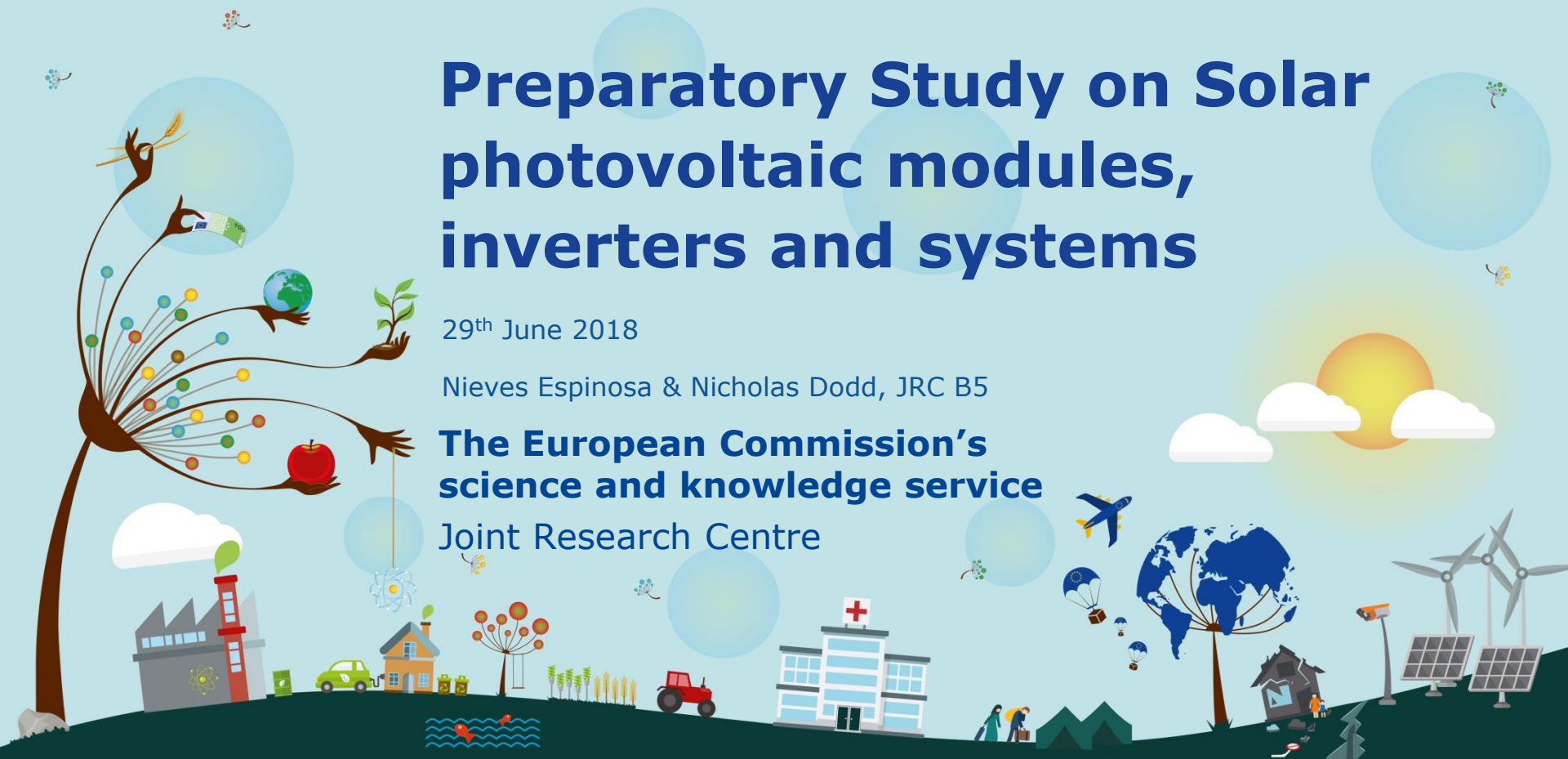


Preparatory Study on Solar photovoltaic modules, inverters and systems

29th June 2018

Nieves Espinosa & Nicholas Dodd, JRC B5

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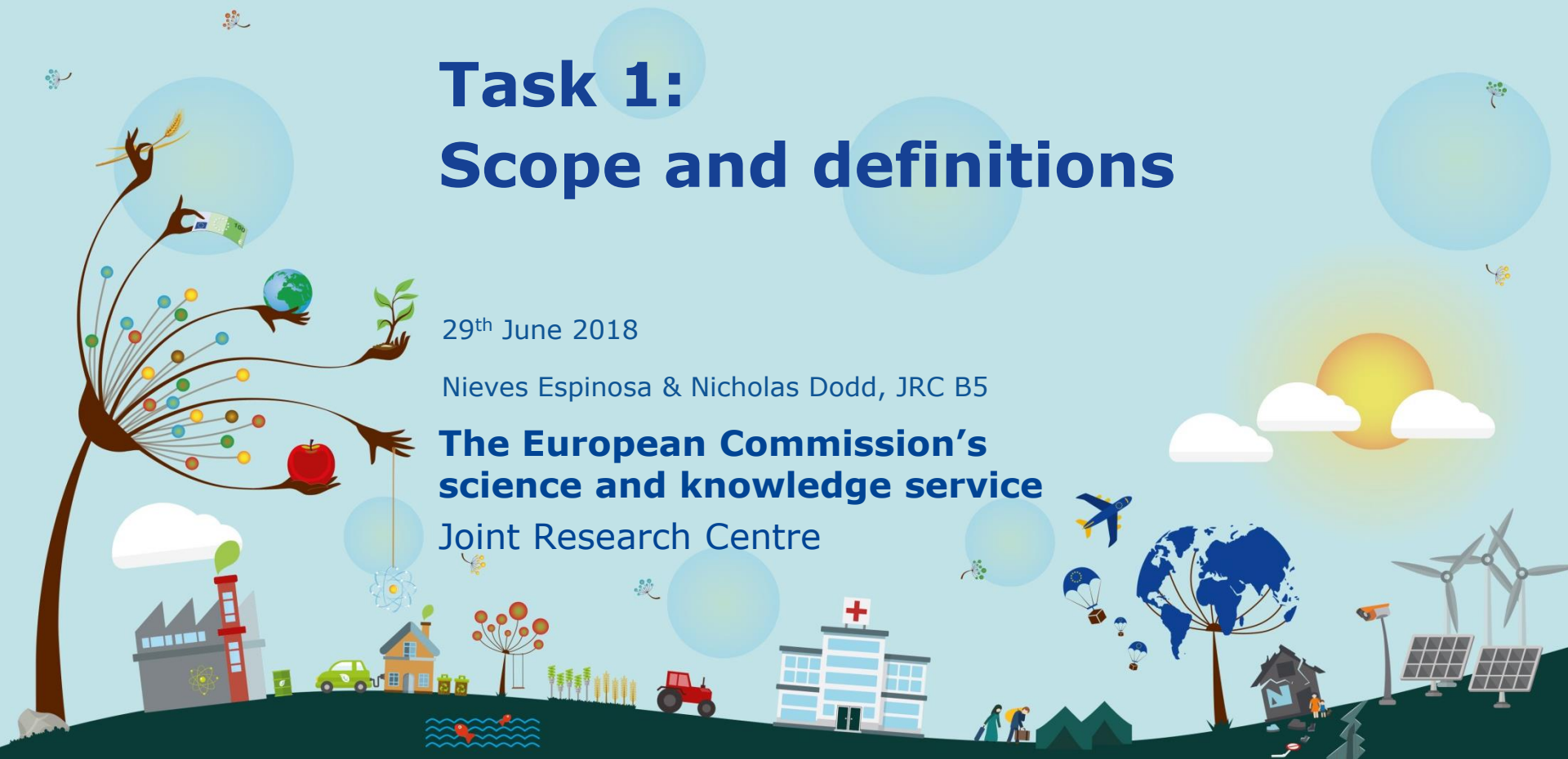
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Task 1: Scope and definitions

29th June 2018

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TASK 1: SCOPE & DEFINITIONS

- Product definitions and scope
- Standards for ecodesign, energy efficiency, other performance characteristics and material resource efficiency
- Legislation for ecodesign, energy efficiency, other performance characteristics
- Conclusions – definitions and scope proposals

TASK 1: SCOPE & DEFINITIONS

- Product definitions and scope

Preparatory study scope

Coherent implementation of product policies to improve life cycle cost and environmental performance.

*Scope: **Modules, inverters and systems***



Sources for scope and definition review

- **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;

CE marking conformity requirements

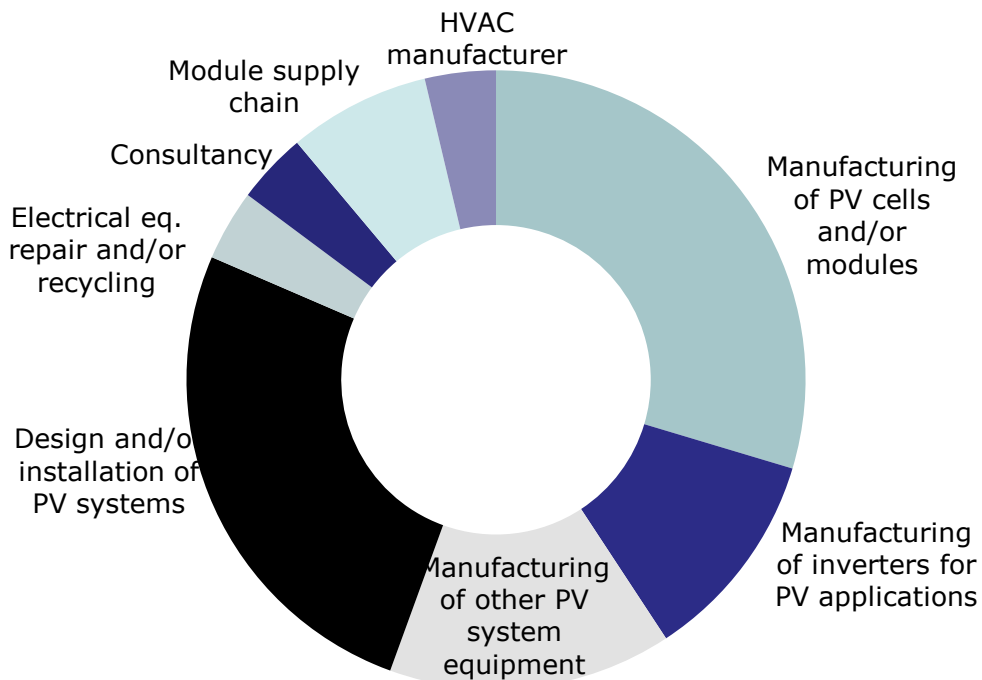
- **Construction products** in accordance with Regulation (EU) No 305/2011,
- **Electromagnetic compatibility** in accordance Directive 2014/30/EU ,
- **Low voltage electrical equipment** in accordance with Directive 2014/35/EU,
- **Restriction of Hazardous Substances in Electrical and Electronic Equipment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

Photovoltaic module definitions

- The [International Electrotechnical Commission \(IEC\)](#) definitions of photovoltaic panels or modules as a complete and environmentally protected assembly of interconnected PV cells.
- The [Underwriters Laboratories'](#) 1703 Standard for Flat-Plate Photovoltaic Modules and Panels
- [Product Environmental Footprint Category Rule \(PEFCR\)](#) for a PV module as analysed by the pilot study
- CENELEC distinction between [Building Attached PV \(BAPV\)](#) modules and [Building Integrated PV \(BIPV\)](#) modules

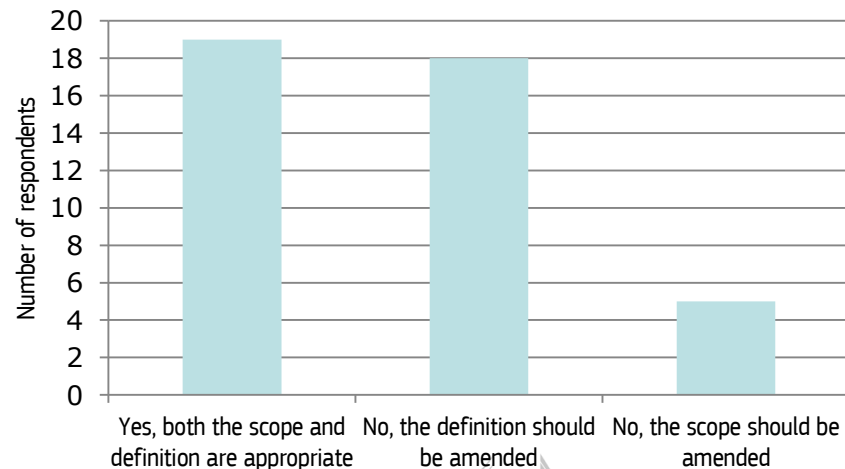
Results from first stakeholder questionnaire

118 registered SHs, 50 replies



❖ **Modules**

- ✓ *Cut-offs limits: 50 Wp, no cell number restriction (78%)*
- ✓ *BIPV 75% of stakeholders in favour*
- ✓ *IEC 61836 standard use*



Inverter module definitions

Fifteen sub-definitions of inverters provided within [IEC standards](#) series.

Can be grouped into three broad categories:

- **Power conversion characteristics:** Inverters that can be distinguished by the aspect of power supply that they are specified to convert or 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.

Power Conversion Equipment (PCE) definitions

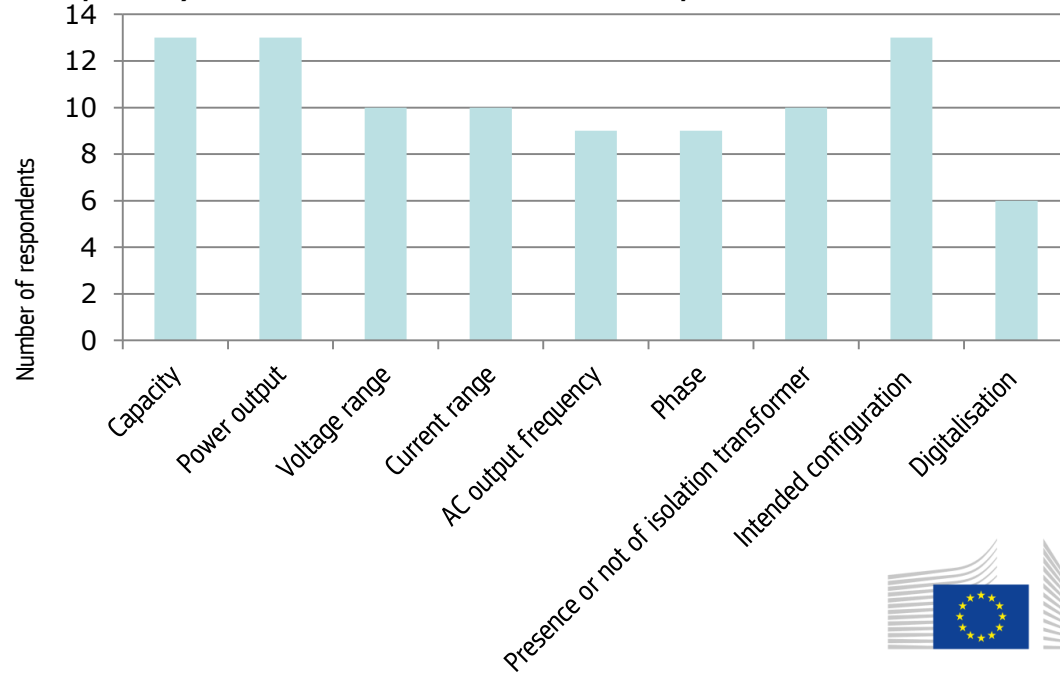
IEC standard 62093 provides a useful common reference point. The standard refers to Power Conversion Equipment (PCE):

- **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.

Results from first stakeholder questionnaire

Inverters

- ✓ All stand-alone sizes included (90%)
- ✓ Microinverters: as a system
- ✓ DC optimisers do not qualify as an inverter since require additional string level electronics



System definitions

IEA identify a range of possible configurations that exist in the market

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

System definitions

Simple IEC definition complemented by sixteen sub-definitions.

Can be grouped 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.

Results from first stakeholder questionnaire

Systems

- ✓ *The scope and definition are appropriate (67%)*
 - Inclusion of *'interconnections (cabling) between sub-systems, as well as transformers' and 'the size of the PV system'*
- ✓ *IN*
 - Tracking structures
 - Cleaning systems
 - Batteries
- ✓ *OUT*
 - Consumer electronic products:
'electric vehicles, watches, calculators, power banks and other gadgets'.

Primary product performance parameter (functional unit)

- **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

Primary product performance parameter (functional unit)

- **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) describes the difference between the modules' (DC) rated performance and the actual (AC) electricity generation, taking into account a number of variables.
- **Degradation:** the level of degradation of a module's efficiency over time.

Primary product performance parameter (functional unit)

Analysis of functional unit definitions used in the context of LCA evaluation is presented below.

1. the European Commission's PEF LCA method solar photovoltaic pilot
2. IEA Life cycle Assessment (LCA) recommendations
3. ADEME life cycle environmental impact evaluation guidance (France)
4. CRE solar photovoltaic tender requirements (France)

Secondary product performance parameters

Additional functional performance characteristics required of the products and/or interactions between the components of an installed PV system and:

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

Review of existing ecolabels

- **TÜV Rheinland:** Green Product Mark ecolabel based on GEC criteria.
- **Blue Angel (Germany):** Criteria set for inverters, successive attempts to introduce criteria for both systems and modules.
- **NSF International (USA):** Module criteria under development with support of US Green Electronics Council (GEC).
- **Cradle to Cradle Products Innovation Institute (USA):** Certification for the inherent circularity of products and their component materials.

Ecolabels in Japan, Korea and Singapore: consumer products incorporating photovoltaic cells

Leading examples

Blue Angel, Photovoltaic inverters product group (Germany, 2012)

- 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.

NSF/ANSI 457 Sustainability Leadership Standard for Photovoltaic Modules (USA, 2017)

- Three levels of performance (EPEAT) with environmental and social criteria

Cradle to Cradle certification (USA, 2016)

- aims to determine the extent to which the design and material composition of a product are able to facilitate future recycling.

Review of EU GPP criteria

- A review of European Commission surveys of Member State GPP criteria showed that
 - EU GPP criteria set for the solar photovoltaic product group does not currently exist.
 - EU projects such as PRIMES and GPP 2020 did not reveal any national criteria sets currently in use

US Programs

- EPA 'Improving Solar PV Results through Collaborative Procurement' covering the Renewable Energy Procurement (REP) in California
- Department of Energy solar procurement guide for Federal Agencies

TASK 1: SCOPE & DEFINITIONS

- Product definitions and scope
- Standards for ecodesign, energy efficiency, other performance characteristics and material resource efficiency



Standards for photovoltaic modules, power conditioning components and systems

Dunlop E.D., Gracia Amillo A., Salis E., Sample T., Taylor N.

***JRC C.2 Energy Efficiency and Renewables Unit
Directorate C Energy, Transport and Climate***

**The European Commission's
science and knowledge service
Joint Research Centre**

1st Stakeholder Meeting of the Preparatory Study for applying EU sustainable product policy instruments to solar photovoltaics,
Brussels, June 29th 2018



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PURPOSE

Support to the ongoing preparatory activities on the feasibility of applying the **Ecodesign, EU Energy label, EU Ecolabel and Green Public Procurement (GPP)** policy instruments to **solar photovoltaic (PV) modules, inverters and PV systems**.

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

Standardisation levels considered

1) Harmonised standard

“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

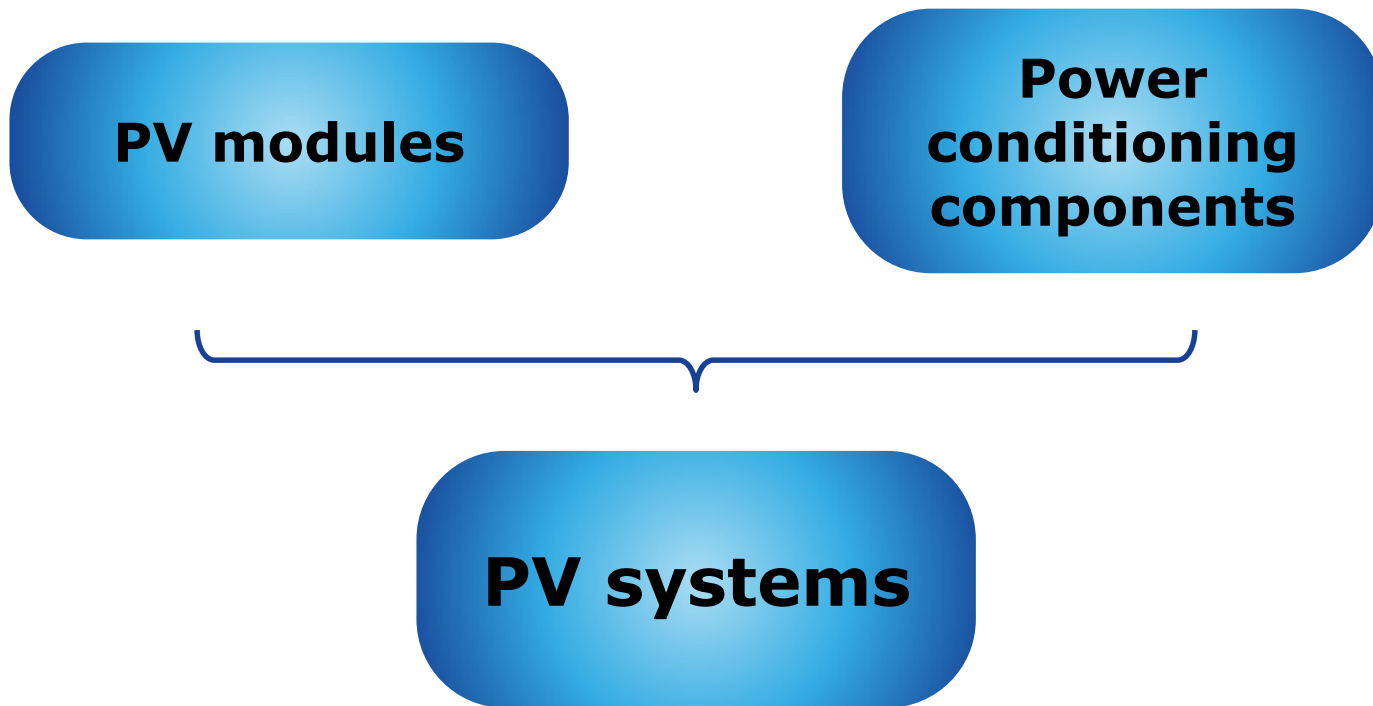
2) CEN-CENELEC (EN)

European Standardisation Organisations (ESOs) in the general or electrotechnical fields. They operate under EU mandate M/089 EN linked to “Completion of the Internal Market” (but not for Ecodesign).

3) International Electrotechnical Commission (IEC)

4) International Organization for Standardization (ISO)

Product categories



PV Modules

Functional parameter	Standards
Module Energy Yield DC	EN 61853-1, EN 61853-2, (draft) IEC 61853-3, (draft) IEC 61853-4
Module Performance Ratio (MPR)	EN 61853-1, EN 61853-2, (draft) IEC 61853-3, (draft) IEC 61853-4
Maximum power at STC	EN 60904-1
Module Energy Conversion Efficiency	Possible next edition of IEC 60904-1 (under revision)
Module Degradation Rates	<i>Not defined by standards</i>
Module Operational Life	<i>Not defined by standards</i>

Proposal from preparatory study for Ecodesign:

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

Power conditioning components (PCEs)

Functional parameter	Standards
Input range voltage, Grid range voltage, Start-up voltage, MPP voltage	IEC 62894 EN 50524 (withdrawn at present)
Inverter efficiency	IEC 61683
Inverter "European efficiency"	EN 50530 (withdrawn at present, new work item considered at CENELEC)

Proposal from preparatory study for Ecodesign:

1 kWh of AC power output from a specified inverter installed as part of a reference photovoltaic system under predefined climatic and installation conditions for 1 year and assuming a service life of 10 years.

PV Systems

Functional parameter	Standards
System Maximum power at STC	<i>Not existing, but it can be based on EN 60904-1, EN 61829</i>
System Energy output	<i>Not existing</i>
System Energy Yield	<i>Not existing</i>
System Performance Ratio (PR)	EN 61724-1 (generic definition, not sufficient as it needs final Energy Yield as input)
System Efficiency	<i>Not existing</i>

Proposal from preparatory study for Ecodesign:

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.

Building Integrated PV Systems (BIPV)

Standard	Notes
EN 50583-1	PV modules used as construction products
EN 50583-2	PV systems integrated into buildings (structural aspects)
IEC 63092-1 (draft)	Based on EN 50583-1
IEC 63092-2 (draft)	Based on EN 50583-2
ISO 52000-1 and other parts	Energy Performance of Buildings
EN 15316-4-3	Method for calculation of system energy requirements and system efficiencies
prEN 50331-1 (draft)	Safety requirements for PV in buildings

Quality and degradation: EN 61215

Standard	Subject covered
<i>EN 61215-1</i>	Design qualification and type approval - Part 1: Test requirements
<i>EN 61215-2</i>	Design qualification and type approval - Part 2: Test procedures
<i>EN 61215-1-1 to -4</i>	Specific requirement for each PV technology

Specific tests covered:

- *Thermal cycle test*, with temperature and electrical current as stressors;
- *Damp heat test*, combination of effects due to temperature and humidity;
- *Humidity freeze test*, on sealing materials and components;
- *UV test*, for polymeric components;
- *Static mechanical load test* simulates loads such as those by constant wind or homogeneous snow accumulation;
- *Hot spot test* linked to partial shading on modules;
- *Hail test*.

Quality and degradation: accelerated tests

Standard	Subject covered
<i>EN 61701</i>	Salt spray testing, mainly of connectors
<i>EN 62716</i>	Ammonia corrosion testing
<i>EN 62782</i>	Load variations on the PV module surface compared to EN 61215
<i>EN 62804-1</i>	Detection of potential-induced degradation (PID)
<i>EN 62804-1-1 (draft)</i>	Delamination due to PID
<i>IEC TS 62804-2 (draft)</i>	Detection of PID in Thin-film PV modules
<i>IEC 62852</i>	Safety requirements and tests for connectors of PV
<i>IEC 62916</i>	Test of susceptibility of by-pass diodes to electrostatic discharges
<i>IEC 62979</i>	Thermal runaway test of by-pass diodes, component of the PV module for its own and eventually the user safety
<i>IEC 62938 (draft)</i>	Non-uniform snow load testing on inclined plane
<i>IEC 63126 (early draft)</i>	Guidelines for qualifying PV modules, components and materials for operation at higher temperatures
<i>IEC 63140 (draft)</i>	Advanced testing of protection and performance measurement of thin-film PV modules when exposed to partial-shading conditions

Operational service life and life cycle

Operational service life
of PV modules or PV systems **not defined** yet



some suggestions or
common practices based on
manufacturer warranty

some standards from
building construction and
building energy efficiency

Transitional methods

Conclusions

1) PV Modules

Standards available for the energy rating of PV modules in different climatic conditions, but degradation rate and operational lifetime need additional scientific and standardisation work (no specific standard at present).

2) Power conditioning components

Standard available to define an overall efficiency according to a weighted combination of efficiencies.

3) PV systems

No standard available to properly calculate the energy yield of a PV system. What is available is a generic calculation for BIPV based on factors and data sets to be defined by the Member States.

Some useful references

- ✓ ***Energy-based metric for analysis of organic PV devices in comparison with conventional industrial technologies***

A. M. Gracia-Amillo *et al.*, Renewable and Sustainable Energy Reviews, 93 (2018) 76-89

- ✓ ***The completed IEC 61853 Standard on PV module energy rating, overview, applications and outlook***

by T. Huld, A. Gracia Amillo, T. Sample, E. Dunlop, E. Salis, R. Kenny

@ 35th European PV Solar Energy Conference and Exhibition,

24th-28th September 2018, Brussels

5DO.9.2 Thursday 27th at 17:00-18:30

<https://www.photovoltaic-conference.com/programme/conference.html>

TASK 1: SCOPE & DEFINITIONS

- Product definitions and scope
- Standards for ecodesign, energy efficiency, other performance characteristics and material resource efficiency
- Legislation for ecodesign, energy efficiency, other performance characteristics

Legislation and agreements at EU level

- 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

EU policy instruments influence

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">• Favourable market conditions for self-consumption and local energy communities• Non-discriminatory handling of grid connections (associated charges and procedures) to support 'active consumers'
Driving the market for renewable electricity generation	<ul style="list-style-type: none">• Self-consumption and storage support by simplified permitting• rooftop solar PV supported in the new methodology for the minimum RES contribution in new buildings and major renovations
Driving the market for building renovation and near zero energy buildings	<ul style="list-style-type: none">• 2020 targets to achieve Nearly Zero Energy performance further drive BAPV & BIPV• Large scale renovation and decarbonisation of the existing building stock (BAPV)• 'Smart readiness' and this will include energy systems• EN ISO 52000 series calculation method for BAPV/BIPV performance
Improving information on construction product performance	<ul style="list-style-type: none">• EN 15804 and EN 15978 LCA standards 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">• Material efficient solutions on CRM indium, gallium and silicon metal• MS reporting on solar PV waste streams will increase the focus on end of life routes
Product policy and consumer information	<ul style="list-style-type: none">• Smart ready products will interact with home management systems and appliances

Legislation at Member State level

Pioneers (pre 2008)

High market penetration

Germany

Medium market penetration

Austria

Denmark

Netherlands

Spain

Late starters (post 2008)

High market penetration

Italy

United Kingdom

Medium market penetration

Belgium

France

Czech Republic

Greece

Low market penetration

Bulgaria

Romania

Market penetration levels

High = >5.0%

Medium = 1.0 – 5.0%

Low = <1.0%

Product & system qualification requirements

- **Italy:** Performance Ratio (PR) of systems field tested in accordance with EN 61724.
 - PR >0.78 where inverter ratings <20kW
 - >0.80 where inverter ratings >20 kW
- **UK:** Modules selected from a pre-approved list. Compliance with EN 61215 (crystalline modules) and EN 61646 (thin film modules). Separate approval process for BIPV.
- **Belgium:** Compliance also with EN 61215 and EN 61464, IEC 61730 where incorporated onto a building.
- **France:** The ATec GS21 'Photovoltaic systems' evaluation was developed in 2008. Role of mounting system, waterproofing and resistance/durability

Effect of MS policies and requirements

Policy or requirement	Influence on solar PV deployment
PV system support	<ul style="list-style-type: none"> • FiTs scaled down to support smaller, largely residential systems of <5-30kW • Auctions of electricity price contracts to support utility scale systems (greater potential reduce bid LCOE)
BIPV support	<ul style="list-style-type: none"> • Two large MS give preference to BIPV , investment subsidy or an increased FiTs rate • BIPV is in some MS required according to building permits and codes.
Self-consumption support	<ul style="list-style-type: none"> • Net-metering permitted in most Member States whereas net-billing is a newer concept • Self-consumption (5-100 kW) incentivised by reduced FiTs below consumer electricity prices
Electricity storage support	<ul style="list-style-type: none"> • At least two MS have subsidies supporting battery storages in small systems (<30 kW).
Module qualification	<ul style="list-style-type: none"> • Modules and inverters pre-qualify in some MS or shown the point of bidding, contract award in others • IEC standards 61215 and 61646 are specified in all of the requirements analysed • Other aspects : performance tolerances, specific BIPV products, minimum warranty periods, factory quality inspections and compliant WEEE take back scheme • Residential investment support linked to use products from a pre-approved list
System qualification	<ul style="list-style-type: none"> • Performance Ratio target with field testing requirement in at least one MS • Award criteria for the modules embodied GWP is included in one MS auction • Performance criteria set in support of product and system warranties in one MS: durability of the mounting system, Waterproofing of the main system components e.g. junction boxes, halogen content of cables

Third country policies & requirements

- Demand side targets:
 - CN and US clear ambitious target for 2020 (105 GW surpassed by 120 GW)
- PV system support:
 - FiTs thresholds decrease in all countries analysed. 15% FiTs cuts in CN since 2016 → CN market expected to shrink up to 2020
 - More price based auctions, Top Runner program in CN for projects using advanced tech modules -high efficiency.
- System and component qualification:
 - Top runner program in CN leading example: module efficiency criteria introduced into an auction process.
 - California (Go Solar!) and the Australian program list of eligible equipment, and requirements for their installation

TASK 1: SCOPE & DEFINITIONS

- Product definitions and scope
- Standards for ecodesign, energy efficiency, other performance characteristics and material resource efficiency
- Legislation for ecodesign, energy efficiency, other performance characteristics
- Conclusions – definitions and scope proposals

PV modules definition and scope proposal

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

- strings of PV cells (crystalline tech.) and/or semiconductor layers (thin film tech.),*
- 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 PV 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.

PV modules definition and scope proposal

Specifically excluded from this scope are:

- *Module that integrate MPL 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.'*

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.*

Inverters definition and scope proposal (1)

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.*

Inverters definition and scope proposal (2)

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.*

Proposed solar inverter functional unit

- ✓ The functional unit shall be 1 kWh of AC power output from a specified inverter installed as part of a reference photovoltaic system under predefined climatic and installation conditions for 1 year and assuming a service life of 10 years.**

** Edited from the version in published Task 1 report*



Systems definition and scope proposal (1)

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 conversion 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.

Systems definition and scope proposal (2)

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*

Proposed photovoltaic 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 61853-4) assuming a service life of 25 years*

Task 2: Market analysis

29th June 2018

Nieves Espinosa & Nicholas Dodd, JRC B5

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Task 2

Market analysis

Analysis for modules, inverters and systems

- **Market and stock data**
 - Technology segmentation and base assumptions
 - Stock data and forecasts
- **Market trends**
 - Market segmentation
 - Trends in product design and features
 - Competitive analysis
 - Channels to market
- **Consumer expenditure base data**

Meta trends in the EU and Global PV market (1)

A global view of the major market trends that may affect the market's evolution in the short to medium term (to 2020 or 2030)

- the possible **technological and market implications**,
- the likely **time horizon** for their mainstream adoption, and
- the related **degree of certainty**.

Main sources: IEA PVPS programme, Solar Power Europe, the PV Market Alliance, GTM Research.

Meta trends in the EU and Global PV market (2)

Trends	Technology and Market Implications	Time horizon	Uncertainty
1. Continued overcapacity in global module production	<ul style="list-style-type: none"> Further rationalisation of technology leaders. 	Short	Medium
2. Phasing out of financial support schemes	<ul style="list-style-type: none"> Larger projects will be incentivised. More attention on efficient module technologies 	Medium	Low
3. Increased use of solar auctions to drive down prices	<ul style="list-style-type: none"> Continuous basis for support. Contracts indexed to market electricity prices. Auctions target larger end of the market. Municipal reverse auctions on behalf of citizens 	Medium	Low
4. An increase in Corporate Power Purchase Agreements	<ul style="list-style-type: none"> Installations driven by diversity of organisations Supports a diversity of sites and project sizes 	Medium	Low

Meta trends in the EU and Global PV market (3)

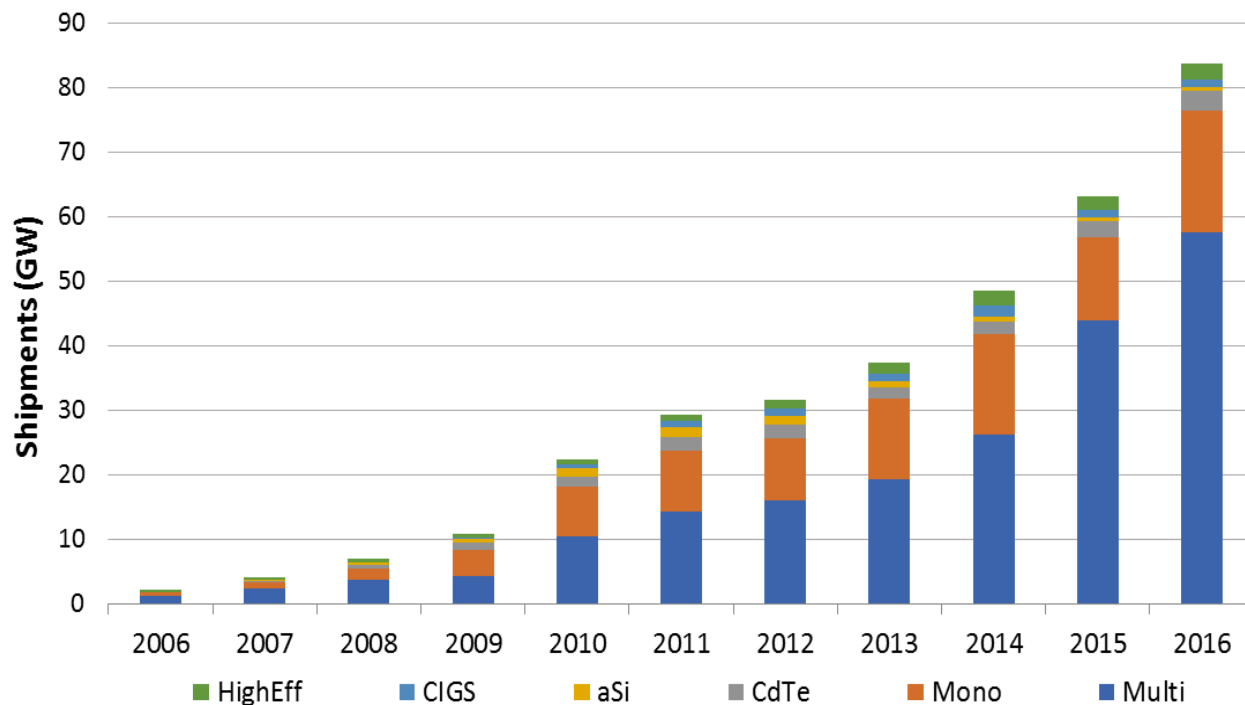
Trends	Technology and Market Implications	Time horizon	Uncertainty
5. An increased focus on operation & maintenance services	<ul style="list-style-type: none"> ○ A range of on-site service offers ○ Real-time data analytics as a key component 	Medium	Medium
6. An increase in utilities providing solar PV services	<ul style="list-style-type: none"> ○ A range of business models could emerge 	Medium	High
7. An increase in self-consumption by system owners	<ul style="list-style-type: none"> ○ Support scheme complexity may limit take-up. ○ Battery storage as an integrated component of BoS and solar PV systems. ○ Market differentiation on the basis of reliability. ○ 'Virtual net-metering' offered by utilities. ○ Collective self-consumption will attract more interest 	Medium	Medium to high
8. Digitalisation of PV systems and components	<ul style="list-style-type: none"> ○ Increased home system integration offers. ○ Increased pooling of data from systems. 	Medium	Low

Module market and stock data

Technology segmentation and base assumptions

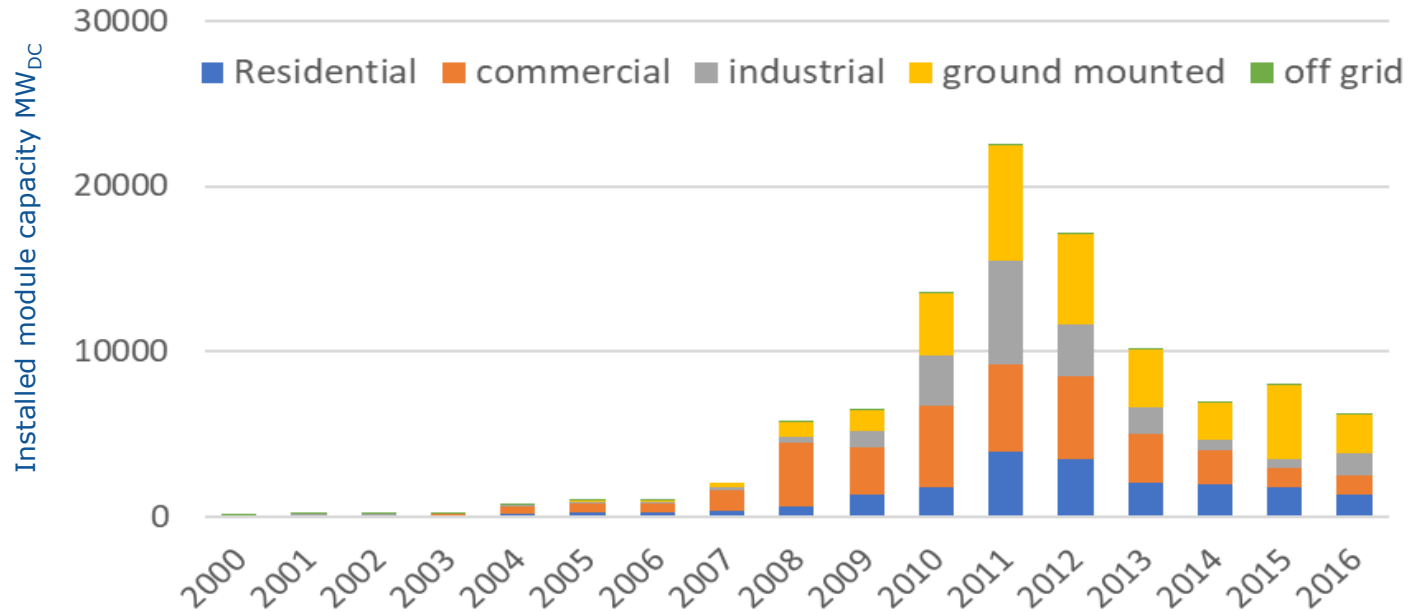
- The shipment and stock data presented is **segmented by technology**
 - multi-Si, mono-Si, a-Si thin films, CdTe films, CIGS films and 'high efficiency' technologies (>22%)
- **Module capacity** is generally expressed in watts of DC rated output (Wp).
- **Lag time** between shipments and installation of no more than 3-6 months, 1 month for direct supply
- Each technology has a **distinct manufactured price**, making them attractive in specific market segments.
- Base assumption of a **technical lifetime 25 years**, in line with the typical product performance warranty periods

Cumulative EU module shipments per technology



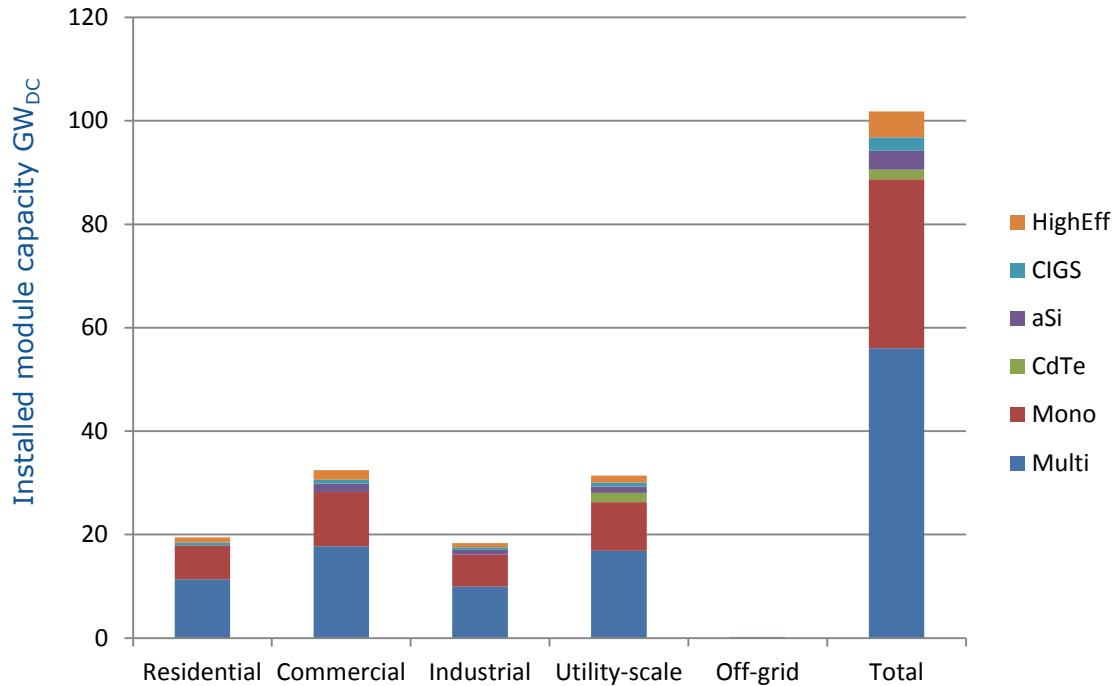
Data provider: Becquerel Institute (2018)

Evolution of the EU module stock



Data provider: Becquerel Institute (2018)

Cumulative EU module stock estimate (2016)



Data provider: Becquerel Institute (2018)

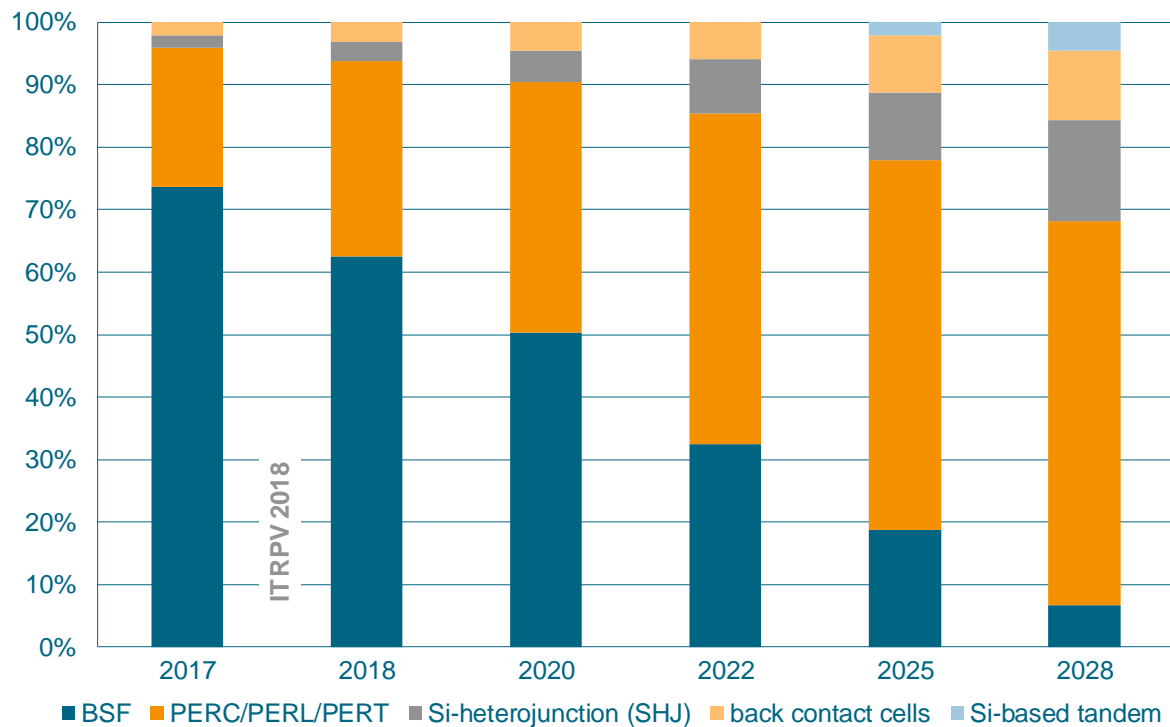
Module market trends

Market segmentation

- **Silicon wafer technology** dominates the a dynamic and rapidly changing market
- **PERC** family of cell types has quickly entered the market,
 - Shift from cast **p-type polycrystalline silicon** to grown **n-type monocrystalline silicon** wafer substrates
- **Bifacial** entry into the market will quickly follow after PERC
 - Projected to reach ~20% market share by 2021, driven by commercial and utility segments

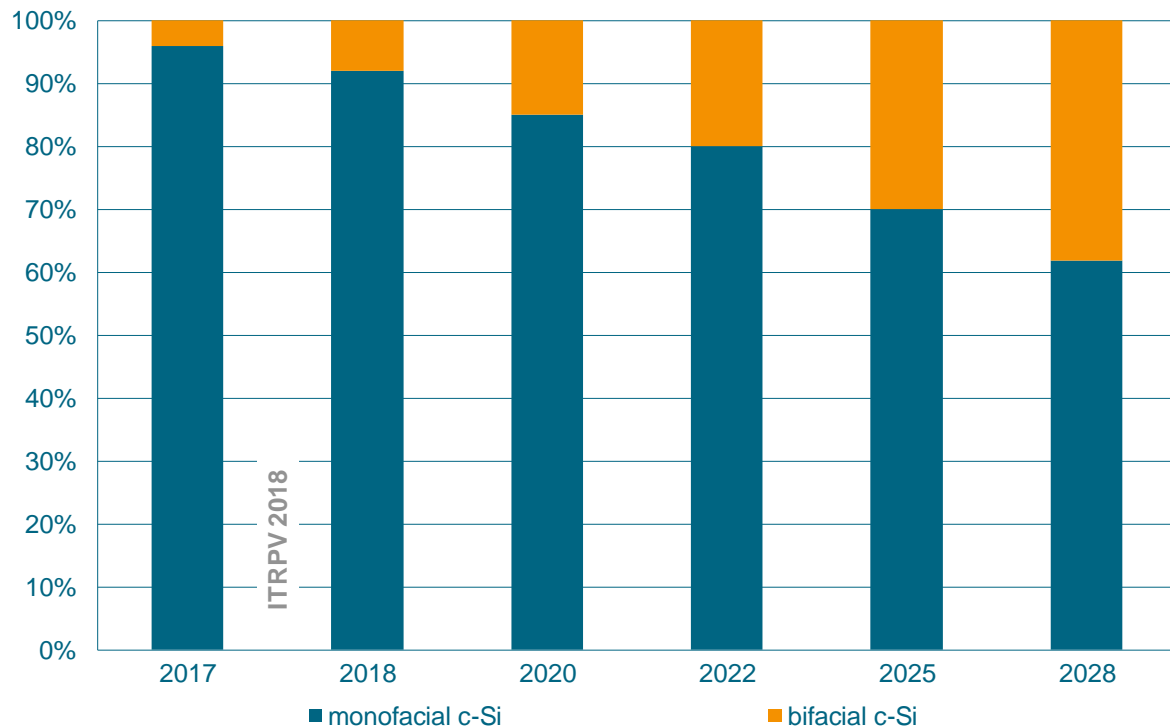
PERC Passivated Emitter and Rear Cell

Global market share for Si cell technologies



Source: ITRPV (2018)

Global market share for bifacial cell technologies



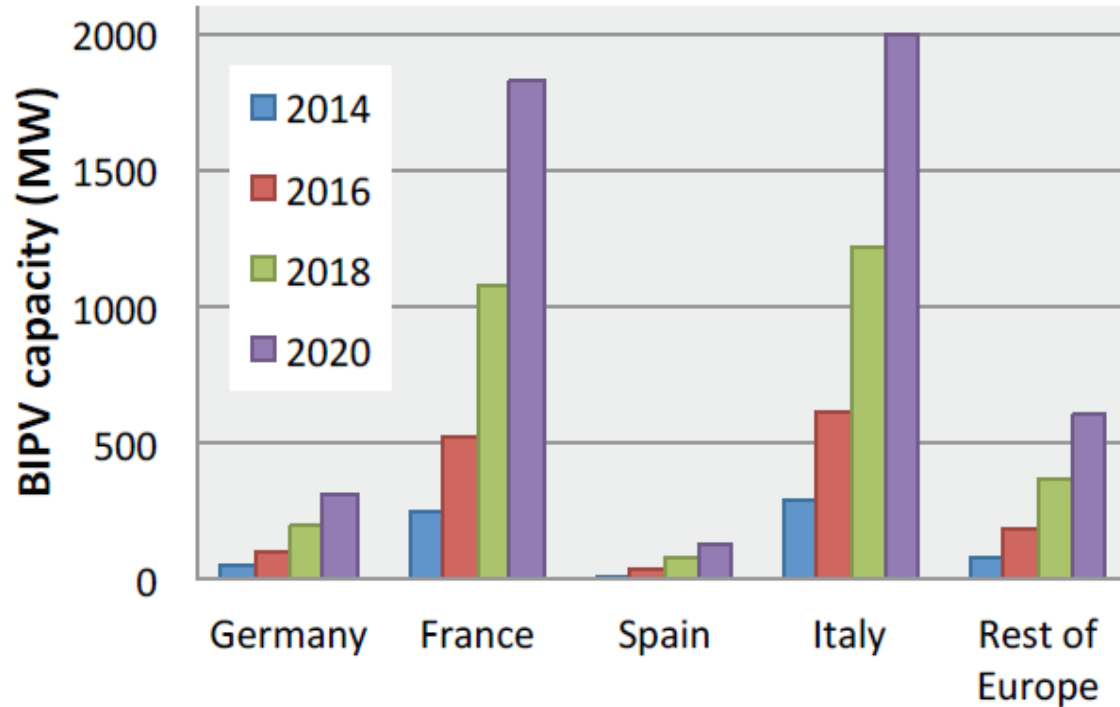
Source: ITRPV (2018)

Building Integrate Photovoltaics (BIPV)

A **niche market segment**, accounting for an estimated 2% of the PV market as a whole

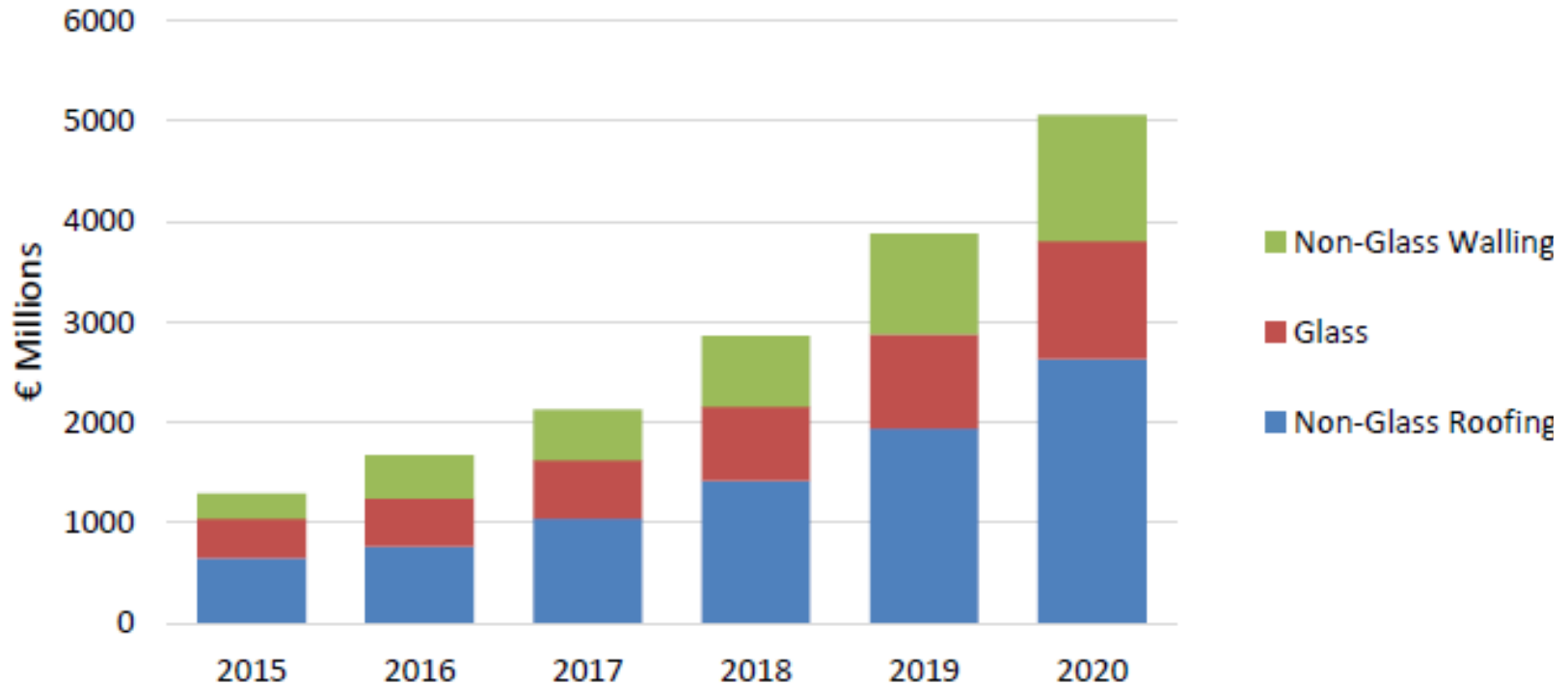
- In 2015 estimated installed EU capacity of 967 MW or approximately 11.4% of EU installed capacity
- France and Italy have led BIPV market development with **subsidy-based incentives** and **product requirements**
- **Market split**: residential buildings (19%), public infrastructure (14 %), showroom offices (13%), universities and schools (9%) and historical buildings (7%).

EU BIPV market 2014-2020 analysis



Source: Global Industry Analysts (2015)

EU BIPV market forecast 2015-2020



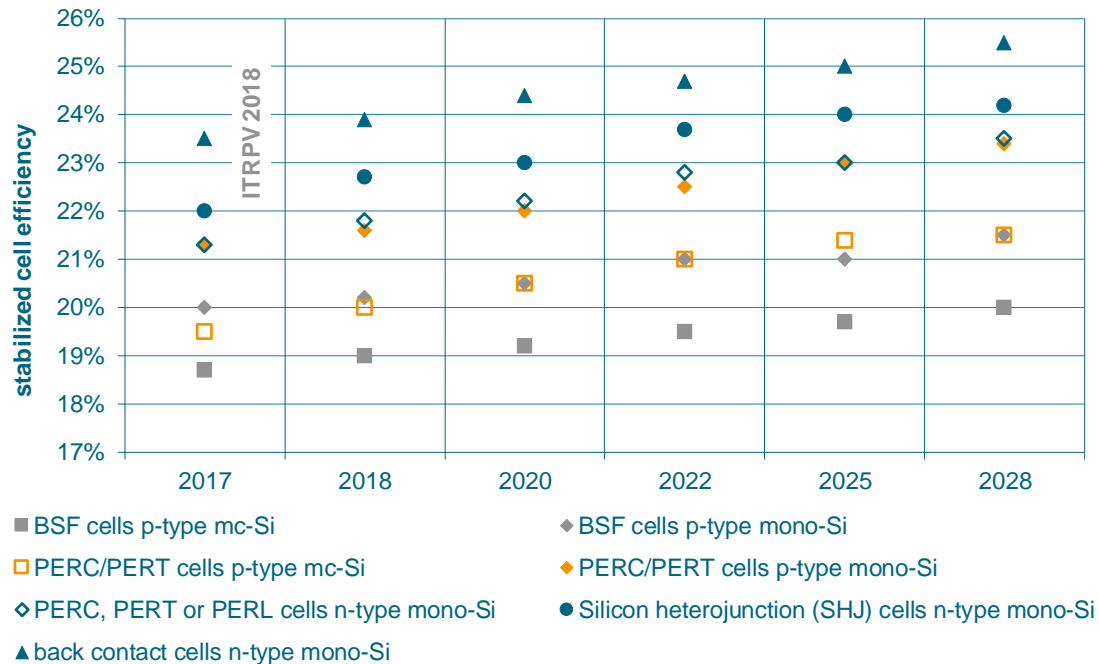
Source: PV Sites project (2016)

Trend in product design and features

Principal apparent trends relate to the **cell structure**

- cell types
- dimensions
- bus bar arrangements
- **p-type** poly-Si cell types upper limit efficiency levels
 - approximately 21% (2016), projected at 23% by 2027
- **n-type** mono-Si cell types upper limit efficiency levels
 - In the range of 21- 23% (2016), projected at 24 -26% by 2027
- **Bifacial** cell types
 - n-type PERT and p-type mcPERT or pPERT

Average stabilised C-Si cell efficiency (156 mm²)



Source: ITRPV (2018)

Module level design innovations

- **Number of cells** in a module is anticipated to increase, **size of cells** to decrease
- **Encapsulation and back sheet material** innovations for cost reduction or durability
- **Alternative framing materials** e.g. steel v. aluminium
- **Frameless modules** rigid protection, bifacial performance gains
- **Simplified fixing systems** reductions in the BoM, time on site, spacing between modules.
- **Anti-soiling coatings** repellent coatings to reduce dust and dirt accumulation.
- **Junction box** ingress protection, connection type ease of repair, cool bypass, decentralised locations, MLPE

Quality and durability

An increasing focus of attention for manufacturers and buyers.

In line process control

- Improvement gains in early stage reliability
- 11 cell and 5 modules control methods, ITRPV roadmap 2018

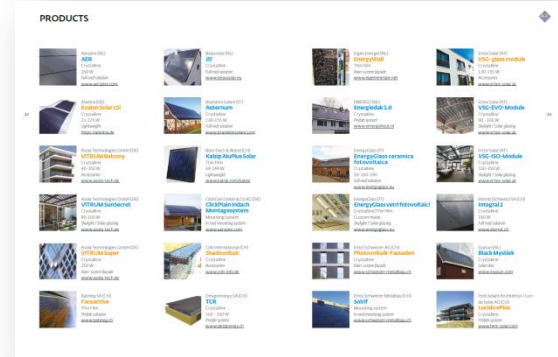
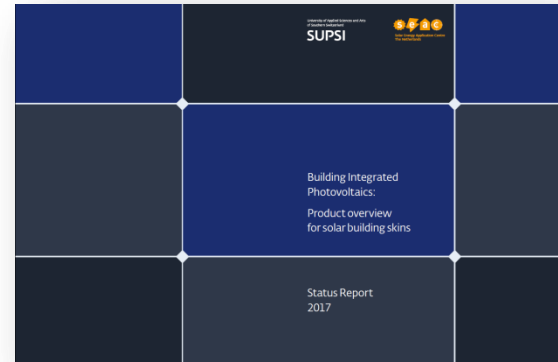
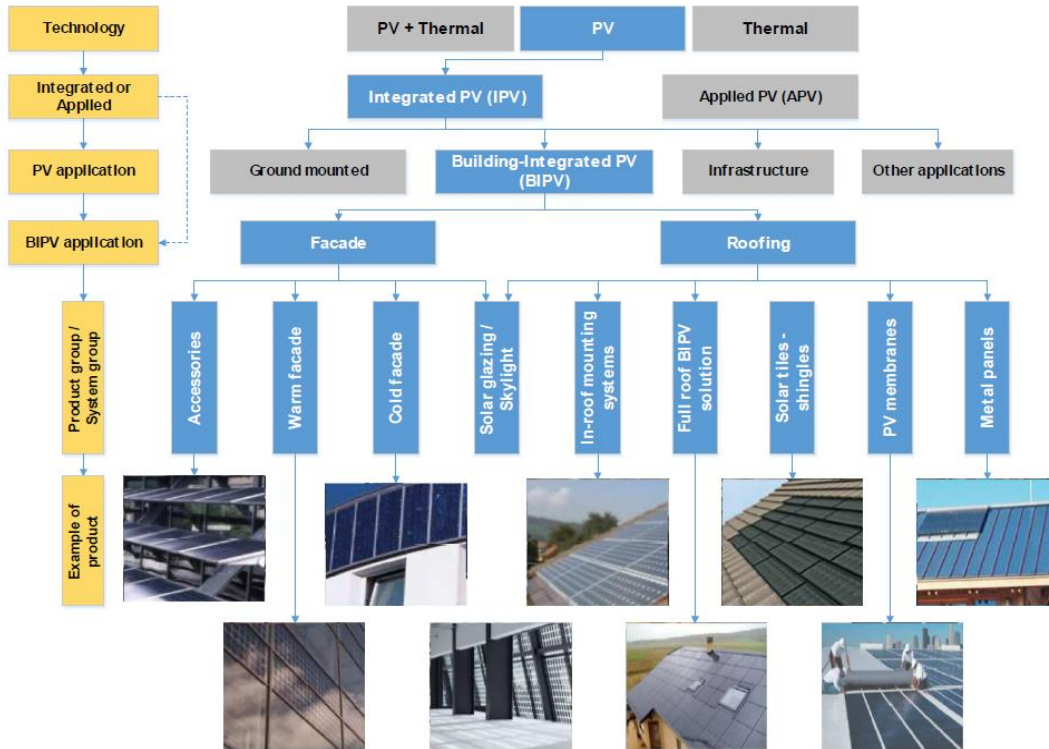
Performance degradation over time

- Burn-in degradation (year 1) projected to improve 3% to 2% (2019)
- Annual degradation projected to improve from 0.7% to 0.5% by 2025

Warranties

- Product warranties: not anticipated to change = 10 years
 - Examples: up to 25 years, specific cell structures and glass:glass modules
- Performance warranties to extend to up to 30 years.

BIPV product range



Feedback from stakeholder questionnaire

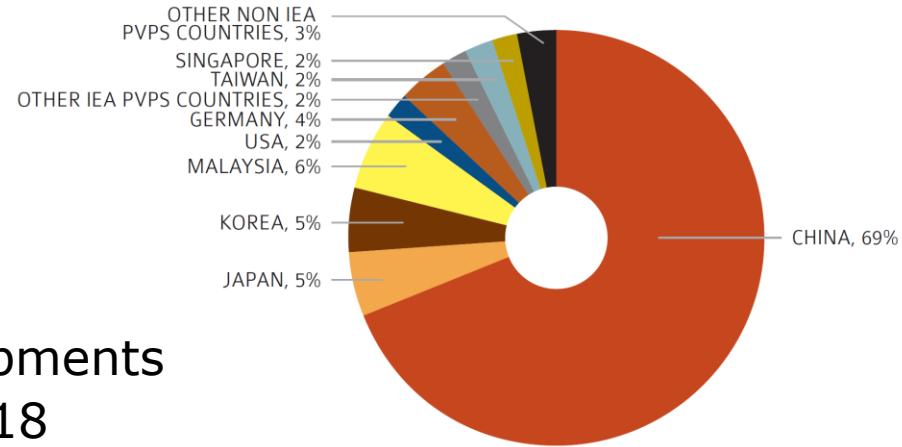
- **Power conversion efficiency**: PERC and Heterojunction technologies as the state of the art.
- **Quality, durability and lifespan**: Extending the module life to over 25 years, or that the warranty is both on product and power output.
 - **New standards** required to estimate the design technical lifetime, existing tests should be extended to combine loads and stresses.
- **Other technical improvements**: glass glass modules, new encapsulants and edge sealing.
- **Material intensity and raw material use**: forecast reduction in silicon, silver reduction in contact fingers and busbars (below 50mg/Wp), replace silver with copper or other substitutes.
- **Hazardous substance presence**: lead free soldering, halogen free backsheets.

Competitive analysis

'Silicon Module Super League'

Canadian Solar, Hanwha Q CELLS,
JA Solar, Jinko Solar, Trina Solar,
LONGi, GCL

- Account for over **50%** of global shipments
- Each expected to ship **>4GW** in 2018
- Technology driven by **Chinese Top Runner programme**
 - end of 2015: standard (full-AI BSF) p-type multi cells, 3-5 busbars
 - end of 2018: advanced cells (PERC and 'black-silicon', p-type Si)
 - 2019-2020: bifacial cells and glass-glass module structures
- EU manufactured turnkey **production line solutions**
 - new PERC, heterojunction and bifacial cell structures



Channels to market

Limited margins restricts the number of intermediaries

- **Direct sales** to developers or large installers
 - Generally systems >100kW
- Sales via **local subsidiaries**
 - Generally systems >100kW
- Sales via **distributors** then to installers, potential OEM/rebranding
 - Smaller systems, well established companies e.g. Krannich Solar
- **New channels?** utilities, retailers, household brands broker link between brands and installers

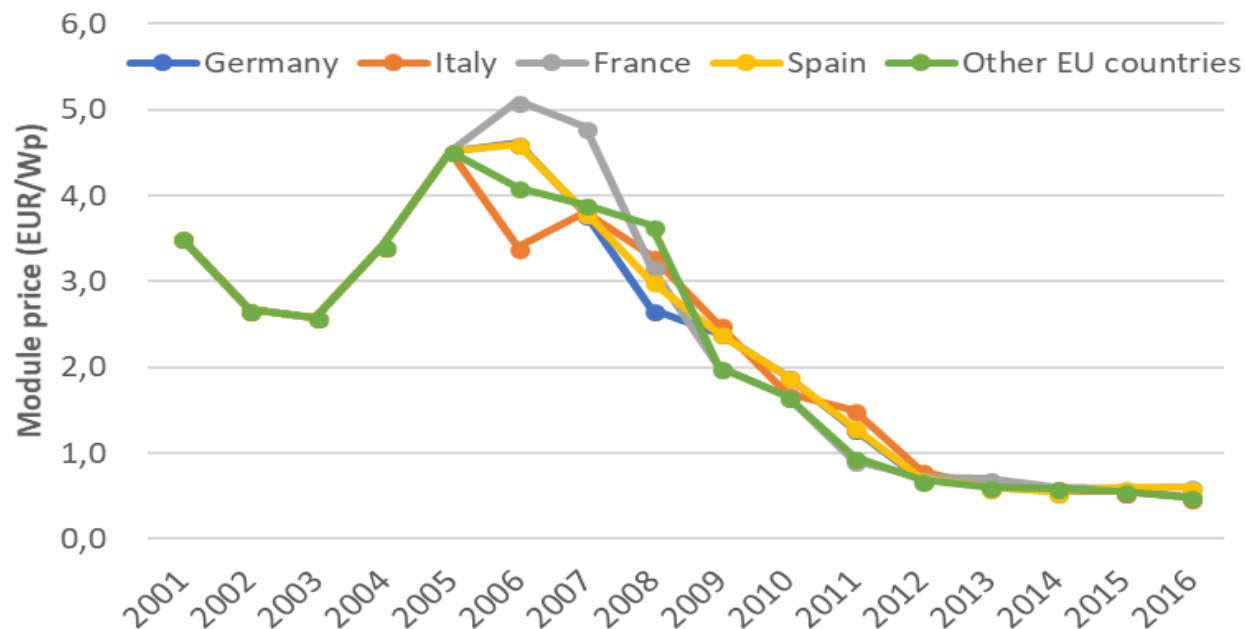
ENF Solar directory identifies wholesalers (496) and distributors (166)

BIPV as distinct case

Specialist suppliers, distributed via the **building trade**

- The building sector is relatively conservative.
- Barriers identified to increased market penetration include:
 - **flexibility** in design and aesthetics considerations,
 - lack of tools **integrating** PV and building performance,
 - demonstration of the **long-term reliability** of the technology,
 - **compliance** with legal regulations,
- Targets at Member State level for building NZEB performance
 - **market driver** for BIPV products in new-build and major renovation projects.

Consumer expenditure base data



Data source: Becquerel Institute (2018)

Inverter market and stock data

Technology segmentation and base assumptions

- Inverter capacity expressed in **watts of AC rated output (W_{AC})**
- Technologies fall into the IEC 62093 Power Conversion Equipment (PCE) categories: **MLPE, string and central** (standalone or packaged)
- **Final destination** for a proportion of EU shipments will be off-grid markets in Africa
- Inverter market data is generally estimated from **module DC capacity, DC:AC ratio** per market segment: Residential (1.15), commercial and industrial (1.22), utility (1.2-1.4)
- Base assumption of a **minimum technical life time** of 10 years, although 13 years is now being used by some investors (Solar Bankability).

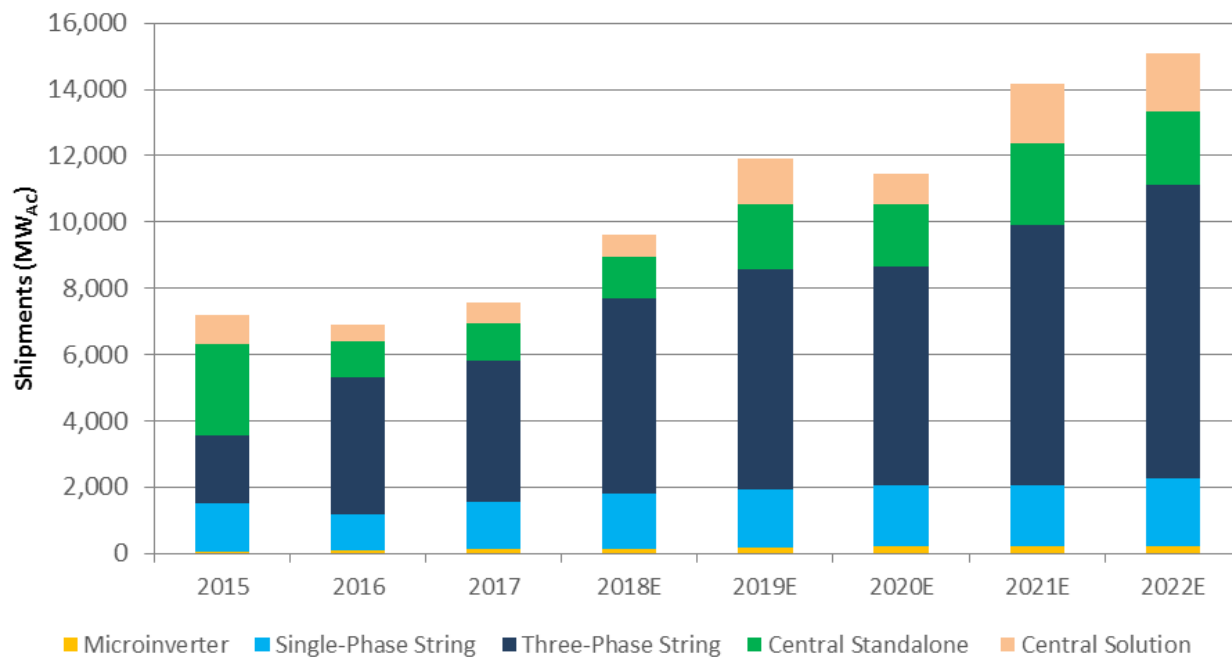
Stock data and forecast

Total new installed **module array capacity** in 2016:
6,216 to 6,734 MW_{DC}

Ajustment of DC:AC for PV system and inverter market segments

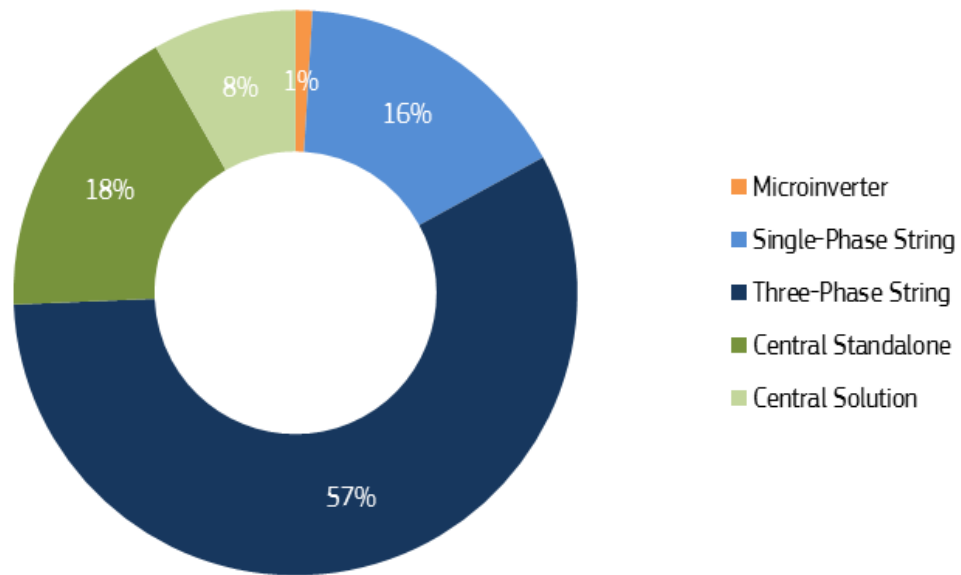
- **New installed** EU inverter stock in 2016:
5,678 - 6,151 MW_{AC}
- **Total installed** EU inverter stock until the end of 2016:
94,400 - 96,913 MW_{AC}

EU inverter shipments by technology (MW_{ac})



Data source: GTM Research (2018)

EU inverter shipments by technology (2016)



Data source: GTM Research (2018)

Trends in product design and features (1)

Inverters have been a major focus of attention for BoS performance optimisation and cost reduction.

- Majority of inverters have a **declared efficiency** up to 98.5%, exception are micro-inverters (up to 95 - 97.5%)
- Attention on **inverter configurations** and **power electronics** to improve system performance.
- Functional requirements that have influenced designs include:
 - an increase in **power density** (or power to weight ratio),
 - the need for **higher reliability** and the management of fault modes, and
 - the use of **smart grid control** under different conditions.

Trends in product design and features (2)

- **Major application trend:** three phase string inverters in larger systems (up to 100 -150 kW)
- **Most significant design trend:** inverter designs with silicon carbide (SiC) and gallium nitride (GaN) semi-conductors
 - Projected as entering the market in 2018
 - Offers reduced bill of materials, solid state components e.g. heat sinks
- **Major integration trend:** hybrid inverters with battery storage
 - Grid parallel (or grid 'feeding') and islanding (or grid 'forming') modes
 - Implications for expected design life and operating characteristics?

Trends in product design and features (3)

- **Module level power electronics:** design integration trends
 - Integrated micro-inverters and DC power optimisers.
 - Inverter and module level monitoring of power output and fault detection are now available.
 - Driven installation cost reductions (USA), claimed improvements in system performance of 5-25%

Feedback from the stakeholder questionnaire (1)

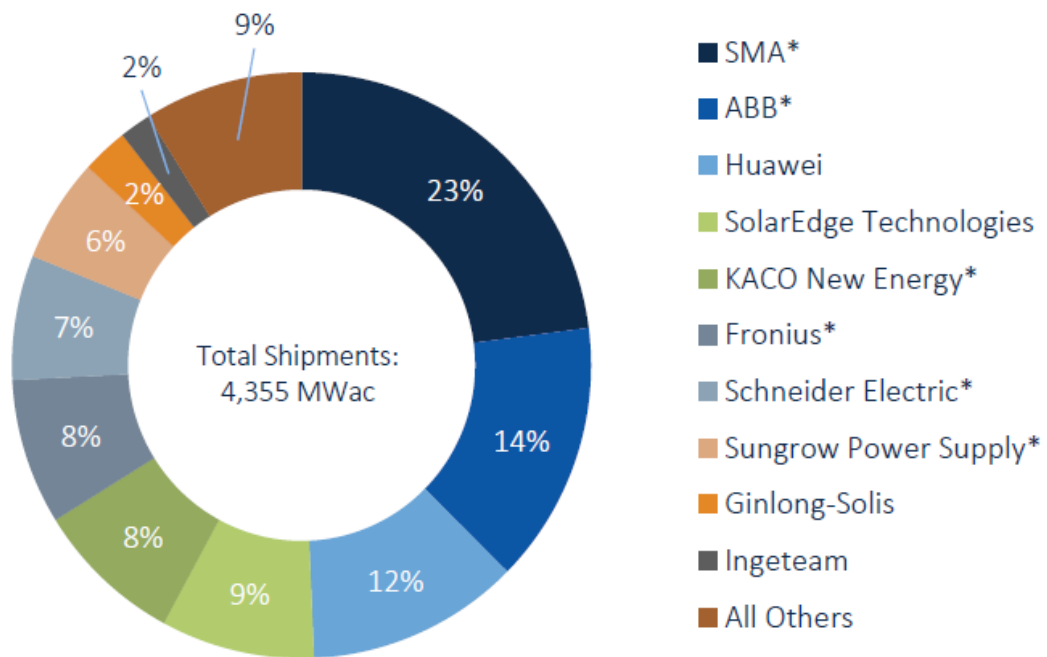
- **Power management:** Module Level Power Management (MLPM) in conjunction with DC optimisers, Maximum Power Point Tracking (MPPT), new power semi-conductor technology (e.g. silicon carbide).

In addition: connectivity, intelligent home energy systems, integrated storage, reactive/active power management.

Feedback from the stakeholder questionnaire (2)

- **Lifespan:** Design life 10 - 20 years.
 - IP (Ingress Protection) standards, salt and ammonia resistance tests.
 - Case design to facilitate heat rejection.
- **Material intensity and raw material use:** Weight to power ratio.
- **Hazardous substance present**
 - Lead-free solder.
 - Practical alternatives to the coolant HFC-134a for larger inverter products (> 1MW).
- **End of life management:** *'typically, defective inverters get refurbished and defective components get recycled or disposed off'*

Competitive analysis (1)



Data source: GTM Research (2018)

Competitive analysis (2)

Three phase string inverters for sub 1MW systems

SMA, ABB, Huawei, SolarEdge Technologies, Fronius and Ginlong Solis
Estimated 67% of the shipped capacity in 2017

high voltage 125kW string inverters (2017): ABB, Sungrow Power Supply and KACO NE

Centralised inverters

KACO NE, Schneider Electric, Sungrow Power Supply and Ingeteam,
Estimated 23% of the shipped capacity in 2017.

Competitive analysis (3)

Micro-inverters

Enphase Energy, AC modules supplied by Jinko Solar, LG and SunPower

Hybrid inverters

- Battery integration: SolarEdge , Huawei and SMA
- Battery: LG Chem

Higher switching frequency inverters

- *Silicon carbide, high voltage:* GE, Delta, SMA, ABB, Fuji Electric, Omron, Sungrow and Schneider Electric
- *Gallium nitride, low voltage:* Yaskawa, Enphase, Tata, SMA and SolPad.

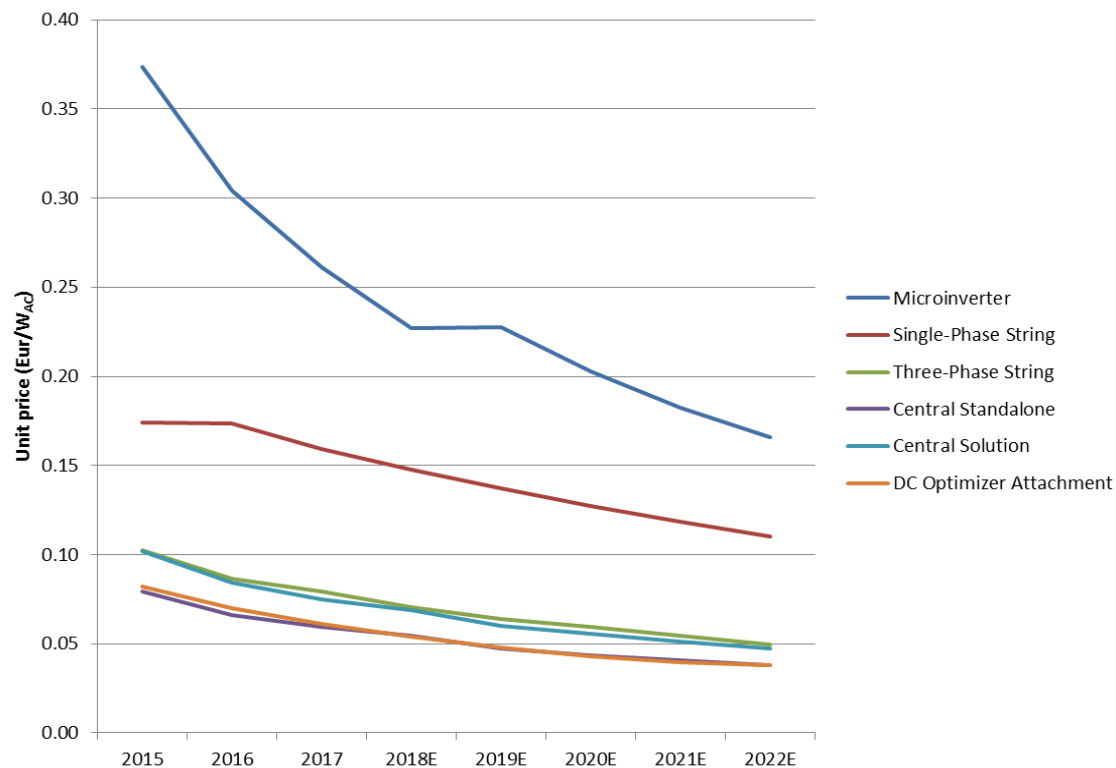
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ENF Solar directory identifies wholesalers (620) and distributors (178)

Consumer expenditure base data



Data source: GTM Research (2018)

System market and stock data

Technology segmentation and base assumptions

- Segmentation follows the one from IEA PVPS
 - **Residential:** systems up to 10 kW
 - **Commercial:** from 10 to 250 KW
 - **Industrial:** Systems above 250 kW,
 - **Utility-scale:** systems above 1 MW, ground-mounted
- Residential PV systems won't be decommissioned unless the roof requires replacing. 47% of electricity generated is self-consumed and the remaining 53% of electricity is exported to the grid
- Commercial and industrial systems may be constrained by factors such as the lifespan of the building itself on the site
- Utility-scale systems developed on 13 to 25 years incentives. They will be decommissioned or repowered after ca . 20 years
- Off-grid systems follow the same pattern as residential systems

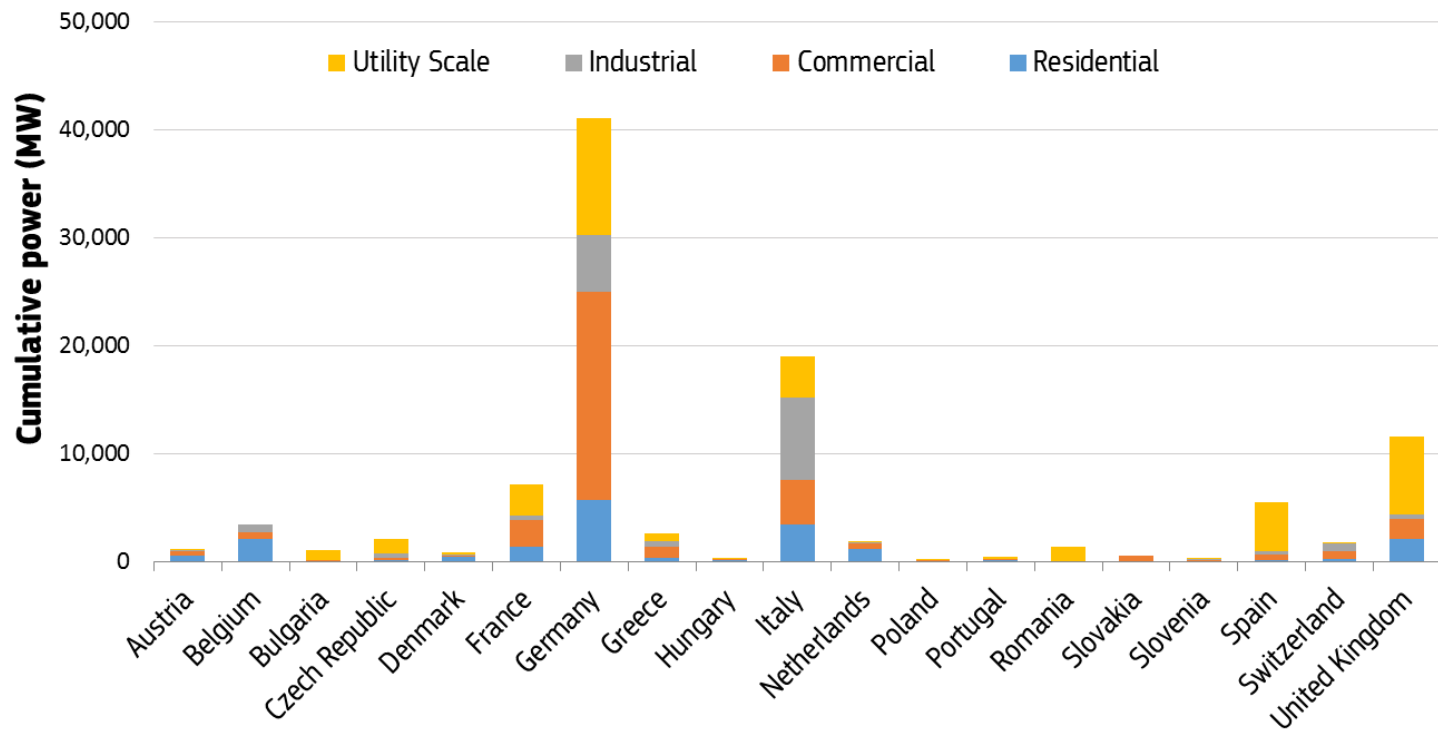
Stock data and forecast

Total new installed **module array capacity** in 2016:
101,788 MW_{DC}

The majority of this stock was accounted for

- **Commercial** (32%) and **ground mounted** (31%) systems:
- **Residential** and **industrial** systems accounted for 19% and 18% respectively

Cumulative Capacity installed up to 2016



Source: Own elaboration with data from Bequerel Institute (2018)

Stock data and forecast

Short term (until 2020)

starting from 107 GW in 2017, the installed capacity in 2020 could reach up to

- 137,5 GW according to the reference scenario
- 146 GW according to the PV Market Alliance high scenario.

Medium term (2020-2030), RES targets two scenarios:

Until 2025, PV Market Alliance scenarios → 281 GW (2:1 ratio PV:Wind)

European Reference scenario → 427 GW in 2030 (starting from 146 GW 2020)

Long term (2030-2050), same methodology as for 2020-30.

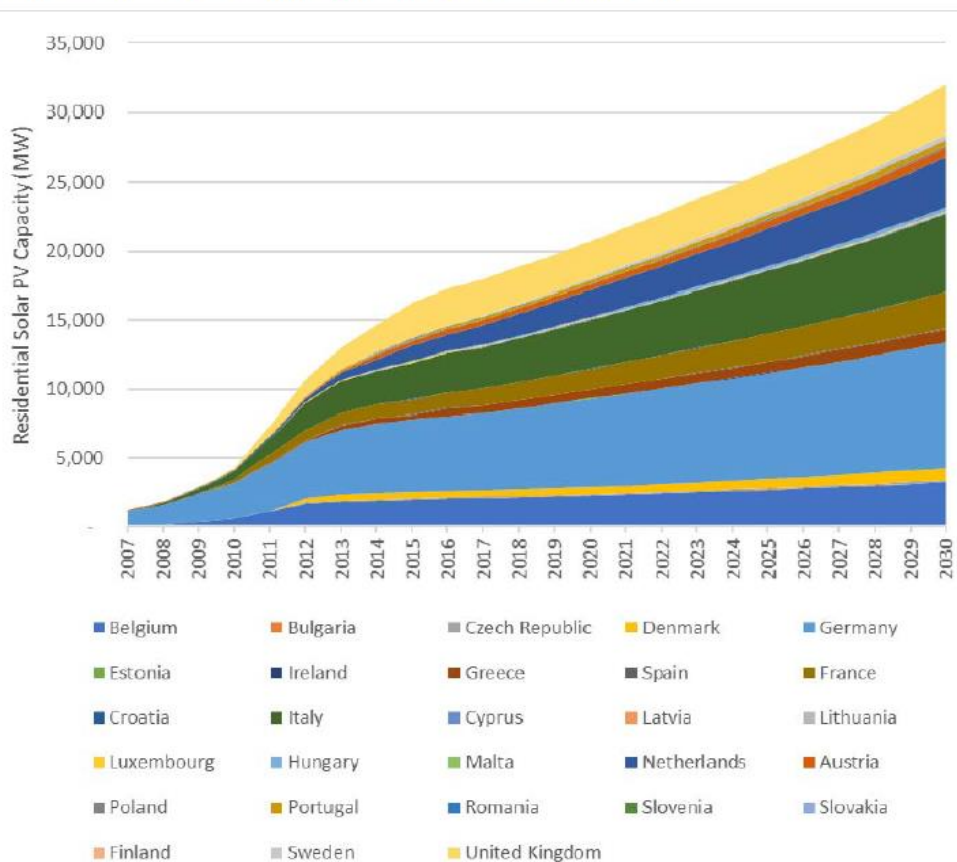
95% of decarbonisation in the electricity sector 2050 → 250 additional GW PV.

System market trends

Market segmentation

0 Generation	1 st Generation	2 nd Generation
PV System Supply	Third-party Ownership and Operation	Full integration
<ul style="list-style-type: none"> • Business models focused on manufacturing, supply and installation of PV systems • End-user is the owner • Utility is largely passive, providing net metering and standard/simplified interconnection, but otherwise, unaffected. 	<ul style="list-style-type: none"> • Business models driven by third parties which develop projects and own PV systems, resulting in: <ul style="list-style-type: none"> –Reduction of hassle & complexity for end-user –Better access to financing –Leveraging of current incentives structure (especially for commercial building applications) • Utility gradually takes on a facilitation role as PV market share grows 	<ul style="list-style-type: none"> • Business models allow PV to become an integral part of the electricity supply and distribution infrastructure • Business models emerge with variation of system: <ul style="list-style-type: none"> –Ownership –Operation –Control • Utility becomes more deeply involved, as PV becomes major consideration • PV product supply chain becomes “commoditized”

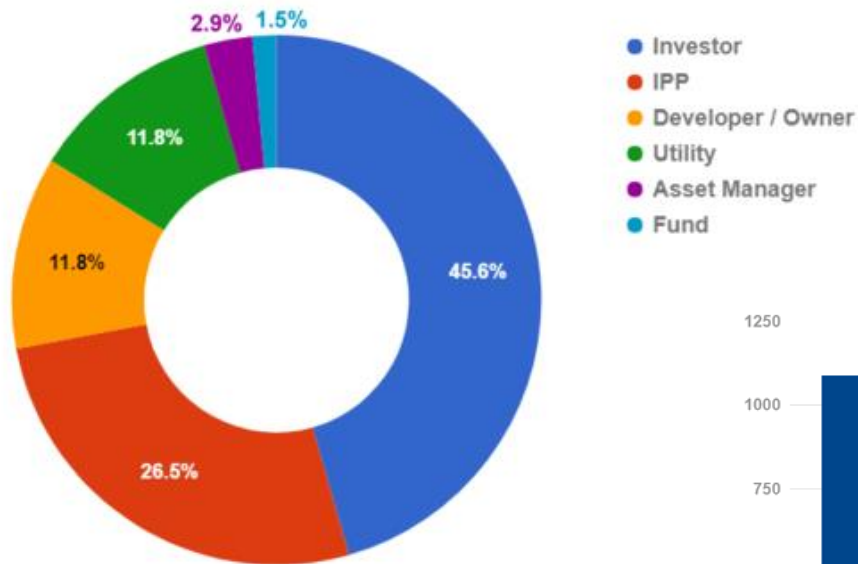
Trends in product design and features (1)



- ✓ Residential and utilities are the two major applications grid-tied PV with 22% and 38% of the total EU capacity

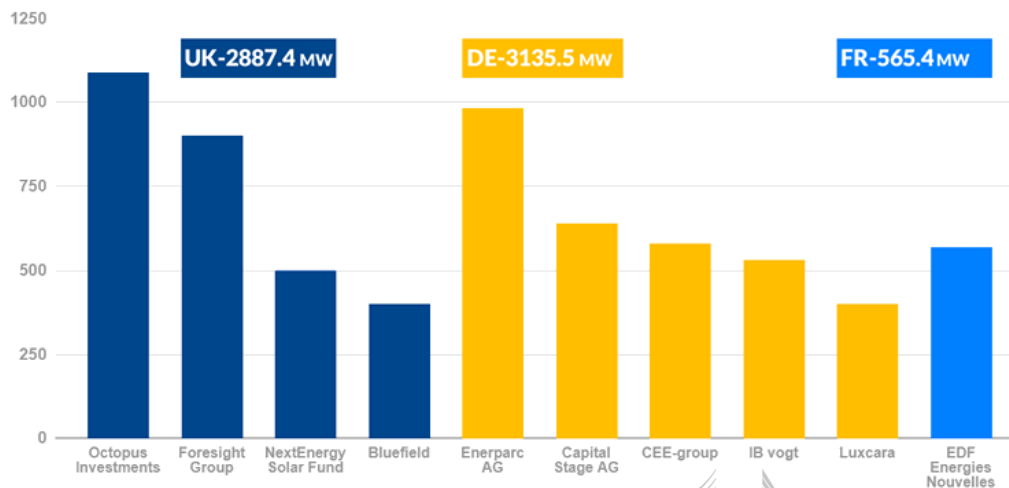
Data source: GTM Research (2018)

Trends in product design and features (2)



Ownership breakdown for the top 70 EU solar investment portfolios

The top 10 EU solar investment portfolios in 2017



Trends in product design and features (3)

Design stage

- **Dynamic** energy **yield** simulation: accuracy for systems with batteries or connected to congested networks
- **Tracking** systems: 1-axis systems will increase the market up to almost 50% by 2020 (ITRPV roadmap)
- Maximise **bifaciality**: array design becomes important
- **Storage** components: greater penetration driven by self-consumption
- **Module** Level Power **Electronics**: micro-inverters and DC optimiser can boost 5-25% overall efficiency
- **Connectors**: use of combiner boxes

Trends in product design and features (4)

Operational stage

- **Monitoring** and data analytics: artificial intelligence and machine learning to verify system performance
- Operation and **maintenance** services: in large PV systems preventive and corrective maintenance contracts

	Operation & Maintenance services
System Health Check	Visual & physical check of all module connectors
Solar Panel Cleaning	Specialist brushes clean and rinse panels thoroughly without damaging delicate hydrophobic coatings
System Upgrades	Air Source Heat Pumps

Feedback from the stakeholder questionnaire (1)

- **Design and optimisation**
 - five dynamic simulations of yield to consider 'real' ambient conditions.
 - spectral response based on real conditions within energy yield simulations.
 - module Level Power Electronics
- **Installation quality and performance:** monitoring and installation quality.
- **Active self-consumption**
 - Demand side management, attention to whole home platform standards
 - Collective self-consumption and micro-grids.
- **Energy storage:** battery storage is at the state of the art and PV systems contribution to the grid stabilisation

Competitive analysis

Storage components of Balance of System

SolarEdge, Huawei, SMA are already offering **inverter level** power electronics that **support battery** integration

Germany leading, with more than 75.000 PV + storage systems by the end of 2017

Tracking systems

Among the **top five** tracker **manufacturers** companies globally, **two** are European, Soltec (SP) and Convert Italia (IT). Both had **12%** of the global shipped capacity in 2017.

Connectors

Main EU company is Multi-Contact AG. Unfair competition from counterfeit products from Asia

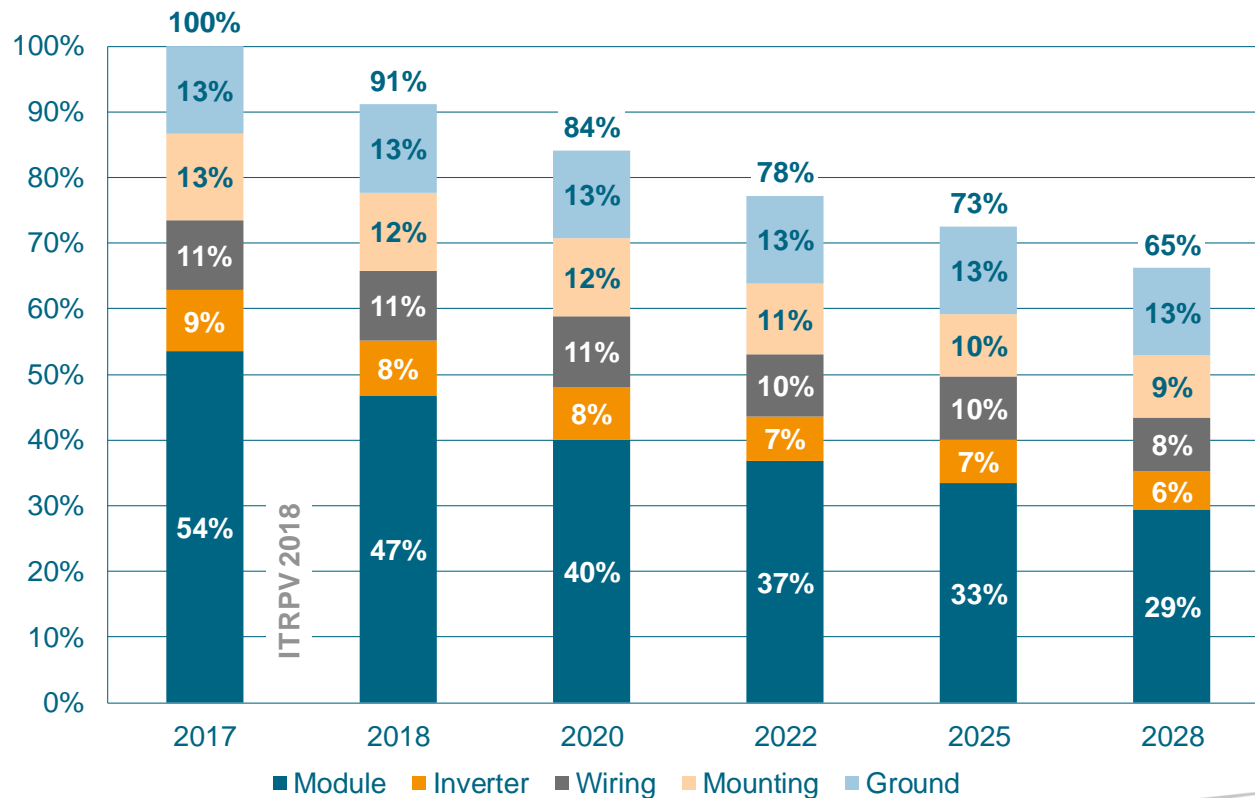
Channels to market

Quite diverse nature depending as well on the system type (R, C, U)

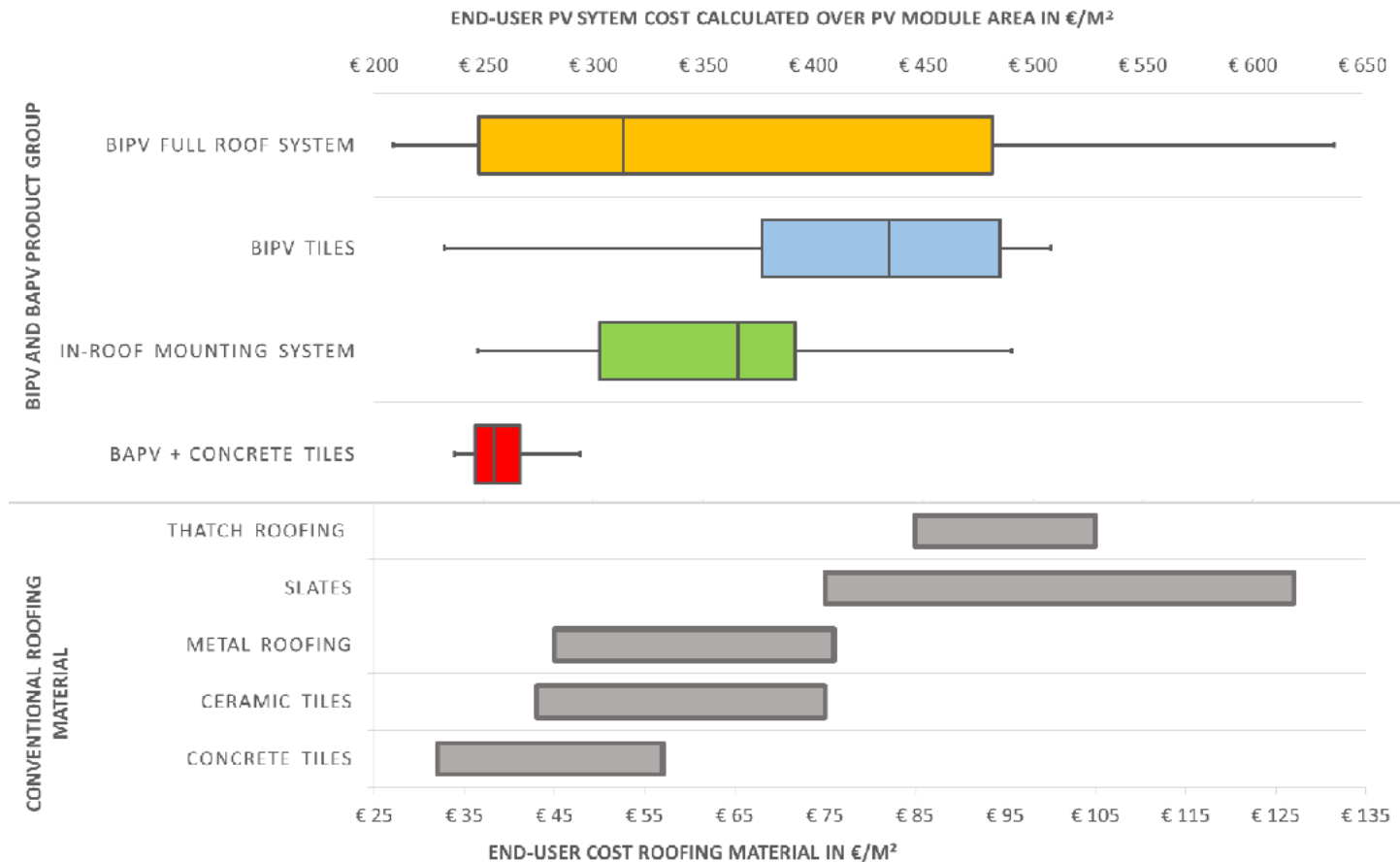
- Project developers and engineering procurement and construction (EPC) companies
 - normally present in large installations
 - In MS as Germany, Spain, the UK, Austria, France and Portugal
- Sales via **local subsidiaries**
 - Generally systems >100kW
- Sales via **distributors** then to installers, potential OEM/rebranding
 - Smaller systems, well established companies e.g. Krannich Solar
- **New channels?** utilities, retailers, household brands broker link between brands and installers

ENF Solar directory identifies wholesalers (620) and distributors (178)

Consumer expenditure (1)



Consumer expenditure (2)



Consumer expenditure (3)

Item	Labour	Costs		Cost share
	[person-hours]	[EUR]	[EUR/kW _p]	[%]
PV module costs				
Module (Si crystalline, Dec. 2013)	-	3000	600	37.8
"Hard" deployment costs				
Inverter (Dec. 2013)	-	1150	230	14.5
Mounting system	-	700	140	8.8
Cabling	-	100	20	1.3
"Soft" deployment costs and related transaction costs				
Customer acquisition (sales calls, site visits, system design, bid preparation, contract negotiation) *	5	175	35	2.2
Administrative processes related to building law*	0.67	23	5	0.3
Administrative processes related to grid connection permit*	1.5	53	11	0.7
Installation of PV system*	45	1575	315	19.9
Grid connection and commissioning*	2.5	88	18	1.1
Marketing and advertising		72	14	0.9
Overhead & profit installer firm		993	199	12.5
SUM		7929	1586	100
Time provided by building owner/client				
Information search	unknown	-	-	-
Site visit with installers	unknown	-	-	-
Contract negotiation with PV installer firm	unknown	-	-	-
Administrative processes related to financing	1	-	-	-
Corporate legal fiscal work	0.08	-	-	-
Registration to the federal Network agency	0.16	-	-	-
SUM	1.24	-	-	-

PV system trends and competitive analysis

Stakeholder consultation points

- 2.1. Are there any significant trends that haven't been captured for PV modules, inverters and systems?
- 2.2. Is there any trend amongst those presented for PV modules, inverters and systems that you do not agree with? If so, please give your reasoning.
- 2.3. Does the description of routes to market for PV systems match the experience across different EU Member States?

Further information on

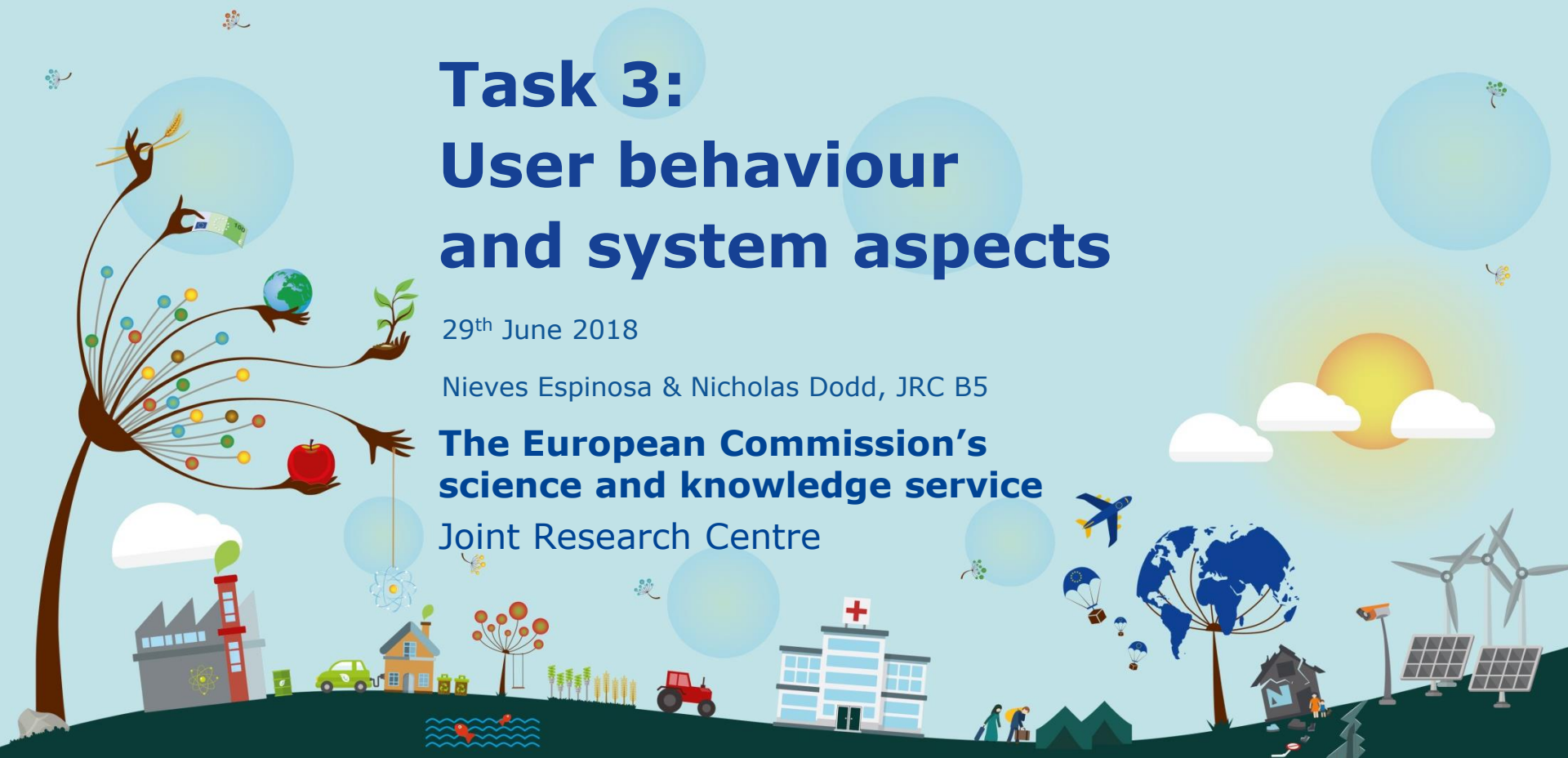
- Market segments anticipated to create demand for the new Si technologies
- Monitoring and data analytics, and O&M services
- BIPV products trends, products segmentation

Task 3: User behaviour and system aspects

29th June 2018

Nieves Espinosa & Nicholas Dodd, JRC B5

**The European Commission's
science and knowledge service**
Joint Research Centre



European
Commission

Task 3

Use behaviour and system aspects

Background: Relevant user and system parameters are an important input for the assessment of the environmental impact of a product during its life cycle

Aim of this task:

- analyse users, procurers and installers **behaviour and practices**;
- identify recent **changes and trends**;
- understand to what extent they are captured by the **existing regulations and standards**;
- provide **inputs and assumptions** for the assessment of the environmental impact and cost, and how the standard measurement conditions may vary.

Photovoltaic users, procurer requirements

The motivations and requirements of owners or end-users

- **Ownership by energy producers only:** Larger systems that have won bidding processes for electricity price subsidies.
- **Independent power producers (IPP):** Entities responsible for developing, building and operating solar PV plants.
- **Third party ownership by Energy Service Companies (ESCO):** Lease or access rights are negotiated for land or roof sites .
- **Ownership by 'prosumers':** Users are both producers and consumers, at the same location or as part of a community of self-consumers.

Prosumer role becoming increasingly important because of a reduction in subsidies.

Photovoltaic users, procurer requirements

Ownership	Application				
	BIPV/BAPV Residential buildings		BIPV/BAPV Non-residential buildings		Ground mounted systems
	New Building	Building retrofit	New building	Building retrofit	
Prosumers	● ● ●	● ●	● ● ●	● ●	○
Energy producers only Self-owned	● ●	●	● ●	●	● ● ●
Energy producers only Third party	●	○	● ●	●	● ●

● ● ● : well established and promoted by the Energy Performance of Buildings Directive (EPBD)
 ● ● : well established
 ● : emerging
 ○ : minimal activity

Other public and private stakeholders

Important influence and power over the decisions and processes

- **Central and regional government:** Support mechanism at the point of making an investment and during a systems service life
- **Municipalities:** Building permitting requirements require Nearly Zero Energy performance, increasing focus on BAPV/BIPV
- **Banks and investors:** Project finance or equity investment come with due diligence requirements *e.g. system and component-level certification and quality assurance*
- **Electricity distribution utilities:** Impose financial and regulatory requirements on the system owner, end-user, contractors

Consumer requirements for PV systems (1)

Major consumer market testing exercises:

CLEAR project (2014), DG Justice (2017)

- Importance of financial savings relative to their current electricity source.
- Other factors?
 - Capital and running costs,
 - the payback time,
 - Aesthetics upon installation on their property
- Potential to reduce their environmental impact an important, but secondary, driver

Consumer requirements for PV systems (2)

Important factor at the design stage:

estimation of a systems annual AC energy yield

- Entails an understanding of
 - a system's Performance Ratio, as defined in IEC 61724-1,
 - the annual solar irradiation for the location
 - Use of automated simulation tools and pre-defined packages of modules and inverters.
- Forms part of the quotation process for installers and retailers.

Other considerations?

Aesthetics, longer term maintenance, access for cleaning and repair/replacement

Consumer requirements for PV systems (3)

EU consumer organisations provide advice on the installation of PV systems, as well the purchase of modules and inverters.

- Own in-house performance testing and auditing of products
- Varying and sometimes non-standard methods and metrics
- Supporting checklists for contracting installers

Test Achats (Belgium), Which? (UK)

- ✓ Audit PV manufacturers factory quality procedures and check production samples

OCU (Spain)

- ✓ Field tests and rates PV module and inverter kits in comparison to manufacturers claims.

Public procurement criteria and requirements (1)

Calls for tender may include four main types of criteria:

- **Selection Criteria (SC):** These criteria refer to the suitability and capability of the tenderer.
- **Technical Specifications (TS):** These criteria constitute minimum compliance requirements that must be met by all tenderers..
- **Award Criteria (AC):** At the award stage, the contracting authority evaluates the quality of the tenders and awards points that will have a weighting together with the price bid.
- **Contract Performance Clauses (CPC):** These clauses are used to specify how a contract must be executed and they may be linked to penalties or bonuses in order to ensure compliance.

Public procurement criteria and requirements (2)

Initial evidence from a [search of tenders published in OJEU](#) and example calls for tender and contracts.

- [Award of points](#) and establishment of [performance clauses](#) on the basis of:
 - AC output power,
 - warranty length,
 - failure response services and
 - availability of spare parts.
- [Monitoring](#) of performance upon grid connection had also been specified.
- Some evidence of [PV services](#) on the basis of Power Purchase Agreements (PPAs), energy service agreements and community investment funds.

Photovoltaic users, procurers and requirements

Stakeholder consultation points

- 3.1 Of the consumer motivations and requirements identified **which do you consider the most important to take into account in our PV system and component modelling?**
- 3.2 Of the performance aspects addressed by EU consumer organisation **which do you consider the most important to take into account in our PV system and component modelling?**
- 3.3 Are you aware of any studies or information sources on **the types of PV contracting used by public authorities?**
- 3.4 In the case that you have participated in a call for tenders for a public authority relative to solar photovoltaics, **what were the technical criteria?**

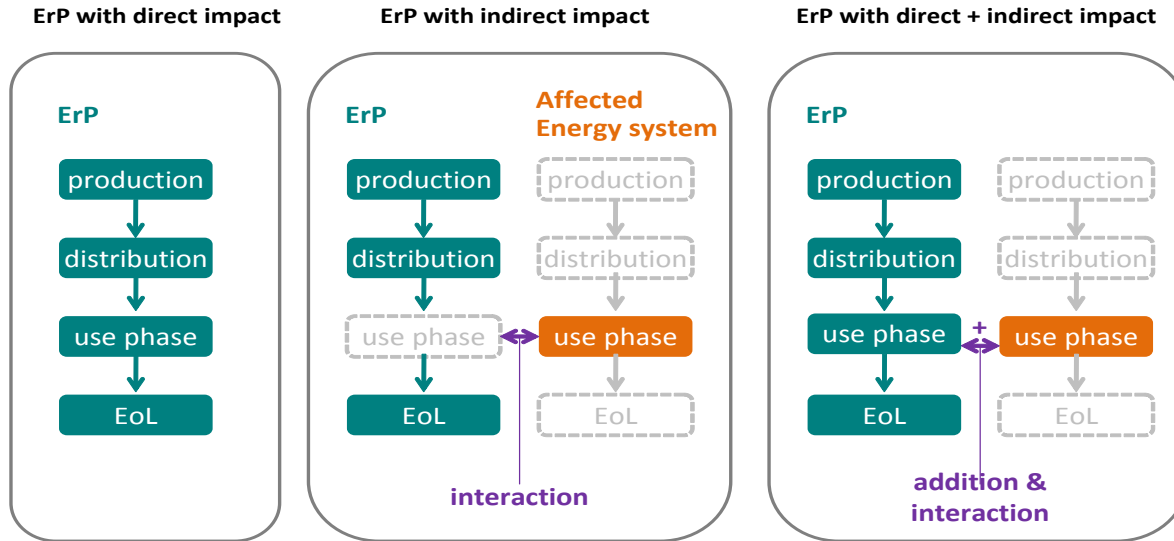
Photovoltaic users, procurers and requirements

Requests for information/case studies

- Further examples of **consumer organisations** that carry out testing and audits of PV systems and components
- Further examples of **public authority calls for tender** and the associated technical specifications for solar PV installations are requested.
- Further examples of the inclusion of **Green Public Procurement criteria** in calls for tender for solar PV installations are requested.

System aspects in the use phase of solar PV

MEErP concept: analysis of the direct and indirect impacts of an Energy related Product (ErP) on associated energy systems.



Source: COWI and VHK (2011)

Direct impacts on energy production (1)

Solar PV is an energy generating product

Proposed approach

Consider direct impacts in negative terms i.e. those parameters that may constrain or reduce the amount of electricity generated during the use phase, or which may be considered as direct losses from a system.

Implication?

Attention on system design and specification decisions which can have a direct impact on the performance of a module, inverter or system.

Direct impacts on energy production (2)

Impact identification

Proposed as being taken into account in the modelling of base cases and scenarios in subsequent tasks:

- Performance Ratio (PR), which is the quotient of the system's final yield Y_f to its reference yield Y_r , and indicates the overall effect of losses
- Derate Factors (DR_x) to disaggregate the Performance Ratio:
 - DR_{capture} for capture losses
 - DR_{BOS} for Balance of System losses
- In plane irradiation(H_i) [kWh/m²] over the specified time period

Reference standard: IEC 61724-1:2017

'Derate' factors for a PV system

Derate Factor (DF) Performance Ratio = $DR_{capture} \times DR_{BOS}$	PV system		Extended Product (non STC)		Strict product (STC)	
	overall	detailed	overall	detailed	overall	detailed
array capture losses derating	$DR_{capture}$	-	-	-	-	-
shading losses	-	$DR_{shading}$	-	-	-	-
snow cover losses	-	DR_{snow}	-	-	-	-
soiling losses	-	SL	-	-	-	-
DC array cable losses	-	$DR_{arraywr}$	-	-	-	-
array mismatch losses	-	DR_{mism}	-	-	-	-
optical reflection losses	-	DR_{refl}	-	-	-	-
other module level capture losses	-	$DR_{cap-mod}$	$DR_{cap-mod}$	-	-	-
module thermal capture loss	-	-	-	DR_{therm}	-	-
module degradation capture loss	-	-	-	DR_{degrad}	-	-
optical reflection losses	-	-	-	DR_{refl}	-	-
spectral effects	-	-	-	DR_{spect}	-	-
module derating at STC	-	-	-	-	1	-
Balance of system (BOS) efficiency	DR_{BOS}	-	-	-	-	-
AC wiring losses	-	$DR_{ac wire}$	-	-	-	-
AC transformer losses (if available)	-	DR_{trafo}	-	-	-	-
losses due to network availability (curtailment)	-	DR_{curt}	-	-	-	-
losses due to inverter failures (drop out)	-	$DR_{inv-fail}$	-	-	-	-
inverter losses (= $DR_{inv-nst} \times \eta_{inv}$)	-	DR_{inv}	-	-	-	-
derating non standard inverter total	-	-	$DR_{inv-nst}$	-	-	-
derating non standard inverter loading	-	-	-	$DR_{inv-loading}$	-	-
derating non standard MPPT transients	-	-	-	$DR_{inv-MPPT}$	-	-
total inverter efficiency standard conditions	-	-	η_{inv}	-	η_{inv}	-
static inverter converter efficiency	-	-	-	-	-	η_{conv}
MPPT inverter efficiency	-	-	-	-	-	η_{MPPT}

Standard Test Conditions (STC): irradiation: 1000 W/m², temperature: 25°C, air mass: 1.5

Non-Standard Test Conditions (Non-STC)

MEErP approach: system definition and modelling

Four different approaches interpreted and applied to a PV system as the 'product'

1. Strict product approach
2. Extended product approach
3. Technical system approach
4. Functional approach

Initial scoping: current system design, yield estimation, operation, monitoring and maintenance practices in the market

Assumptions derived from these real-life practices will play an important role in the later modelling

1. Strict product approach

Description: System boundary only contains the PV installation with its components. The operating conditions are nominal as defined in traditional standards.

Technical implications?

- Modelling of a PV systems performance shall be carried out under Standard Test Conditions (STC) as defined in IEC 61853-1
- Standardised methods of estimating a PV modules efficiency and yield under STC, as well as the inverter conversion and MPPT efficiency according to a standard load profile.

Proposed modelling basis

Module component

- 'Maximum Power at STC' P_0 [kWp] Input parameter for estimating the annual PV system yield(Y_f).
- 'Module Efficiency' η_A [%] conversion efficiency of solar radiation.

Inverter component

- Overall efficiency (η_t) ratio of AC energy output to the theoretically available energy in the Maximum Power Point (MPP).
- Conversion efficiency (η_{CONV}) ratio of the AC energy output to the DC energy input. Standard load profiles, static efficiency measure.
- MPPT efficiency (η_{MPPT}) ratio of the energy drawn by the device under test to the energy provided theoretically by the PV simulator

2. Extended system approach

Description: Influence of real-life deviations from standard conditions introduced, such as local weather data for a chosen location.

Technical implications?

- Weather data representative for the location shall be used to estimate the final system yield in comparison to a reference yield.
- A reference source of solar radiation data, ambient temperature and wind speed data is required.
 - Hourly time interval, Typical Meteorological Year (TMY), 20-30yr time series.
- The use of representative climate data will enable more accurate modelling of module capture losses due:
 - Derate factors: temperature, spectral mismatch, reflection and degradation

Proposed modelling basis

To be considered within the **transitional methods**:

- Impact of **real life weather conditions** on the final system yield (Y_f) +/-5%
- Module capture losses due to **temperature impact** (DR_{therm}) 5-11%
- Module capture losses due to **spectral differences** (DR_{spect}) 1-1.5%
- Module capture losses due to **reflection and angle of incidence** (DR_{refl}) 2.6-3%
- The impact from module **degradation over life time** (DR_{degrad}) up to 1%/yr
- The impact from inverters operating in **non-standard conditions** ($DR_{\text{inv-ns}}$)

3. Technical system

Description: PV system is embedded in the building system or site, with scope for interactions between supply and demand for electricity

Technical implications?

- Factors related to the **urban siting** of the PV system shall be described *e.g. shading, soiling, low voltage cabling losses*.
- Grid related **curtailment and system failures** will inform assumptions about potential downtime.
- **System failures** could include catastrophic module or inverter failures, necessitating a probabilistic assessment of reliability.
- A knowledge of **operational, monitoring and maintenance practices** *e.g. maintenance to clean module soiling, fault identification to prioritise repairs or replacements*.

Proposed modelling basis

Extension to other factors, some beyond a yield calculation:

- The impact from **shading** (DR_{shading})
- The impact from **soiling** and regular cleaning (SL)
- Impact of other **PV system losses** in cables and transformers *behind the meter* (DR_{acwire} and DR_{trafo})
- Impact from system unavailability due to **grid curtailment** and other **system failures** (DR_{curt})

Influencing factors? Optimisers, O&M procedures, BoS design and junction box/inverter configurations, storage losses

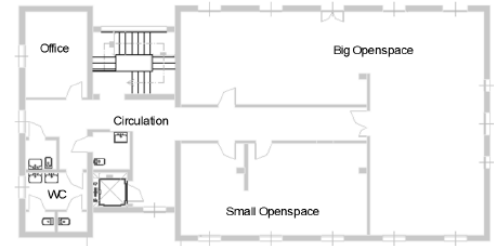
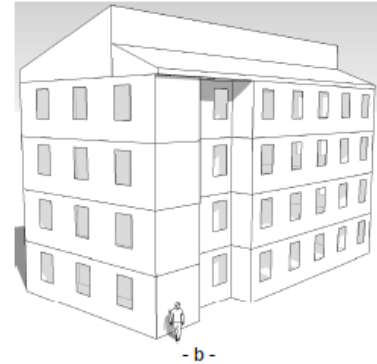
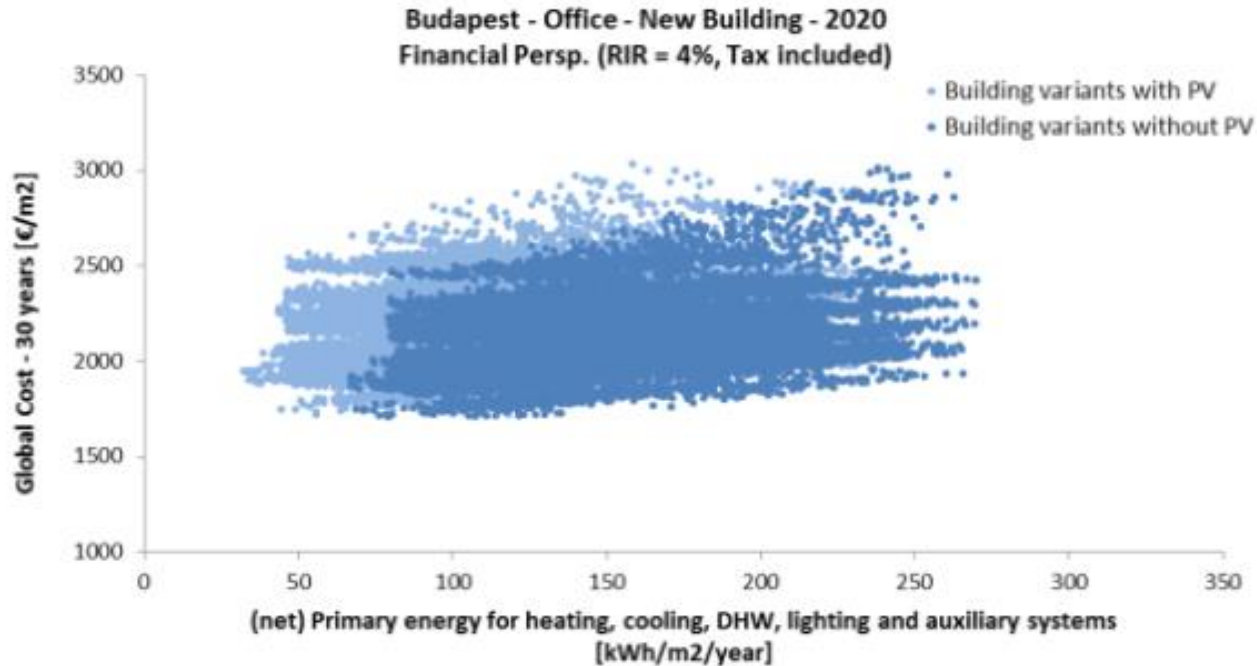
4. Functional approach

Description: Focus on only the basic functions of a photovoltaic system, i.e. producing renewable energy and reducing CO₂ emissions, in comparison with other building technical systems that can satisfy the same functions.

Technical implications?

- For BAPV and BIPV, solar PV shall be compared with different building technical systems that may be used to deliver either:
 - a specific level of **reduction in primary energy use and CO₂ emissions**, or
 - to supply a **specific proportion of a buildings energy from renewables**, or
 - To substitute the **consumption on-site of a specific grade of energy** e.g. heat for domestic hot water

Proposed modelling basis



Source: Ecofys et al (2012)

Indirect impacts from solar photovoltaics (1)

Solar PV is an energy generating product

Proposed approach

Consider indirect impacts as positive impacts from the produced electricity due to the substitution effect of average electricity. Other indirect impacts are e.g. local on-site production indirectly reducing transmission and distribution losses.

Implication

Attention on the context or affected system onto which the PV can have an indirect impact.

Indirect impacts from solar photovoltaics (2)

Impact identification

Proposed as being taken into account in the modelling of base cases and scenarios in subsequent tasks:

- Environmental impacts due to substitution of non-renewable electricity with PV electricity
- Transmissions and distribution losses associated with the grid
- Increased need for demand side management or for grid storage
- Increased use of storage and therefore losses
- Ancillary grid support, e.g. congestion management.
- Substitute hot water production with fossil fuel in a building.
- Provide renewable energy for local consumption (HVAC, home appliances, etc., ..)

Substitution effect of grid electricity

Description

Avoided environmental impacts due to the substitution of non-renewable electricity with photovoltaic energy.

Technical implications

- Modelling of the substitution of the average EU impact resulting from the generation of 1 kWh of electricity
- For a more accurate modelling the hourly or half hourly grid mix for a specific Member State should be used

Substitution effect of grid electricity

Metrics

- **Primary Energy Factor:** non-renewable and renewable primary energy divided by delivered energy, where the primary energy is that required to supply one unit of delivered energy, incl. the energy required for extraction, processing, storage, transport, generation, transformation, transmission, distribution, and any other operations necessary for delivery to the building in which the delivered energy will be used.
- **Global Warming Potential (GWP):** term used to describe the relative potency, molecule for molecule, of a greenhouse gas, taking account of how long it remains active in the atmosphere.

Modelling purposes, the MEErP tool uses "Primary Energy" as defined in the EED (2012/27/EU) means gross inland consumption, excluding non-energy uses.

Distribution and transmission grid losses

Description

Transmissions and distribution losses associated with the grid transport of electricity. Ancillary grid support in order to curtail generation and adjust the grid frequency in order to manage asynchronous generation.

Technical implications

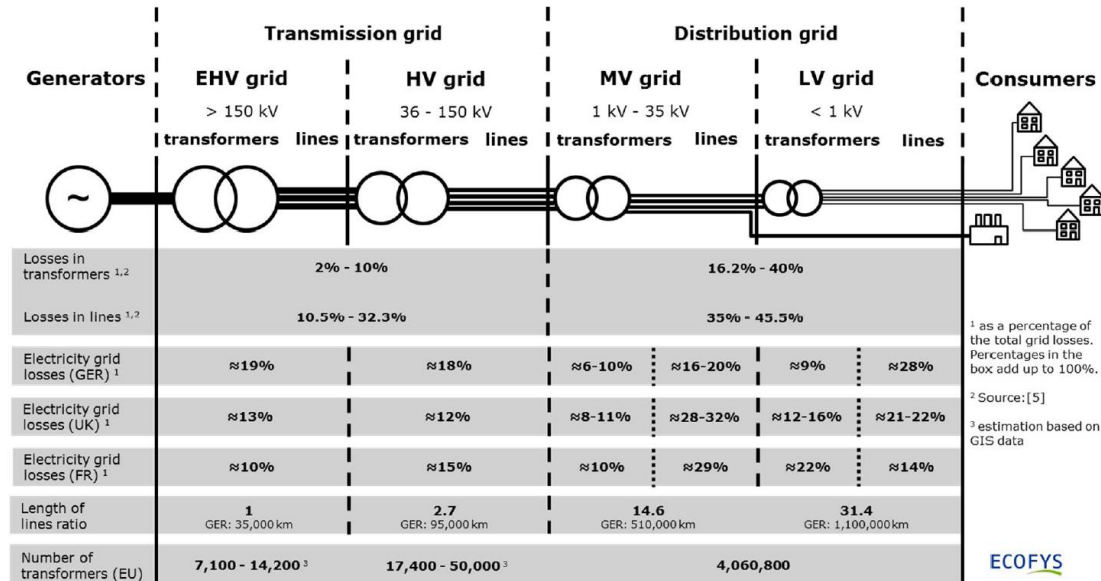
- Modelling of the solar PV electricity generation under low, medium and high grid penetration scenarios because of the variance in anticipated grid losses.
- Consideration of the potential role of inverters which provide grid ancillary services e.g. reactive power to avoid congestion and frequency mismatches.

Losses in transmission and distribution networks

Country	Average % of losses in TNs	Average % of losses in DNs
France	2.3%	5.0%
Austria	1.5%	4.5%
Czech Republic	1.5%	7%
Slovakia	1%	8.3%
Romania	2.6%	13.5%

- ✓ For high PV penetration rates it is practically a better option to install grid scale PV compared to residential PV in order to keep grid losses low and/or to avoid congestion.
- ✓ **Base case:** no impact on grid losses (+/- 2 % can be used in a sensitivity analysis)

Losses in TN and DN based on voltage level



Sources: Own illustration based on BMWI 2014, Eurelectric 2013, Waide Strategic Efficiency Limited 2014, Tennen 2013, Thüringer Energienetze 2013, BNetzA 2014, Cired 2013, Schneider, Ofgem, Energia 2013 GIS data

¹ as a percentage of the total grid losses. Percentages in the box add up to 100%.

² Source:[5]

³ estimation based on GIS data

ECOFYS

✓ Demand Response (DR) can evidently further reduce distribution grid losses (<0,2%)

Demand side management and self-consumption

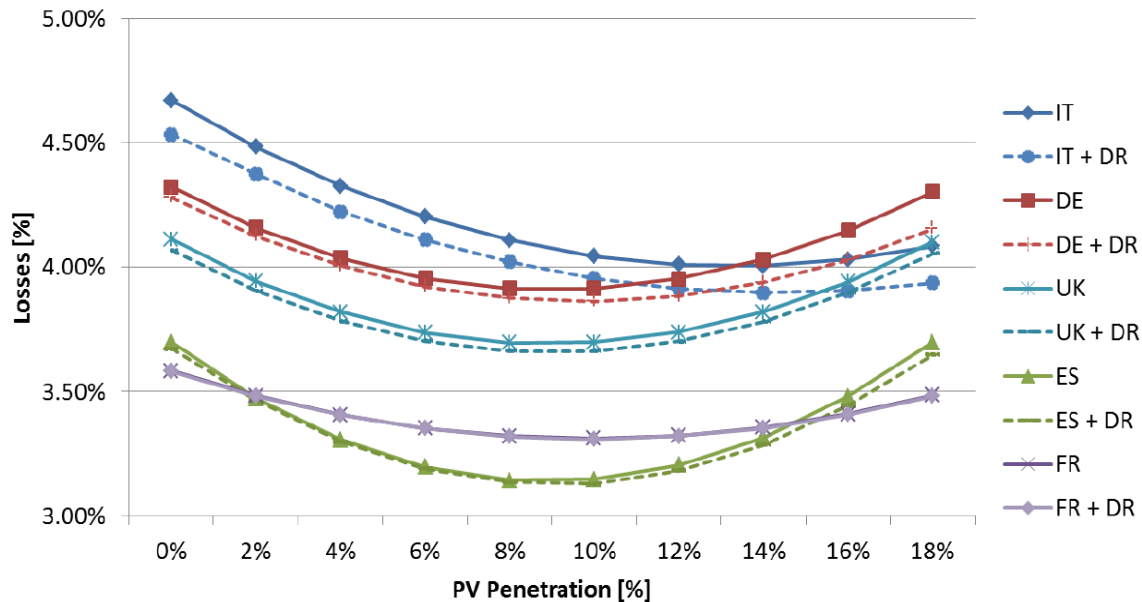
Description

Reshaping load profiles for a better load matching with the supply. PV system integrated or grid level storage in order to load match within a 12-24 hour period of time

Technical implications

- Consideration of demand response at building level as a means of maximising self-consumption and minimising grid losses.
- Measures to maximise self-consumption could comprise smart monitoring systems, the use of optimisers, smart appliances and battery storage

PV penetration combined with Demand Response



(source: PV Parity project)

✓ Demand response for local consumptions is evidently the most efficient solution and can reduce grid losses and provide also a good value proposition

System aspects in the use phase of solar PV

Stakeholder consultation points

- 3.5 Should the **direct and indirect impacts** be interpreted in any different way?
- 3.6 Should the **scope of the direct impacts** and the proposed derate factors be modified in anyway? (see table 5, page 24)
- 3.7 Do you agree with the **product approaches** as proposed to be addressed within the modelling of PV systems and components? (see Table 16)

System aspects in the use phase of solar PV

Stakeholder consultation points

- 3.8 Do you agree that a comparison of solar PV with other building technical systems that can deliver renewable energy of primary energy reductions, referred to as the 'functional approach', **can be left out of the scope?**
- 3.9 Should the **scope of the indirect impacts** be modified in anyway? (see Table 17)
- 3.10 For the purpose of PV system modelling 3-4 climate zones shall be defined and a location selected for each – **which zones and locations would be the most representative?** (see table 6, page 29)

End of life behaviour

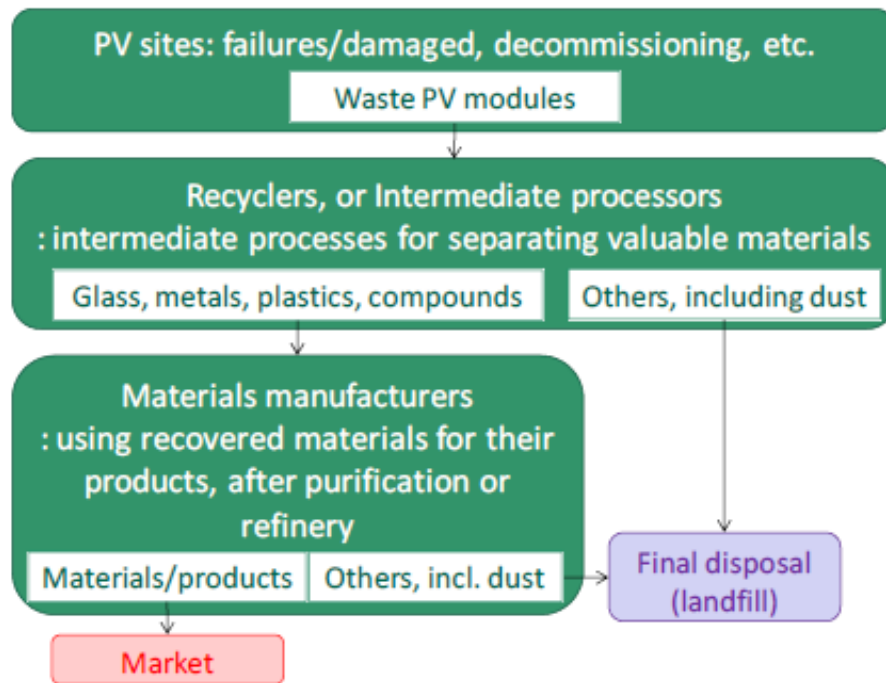
Description

Due to the long life time of PV modules (>20 years) and inverters (>10 years), reliable and representative data for these tasks is not yet readily available.

Technical implications

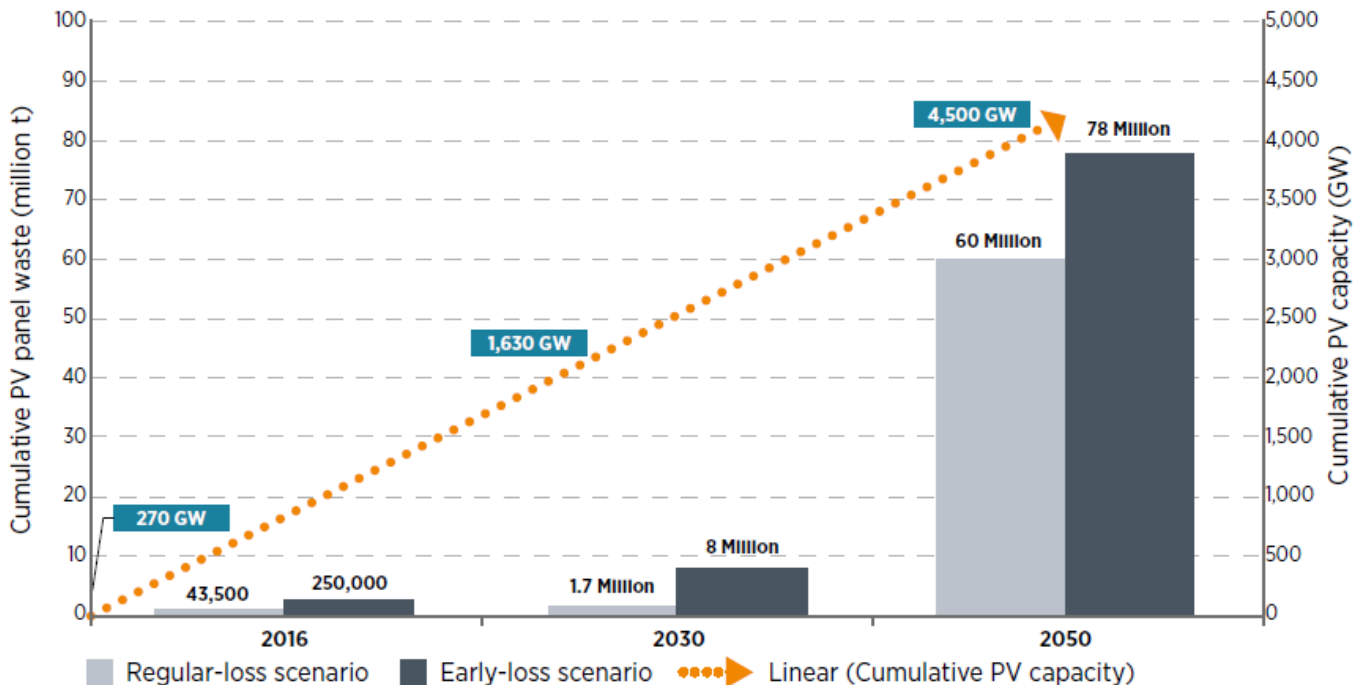
- Recycling and disposal practices and the collection
- Module and inverter technical lifetime, degradation and failure mechanisms.
- Repair, refurbishment and second hand use of PV systems

General flow of the EoL treatment of waste PV modules



Recycling & disposal practices – waste projections

Overview of global PV panel waste projections, 2016-2050



Recycling & disposal practices – EU

- ✓ In the framework of WEEE Directive, EU countries are setting up PV module recycling take back schemes such as PV CYCLE.
 - ✓ 2500 tonnes of solar module waste (Si based) was generated in 2016 in the EU (WEEE calculator tool)
 - ✓ Ca. 15 000 tonnes of waste PV modules were collected by the end of 2016 by PV CYCLE,
 - ✓ and most of them were Si-based PV modules
- ✓ Estimates available till 2020 → 5000 tonnes of solar module waste (Si-based)



Repair, refurbishment & second hand use

Typical damages

- ✓ faulty bypass diodes and connectors
 - ✓ punctured backsheets
 - ✓ damaged frames
- The 'healing' of PV modules affected by Potential Induced Degradation (PID) is also offered by some companies
 - Two years warranty on the reparation

Common failures that cannot be repaired

- ✓ linked to damaged cell connections
- ✓ delamination of the encapsulant
- ✓ glass breakage

End of life behaviour

Stakeholder consultation points

- 3.11 Does the analysis of technical lifetime, degradation and failure reflect **current feedback from the field**?
- 3.12 Does the analysis of technical lifetime, degradation and failure reflect **current assumptions used in business cases**?
- 3.13 Are there **any other aspects of performance** that should also be addressed? *If yes, please cite your supporting evidence.*
- 3.14 To what extent are these **repair practices and services** available 1) in other Member States, 2) available to consumer PV system owners?
- Further examples of **repair, remanufacturing and repowering practices** and companies are requested.

Tasks 4-6: Base cases and scenarios for improvement proposal

29th June 2018

Nieves Espinosa & Nicholas Dodd, JRC B5

**The European Commission's
science and knowledge service**
Joint Research Centre



European
Commission

MEErP methodology

Task4 Technical Analysis + EoL

- Tech. product description

- Base cases, BAT & BNAT

-Production, distribution

- Bill of materials BoM
- Material efficiency
and EoL**

Task5 Environmental and economic assessment

- Base case environmental & economic assessment

- MEErP, Ecoreport tool
- LCOE

- Identification of environmental hotspots

- LCA review
- EU Ecolabel and GPP
criteria

Task6 BAT assessment & improvement potential

- Design options identification

- Cost estimations

- BAT and LLCC assessment

- Long term potential (BNAT)

- Tests and standards for
verification
- Improvement potential
of EU Ecolabel and GPP

Ecoreport tool

Basic **Macro Security** Add-Ins Mode **Multi-User** **Microsoft Lists** Panel **Modify**

Code Add-Ins Controls XML

E16

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Version 3.06 VBE for European Commission 2011, modified by IZM for european commission 2014													
EcoReport 2014: OUTPUTS Assessment of Environmental Impact													

Eco-DESIGN OF ENERGY-RELATED PRODUCTS

Life Cycle Impact (per unit) of Products

Nr	Life cycle impact per product:	Reference year	Author
0	Products	2014 vnk, izm	

Life Cycle phases -->

	Material	PRODUCTION			DISTRIBUTION	USE	END-OF-LIFE			TOTAL	RBR
		Manuf.	Total				Disposal	Recycl.	Stock		
Materials											
1	Bulk Plastics	g	0	0	0	0	0	0	0	0	0
2	Tec/Plastics	g	0	0	0	0	0	0	0	0	0
3	Fero	g	0	0	0	0	0	0	0	0	0
4	Non-fero	g	0	0	0	0	0	0	0	0	0
5	Coating	g	0	0	0	0	0	0	0	0	0
6	Electronics	g	0	0	0	0	0	0	0	0	0
7	Misc.	g	0	0	0	0	0	0	0	0	0
8	Extra	g	0	0	0	0	0	0	0	0	0
9	Auxiliary	g	0	0	0	0	0	0	0	0	0
10	Refrigerant	g	0	0	0	0	0	0	0	0	0
Total weight											
Other Resources & Waste											
11	Total Energy (ISER)	MJ	0	0	0	0	0	0	0	0	0
12	of which, electricity (in primary MJ)	MJ	0	0	0	0	0	0	0	0	0
13	Water (process)	l	0	0	0	0	0	0	0	0	0
14	Water (cooling)	l	0	0	0	0	0	0	0	0	0
15	Waste, non-haz./landfill	g	0	0	0	0	0	0	0	0	0
16	Waste, hazardous/landfilled	g	0	0	0	0	0	0	0	0	0
Emissions (Air)											
17	Greenhouse Gases in GWP100	kg CO2 eq.	0	0	0	0	0	0	0	0	0
18	Acidification, emissions	g SO2 eq.	0	0	0	0	0	0	0	0	0
19	Volatile Organic Compounds (VOC)	g	0	0	0	0	0	0	0	0	0
20	Persistent Organic Pollutants (POP)	ng-Teq	0	0	0	0	0	0	0	0	0
21	Heavy Metals	mg Ni eq.	0	0	0	0	0	0	0	0	0
22	PAHs	mg Ni eq.	0	0	0	0	0	0	0	0	0
23	Particulate Matter (PM, dust)	g	0	0	0	0	0	0	0	0	0
Emissions (Water)											
24	Heavy Metals	mg Hg/20	0	0	0	0	0	0	0	0	0
25	Eutrophication	g PO4	0	0	0	0	0	0	0	0	0

Legal notice

Inputs Input RBR RESULTS Extra Materials RAW EOL Data RBR Manual Data Sources CRM

C11

Record Macro Use Relative References Add-Ins COM Add-Ins Insert Design Mode View Code Properties Macro Security Macro Security Add-Ins Add-Ins Run Dialog Source

A	B	C	D	E
not affected				

Pos USE PHASE **direct ERP impact** unit

Nr	Description	unit	Subtotals
226	ErP Product (service) Life, in years	0 years	
Electricity			
227	On-mode: Consumption per hour, cycle, setting, etc.	0 kWh	0
228	On-mode: No. of hours, cycles, settings, etc. / year	0 #	
229	Standby-mode: Consumption per hour	0 kWh	0
230	Standby-mode: No. of hours / year	0 #	
231	Off-mode: Consumption per hour	0 kWh	0
232	Off-mode: No. of hours / year	0 #	
TOTAL over ErP Product Life		0.00 MWh (+000 kWh)	66
Heat			
233	Avg. Heat Power Output	0 kW	
234	No. of hours / year	0 hrs.	
235	Type and efficiency (Click & select)		86-not applic.
TOTAL over ErP Product Life		0.00 GJ	
Consumables (excl. spare parts)			
236	Water	0 m³/year	84-Water per m3
237	Auxiliary material 1 (Click & select)	0 kg/year	86-None
238	Auxiliary material 2 (Click & select)	0 kg/year	86-None
239	Auxiliary material 3 (Click & select)	0 kg/year	86-None
240	Refrigerant refill (Click & select type, even if there is no re	0 kg/year	3-R404a; HFC blend; 3920
Maintenance, Repairs, Service			
241	No. of km over Product-Life	0 km / Product Life	87
242	Spare parts (fixed, 1% of product materials & manuf.)	0 g	1%

Pos ENERGY TOTAL (indirect + direct ErP impact in use phase) unit Subtotals

Nr	Description	unit	Subtotals
Electricity			
243	TOTAL over Product Life of ERP	0.00 MWh (+000 kWh)	66
Heat			
244	extra for extraction and transport, ErP indirect	0%	
245	extra for extraction and transport, ErP direct	0%	
TOTAL over Product Life of ERP indirect		0.00 GJ	86-not applicable
246	TOTAL over Product Life of ERP direct	0.00 GJ	86-not applicable

A	B	C	D	E	F	G	H
208	Is it an ICT or Consumer Electronics product <15 kg ?			NO		60	
209	Is it an installed appliance (e.g. boiler)?			NO		61	
						63	
210	Volume of packaged final product in m³		in m3	0		64	
						65	

Pos USE PHASE **indirect ERP impact** unit Subtotals

Nr	Description	unit	Subtotals
211	ErP Product (service) Life, in years (see comment)	0 years	
Electricity			
212	On-mode: Consumption per hour, cycle, setting, etc.	0 kWh	0
213	On-mode: No. of hours, cycles, settings, etc. / year	0 #	
214	Standby-mode: Consumption per hour	0 kWh	0
215	Standby-mode: No. of hours / year	0 #	
216	Off-mode: Consumption per hour	0 kWh	0
217	Off-mode: No. of hours / year	0 #	
TOTAL over ErP Product Life		0.00 MWh (+000 kWh)	66
Heat			
218	Avg. Heat Power Output (when saving use a negative value)	0 kW	
219	No. of hours / year	0 hrs.	
220	Type and efficiency (Click & select)		86-not applicable
TOTAL over ErP Product Life		0.00 GJ	
Consumables (excl. spare parts)			
221	Water	0 m³/year	84-Water per m3
222	Auxiliary material 1 (Click & select)	0 kg/year	86-None
223	Auxiliary material 2 (Click & select)	0 kg/year	86-None
224	Auxiliary material 3 (Click & select)	0 kg/year	86-None
225	Refrigerant refill (Click & select type, even if there is no re	0 kg/year	1-none:0000
Maintenance, Repairs, Service			
not affected			

Pos USE PHASE **direct ERP impact** unit Subtotals

Nr	Description	unit	Subtotals
226	ErP Product (service) Life, in years	0 years	
Electricity			
227	On-mode: Consumption per hour, cycle, setting, etc.	0 kWh	0
228	On-mode: No. of hours, cycles, settings, etc. / year	0 #	
Consumables (excl. spare parts)			
236	Water	0 m³/year	84-Water per m3
237	Auxiliary material 1 (Click & select)	0 kg/year	86-None
238	Auxiliary material 2 (Click & select)	0 kg/year	86-None
239	Auxiliary material 3 (Click & select)	0 kg/year	86-None
240	Refrigerant refill (Click & select type, even if there is no re	0 kg/year	3-R404a; HFC blend; 3920
Maintenance, Repairs, Service			
241	No. of km over Product-Life	0 km / Product Life	87
242	Spare parts (fixed, 1% of product materials & manuf.)	0 g	1%

Pos DISPOSAL & RECYCLING unit Subtotals

Nr	Description	unit	Subtotals
253	product (stock) life L, in years	0	Please edit values with red
current L years ago period growth PG			
254	unit sales in million units/year	0.000	0.000
255	product & aux. mass over service life, in g/unit	0	0.0%
256	total mass sold, in (1000 kg)	0	0.0%



EOL

BAT/BNAT DEFINITIONS

Best Available Technology (BAT)

- represents the best **commercially** available product with the lowest **verified** resource use and/or emissions

Example based on market data: HIT heterojunction modules (e.g. Panasonic) and Black back contact mono Si modules (e.g. Sunpower) commercially available > 10 yr.

Best Not yet Available Technology (BNAT)

- represents an **experimentally proven** technology that is **not yet** brought to **market**, e.g. it is still at the stage of field-tests or official approval.
- could be accelerated to market by incentive programs once they have been evaluated as such in the Ecodesign preparatory study.

Example based on R&D status: Tandem mono Si cells + perovskite top layer - strong pull into the market may accelerate product field tests/pilot testing → manufacturable cell product within 3-5 years?

Proposals of BC, BAT and BNAT for modules

Base Case	BAT	BNAT
Multi BSF	Bifacial	+ BoM (material improvements, enhancing durability)
CdTe	SHJ HIT Heterojunction	+ Quality (factory inspections)
Rooftiles, façade products (to be defined)	PERC (variations)	Si perovskite tandem, Si-epitaxial growth
	Back contact	
	+ BoM (material improvements, enhancing durability)	

Proposals of BC, BAT and BNAT for inverters

Base Case	BAT	BNAT
String 1 phase	string 3 phases (high power rating)	+Semiconductor tech (GaN, SiC)
String 3 phases	Module level power electronics (microinverter, optimiser)	+ BoM (enhancing durability)
Central	Hybrid inverter + Storage	

Proposals of BC, BAT and BNAT for systems

Base Case	BAT	BNAT
R- BAPV. MultiBSF, string 1 phase inverter	tilted roof optimum angle	
	R- BAPV. MultiBSF optimiser/module+ string inverter	
	R- BAPV. MultiBSF, string 1 phase inverter, storage	
	R- BAPV. MultiBSF, string 1 phase hybrid inverter (storage)	
	R- BAPV. MultiBSF, microinverter	
		R-BAPV. MultiBSF, string 1 phase inverter designed for repair
C- BAPV. MultiBSF, string 3 phase inverter		
	C- BAPV. Bifacial, string 3 phase inverter	
		C - Bifacial, string inverter 3-phase (GaN, SiC)
U- CdTe, central inverter		
U- MultiBSF, central inverter		
	U- MultiBSF central + O&M	
	U- MultiBSF, string 3 phase inverter +1 axis tracker	
	U- CdTe, string 3 phase inverter +1 axis tracker	

Modelling assumptions

- Same **method and conditions** to estimate the yield
 - System modelling replicates module conditions, e.g. orientation & tilt angle equal in all type of systems (R,C,U)
- **Technical lifetimes:** modules 25 years, inverters 10 years (13?), systems 25 years
- **Degradation rate:** 0.5-0.6 (best case), 1% (worst case)
- **Failure rate:** modules 2% year 10-12, inverters 1%-15% annual, 3-4% infancy
- **Catastrophic failure:** modules 5% linked to transport and installation
- **Wp to Wn ratio:** modules DC peak power to inverter AC rated output

Data and information requirements

- **Bill of Materials**
 - New cell technologies and structures
 - New generation of high power density inverters
- **Operating profiles and efficiencies**
 - Hybrid inverters
 - Standalone battery systems
- **Life cycle assumptions**
 - Operation & Maintenance programmes

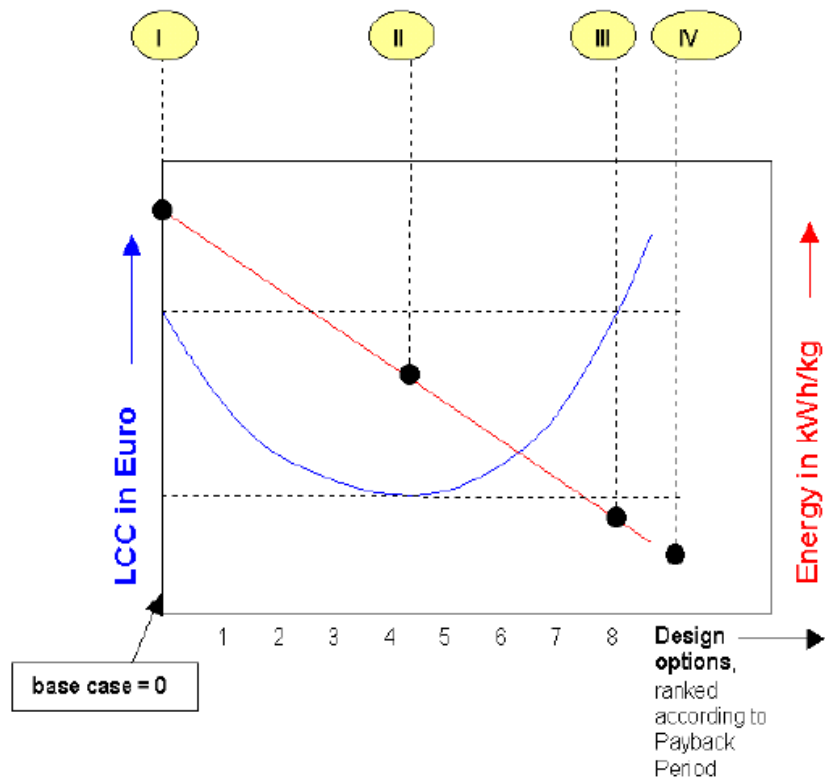
Modelling Life Cycle Costs

- **ErP product consumer decisions** based on CAPEX, WACC and energy savings = Life Cycle Cost (ISO 15686)
- **Solar PV consumer decisions** based on CAPEX, WACC and electricity revenue = Whole Life Cycle Cost (ISO 15686)

Proposed approach?

Use of Levelised Cost Of Electricity (LCOE) as the calculation method following PV Technology Platform and IEA guidance

MEErP and LCC



I = BaseCase; II = Least LCC; III = No financial loss (break-even point); IV = BAT point

Levelised Cost of Electricity (LCOE)

$$LCOE = \frac{CAPEX + \sum_{t=1}^n [OPEX(t) / (1 + WACC_{Nom})^t]}{\sum_{t=1}^n [Utilisation_0 \cdot (1 - Degradation)^t / (1 + WACC_{Real})^t]}$$

Normalised to 1 kWp of PV system

t = time (in years)

n = economic lifetime of the system (in years)

CAPEX = total investment expenditure of the system, made at t=0 (in €/kWp)

OPEX(t) = operation and maintenance expenditure in year t (in €/kWp)

WACC_{Nom} = nominal weighted average cost of capital (per annum)

WACC_{Real} = real weighted average cost of capital (per annum)

Utilisation₀ = initial annual utilisation in year 0 without degradation (in kWh/kWp)

Degradation = annual degradation of the nominal power of the system (per annum)

WACC_{Real} = (1 + WACC_{Nom}) / (1 + Inflation) - 1

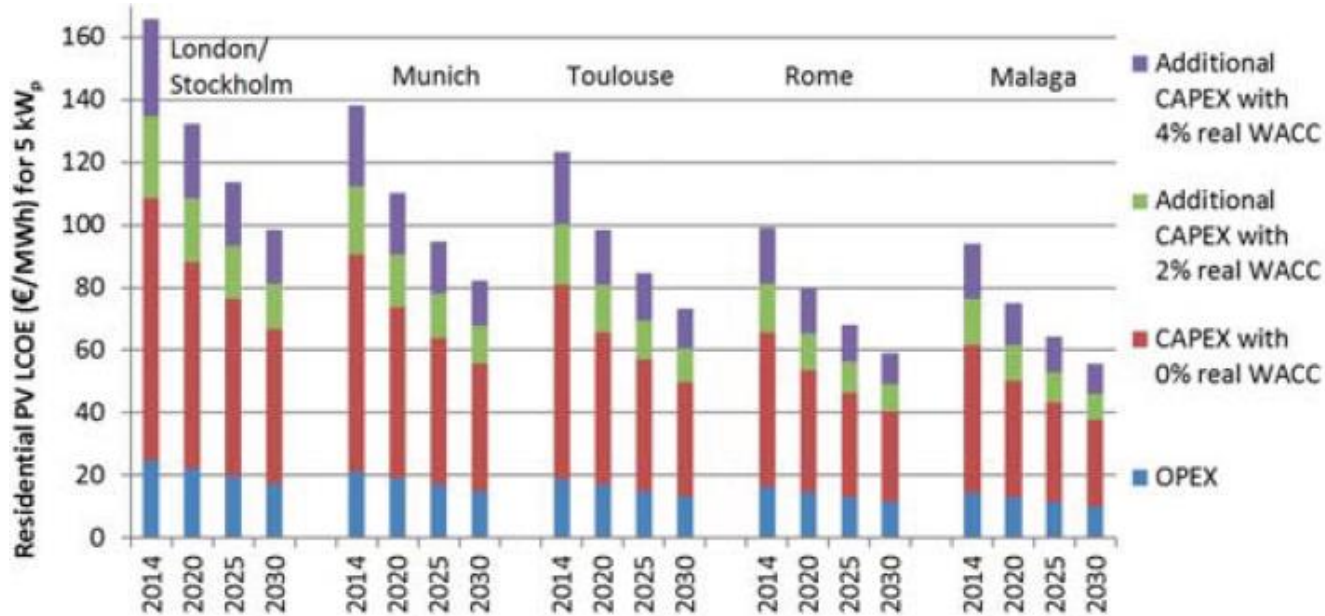
Inflation is the annual inflation rate.

Variable based on market segment?

Source: PV Technology Platform (2015)

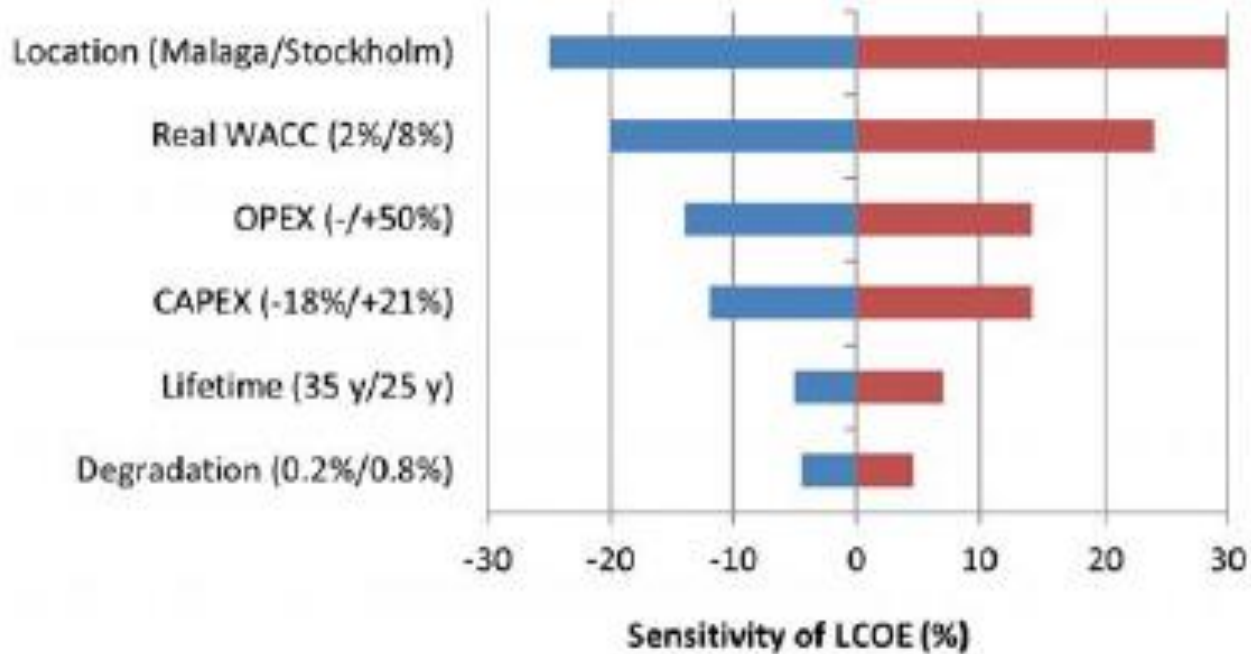
System yield (IEC 61274/Transitional standard)

CAPEX, OPEX, WACC for residential system (5 kW_p)



Source: PV Technology Platform (2015)

Sensitivity of LCOE



Source: PV Technology Platform (2015)

The European Commission's science and knowledge service

Joint Research Centre

Transitional methods

C2 Energy Efficiency and Renewables Directorate Energy, Transport and Climate

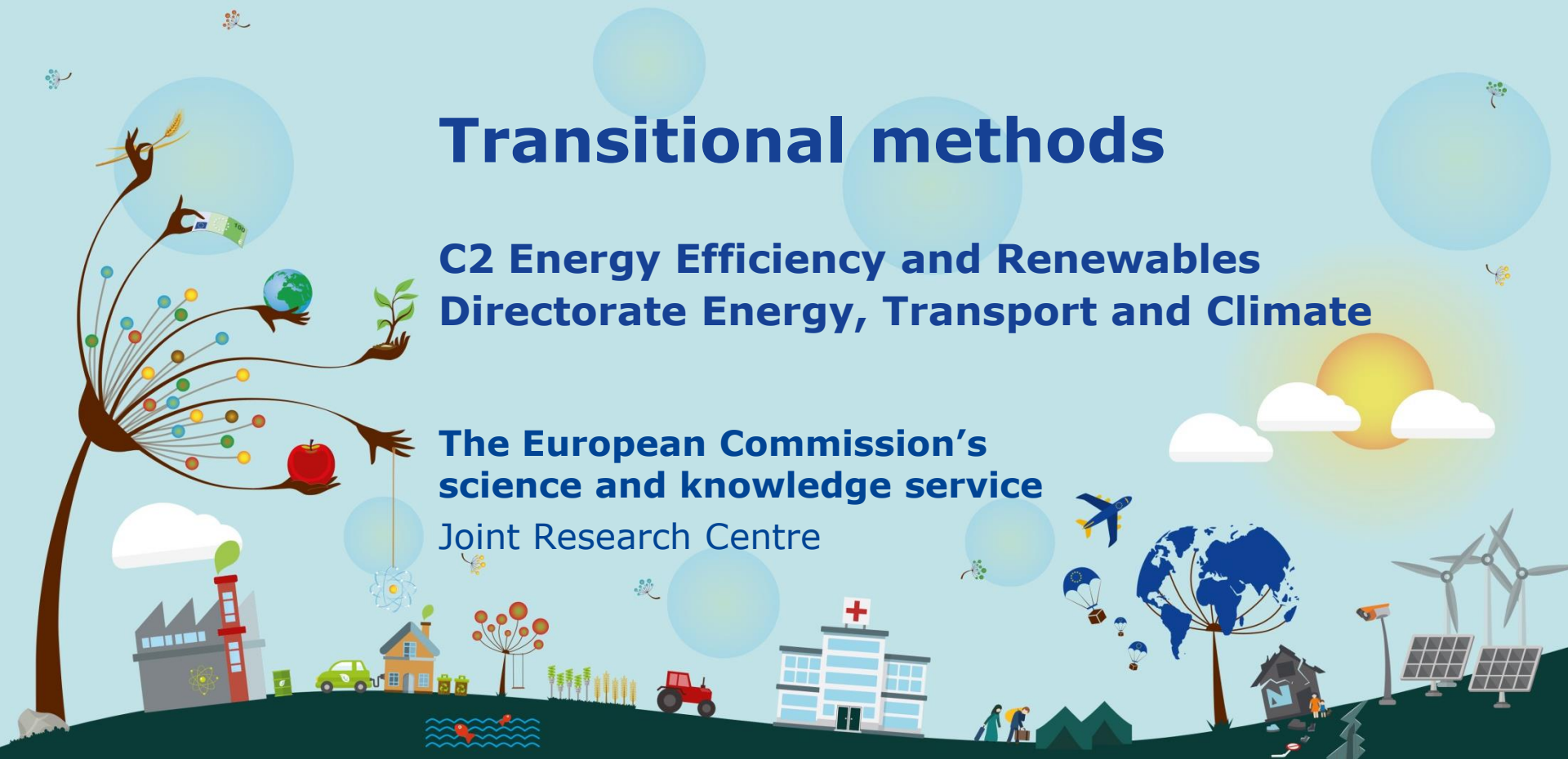
1st Stakeholder Meeting of the Preparatory Study for applying EU sustainable
product policy instruments to solar photovoltaics,
Brussels, June 29th 2018



Transitional methods

**C2 Energy Efficiency and Renewables
Directorate Energy, Transport and Climate**

**The European Commission's
science and knowledge service
Joint Research Centre**



1st Stakeholder Meeting of the Preparatory Study for applying EU sustainable product policy instruments to solar photovoltaics, Brussels, June 29th 2018

Transitional methods

Following the detailed study of existing and drafting new standards relevant to EU sustainable product policy for photovoltaics, we have identified certain aspects which are not covered by the said standards and may therefore require the development of transitional methods.

These methods are required to implement the regulations until suitable standards are adopted.

Energy Yield of PV systems

The proposed functional parameter for PV system 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".

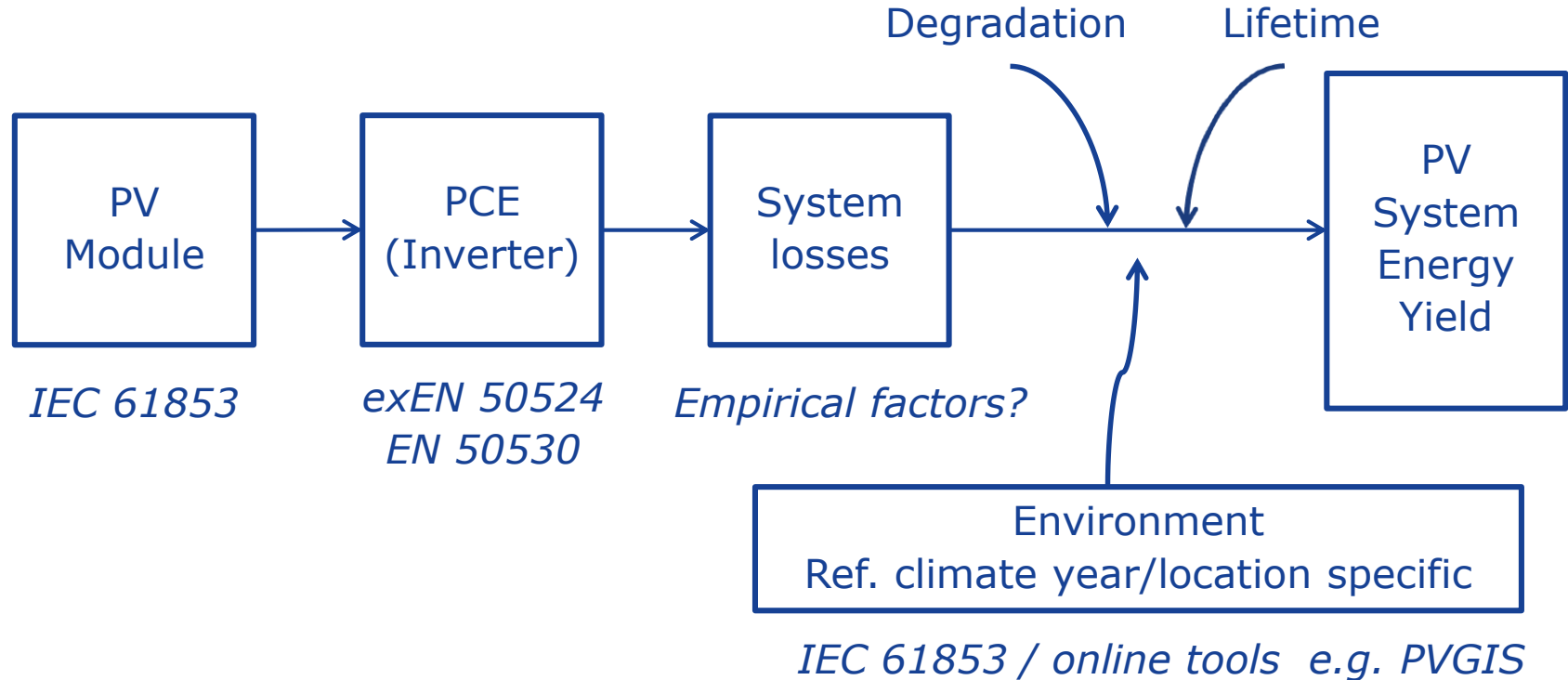
There are no standards that account for all the factors that affect the energy yield of a PV system, as described by the functional parameter, e.g.:

- Layout: free-standing, roof systems, facades, mixed orientations, tracking etc.
- Location and configuration: environmental conditions, inverter sizing, battery losses; grid support services
- Durability of components: degradation (rate, linear/non-linear), operational life ...

N.B. 1 EN 17024 defines Energy Yield. However it is based on onsite monitoring of typically one year operation. This is not considered a viable option for these regulations.

N.B. 2 EN 15316-4-3. Calculation method of energy performance in buildings: simplified approach requires various input parameters (irradiation, loss factors) to be defined at national level.

Energy Yield of PV systems



Durability of PV modules and inverters

Functional lifetime is referenced for several functional parameters and for environmental footprint.

Directly related to:

- Lifetime.
- Degradation rates (maybe different rates over the life span).
- Quality.

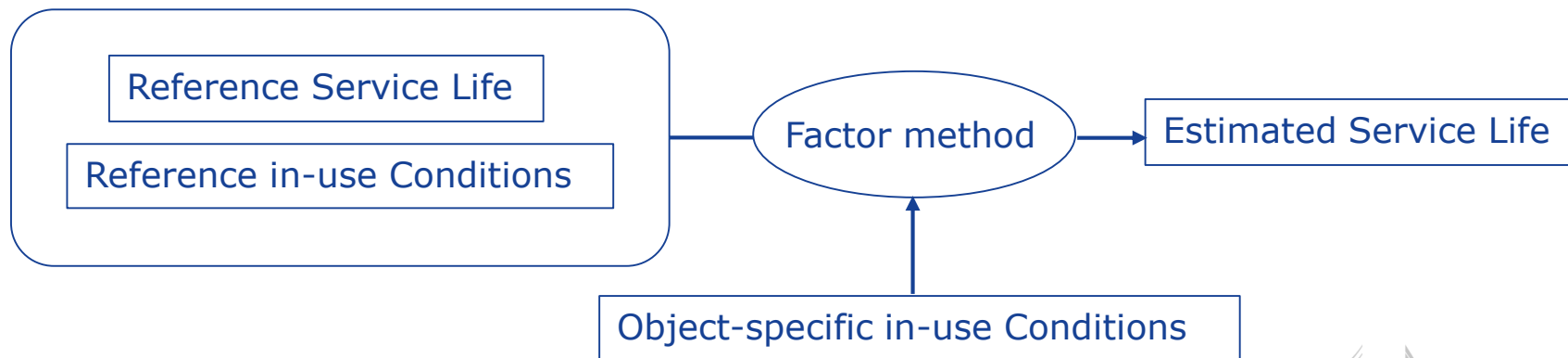
Dependent on factors like:

- Location (climatic conditions).
- Operational set-up (environmental exposure, building integration etc.)

Durability of PV modules and inverters

Possible ways of defining the durability by means of:

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



Efficiency of PV inverters

Overall efficiency of grid-connected PV inverters defined in former EN 50530 (withdrawn).

But

CENELEC TC82 WG2 has a new work item to include the Euro efficiencies from EN 50530 in a new standard, expected to be approved by the end of 2019.

Circular economy and material efficiency

Dismantlability of PV modules.

Disassemblability of PV systems.

Remanufacturing of PV systems.

These are treated under CEN mandate M/543: standardisation request to the European standardisation organisations as regards Ecodesign requirements on material efficiency aspects for energy-related products.

General top level standards are being defined but product (PV) specific standard is missing.

Draft horizontal standards under Mandate M/543

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

Technical meeting

TITLE: Expert meeting on photovoltaic standards for Ecodesign.

When: October 31st 2018

Where: Ispra, Varese, Italy

Registration:

<https://web.jrc.ec.europa.eu/remjrc/screen/meeting/362/registration-form>

Questions?

Next steps?

- Circulation of [slides](#) followed by [meeting minutes](#)
- Deadline for stakeholder written comments, [Friday 27th July](#)
- Next stakeholder meeting, provisionally [December 2018](#)

Please use [BATIS](#) to submit your comments

<http://eippcb.jrc.ec.europa.eu/batis/login.jsp>

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Study home page

http://susproc.jrc.ec.europa.eu/solar_photovoltaics



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