their solar photovoltaic markets, in terms of combination of historical, present and projected deployment (Table 25). An analysis of the currently in place policies addressing regulatory framework and grid integration, and their effects in the PV market has been made.

⁵⁸ PV Magazine, *EBRD launches loan scheme for rooftop solar in Romania*, July 2017, www.pv-magazine.com/2017/07/06/ebd-launches-loan-scheme-for-rooftop-solar-in-romania/

⁵⁹ PV Magazine, *Romania to introduce net metering for solar up to 100 kW*, January 2018, <https://www.pv-magazine.com/2018/01/02/romania-to-introduce-net-metering-for-solar-up-to-100-kw/>

⁶⁰ JRC PV Status report 2016

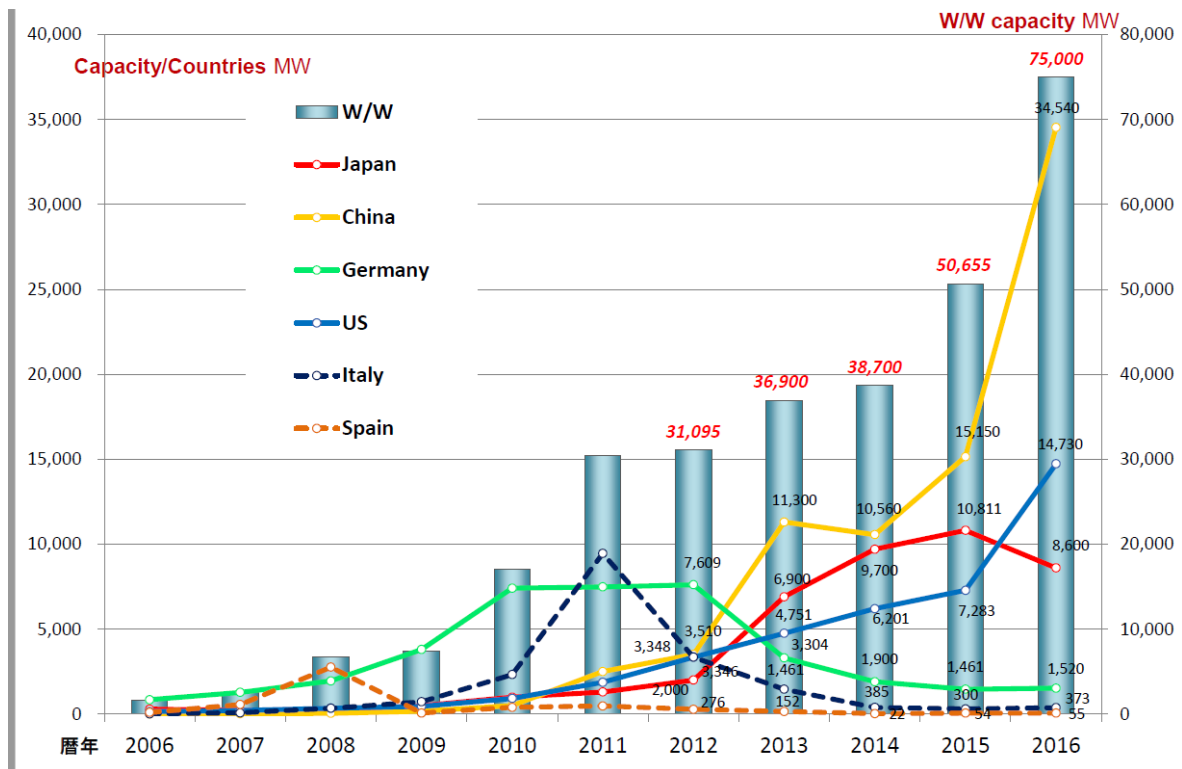


Figure 16. Annual capacity in the major PV players in the world.

Source: JPEA, 2017⁶¹

⁶¹ PV in Japan, current status and the way to go, the Japan Photovoltaic Energy Association (JPEA) 2017. www.nedo.go.jp/content/100866173.pdf

Table 25. Overview of PV policy instruments in the selected countries. Source: Trinomics study 2016 and own elaboration; marks in red to be implemented by governments in the near future

Policy instruments	US	China	Japan	India	
FIT (\$/kWh)	✓ (some states)	✓	✓		Market
Direct capital subsidy	✓ (some states)		✓	✓ (for residential)	
Renewable portfolio standards	✓ (most states)	✓		✓	
PV RPS	✓ (some states)	✓		✓	
Green electricity scheme ¹	✓ ²		✓		
Financing schemes PV	✓		✓	✓	
Tax credits	✓ (30%)				
Net metering	✓ (most states)		✓	✓ (most states)	
Depreciation scheme	✓			✓	
Tax incentives	✓		✓	✓	
Local component requirement				✓	Manufacturing
Financing manufacturing		✓		✓	
Tax incentives manufacturing		✓		✓	
Subsidies/refunds		✓			
RD&I programmes	✓	✓	✓	✓	Research & innovation

Notes: 1: Allows the consumers to purchase RE electricity; 2: In the US, this exists even for PV specific electricity; 3: It is not explicitly called net metering in any official document but PV owners do receive payment for excess electricity exported back to the grid

1.3.3.1. China

PV system support: one of the diversity of on-going mechanisms to promote solar photovoltaics in China are feed in tariff mechanisms (FIT). The FIT program provided the strongest support when the price of solar was still significantly higher than other energy resources – but is still the main incentive for solar power, though now at much lower levels which are adapted annually. They do have different tariffs paid in 3 different regions - from sun-rich to sun-poor and geographically from northwest to the east coast. In December 2016, China reduced the FIT for utility scale plants by 19%, 15%, 13% respectively to 0.65/0.75/0.85 CNY per kWh⁶². At the same time, the

⁶² 1 EUR= 7.77 CNY (April 2018)

FIT for distributed solar has remained the same. The Chinese government has revealed its new feed-in tariffs (FIT) for different types of PV projects, with rates set to fall by as much as 15% from the start of 2018⁶³. Such adjustments are intended to shift the market segmentation towards distributed generation, which is expected to grow strongly to about 5 GW in 2017. Based on the Photovoltaic Industry Roadmap (PVIR), the Chinese market is supposed to shrink between 2018 and 2020 to a level of 20 to 30 GW due to FIT cuts, but resume at an even higher installation rate in the first part of the following decade.

Self-consumption support: self-consumption is allowed in China. Self-consumed electricity gets a bonus (0.42 CNY/kWh) on top of the saved retail price. PV system owners can choose whether they want to use the FiT policy or opt for self-consumption with the bonus. Excess PV electricity injected into the grid is remunerated at wholesale price of electricity (based on coal-fired power plants' electricity prices) plus a bonus on top of it (0.42 CNY/kWh).

Ground mounted systems: "PV + agriculture" is becoming popular. Crops, flowers and herbs that prefer shady ambience are now being planted underneath solar power plants to use precious farming land as efficiently as possible. (Solar Power Europe, Global Market Outlook, 2017).

Product and system qualification requirements

Top Runner Program (China)

The so-called "top runner program" was developed by the Ministry of Industry and Information Technology (MIIT), the national Energy Administration, and the Certification and Accreditation Administration in 2015. It is an auction based tender program for projects using high efficiency modules and advanced technologies. The idea is to guide project developers to adopt the latest technology, increase system efficiency and reduce LCOE. Results have been encouraging: by the end of 2016, the average cell efficiency of mono Si produced in Mainland China increased to 20.5%, the LCOE in sun-rich areas was below 0.65 CNY/kWh, and the record auction price reached was as low as 0.45 CNY/kWh (due in 2017).

There are two programs within the main one, the application and the technology:

- The application top runner program requires that modules fulfill a particular conversion efficiency requirement (e.g. poly module $\geq 17\%$ /mono module $\geq 17.8\%$)
- The efficiency requirements of the technology program are stricter. Any new tech such as PERC/MCT/HC which can improve module conversion efficiency would get higher score based on the aforementioned 17%/18%

Other requirements of top runner program are for PV project developers. Investors are selected depending on enterprise investment ability, performance level, technology available, offered electricity price etc. The threshold for business bidding requires a price of 10% lower than the local electricity price

1.3.3.2. Japan

PV system support: Feed-in tariff (FiT) introduced in Japan from July 2012 to promote the renewable energy, particularly after the nuclear accident of Fukushima Nuclear Power Plant in March 2011. PV systems rapidly increased and have a monopoly on renewable energy with 99.9% of the accredited system numbers. PV domestic shipments expand 2.7 times from the previous year. The 2013 FiT price was reduced 10 % of solar energy, but others were deferred. Thus, it is clear that FiT is expanding PV market in Japan. Over 80 GW have been approved since the FiT started in 2012, from where only 30 GW have been commissioned but around 50 GW were not

⁶³ <https://www.pv-magazine.com/2017/12/22/china-sets-lower-solar-fit-rates-for-2018/>

operated up to the end of 2016⁶⁴. FIT scheme is most attractive in the commercial segment, where 34.4 GW FIT are in the pipeline. Under FIT, many new comers start to install 10~50kW PV systems in the residential sector, where FIT accounts for 4.1 GW. Grid parity has been achieved in the residential sector and probably in the commercial where in 2016 was imminent. For the utility scale, grid parity will not be reached in foreseeable future. FIT scheme for same as for commercial sector (43.2 GW in the pipeline, Trinomics, 2016), is therefore less attractive. FIT have started to decline, which together with competition and Yen depreciation is expected to cause a cost reduction (Table 26).

Table 26. FIT cuts for Japanese installations for 2017 and 2018 and the projected FIT for 2019, in Japanese yen⁶⁵

Energy Source	Procurement Category		Price per 1kWh		
			2017	2018	2019
Solar power	10kW or less	Output control equipment not required	28 yen	26 yen	24 yen
		Output control equipment required	30 yen	28 yen	26 yen
	10kW or less ("double generation")	Output control equipment not required	25 yen		24 yen
		Output control equipment required	27 yen		26 yen
	10kW or more, but less than 2,000kW		21 yen + tax	-	-

For owner, constructor, and investor of such systems, the Japan Photovoltaic Energy Association has published the check list of design/construction of foundation and cradle (mounting base) for more than 10kW.

Since the FIT law revision in June 2016, maintenance and periodic inspections are obliged to the PV system owners, as they are considered important key roles for long life operation. Guidelines have been published but only in Japanese⁶⁶.

PV auctions framework: From October 2017, a FIT auction process has been launched for 10 kW to 2 MW with a ceiling price (21 JPY/kWh) which is intended to minimise the amount of subsidy given and make PV more competitive⁶⁷.

PV Storage: subsidy is available for home storage from national and local governments for year 2018: Zero Energy Building program promotion subsidy: 10 billion JPY. The subsidy is: 50,000Yen/W (442 USD/kWh) and the Typical price : 1500 – 1750 USD/KWh. This opens opportunities for residential storage in 2019. Moreover, FIT projects with storages are ongoing to address grid connection issues.

1.3.3.3. United States

The state of California is notable for already accounting for 23.738 GW of PV installed capacity⁶⁸. The Go Solar California! Campaign is a joint effort of the California Energy Commission and the California Public Utilities Commission⁶⁹. The solar incentives and rebates for self-consumption were launched in California in 2006 with ambitious goals - 3,000 megawatts of solar energy systems on homes and businesses by the end of 2016 – funded with \$3,351 million between 2007-2016⁷⁰. The ultimate goal is to establish a self-sufficient solar industry in 10 years so that solar energy systems are a viable mainstream option for homes and commercial buildings, and in 13 years to put solar energy systems on 50 percent of new homes.

⁶⁴ PV in Japan 2017. RTS Corporation. https://unef.es/wp-content/uploads/dlm_uploads/2017/05/japan-pv-market_apr-2017.pdf

⁶⁵ 1 EUR= 132 JPY (April 2018)

⁶⁶ PV in Japan, Current status and The way to go, 2017. Japan Photovoltaic Energy Association

⁶⁷ PV in Japan, 2017. RTS Corporation

⁶⁸ Tracking Progress. California's Installed Electric Power Capacity and Generation California Energy Commission August 2017, http://www.energy.ca.gov/renewables/tracking_progress/documents/installed_capacity.pdf

⁶⁹ Go solar campaign: <http://www.gosolarcalifornia.org/about/index.php>

⁷⁰ 1 EUR= 1.24 USD (April 2018)

Table 27. US: historical and projected cumulative installed capacity (MW) GTM research 2017

	2016	2017	2018	2019	2020	2022
Residential	2500	2642	3000	3270	3650	4750
Non –residential	800	900	950	1000	1050	2775
Utility-scale	10975	8300	6600	8000	9400	10000

PV system support: the rebates are tax credits in effect through 2021. The 30% of the cost is subject to the return (including installation costs), with no upper limit (Credit decreases to 26% for tax year 2020; drops to 22% for tax year 2021) It must be installed in a private home used as a residence - no rentals, but second homes qualify).

Self-consumption support: it has been mentioned above the program from the state of California. The incentive structures shall promote high-quality designs and installations.

Product and system qualification requirements

Eligibility requirements for equipment from the California Energy Commission

In order for an installation to be eligible to receive the FIT, PV modules and inverters must be listed on the California Energy Commission’s Eligible Equipment Lists. Moreover, all solar energy equipment for electricity generation (e.g. PV modules, inverters, tracking mechanisms, etc.) shall have a minimum 10-year manufacturer performance warranty to protect against degradation of electrical generation output of more than 15% from their originally rated electrical output.

Modules

For incentive eligibility in the California program all flat-plate PV modules shall have certification conducted by an NRTL73 to UL 1703. Additional testing shall be conducted to specific subsections of IEC Standard 61215, *Crystalline Silicon Terrestrial Photovoltaic (PV) Modules Design Qualification and Type Approval, Edition 2.0, 2005-04* or IEC Standard 61646, *Thin-Film Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval, Edition 2.0, 2008-05*.

Inverters

All inverters shall have certification conducted by an NRTL76 to UL 1741. Each model of inverter shall also be tested by a NRTL for performance ratings according to sections of the test protocol titled Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems⁷¹. The CEC provides a list of currently certified eligible equipment on the Go Solar California site at <http://www.gosolarcalifornia.ca.gov/equipment/>

Systems

There are three approaches: flexible installation incentive (FII) approach, the performance-based incentive (PBI) approach, and the expected performance-based incentive (EPBI) approach.

- In the flexible approach, systems shall be installed with an azimuth and tilt angle within a designated range as determined by the program administrator. The performance based is the preferred way to promote high-performing systems since the solar energy systems receive incentives based on the actual production (kWh) over the period during which the incentives are being paid.
- The PBI incentive payment is calculated by multiplying the incentive rate (\$/kWh) by the measured kWh

⁷¹ Sandia National Laboratories, Endecon Engineering, BEW Engineering, and Institute for Sustainable Technology, October 14, 2004,

output. The expected performance-based incentive (EPBI) approach pays an upfront incentive based on calculated expected performance, taking into account all major factors that affect performance of the particular installation in a given location.

- The EPBI calculation shall be based on hourly modelling of the interactive performance of solar energy systems using the third-party tested performance characteristics of the specific modules and the inverter over the range of conditions that affect component performance.

At country level there are two programs currently to refund PV systems providing electricity for the residences:

- New Solar Homes Partnership (NSHP): financial incentives and other support to home builders, encouraging the construction of new, energy efficient solar homes that save homeowners money on their electric bills and protect the environment.
- Multifamily Affordable Solar Housing (MASH) is another program administrated by the Pacific Gas and Electric Company, funded with \$162 million to encourage building owners to install solar panels on low-income, multifamily dwellings like apartment buildings, and tenants receive incentives.

There 3 major pricing or "tariff" options for solar customers are:

- Net Energy Metering, which will include net surplus compensation by 2011 where customers can receive compensation at the end of the year if they produce more electricity with their solar system than they consume from the grid.
- Virtual Net Metering, which allows the electricity produced by a single solar installation to be credited toward multiple tenant accounts in a multifamily building without requiring the solar system to be physically connected to each tenant's meter. For now, this program is only available as a pilot program to multifamily affordable housing, but the CPUC is currently considering expanding the program in the future.
- Renewable Energy Self-Generation - Bill Credit Transfer (RES-BCT), which enables solar customers transfer excess credits to another account. This works similar to net metering, but any production credits that normally would be received by the consumer can be transferred to another account.

The formula varies from program to program but applicants must pay a minimum percentage of eligible project costs after the Federal Investment Tax Credit (ITC) is subtracted from the project costs (within certain limits).

Grid integration support: The high numbers of installations in some areas has driven the introduction of new regulations. Interconnection data on California Solar Statistics fully captures solar PV net energy metering (NEM) participation in IOU territories (PG&E, SCE and SDG&E)

Electricity storage support: The California Energy Commission (CEC) proposed its own weighting factors for calculating the efficiency. It considers, for example, less likely that the real working conditions of the inverter make it work at its maximum efficiency in comparison to the Euro Efficiency definition (see section 1.2)

1.3.3.4. India

India was one of major countries that accounted for the highest cumulative installations at the end of 2017 almost reaching 17 GW⁷² (13 GW having been installed in the last three and a half years, with a production of

⁷² <https://www.pv-magazine.com/2018/01/04/indias-impressive-solar-achievements-in-2017/>

around 13 MWh in 2017). India is the third country in the world that has added more PV capacity (India solar handbook 2017).

PV system support: The National Solar Mission (NSM) contains an elaborate set of policies and incentives capturing accelerated depreciation, capital subsidies, renewable portfolio obligations and more. The government has set an ambitious target of achieving 40% cumulative electric power through renewable energy sources by 2030, and an installation of 175 GW of renewable energy source by 2022, 100 of which are allocated to solar technology.

The government has issued guidelines for the procurement of solar and wind power through a tariff-based competitive bidding process, and has expanded Renewable Purchase Obligation (RPO) up to the year 2018-19 while notifying standards for deployment of solar photovoltaic systems/devices.

PV modules and equipment: there is no formal information relating to any specific solar equipment or component being of low quality and sold in the Indian market. To impose strict quality norms for solar equipment and components, and to restrict low quality solar PV equipment in the Indian market, the central government, after consulting the Bureau of Indian Standards, has issued the “Solar Photovoltaics, Systems, Devices and Components Goods (Requirements for Compulsory Registration) Order, 2017” dated September 5, 2017, for the quality control of solar photovoltaic systems, devices and components. In a second phase India recently allocated 7.5GW of local content tenders to Central Public Sector Undertakings (CPSUs), which provides for installation of entire capacity of solar projects based on domestically manufactured solar PV cells and modules. However, analysts in the solar sector have noted this measure is not competitive due to the price of the modules. Their quality may be as well an issue in a country with many obsolete manufacturing lines⁷³.

NSM includes specific targets for manufacturing: a capacity of PV module production of 4-5 GW by 2020 and the necessary manufacturing capacity of poly silicon material to produce 2 GW of solar cells. Policy instruments are special incentive packages to set up manufacturing plants and access to low interest loans amongst others.

Grid integration support: the majority of the capacity in India is in utility scale, which may create some issues. Current PPAs being signed for new schemes are around 0.045 \$/kWh (0.066 €/kWh) and even reaching a lowest winning bid of 0.037 \$/kWh (0.058 €/kWh) (MNRE 9, 2016). Every new auction is hitting a new low, which is worrying developers and manufacturers according to Mercom Capital⁷⁴. The result of aggressive bidding is that projects below the 0.045 \$/kWh mark are considered extremely risky and difficult to finance. Local lenders are avoiding funding these as some of the companies with similar awarded projects are in financial trouble. With these low PPAs being reached, the utility segment is about to reach grid parity in the near future.

Self-consumption support: India has foreseen up to 2 GW of off-grid installations by 2017, including 20 million solar lights in its National Solar Mission. (IEA Trends in PV applications 2016) PV is perceived as a way to provide electricity without first building complex and costly grids. The challenge of providing electricity for lighting and communication, including access to the Internet, will see the progress of PV as one of the most reliable and promising sources of electricity in developing countries in the coming years.

1.3.3.5. Australia

Each state in the country has different laws regarding feed-in tariffs. The Clean Energy Council (CEC) has established an exhaustive accreditation program that covers installations, equipment and installers. The solar accreditation program for solar PV installations is meant for installations to be eligible for government rebates such as Small-scale Technology Certificates and feed-in tariffs. The CEC has also launched a Solar Retailer Code of Conduct in 2013 on behalf of the solar industry to improve customer service and industry standards, and an

⁷³ <https://www.pv-tech.org/news/problems-with-indias-newest-domestic-pv-manufacturing-support-idea>

⁷⁴ Trinomics, 2016

accredited installer process with clear steps. Accredited installation guidelines are published and summarized below.

PV modules and equipment: modules and inverters have to be in Clean Energy Council's approved lists to be eligible. See the table below

PV systems installations: To ensure the high quality of solar installations by accredited installers, the Clean Energy Council produces both design guidelines and install and supervise guidelines for grid-connect systems. A system of demerit points is also in place with the aim of addressing instances of continued non-compliant work that can result in direct suspension (e.g. a possible safety hazard which poses an imminent risk of damage to property or persons could be that the DC isolator enclosure or cable junction boxes are not suitably installed to prevent water ingress. It would be categorized as serious non-compliance and unsafe and would incur in 10 demerit points).

Product and system qualification requirements

Approval for equipment listing to be eligible for FiTs and rebates

Modules

All crystalline and thin film PV module listing applications must demonstrate compliance with new versions of IEC 61215 and application class 2 of IEC 61730, plus the following:

- PV modules are Fire Class C per UL790 under IEC 61730 certification.
- PV systems above 50 volts (open circuit) or 240 watts rated power must meet Application Class A of IEC 61730.
- PV modules installed on buildings must also be certified as meeting Fire Safety Class C or better per UL 790.
- Roof integrated modules may have additional requirements under the Building Code of Australia (BCA).
- For PV systems with total power of less than 240W and open circuit voltage less than 50 volts, modules do not need to meet IEC 61730 Class A, however they should meet 61730 Class C. Class B modules are not to be used in Australia.
- Certificates are a type that requires periodic factory inspections, and identifies all factories which are covered by the certification

Inverters

Apart from fulfilling the relevant Australian standard (e.g. for a Multiple Mode Inverter - PV and Battery, AS/NZS 4777.2:2015, or for a grid connected AS/NZS 4777.2:2015) inverters shall fulfil the IEC 62109-1 and IEC 62109-2 and the isolation of the PV array, must be of at least IP 55.

For microinverters, in addition to the requirements for all inverters, the following has to be fulfilled:

- Each input of the micro inverter is limited to 350W PV power at STC and at ELV.
- DC cable length is less than 1.5m (including any adaptor cables)
- The method of cable support for the interconnecting AC cable and DC panel cables shall have a life as long as the system.
- Cable support shall ensure that there is no stress placed on connectors.
- Plugs, sockets and connectors shall only be mated with those of the same type from the same manufacturer
- A PV array disconnection device is not required for PV modules connected to micro inverters (AS/NZS5033:2014 clause 4.4.1.2)

PV array installation

Among others related to safety conditions, the following particular requirements for the PV array were found worth to mention here:

- There is an specific Australian standard (AS/NZS 5033) for the installation of photovoltaic (PV) arrays.
- Unless specified by the CEC system designer, the installer shall not install two parallel strings, connected to the same MPPT input at the inverter, installed on different orientations (e.g. east and west).
- the array structure meets AS1170.2 certification
- PV wiring losses are less than 3% at the maximum current output of the array

Specific earthing, wiring instructions, insulation levels of the wiring cables between array and inverters are as well listed with a great level of detail

1.4. Conclusions and recommendations

1.4.1. General conclusions and recommendations

1.4.1.1. Product definition according to statistical and legislative references

Consultation of the EU's industrial production statistics as compiled under Eurostat PRODCOM codes and activities has revealed that whilst divisions and activities can be identified that are likely to contain data on module, inverter, system equipment and system installation data, there are currently no specific divisions or classes that correspond exactly to photovoltaic modules or inverters, or to the installation of systems.

The same is true for CE marking, where there exist relevant marking requirements for construction products, the electromagnetic compatibility of electrical equipment, safety requirements for low voltage electrical equipment and the restrictions on hazardous substances in electrical equipment, but no specific conformity requirements that contain a product definition.

1.4.1.2. Establishing a basis for product system comparisons

1.4.1.2.1. Defining the life cycle stages

In order to adopt a life cycle approach to the identification of improvements in the environmental performance of a product it is important to analyse the environmental impacts associated with the different life cycle stages. Emulating the approach adopted in the criteria developed for the French national PV capacity auction process and by NSF International for the Green Electronics Council (GEC), it is proposed to refer to a schematic of the life cycle stages.

Pending conclusion of the European Commission's Product Environmental Footprint (PEF) the most suitable standardised reference point is considered to be the life cycle modules and stages laid down in the EN standards 15804 and 15978. These provide a standardised approach to the life cycle assessment of construction works. Reference to these modules and stages would have the advantage of allowing for the narrowing or broadening of the life cycle scope depending on the opportunities or constraints of each policy instrument. So, for example, the boundary for Ecodesign implementing measures would normally be limited to addressing the use stage performance, whereas Ecolabel criteria could also address aspects of the production stage. The reference to project stages can therefore be adjusted to the policy context under study.

1.4.1.2.2. Defining generic project stages

Moreover, in order to support a practical understanding of when performance criteria can be applied to products or systems – for example, in Green Public Procurement (GPP) – it is proposed to also refer to a schematic of common project stages. The following generic stages can be identified as relating to project activities and can be mapped onto the IEC's Renewable Energy (RE) system project timeline (see also Figure 17):

- Design stage: system design/specification and performance assessment based on calculations and simulations
- Implementation stage: construction and installation of a system based on drawings and specifications
- Commissioning stage: functional commissioning and testing based on defined routines
- Operational stage: monitoring and maintenance of performance according to agreed parameters
- Decommissioning stage: based on the potential for recovery of products or materials from a product or system

The reference to project stages can therefore be adjusted to the policy context under study.

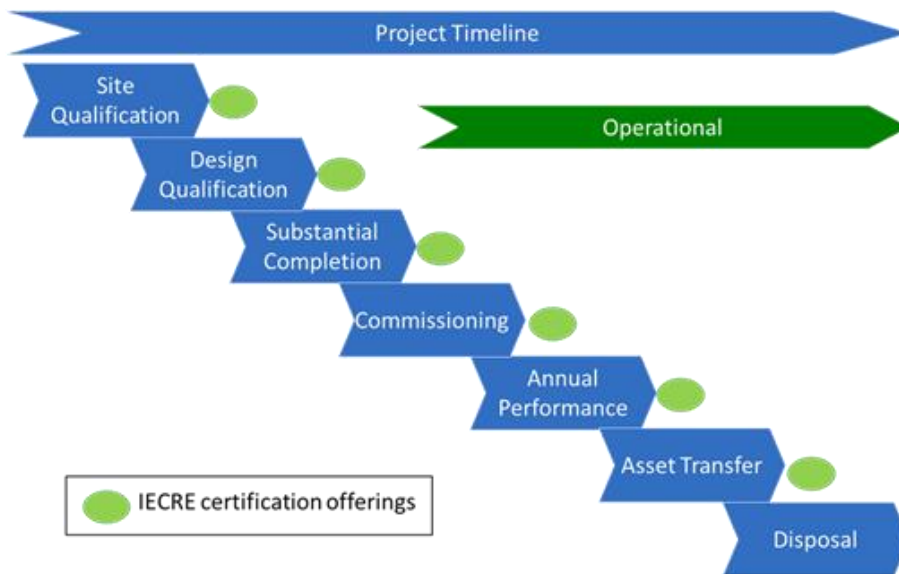


Figure 17. IEC RE system project timeline Gantt

Source: IEC (2017)

1.4.1.2.3. Defining functional units of performance

In order to carry out meaningful modelling of the life cycle of a product it is important to define the function being provided, and linked to that a common reference unit of comparison between different products designs or systems – a functional unit of performance.

In accordance with the definition contained in the ISO standards series 'Building and constructed assets – service-life planning' it is proposed to use the following definition of the (first) intended service lifetime of a product or system:

'the period of time after installation during which a component or an assembled system meets or exceeds the technical performance and functional requirements laid down by the end user'.

Moreover, based on the recommendations of the IEA PVPS programme it is proposed to define the functional units for modules, inverters and systems according to the following fundamental parameters and conditions that influence performance during a product or systems service lifetime (see the box below). The proposal would allow for a combination of the location, design decisions and lifetime estimations at component and system level to be taken into account.

Proposed approach to defining solar PV functional units of performance

The following parameters and conditions shall be taken into account when modelling the performance of modules, inverters and systems:

- Irradiation: the irradiation collected by modules depends on the climate, their orientation and how they are installed.
- Performance ratio: the system Performance Ratio (PR) (also called *derate factor*) takes into account the modules' (DC) rated performance, the inverters' rated performance and other operational variables in order to estimate the actual (AC) electricity generation.
- Service life expectancy: based on a manufacturers performance guarantee or the period of time before the combined probability of failures and the level of degradation in performance become unacceptable.

1.4.1.3. Lessons and potential implications of existing legislation

1.4.1.3.1. European Union policy level

The review of relevant European Union level legislation and agreements in section 1.3 has revealed a number of important potential short to medium term influences on the EU solar photovoltaic market. They are briefly summarised in Table 28. These influences can later be taken into account in the selection of base cases, introduction of sensitivities into the modelling and into considerations as to how policy instruments could act within the market.

Table 28 Potential influence of EU policy instruments on the EU solar PV market

Thematic policy area	Possible influence on the EU solar PV market
Energy Union and reshaping of the EU electricity market	<ul style="list-style-type: none"> The proposed new common rules for the electricity market will impose more favourable market conditions for self-consumption and local energy communities Provisions for non-discriminatory handling of grid connections, including associated charges and procedures, will support 'active consumers'
Driving the market for renewable electricity generation	<ul style="list-style-type: none"> The proposed recast Directive will support self-consumption and storage by simplifying permitting and removing restrictions. A new calculation methodology for the minimum contribution of renewable sources in new buildings and major renovations will further support rooftop solar PV
Driving the market for building renovation and near zero energy buildings	<ul style="list-style-type: none"> Targets for all new buildings and major renovations to achieve Nearly Zero Energy performance by 2020 will further drive BAPV and BIPV, which are already favoured options. A renewed focus on the large scale renovation and decarbonisation of the existing building stock could further drive BAPV deployment. Buildings will increasing need to demonstrate their 'smart readiness' and this will include energy systems The EN ISO 52000 series calculation method for BAPV/BIPV performance will be widely used
Improving information on construction product performance	<ul style="list-style-type: none"> The EN 15804 and EN 15978 LCA standards, together with the Commission's Level(s) framework will drive an increased focus on the life cycle performance of building components. Circular thinking will increasingly need to form part of building design and operation.
Improving material efficiency and creating a Circular Economy	<ul style="list-style-type: none"> The Critical Raw Materials indium, gallium and silicon metal will be the focus of actions to foster material efficient solutions Member State reporting on rising solar PV waste streams will increase the focus on end of life routes
Product policy and consumer information	<ul style="list-style-type: none"> Products will need to be smart ready, with the potential to interact with home management systems and appliances.

1.4.1.3.2. Market leaders at Member State level

A review of the current legislation for thirteen Member States, as well as four examples of component and system requirements, has identified a number of important actions that are influencing the deployment, quality and performance of solar photovoltaic systems. They are briefly summarised in Table 29. These influences can later be taken into account in the description of representative base cases and further identification of accepted performance metrics and standards.

Table 29 Effect of Member State policies and requirements on solar PV deployment

Policy or requirement	Influence on solar PV deployment
PV system support	<ul style="list-style-type: none"> • Feed-in tariffs are progressively being scaled back and are increasingly being weighted to support smaller, largely residential systems of <5-30kW . • Auctions of electricity price contracts are increasingly being used for larger systems (>100-200kW), but tend to support larger utility scale systems with greater potential to reduce bid LCOE
BIPV support	<ul style="list-style-type: none"> • Only two large Member States give BIPV preferential subsidy, either in the form of investment subsidy or an increased feed-in tariff rate. • BIPV is in some Member States required according to building permits and codes.
Self-consumption support	<ul style="list-style-type: none"> • Net-metering is in permitted in most Member States whereas net-billing is a newer concept • A variety of adjustments have been made to legislation and support schemes in order to incentivise self-consumption at <5-100 kW. These include: <ul style="list-style-type: none"> – Reducing feed-in tariffs to below consumer electricity prices – Waving grid connection study and connection costs
Electricity storage support	<ul style="list-style-type: none"> • At least two Member States have established investment subsidies that support the installation of battery storages in small systems (<30 kW).
Module qualification	<ul style="list-style-type: none"> • In some Member States modules and inverters must pre-qualify whilst in others qualification must be shown the point of bidding/contract award • The IEC standards 61215 and 61646 are specified in all of the requirements analysed. • Other performance aspects include: <ul style="list-style-type: none"> – Performance tolerances, including for specific types of BIPV products – minimum warranty periods, – factory quality inspections and – coverage by a compliant WEEE take back scheme • Residential investment support available in former ascension states is linked to a requirement to use products from a pre-approved list
System qualification	<ul style="list-style-type: none"> • In at least one Member State a system Performance Ratio target with field testing requirement has driven a focus on installed performance. • In one Member State an award criteria for the embodied GWP the modules to be used in a system is included in auction requirements. • In one Member State performance criteria have been set in support of product and system warranties. These include coverage of: <ul style="list-style-type: none"> – The durability of the mounting system – Waterproofing of the main system components <i>e.g. junction boxes</i> – The halogen content of cables

1.4.1.3.3. Market leaders at International level

A review of the third country countries China, Japan, United States, India and Australia has identified a number of policy actions and programmes that are influencing the deployment, quality and performance of solar photovoltaic systems. They are briefly summarised in Table 29.

Possibly, the policy instrument of greatest potential significance to this study is China's Top Runner programme. The programme forms part of the capacity auction process and establishes criteria for module performance and

the PV technology to be deployed. This programme has been successfully used to drive manufacturers to progressively increase the performance of modules and to accelerate new technologies such as PERC, black silicon and bifacial cells into full-scale production phase.

Table 30 Selected third country policies and requirements for solar PV deployment

Policy or requirement	Influence on solar PV deployment
Demand side targets	<ul style="list-style-type: none"> China and US have clear and ambitious targets defined for near future electricity generation from RES and explicitly for PV. The Chinese government's official 2020 installation target is 105 GW (despite they have reached almost 120 GW⁷⁵ at the end of 2017) India on the other hand has a PV capacity target for 2022.
PV system support	<ul style="list-style-type: none"> China has repeatedly reduced the FIT for utility scale plants by 15% as an average since 2016. The Chinese market is expected to shrink between 2018 and 2020 to a level of 20 to 30 GW due to FIT cuts according to IRENA Roadmap . Remaining FiTs are focused on small and residential. Self-consumption is being incentivised, and this starts to include storage. PV system owners in China can choose whether they want to use the FiTs policy or opt for self-consumption with the bonus. The threshold to get the FiTs has as well a tendency to decrease in the majority of the third countries analysed. More price based auctions seem to exist in those countries. This is resulting in large systems to have a predominant role. Japan has a tender for 500MW with the right to apply for FiTs. China has launched the Top runner program, an auction based tender program for projects using high efficiency modules and advanced technologies.
System and component qualification	<ul style="list-style-type: none"> The Top runner program in China is a leading example, which has introduced module efficiency criteria into an auction process in order to drive improvements in performance. The most complete set of criteria from the analysed ones are the California (Go Solar!) and the Australian program. Both programs state the tests and standards that must be met by modules, inverters and other components, in order to be part of a list of eligible equipment, but also requirements for their installation.

1.4.2. Photovoltaic modules: recommendations and proposals

1.4.2.1. Product definition and scope

Product definitions developed by the IEC and IEA, as well for UL, NSF International and the PEF pilot, were consulted in order to develop a definition for the Preparatory Study. Stakeholders were consulted on an example definition and possible scope delimitations from December 2017 to January 2018. The headline results were as follows, and are reflected in the first formal proposal to stakeholders:

- The majority of respondents supported an output power cut off of less than 50 Watts.
- The encapsulant and junction box should be included in the product definition and scope.
- The number of cells, the module area or the form factor should not form part of the product definition and scope.

⁷⁵ <https://www.pv-magazine.com/2017/11/22/bnef-china-to-install-54-gw-in-2017/>

In addition, the majority of respondents considered that Building Integrated PV should be included within the scope, but will need to be handled separately from standard modules so as not to hinder innovation and growth of what is currently a relatively small niche in the market.

Examples of feed-in tariff qualification criteria for BIPV modules, such as those of the UK Micro Generation Scheme, suggest that one option for managing this could be to focus on the performance of cells, rather than the diversity of different construction product form factors into which they may be integrated.

Module level power electronics are proposed to be excluded from the scope of PV modules. Instead it is proposed that the potential benefits are analysed within the PV systems scope.

The first proposal for the solar photovoltaic module product definition and scope are presented below.

Proposed solar photovoltaic module definition and scope

A photovoltaic module is a framed or unframed assembly of solar photovoltaic cells designed to generate DC power. A photovoltaic module consists of:

- strings of photovoltaic cells (crystalline technology) and/or semiconductor layers (thin film technology),
- a substrate, encapsulation and cover materials,
- the interconnections of the cells,
- the junction box and associated cabling, and
- the framing material (where applicable).

The scope shall correspond to photovoltaic modules produced for use in photovoltaic systems for electricity generation. The scope shall include Building Integrated Photovoltaic (BIPV) modules that incorporate solar photovoltaic cells and form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011.

Specifically excluded from this scope are:

- Module that integrate module level power electronics, such as micro-inverters and power optimisers
- Modules with a DC output power of less than 50 Watts under Standard Test Conditions (STC),
- Modules intended for mobile applications or integration into consumer electronic products.

1.4.2.2. Measurement and test standards

Photovoltaic modules have been found to be well covered by existing standards for production, design qualification and type approval, power and energy yield. An extensive collection of operational data and correlation with laboratory testing results give confidence in building an appropriate definition of failure modes and degradation effects, although an intermediate method may be required for quantifying them.

A definition of technical lifetime and operational service life 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 is considered to be achievable. The issues of recyclability, reparability and durability will be covered by the general framework of standards being developed under the Mandate M/543. but PV-specific standards deriving from the horizontal ones will be necessary.

1.4.2.3. Product functional unit

In addition, a proposal has been formulated for definition of the primary product performance parameter (functional unit) for solar photovoltaic modules. This definition would limit the scope to DC generating modules without module level power electronics, so as to ensure comparability at product level.

The definition has been aligned with the proposed IEC 61853-3 method for calculating a Module Performance Ratio and then estimating the energy yield according to irradiance and temperature conditions. This method is considered the most suitable for making estimates of the primary function provided by a module, which is to generate DC power for a determined period of time.

To ensure that performance along the life cycle of a module is taken into account, the proposal supposes that the yield is modelled for a reference service life. To be representative the impact on energy yield of degradation and fault mechanisms would therefore also need to be taken into account.

Proposed solar photovoltaic module functional unit

The functional unit shall be 1 kWh of DC power output under predefined climatic and installation conditions for 1 year and assuming an intended service life of 25 years.

1.4.3. Inverters for photovoltaic applications: recommendations and proposals

1.4.3.1. Product definition and scope

Product definitions developed by the IEC and the US EPA addressing both inverters and more broadly power conditioning equipment were consulted in order to develop a definition for the Preparatory Study. Stakeholders were consulted on an example definition and possible scope delimitations from December 2017 to January 2018. The headline results were as follows, and are partly reflected in the first formal proposal to stakeholders:

- The majority of respondents considered that:
 - All types of inverters should be included in the scope
 - Power output and intended configuration should be addressed in the scope and definition
- Power Conversion Equipment categories in the standard IEC 62093 should form a component of the scope and definition
- It shall be made clear that DC optimisers shall not qualify as inverters

The comments have largely been addressed by redrafting the proposal to incorporate the thresholds and categories of IEC 62093. However, upon further consideration of the possible grid and module configurations that may need to be modelled, the following new proposals are presented for discussion:

- That the scope shall encompass those that are able to function in a utility interactive mode. The rationale is that the majority of inverters will be connected to distribution grids and this configuration is specifically covered in testing standards.
- That 'central solution' inverters combining a transformer connected to a distribution network are proposed as being excluded. The rationale is to ensure comparability and to avoid an overlap with existing Ecodesign Regulations.
- That inverters falling within IEC 62093 Category 1⁷⁶ should be excluded from this scope, but shall be within the scope of photovoltaic systems. The rationale is the potential difficulty in making a meaningful

⁷⁶ Category 1: Module-level power electronics (MLPE) – specified to operate at a PV module base level interfacing up to four modules.

comparison between standalone and module-integrated functions. Moreover, this approach would reflect that adopted by Germany's Blue Angel ecolabel inverter criteria.

The first proposal for the product definition and scope of inverters for photovoltaic applications is presented below.

Proposed definition and scope of inverters for photovoltaic applications

An inverter is as an electric energy converter that changes the direct electric current (DC) output from a solar photovoltaic array to single-phase or polyphase alternating current (AC). The scope shall correspond to:

- Utility interactive inverters that are designed to operate grid connected in stand-alone and parallel modes.
- Inverters with a maximum circuit voltage of 1500 V DC and connections to systems not exceeding 1000 V AC.
- String inverters falling within category 2 as defined in IEC 62093 ('String-level power electronics') and designed to interface multiple series or parallel connected modules and specified for wall, roof, ceiling or rack mounting.
- Central inverters falling within Category 3 as defined in IEC 62093 ('Large-scale power electronics') and designed to interface multiple series or parallel connected modules, but due to its complexity, size and weight are housed in a free-standing electrical enclosure.

Specifically excluded from this scope are:

- Module integrated inverters falling within category 1 as defined in IEC 62093 ('Module-level power electronics') and specified to operate at a PV module base level interfacing up to four modules.
- Central inverters that are packaged with transformers (sometimes referred to as central solutions) as defined in Commission Regulation (EU) No 548/2014 on Ecodesign requirements for small, medium and large power transformers.
- Inverters that integrate battery charge converters and/or DC-to-DC converters, and/or DC optimisers.

1.4.3.2. Measurement and test standards

Dedicated standards have been developed for PV inverter performance, such as EN 50530. This however is officially marked as withdrawn, although the procedure for determining the "European Efficiency" could still be considered technically valid. This would allow a transitional method for calculating a functional parameter in terms of AC power output for a nominal PV array. Regarding the definition of technical lifetime and operational service life the situation is similar to that for PV modules and again a transitional method may be required, also taking into account field data.

1.4.3.3. Product functional unit

In addition, a proposal has been formulated for definition of the primary product performance parameter (functional unit) for inverters. This definition would limit the scope to standalone inverters, so as to ensure comparability at product level.

The definition has been aligned with the IEC 61683 method for calculating the efficiency of a utility interactive inverter. This method is considered the most suitable for making estimates of the efficiency of an inverter in converting DC power to AC power according to a pre-determined annual load profile.

To ensure that performance along the life cycle of an inverter and in a system context is taken into account, the proposal supposes that the performance is modelled for a reference service life and as a component of a system.

To be representative the anticipated reliability and associated fault mechanisms for inverters would therefore also need to be taken into account.

Proposed inverter functional unit

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

1.4.4. Photovoltaic systems: recommendations and proposals

1.4.4.1. System definition and scope

As for modules and inverter products, system definitions developed by IEC and IEA, were consulted with the aim to develop a suitable system definition. They all establish several concepts used to make the categorisation. Systems can be categorised according to the following distinguishing features/properties:

- Spatial arrangement: Based on the spatial relationship between the different component arrays (e.g. centralised, distributed).
- Electricity end-use: Based on the primary end use that the electricity generated is earmarked for (e.g. domestic, non-domestic).
- Grid configuration: Based on the type of physical interface with the electricity distribution grid (e.g. grid connected, off-grid, hybrid).
- Electrical configuration: Based on the systems modes of operation (e.g. isolated, utility interactive).

In the same way as for modules and inverter products, stakeholders were consulted in the same questionnaire on an example and possible scope delimitations for photovoltaic systems. The feedback received can be summarized as it follows:

- Market segmentation, i.e. residential, commercial, utility, and system size, should be included in the definition and scope
- The main scope exclusion selected by respondents is 'specific end-uses' of the electricity such as street lighting and urban furniture or consumer electronic products and other gadgets.
- Grid configuration, module array, power conditioning, tracking systems, spatial configuration, roof or ground mounted, and were considered to be of relevance for the definition and scope of PV systems.

In addition, the majority of respondents considered that all systems should be included within the scope. However, to reflect the main scope exclusion proposed by some respondents, and given that most systems are connected to the grid, the scope of the Preparatory study does not include street lighting, urban furniture, consumer electronic products nor standalone systems. These systems are not designed to generate electricity for the grid, which accounts for the largest proportion of the solar PV systems in the market. Moreover, public authorities or consumers are buying these products with solar PV integrated or not, whereas our focus is on the purchase of a solar PV system.

Substations and transformers for power conditioning directly connected to the distribution network, that may be present in utility scale PV plants are neither considered within the scope. Transformers are already in the scope of the Commission Regulation (EU) No 548/2014 on Ecodesign requirements for small, medium and large power transformers.

The first proposal for the product definition and scope of photovoltaic systems is presented below.

Proposed solar photovoltaic system definition and scope

A photovoltaic system is an assembly of components that produce and supply electricity based on photovoltaic conversion of solar energy. It comprises the following sub-systems: module array, switches, controls, meters, power conditioning equipment, PV array support structure, and electricity storage components.

Included in the scope of systems are therefore module level power electronics, i.e. modules with integrated microinverters or DC optimisers.

The provision of energy generated by solar PV systems as a service shall be included within the scope for the purpose of public procurement.

Excluded from the scope are products which are only designed for the following specific applications:

- For use only in street lighting, urban furniture, electric vehicles
- PV integrated consumer and electronic products, i.e. power banks, watches, calculators, etc.
- Systems in which there are modules with DC output power of less than 50 Watts under Standard Tests Conditions (STC)
- Substations and transformers for power conditioning

1.4.4.2. Measurement and test standards

The situation for PV systems reflects a combination of the situation for PV modules and inverters, as well as the system location and design. Aspects of PV system design are the subject of new draft norms, including the full construction cycle and the local environmental conditions, that can have a significant effect on the final energy yield (and therefore also on the material balance).

On-site power measurement and verification standards exist. However, there is no single standard for the calculation of expected energy yield of a PV system. A transitional method would be required here, based either on existing monitoring standards or on the module energy rating standards and integrating a model to include the effects of local environment relative to the specific geophysical position and other derate factors.

1.4.4.3. Proposed functional unit

In addition, a proposal has been formulated for definition of the primary product performance parameter (functional unit) for systems. This definition would limit the scope to grid connected systems.

The 'PV system' encompasses all components required to deliver the functional unit. If it has some storage options (e.g. battery) that if included would extend the boundaries of the system used to supply AC electricity. If a transformer is required, for example on larger utility scale installations, this would be included within this boundary, but may require allocation if only part of its capacity is used.

Proposed system functional unit

The functional unit shall be 1 kWh of AC power output supplied under fixed climatic conditions for 1 year (with reference to IEC 61853 part 4) and assuming a service life of 25 years.