2nd Stakeholders meeting
PV ECODESIGN
Preparatory study status and Transitional methods

19th December

The European Commission's science and knowledge service

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PV ECODESIGN

Preparatory study status and Transitional methods

Nicholas Dodd, Nieves Espinosa (**Seville**)

European Commission

Outline

General introduction to the preparatory study

- Previous work from Tasks 1,2,3

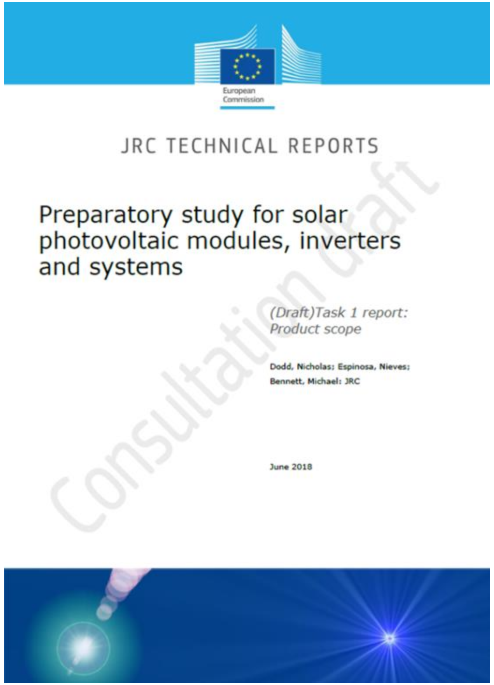
Task 4

- Description of processes involved in the functional performance of the products
- Base cases, Best Available and Best Not yet Available candidates
- Data sources to model production for lifecycle analysis

Task 5

- LCA of Base Cases and BATs and BNATs
- Hazardous substances
- Background: consortium work

One policy development process:
DGs GROW, ENER, ENV


European Commission

JRC TECHNICAL REPORTS

Preparatory study for solar photovoltaic modules, inverters and systems

(Draft)Task 1 report: Product scope

Dodd, Nicholas; Espinosa, Nieves; Bennett, Michael: JRC

June 2018

Consultation draft

- *Ecodesign minimum requirements*
- *Energy Label classes*
- *Ecolabel criteria*
- *GPP criteria*

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Study progress and outlook

1st stakeholder meeting, Brussels (29/06/2018)

- Scope and definitions, existing standards and legislation, market figures, user behaviour

PV experts, standards meeting in Ispra (31/10/2018)

- Development of transition methods

2nd stakeholder meeting, Brussels (19/12/2018)

- Techno-economic /environmental analysis: technological alternatives evaluation, hotspots analysis

3rd stakeholder meeting (Q2-3 2019)

- Identification and evaluation of potential policy options (Ecodesign, Energy Labelling, Ecolabel, GPP) for each of the 3 product groups (PV modules, inverters and systems)

Previous work

Task 1 (Product scope)

- Scope and components definitions
- Measurements and test standards in place
- Functional unit, lifetime and assumptions for the study, same as PEF

Task 2 (Market data and trends)

- Global market share dominated by crystalline Si types, China dominating the whole value chain
- Quality and durability is a major focus
- Hazardous substances substitution: Lead-free soldering, Fluoride-free back sheet

Task 3 (User Behaviour and System Aspects)

- Consumer requirements
- Direct and indirect impacts
- Understanding factors affecting product lifetime and EoL

Scope

Proposed solar photovoltaic module definition and scope

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

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

The scope shall correspond to photovoltaic modules produced for use in photovoltaic systems for electricity generation. The scope shall include Building Integrated Photovoltaic (BIPV) modules that incorporate solar photovoltaic cells and form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011. The scope shall include street furniture that incorporates solar photovoltaic cells, but it does not include street lighting equipment.

Specifically excluded from this scope are:

- Module level power electronics, containing 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.

Scope

Proposed definition and scope of inverters for photovoltaic applications

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

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

Specifically excluded from this scope are:

- 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.

Scope

Proposed solar photovoltaic system definition and scope

A photovoltaic system is an assembly of components that produce and supply electricity based on photovoltaic conversion of solar energy. It comprises the following sub-systems: module array, switches, controls, meters, power conditioning equipment, PV array support structure, and electricity storage components. It also comprises cabling connecting these components.

Included in the scope of systems are therefore DC optimisers and 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.

The provision of energy generated by solar PV systems as a service shall be included within the scope for the purpose of public procurement.

Excluded from the scope are products which are only designed for the following specific applications:

- For use only in street lighting, urban furniture, electric vehicles
- PV integrated consumer and electronic products, i.e. power banks, watches, calculators, etc.
- Systems in which there are modules with DC output power of less than 50 Watts under Standard Tests Conditions (STC)
- Substations and transformers for power conditioning

Definitions and functional units

PV Modules

- 1 kWh of DC power output under predefined climatic and installation conditions as defined for a typical year and for a service life of 30 years.

Need to know;

- Output power under a specific climate and Installation (EN 61853)

Definitions

- Service life expectancy
  - For the purpose of the modelling we are considering the yield at a notional lifetime of 30 years
- DC power output at the terminals of the junction box

Definitions of functional units

Inverters

- 1 kWh of AC power output from a reference photovoltaic system (incorporating the efficiency of a specific inverter) under predefined climatic and installation conditions as defined for a typical year and for a service life of 10 years.

Need to know

- Efficiency calculated from direct measurement of input and output power at various levels of rated power (IEC 61683)

Definitions

Definitions of functional units

PV Systems

- 1 kWh of AC power output supplied under fixed climatic and installation conditions as defined for a typical year (with reference to IEC 61853-4) and for a service life of 30 years.

Need to know;

- Output power under a specific climate and Installation (EN 61853)
- Degradation rate
  - c-Si: **0.7 %**/year
  - thin-film (including µc-Si) and Heterojunction **1 %**/year
- Module failure rate / replacement rate (as impact to MEErP)
- Inverter replacement rate (every 10 years)

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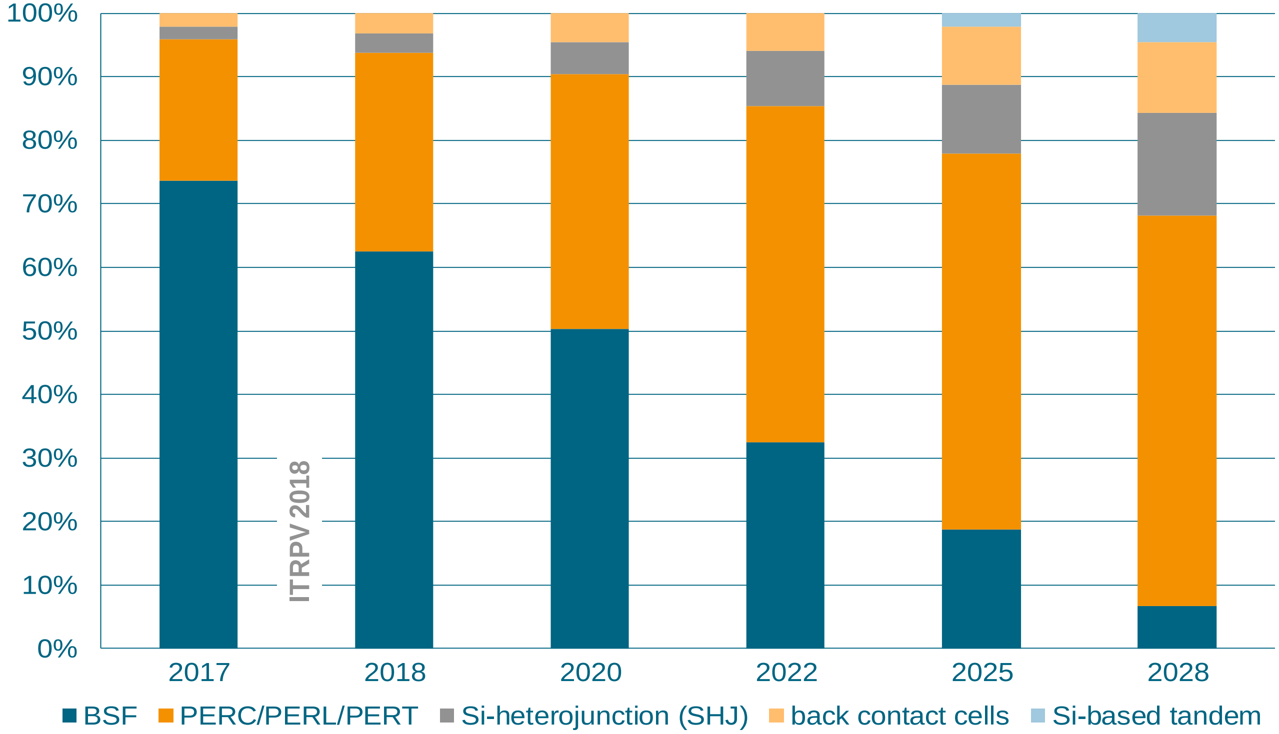
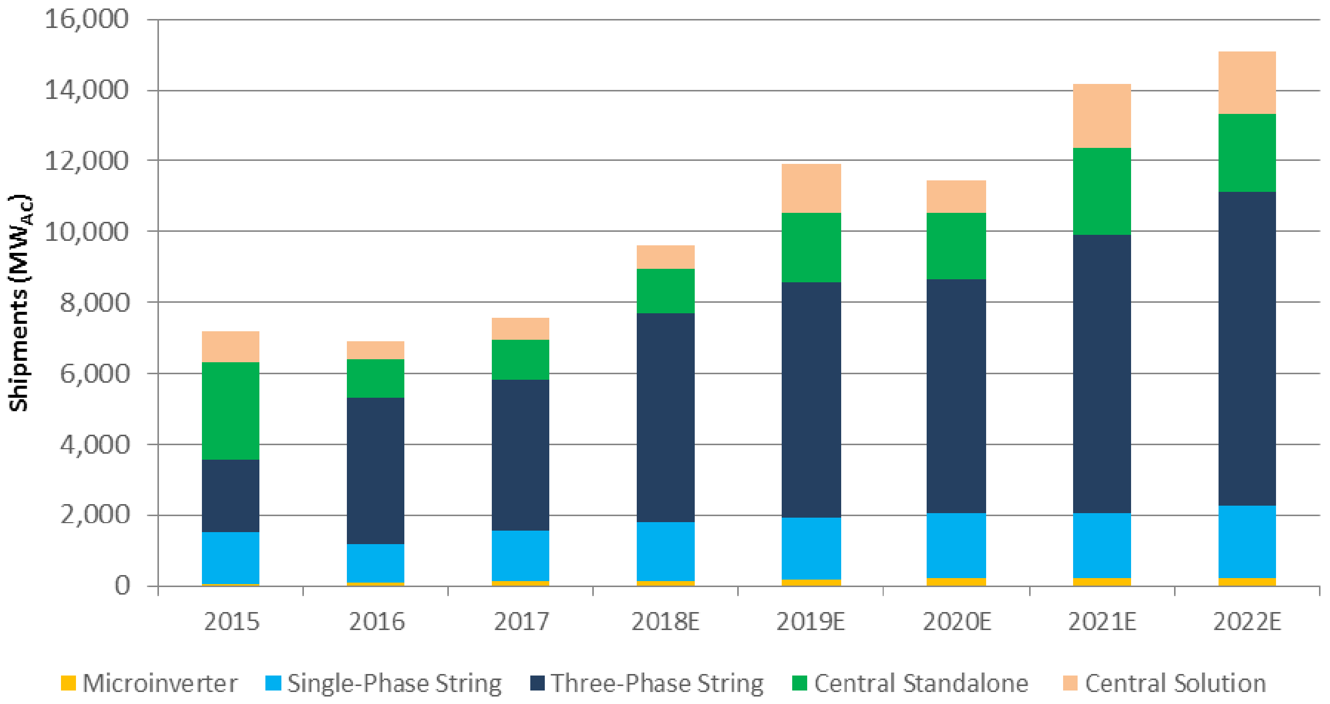
Market analysis for modules



Source: ITRPV (2018)

Market analysis for Inverters



Source: GTM Research (2017)

Consumer behaviour

- A range of potential stakeholders are involved in PV system use who have influence over the decisions and processes involved in installation.
- The dual role of system owners as prosumers is becoming increasingly important because of a reduction in subsidies.
- The priority placed by consumers on the savings potential means that the estimation of a systems energy yield is important
- Residential PV installations are supported by automated simulation tools and pre-defined packages of modules and inverters.
- Public authorities across the EU are increasingly looking at the potential to install solar PV systems on a range of buildings and sites.
- Public authorities are awarding points or establishing performance clauses on the basis of AC output power, warranty length, failure response services and the availability of spare parts.

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

Task 4:
Technical analysis including end-of-life

- Description of processes involved in the functional performance of the products
- Base cases, Best Available and Best Not yet Available candidates
- Data sources to model production for lifecycle analysis

Base Case, Best Available and Best Not (yet) Available Techniques

Base Case (BC) represents the average product on the market in terms of resources efficiency, emissions and functional performance.

Best Available Technology point (BAT) represents the best commercially available product with the lowest resources use and/or emissions.

Best Not yet Available Technology point (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.

Coverage of the technical analysis

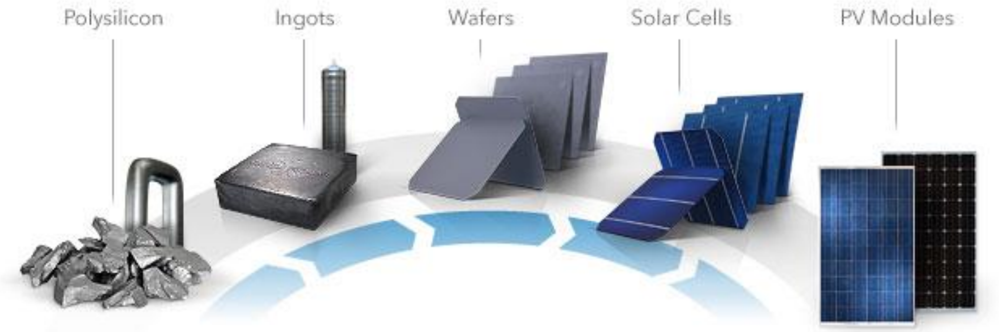
Wafer and cell technology - Silicon Wafer and cells

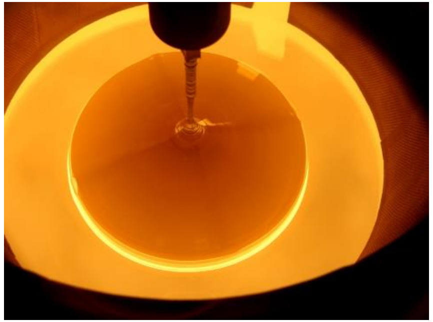
Module technology – Crystalline and thin film technologies

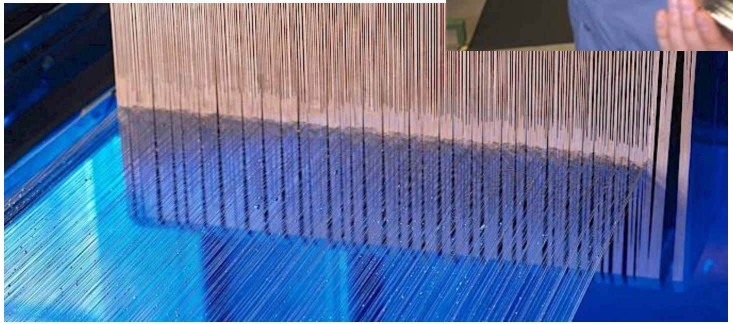
Inverter technology – design features by category

System technology – design, monitoring and inspection

Wafer and cell technology







Module design (1)

Base case: Multi- Si BSF

Possible BAT candidates*:

- Thin film: CdTe and CIGS
- Crystalline cells: PERC/PERT, back contact, heterojunction and bifacial

Possible BNAT candidates*:

- Lift off – epitaxial growth
- Tandem perovskite

Additional options

- Interconnections: thinner busbars, multiwires and half cells, lead-free solder
- Encapsulation: reduction of water ingress and permeation
- Backsheet: durability and water permeability, fire protection

* depending on MEErP analysis conclusions

Module design (2)

Opportunities

- Product design stage: accelerated life testing, individual component and product level
- Manufacturing stage: Minimise defects - factory quality testing
- Transport stage: Minimise damage by considering the packaging
- Use stage: accessibility and ready exchange of bypass diodes

Recycling of PV modules

- Bulk or high-value recycling
  - Optimized thermal delamination
  - mechanical approaches
  - Chemical processes
- Purification of the recovered Si, while for CdTe 80% of the semiconductor is recovered

Module design (2)

Recycling of PV modules

- Bulk or high-value recycling
    - Optimized thermal delamination
    - mechanical approaches
    - Chemical processes
- Purification of the recovered Si, while for CdTe 80% of the semiconductor is recovered
- Designed for circularity
    - Frameless with no encapsulation material

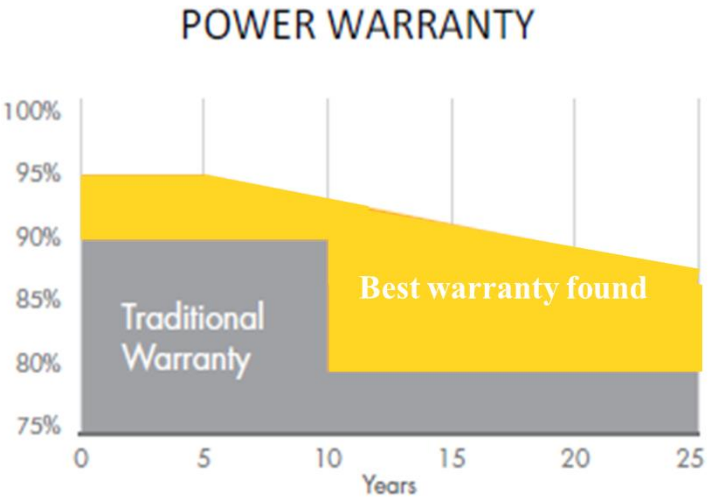
Module design (3)

Table 4.2 Design options for the improvement of crystalline PV modules

Table 4.3. Design options for the improvement of thin film PV modules

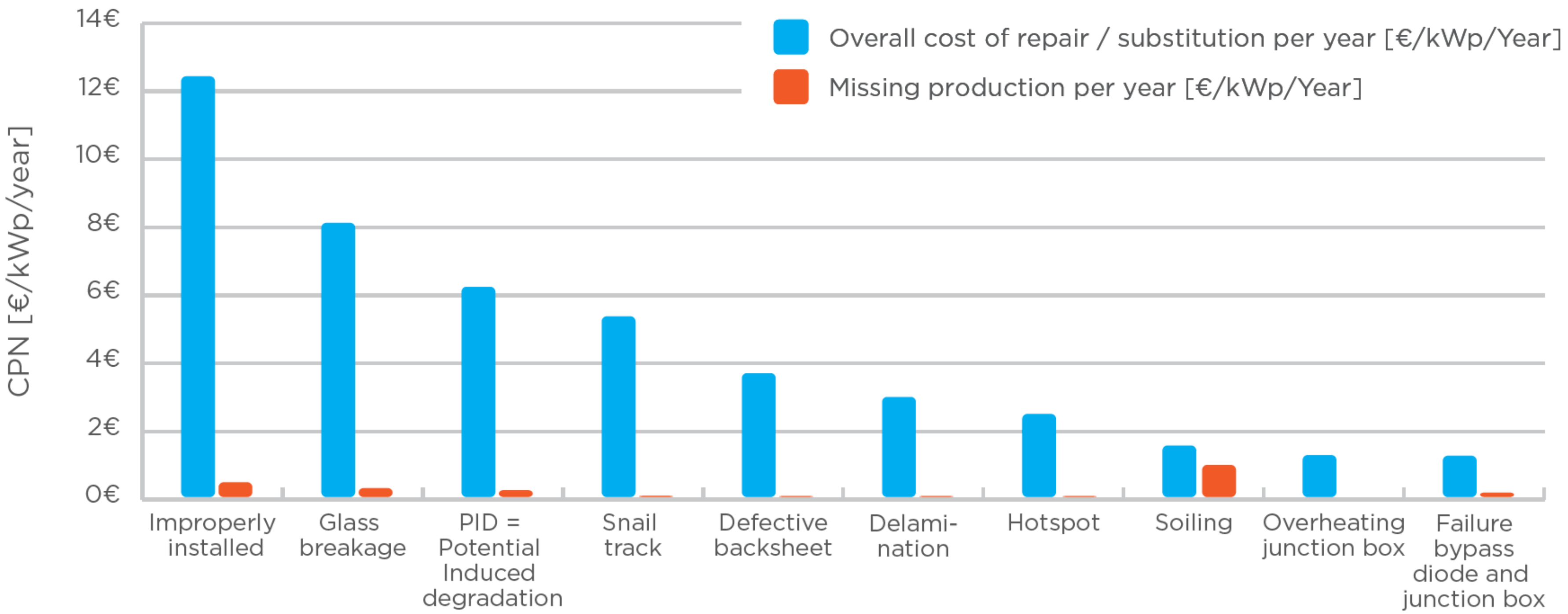
Module design (3)

Whilst warrantied product performance provides extended coverage of manufacturing defects and more stable long term efficiency, these have limited validation based on standardised product testing and performance in the field.



Module design (4)

Costs and performance losses for Top ten risks for all system sizes



Inverter design (1)

Base case:

- 97.5% Euroefficiency

Possible BAT candidates:

- Micro –inverters
- Inverters incorporating wide band gap SiC/GaN semiconductors

Possible BNAT candidates:

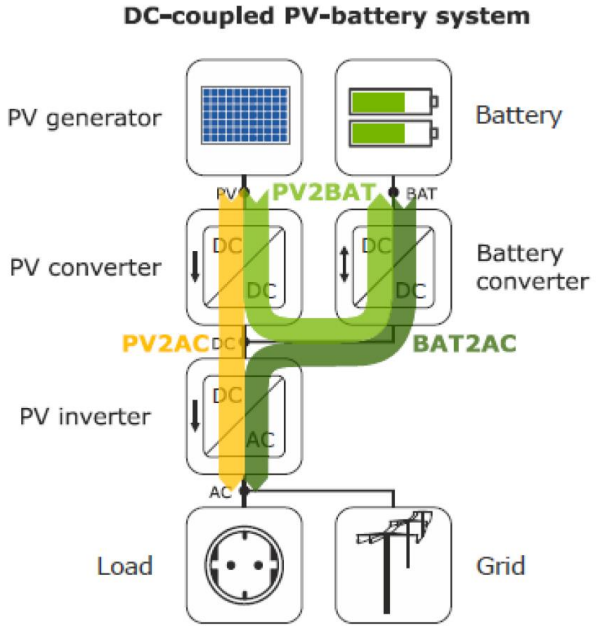
- Inverters incorporating wide band gap SiC/GaN semiconductors

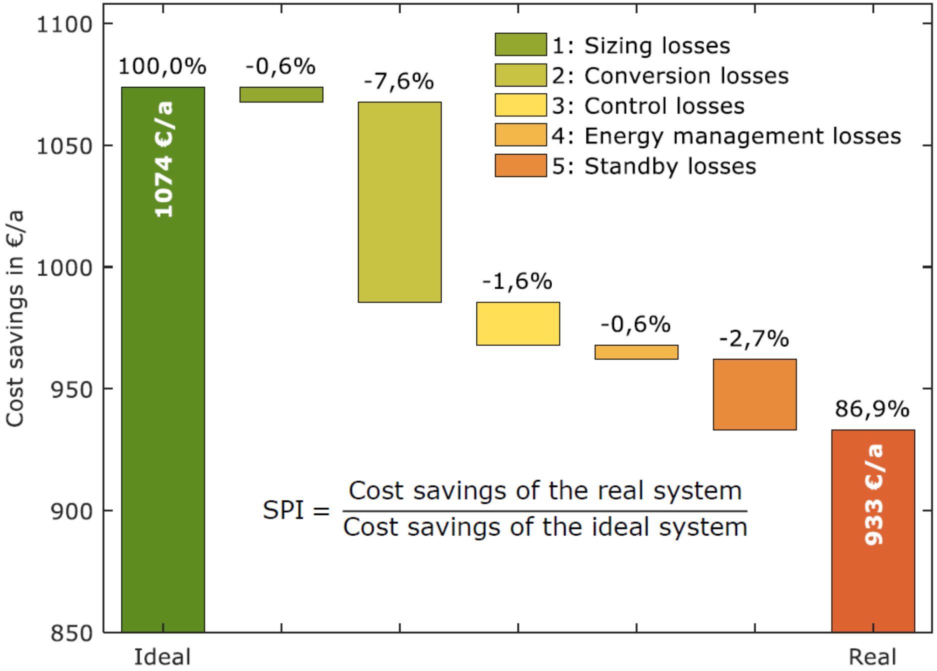
Additional options

- Repair and replacement of primary components, e.g. main circuit board, AC contactors, fuses, etc.
- Remote smart control, fault diagnosis, firmware update

Inverter design (2)

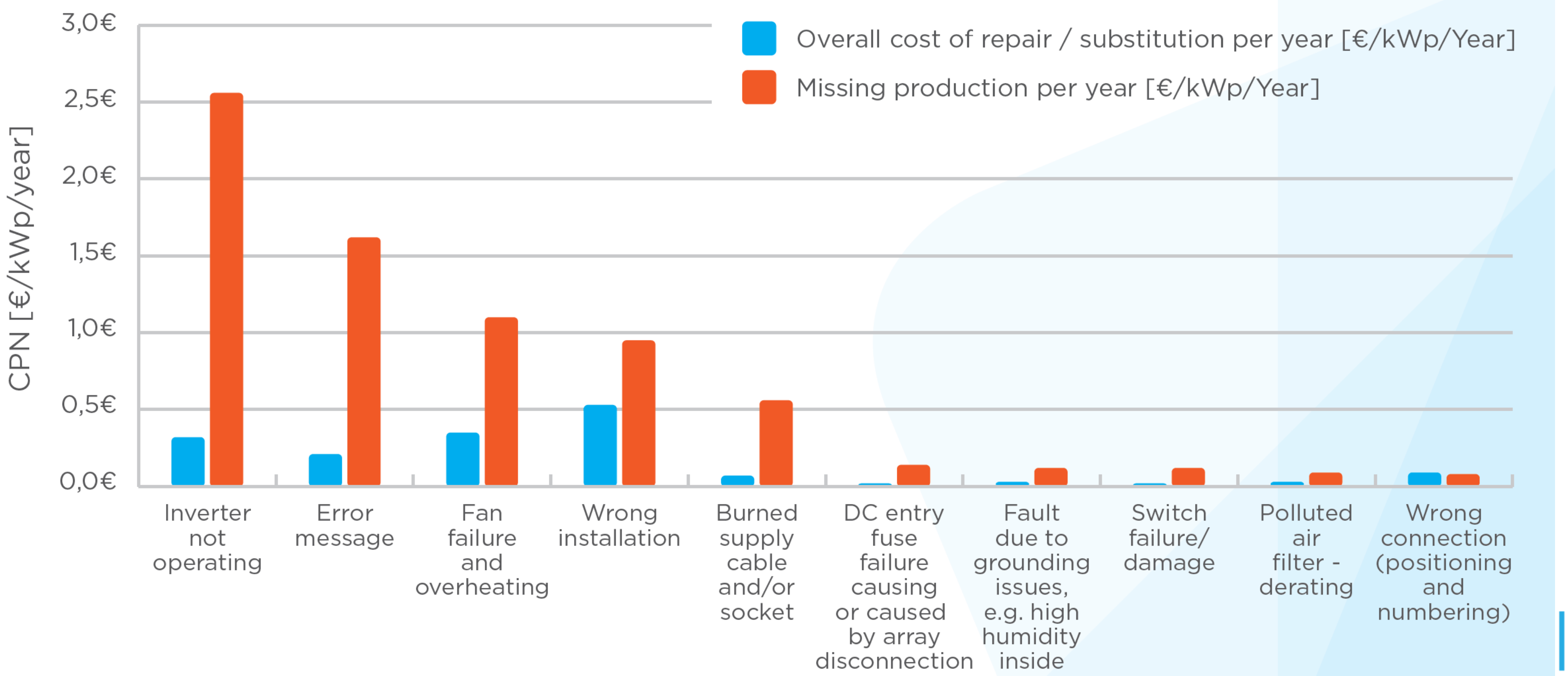
Battery storage combinations





Inverter design (3)

Costs and performance losses for Top ten risks for all inverter sizes



Inverter design (4)

Table 4.5 Base Case 1 single phase string inverters and improvement options

Table 4.6 Base Case 2 three phase string inverters and improvement options

Table 4.7 Base Case 3 large central inverters and improvement options

System design (1)

Base case:

- BC 1: 2.5 kW residential PV system
- BC 2: 20 kW commercial PV system
- BC 3: 1.5 MW utility scale PV system

Possible BAT candidates:

Focus on the potential to transfer optimised performance improvement practices from the utility scale segment to the residential and commercial segment

Additional options

- Optimised design and yield forecasting: P90 dynamic yield modelling
- Optimised monitoring and maintenance: class C system, component repair, remote field inspection
- New components that improve performance: single axis tracker, roof surface reflecting treatments

System design (2)

Table 4.9. System level improvement options for a residential PV system

Table 4.10. System level improvement options for a medium size commercial PV system

Table 4.11. System level improvement options for a large utility scale system

Task 5: Environmental and economic assessment of base cases

- LCA of Base Cases and BATs and BNATs
- Hazardous substances
- Background: consortium work

Product specific inputs

- Selection of base cases
- Functional unit for the LCA
- Life cycle cost and Levelised cost of electricity
- Stock and/or sales
- Product service life
- Purchase price and repair and maintenance cost
- Other economic parameters

Product specific inputs

Selection of base cases

Table 5.1. Overview of selected Base-Cases for systems

Product specific inputs

Functional unit

Modules: 1 kWh DC under predefined climatic and installation conditions for a typical year. Service life: 30 years

Inverters: 1 kWh AC from a reference photovoltaic system (excl. the inverter efficiency) under predefined climatic and installation conditions for a typical year. Service life: 10 years

Systems: 1 kWh AC supplied under fixed climatic conditions for a typical year (with reference to IEC 61853 part 4). Service life: 30 years

	BC1	BC2	BC3	unit
System	3	24.4	1875	kWp
Inverter	2.5	20	1500	kW
Inverter:module DC capacity	1:1.20	1:1.20	1:1.25	
Life span system	30	30	30	years
Life span inverter	10	10	30	years
Inverter units in the LC	3	3	1 (replacement of parts)	unit
Electricity output system	81	662	50862	MWh
Inverter units per kWh	3.69E-05	4.53E-06	1.97E-08	inverters per kWh

	Module parameters
Module Size (m^2/module)	1.6
Module weight (unframed) (kg/m^2)	11.2
Module conversion efficiency (%)	14.7
Wafer thickness (micrometer)	200
Cell size (mm^2)	156*156
Technology	Average technology mix of front/back cell connection, diffusion and front collection grid
Main data source	De Wild-Scholten (2014)
Rated power (Wp/m^2)	147
Cells area per module (%)	95.39%
Yield (kWh/kWp) 30 year	926
Expected life time (years)	30
Module area per kWh energy produced (m^2)	**2.45E-04**

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Product specific inputs

Life cycle cost and Levelised cost of electricity

- The MEErP methodology is usually based on an analysis of life cycle cost (LCC). Why LCOE instead of LCC?
- Levelised Cost of Electricity (LCOE) is widely used in the electricity sector to express the total life cycle cost of delivering electricity to the grid.
- The difference of LCOE with respect of LCC is that it is normalized to the unit of power generated.

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

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Product specific inputs
Stock and/or sales

- Module stock worked from the installed capacity → module size relevant
- Inverter stock from shipment data → DC/AC ratio and EU/GLO ratio*
- System stock is the sales of the reference year

	Multi	Mono	CdTe	aSi	CIGS	HighEff
Rated power residential	270	285	-	-	145	245
Rated power commercial	325	340	-	-	145	375
Rated power utility	325	340	118	-	-	375

Product specific inputs

Purchase price and repair and maintenance cost

Table 5.4. Input data for Life Cycle Cost calculations

Product life cycle information for base cases on BOM

Modules

- Product Environmental Footprint screening study
- Ecoinvent
- IEA PVPS Task 12
- Vellini et al. (2017)
- Stolz et al., 2016, recycling

Inverters

- Tschümperlin et al. 2016
- ENER Lots 27, 19 and 30

Systems

Table 1 Overview of selected Base-Cases for systems

Modelling assumptions

PRODUCTION

- Repair or replacement is assigned to the production stage
- Additional materials had to be imported into Ecoreport (Annex A), e.g.

  Multi Si photovoltaic cell, tin, lead, ethylvinylacetate, polyvinylfluoride, silicone, solar glass and tempering
- Tschümperlin provides most recent primary data for inverters

  Printed circuit board had to be imported
- DC cabling and mounting structure is imported from PEF pilot

DISTRIBUTION

- Impacts in this phase is dependant in a series of questions which distinguishes between a 'package consumer products' and an 'installed appliance'

Modelling assumptions

USE

- Mainly dependent on parameters that influence the long term energy yield and the nature and frequency of maintenance operations.

END OF LIFE

- Not possible to bring new scenarios distinct to the default for the Extra materials imported into Ecoreport
- This will have to be modelled separately in Simapro and the results imported

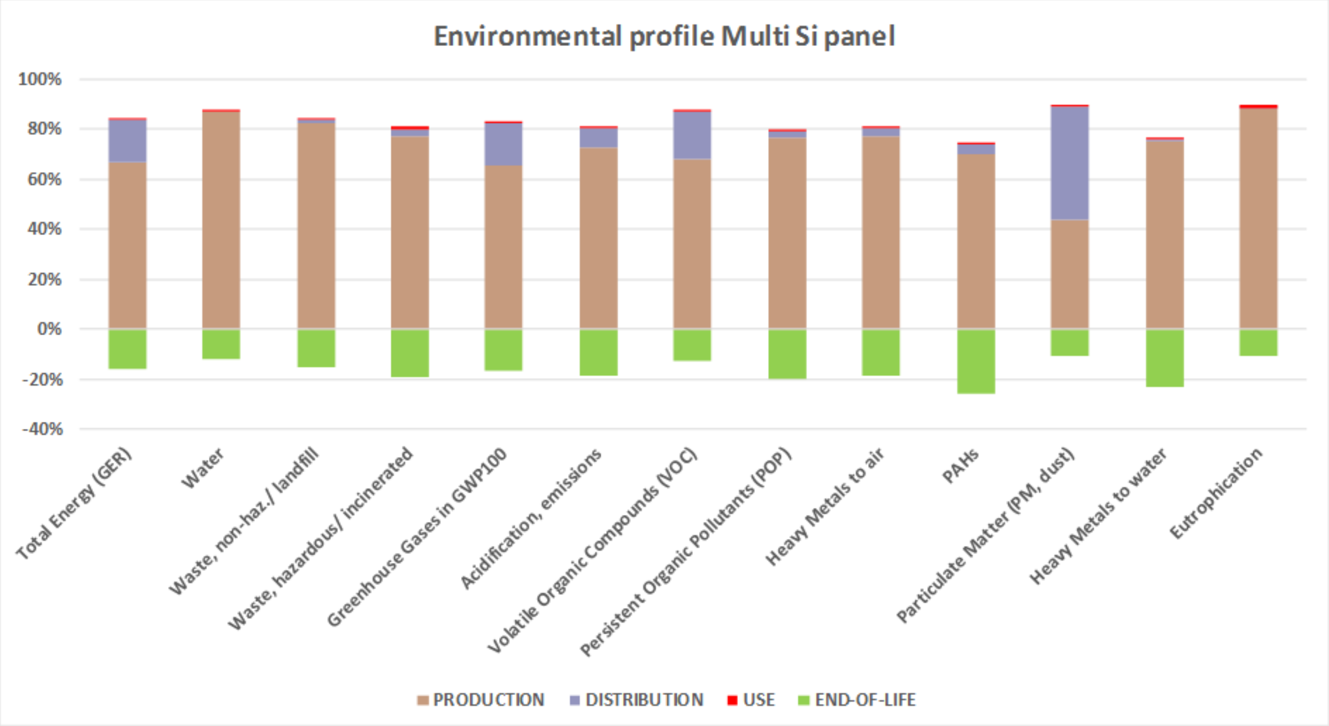
Base Case Environmental Impact Assessment (using EcoReport 2014)

For modules, inverters, system the environmental profiles have been assessed by using the MEErP methodology for the life cycle stages:

- Raw Materials Use and Manufacturing;
- Distribution;
- Use phase*;
- End-of-Life Phase.

* Displaced impacts due to electricity production in the use phase not included

Module environmental profile



Hotspots by materials and components

	weight	GER	water (proces + cool)	haz. Waste	non-haz. Waste	Greenh ouse Gases in	Acidifica tion, emissio	Volatile Organic Compou	Persiste nt Organic	Heavy Metals to air	Polycycli c Aromati	Particula te Matter	Heavy Metals to water	Eutrophi cation freshwa
photovoltaic cell	4%	72%	96%	98%	91%	79%	80%	70%	77%	91%	12%	76%	35%	86%
interconnection - Tin	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	1%	0%	0%
interconnection - Lead	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
interconnection - Copper	1%	0%	0%	0%	0%	0%	2%	0%	1%	1%	0%	0%	6%	0%
encapsulation - ethylvinylacetate	7%	3%	1%	0%	1%	1%	0%	9%	0%	1%	0%	0%	0%	3%
backsheet - PVF	1%	1%	0%	0%	1%	1%	1%	2%	1%	1%	0%	0%	0%	2%
backsheet - PET	3%	1%	0%	0%	0%	1%	1%	2%	0%	0%	0%	1%	0%	0%
pottant & sealing	1%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%
alu frame	16%	15%	0%	0%	4%	11%	9%	1%	19%	2%	87%	17%	46%	0%
solar glass	66%	6%	1%	0%	4%	6%	6%	15%	2%	4%	0%	3%	2%	6%
junction box - diode	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
junction box - HDPE	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
junction box - glass fibre	2%	1%	1%	1%	0%	1%	1%	0%	0%	0%	0%	1%	9%	1%

contribution to impact category	X > 50%
contribution to impact category	25% < X < 50%
contribution to impact category	10% < X < 25%
contribution to impact category	<10%

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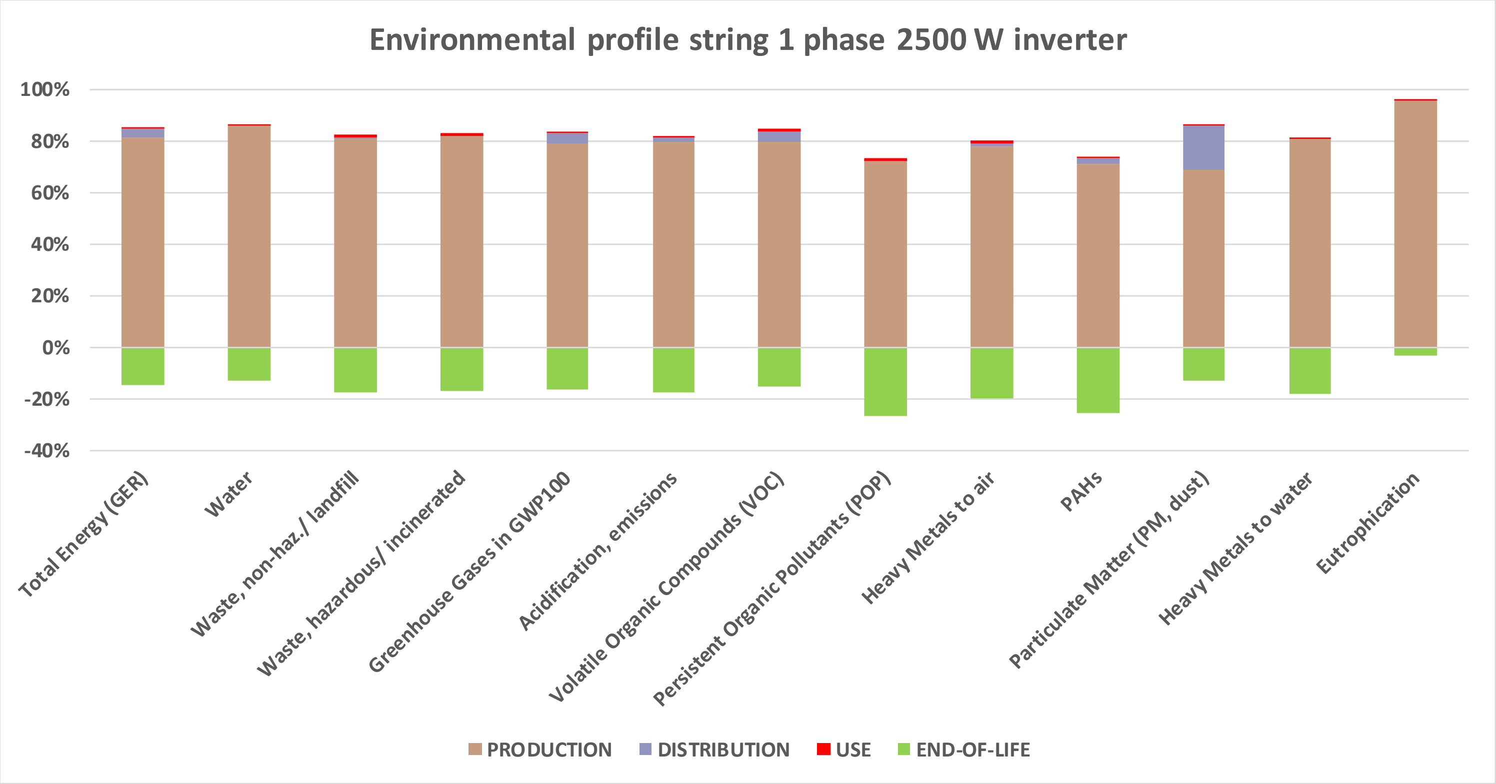
Inverter 2.5 kW environmental profile

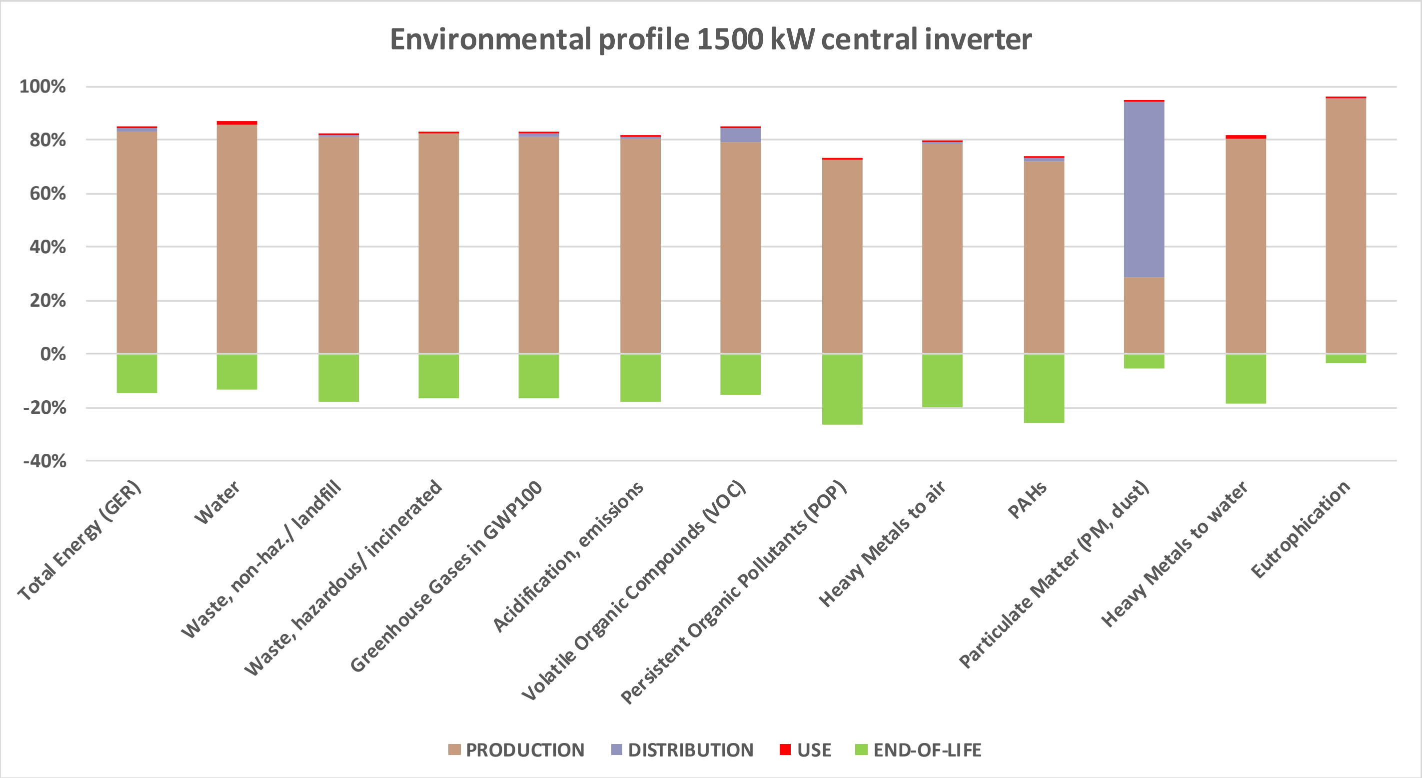


Hotspots by materials and components

	weight	GER	water (proces + cool)	haz. Waste	non-haz. Waste	Greenho use Gases in	Acidificat ion, emission	Volatile Organic Compou	Persisten t Organic Pollutant	Heavy Metals to air	Polycycli c Aromatic	Particulat e Matter (PM,	Heavy Metals to water	Eutrophic ation freshwat
aluminium	43%	10%	0%	0%	12%	11%	7%	2%	70%	2%	79%	27%	3%	0%
copper	17%	3%	0%	0%	0%	3%	10%	0%	8%	27%	9%	4%	7%	2%
steel	8%	1%	0%	0%	25%	2%	1%	1%	10%	1%	0%	3%	0%	1%
pp	8%	2%	7%	1%	0%	1%	0%	0%	0%	0%	0%	1%	0%	2%
PC	10%	5%	29%	2%	3%	4%	3%	0%	0%	0%	0%	11%	0%	8%
cable	1%	1%	0%	0%	0%	0%	3%	0%	0%	3%	1%	1%	1%	0%
integrated circuits	2%	64%	0%	7%	31%	67%	53%	90%	5%	40.9953%	3%	22%	82.7118%	66%
ferrite	0%	0%	3%	0%	2%	0%	0%	1%	1%	1%	0%	3%	0%	1%
PVC	3%	1%	4%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	1%
PA	1%	1%	7%	0%	0%	1%	1%	0%	0%	0%	0%	1%	1%	4%
PWB	3%	4%	35%	88%	21%	3%	11%	2%	1%	9%	2%	17%	4%	11%
tin	0%	0%	3%	0%	0%	0%	0%	1%	0%	0%	0%	3%	0%	1%
transistor/diode/resistor	1%	7%	12%	1%	3%	7%	9%	3%	0%	12%	0%	5%	0%	2%
capacitor	4%	1%	0%	0%	1%	1%	1%	0%	5%	4%	5%	2%	0%	0%

contribution to impact category	X > 50%
contribution to impact category	25% < X < 50%
contribution to impact category	10% < X < 25%
contribution to impact category	<10%

Central inverter environmental profile

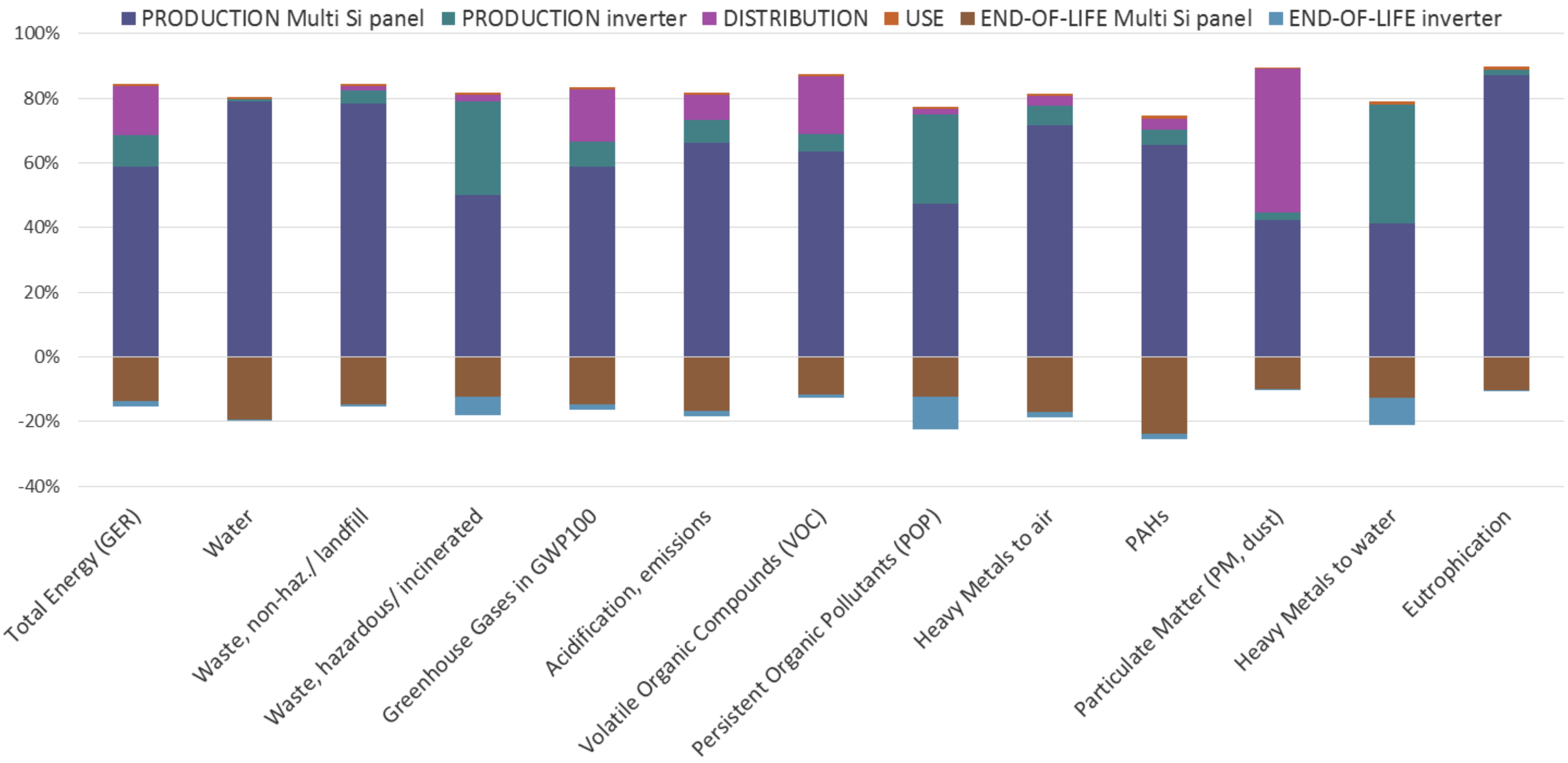


Hotspots by materials and components

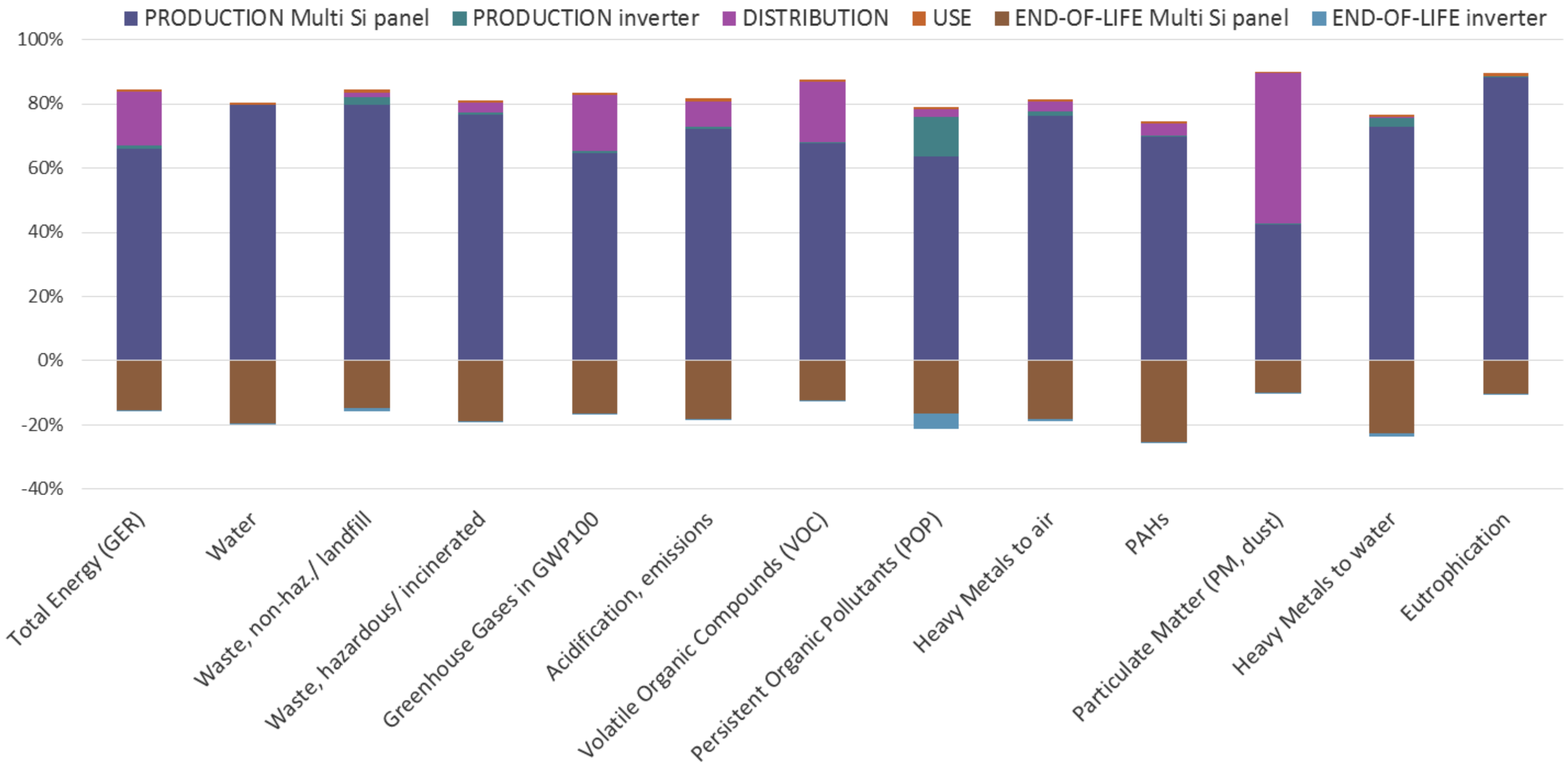
	weight	GER	water (proces + cool)	haz. Waste	non-haz. Waste	Greenhouse Gases in	Acidification, emission	Volatile Organic Compou	Persistent Organic Pollutant	Heavy Metals to air	Polycyclic Aromatic	Particulate Matter (PM,	Heavy Metals to water	Eutrophication freshwat
aluminium	6%	8%	0%	0%	1%	7%	5%	4%	9%	0%	48%	9%	3%	0%
copper	22%	23%	0%	1%	0%	17%	58%	1%	14%	78%	48%	11%	53%	7%
steel	65%	50%	0%	0%	98%	59%	24%	88%	76%	21%	2%	67%	20%	27%
HDPE	1%	2%	3%	2%	0%	1%	0%	2%	0%	0%	0%	0%	0%	0%
PC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
alkyd paint	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
integrated circuits	0%	1%	0%	0%	0%	1%	1%	3%	0%	0%	0%	0%	1%	1%
ferrite	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PVC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PA	5%	14%	92%	33%	1%	14%	10%	0%	0%	0%	1%	11%	22%	63%
PWB	0%	1%	4%	63%	0%	1%	2%	1%	0%	1%	0%	1%	1%	2%
tin	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
transistor/diode/resistor	0%	1%	1%	1%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%
capacitor	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

contribution to impact category	X > 50%
contribution to impact category	25% < X < 50%
contribution to impact category	10% < X < 25%
contribution to impact category	<10%

System 3 kW environmental profile



System 1500 kW environmental profile



System 3 kW environmental profile (modules, inverter and rest of BOS)

	weight	GER	water (proces + cool)	non-haz. Waste	haz. Waste	GWP	AD	VOC	POP	Hma	PAH	PM	HMw	EUP
Module	64%	68%	99%	80%	62%	74%	73%	91%	38%	81%	45%	75%	39%	98%
Inverter	8%	11%	1%	4%	36%	10%	8%	8%	23%	7%	3%	5%	35%	2%
Electric cabling	7%	5%	0%	1%	2%	3%	10%	0%	3%	7%	1%	2%	1%	0%
Mounting structure	20%	16%	0%	15%	0%	13%	9%	1%	36%	5%	51%	19%	25%	0%

contribution to impact category	X > 50%
contribution to impact category	25% < X < 50%
contribution to impact category	10% < X < 25%
contribution to impact category	<10%

System 1500 kW environmental profile (modules, inverter and rest of BOS)

	weight	GER	water (proces + cool)	non-haz. Waste	haz. Waste	GWP	AD	VOC	POP	Hma	PAH	PM	HMw	EUP
Module	47%	69%	100%	71%	98%	74%	66%	96%	29%	71%	38%	72%	47%	98%
Inverter	2%	1%	0%	2%	1%	1%	1%	0%	6%	1%	0%	1%	2%	0%
Electric cabling	7%	7%	0%	0%	1%	5%	21%	0%	4%	15%	2%	2%	3%	0%
Mounting structure	44%	24%	0%	26%	0%	20%	13%	3%	61%	13%	60%	26%	48%	1%

contribution to impact category	X > 50%
contribution to impact category	25% < X < 50%
contribution to impact category	10% < X < 25%
contribution to impact category	<10%

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Summary of LCA Bases Cases

Modules

Production of the photovoltaic cell is responsible for the majority of the impacts. The aluminium frame is a significant contributor.

Inverters

- ✓ For small inverters: Al and the integrated circuits contribute strongly to the most impact categories. Other metals (Cu, steel) and printing wiring board are significant contributors.
- ✓ For central inverters : Cu, steel and fibre glass contribute strongly to the most impact categories.

Systems

For small and large systems: Modules contribute strongly to the majority of impact categories, mounting structure is also significant for some categories.

LCOE results base cases for systems

Table 26 Calculated LCC and LCOE for BC 1 (residential system)

Table 27 Input data used for LCC and LCOE performance modelling

Table 28 CAPEX and OPEX input data and calculated results

MEErP, EU Ecolabel and GPP overlay

	Ecodesign	EU Ecolabel		GPP	
Task 1: Scope	✓	✓	○ Existing labels and certifications	✓	○ Existing national criteria ○ May include services
Task 2: Market	✓	✓	○ **Front runner and niche characterisation**	✓	○ **Procurement options and routes**
Task 3: Users	✓			✓	○ Identification of specific end-uses
Task 4: Technology	✓	✓	○ Screening of **hazardous substances** ○ Other **non-LCA aspects**	✓	○ **Service** and installation aspects
Task 5: LCA/LCC	✓	✓	○ Screening of existing LCA studies ○ Other impact categories	✓	○ Life cycle cost is important focus
Task 6: Design options	✓	✓	○ Front runner improvement options ○ Tests and standards	✓	○ Front runner improvement options ○ Tests and standards
Task 7: Scenarios	✓	✓	○ Identification of possible **criteria areas**	✓	○ Identification of possible **criteria areas**

EU Ecolabel and GPP criteria

- Systematic assessment of LCA literature, 30 recent studies, only 1 inverter study
  - *Subject of the studies*
  - *Time-related coverage of data*
  - *Comprehensiveness and robustness*
- Six selected studies, only 1 on inverters
- Hot spots: modules, inverters and systems
- PEF and MEErP cross-check

Modules hot spot identification (1)

- Production of Si feedstock, ingot and wafer (IEA, Frischknet 2015) & (UNEP 2016) & (Lecissi, 2016)
- Crystalline Si has the highest environmental impacts among PV technologies, and CdTe the lowest (UNEP 2016) & (Lecissi, 2016) & (Wyss, 2015)
- CRM usage: Gallium, Indium and Silicon (UNEP 2016)
- Important to consider disposal stage (Chatzisideris, 2016), recycling can provide a credit up to 17% for some impact categories; e.g. human toxicity, cancer, freshwater eutrophication, ionizing radiation and water resource depletion (Wyss, 2015)

Modules hot spot identification (2)

- Toxicity (Chatzisideris, 2016) and Resource depletion are the most important categories (Chatzisideris, 2016) & (Wyss, 2015)
- Metal deposition processes (under vacuum and high temperatures) are hot spots for primary energy demand (Chatzisideris, 2016)
- Grid emissions factors of the country manufacturing the components contribute strongly, e.g. China (Wyss, 2015)

Inverters hot spot identification

Only one specific study was found, Tschümperlin et al. 2016

- Impact categories: Climate change, human toxicity (cancer and non-cancer effects), PM emissions, freshwater ecotoxicity and resource depletion
- Primary data form 3 manufacturers was collected and extrapolated to 2.5 kW, 5 kW, 10 kW and 20 kW
- Printed board assembly (including all components) responsible for high proportion of impact categories (50% to 75%)
- Increase in 5 out of 7 impact categories between 2006 and 2016: 30 to 200% (2.5 kW model)
    - Will trend continue for wide band gap SiC/GaN inverters?

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Systems hot spot identification (1)

- The manufacturing phase for GWP, particulates and toxicity (UNEP 2016)
- The PV modules for residential rooftop systems (IEA, Frischknet 2015)
- When comparing system sizes, ground mounted has higher impacts due to land use, mounting system and cabling (Wyss, 2015)
- Inverters, transformers, wiring, mounting and construction for metal resource use (UNEP 2016)
- BOS low contribution except for some impact categories (e.g. Acidification due to Cu and Al mining/smelting) and for some module combinations (e.g. thin film) (Lecissi, 2016)

Systems hot spot identification (2)

- Contribution of BOS can be relatively significant for CdTe -based systems, indicatively 40-51% (Chatzisideris, 2016)
- One-axis tracking installations can reduce the environmental burden by ~10% for most impact categories (Lecissi, 2016)

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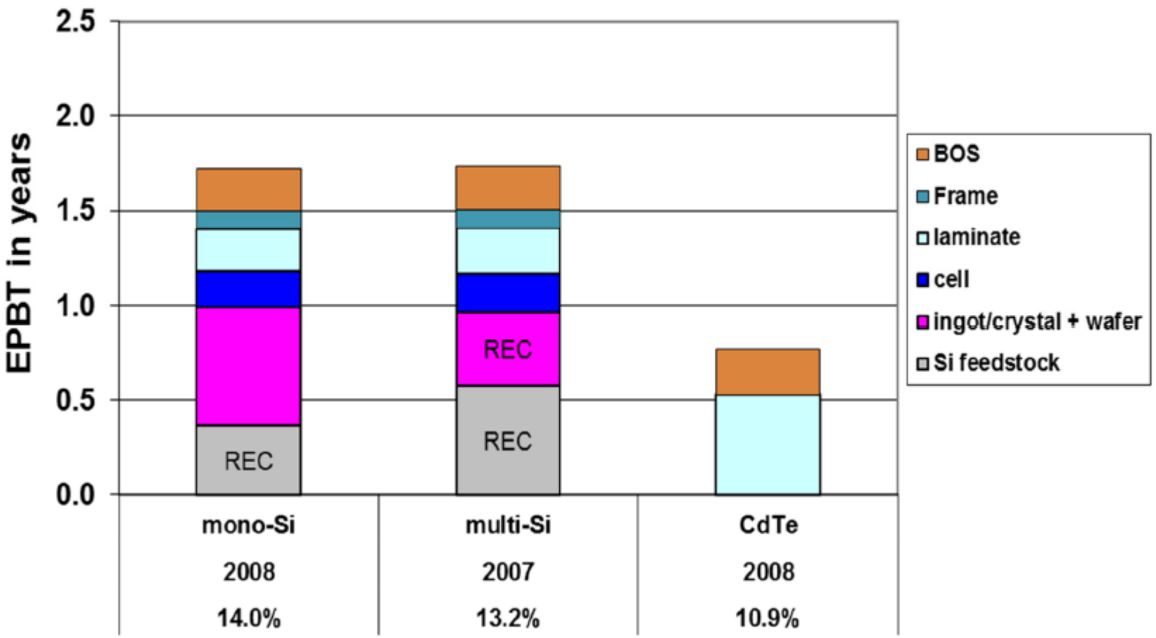
Systems hot spot identification (2)



PEF MEErP cross-check (1)

- The environmental impact categories of the two methods;
- The results for the impact categories used in the PEFCR 2018 pilot and the MEErP methodology used in Task 5 to perform the Environmental impact assessment of the Preparatory study for Solar Photovoltaics,
- The hot spots identified by the interpretation provided by the first set of 2015 results from the PEF pilot and those of the MEErP Task 5 assessment.

PEF MEErP cross-check (2)

PEF[1]		MEErP[2]	
Impact category	**Unit**	**Impact category**	**Unit**
Climate change GWP100 (IPCC 2013)	*kg $CO_{2\ eq}$*	*Greenhouse Gases in GWP100 (IPCC 2007)*	*Mt CO2 eq.*
Ozone depletion	*kg CFC-11 $_{eq}$*	-	-
Human toxicity, cancer	*CTUh*	-	-
*Human toxicity, non-cancer**	*CTUh*	-	-
Particulate matter	*disease incidence (number of cases per kg of PM 2.5 inhaled)*	*Particulate Matter (PM10 equivalent, dust)*	*g*
Ionising radiation, human health	*kBq $U^{235}{}_{eq}$*	-	-
Photochemical ozone formation, human health (LOTOS-EUROS 2008, ReciPe)	*kg NMVOC $_{eq}$*	*NMVOC*	*g NMVOC*
Acidification (Accumulated Exceedance)	*mol H+ eq*	*Acidification, emissions (UNECE 1999 CLRTAP protocol)*	*kt SO2 eq*
Eutrophication, terrestrial (Accumulated Exceedance)	*mol N $_{eq}$*	-	-
Eutrophication, freshwater (EUTREND 2009 ReciPe)	*kg P $_{eq}$*	*Eutrophication (water) (Directive 91/271/EC (Urban Waste Water Treatment)*	*g PO_4*
Eutrophication, marine	*kg N $_{eq}$*	-	-
*Ecotoxicity, freshwater**	*CTUe*	-	-
Land use	• *Dimensionless (pt)* • *kg biotic production*[3] • *kg soil* • *m^3 water*	-	-

PEF MEErP cross-check (3)

Impact category	***PEFCR 2018 pilot***		***MEErP***	**Variance**
Climate change GWP100	0.04881		0.0495	+1.26%
Resource use, fossils, MJ	0.61604		-	+11.09%
Total Energy, MJ	-		0.77901	

PEF MEErP cross-check (4)

Impact category	*PEFCR 2018 pilot*	*MEErP*
Climate change GWP100	Wafer production (~88%)	Photovoltaic cell (79%) Aluminium frame (11%)
Particulate matter	Silicon production (95%)	Photovoltaic cell (76%) Aluminium frame (17%)
Photochemical ozone formation/ NMVOC	Supply chain of electricity production-coal- (90%)	Photovoltaic cell (70%) Solar glass (15%)
Acidification	Supply chain of electricity production-coal- (90%)	Photovoltaic cell (80%)
Eutrophication freshwater	Hard coal and Silver mining (48%) and Copper mining (50%)	Photovoltaic cell (86%)
Water use/ Process water and cooling	Silicon production from hydro power (85%)	Photovoltaic cell (96%)

PEF MEErP cross-check (5)

- A sensitivity analysis was carried out (v1.4, 2015) including an inverter for a 3 kW system.
- Most impacted category: Eutrophication freshwater due to the supply chain of copper (phosphate emissions when disposing sulphidic tailings off-site).
- Also found to be sensitive: Resource depletion (due to silver and tantalum) and Human toxicity (due to copper, steel and aluminium)
- Differences in MEErP: greatest contributions from alumium, integrated circuits printing wiring boards and copper

Summary of the LCA review and PEF MEErP cross-check

- ✓ From a literature review of 30 studies, 6 were selected. Only one study could be identified for inverters.
- ✓ For Modules,
  - ✓ crystalline Si, production of Si feedstock, ingot and wafer contribute strongly, for thin films deposition processes are hot spots
  - ✓ CRM use and end of life routes are important to address for all technologies
- ✓ For inverters: printed board assembly (including all components) responsible for high proportion of impact categories (50% to 75%)
- ✓ For systems:
  - ✓ PV modules for residential rooftop systems contribute strongly
  - ✓ Ground mounted has higher impacts due to land use, mounting system and cabling
  - ✓ For thin film, BOS can be relatively significant

Non LCA environmental impacts

- Hazardous substances in solar photovoltaic products
- Hazardous substances in manufacturing processes
- Use of Critical Raw Materials
- Social and ethical issues

Non LCA environmental impacts

Hazardous substances in solar photovoltaic products

Ecolabel Regulation (EC) 66/2010 contains in Article 6(6) and 6(7) specific requirements that ecolabelled products shall not contain hazardous substances

- REACH Candidate List substances
- Substances classified with CLP hazards
- Substances restricted by the RoHS Regulation

Non LCA environmental impacts

Hazardous substances in solar photovoltaic products

- **REACH**

✓ IEC 62474 substance declaration list is used to pre-screen the Candidate List for relevance.

✓ CEA Tech and Fraunhofer ISE consortium made a preliminary screening and identified some Phthalates and Cadmium sulphide were used in the PV industry

- **CLP**

✓ Screening threshold for substances classified with CLP hazards is 0.1 %wt.

✓ Progress to substitute or eliminate substances may vary.

✓ There is provision for derogation, only with strong justification

Non LCA environmental impacts

Hazardous substances in solar photovoltaic products

- **CLP**

Substance	Use	Alternatives	Information gaps
Plastizicers	• Cable sheathing • Module encapsulation	• Phtalate free plastiziers, e.g. TOM, DOTP) • Cable sheating materials (e.g. TPE, EVA)	Extent of use of the alternatives
Flame retardants	• Polymer back sheet material for fire protection • Cable sheathing	• Fluoropolymers • Thicker materials, e.g. PET • Metal phosphinates with TPEs	• Use in junction boxes and electronic components in inverters • Suitability of inorganic alternatives
Water and dirt repellents	• Module glass	• Silicon or paraffin based repellents (PFOs phased out)	Substances currently used and their migration potential

Non LCA environmental impacts

Hazardous substances in solar photovoltaic products

- **RoHS**

Solar photovoltaic products are exempted from the requirements of the RoHS Regulation, however manufactures in the sector differentiate themselves by claiming 'RoHS compliance' for substances such as lead, cadmium and phthalates.

LEAD

✓ Metallization paste and contacts, 0.05% - 0.25% wt.

✓ Lead-free or RoHS compliant modules exist

CADMIUM

✓ Semiconductor layers as CdTe and CdS in CdTe and CIGS, 0.05 % wt.

✓ CIGS manufacturers claim 0.01% wt. RoHS compliance

Non LCA environmental impacts

Hazardous substances in manufacturing processes

- High GWP (Global Warming Potential) production emissions

  - Use of CF_4, C_2F_6, SF_6 and or NF_3 for edge isolation and reactor cleaning

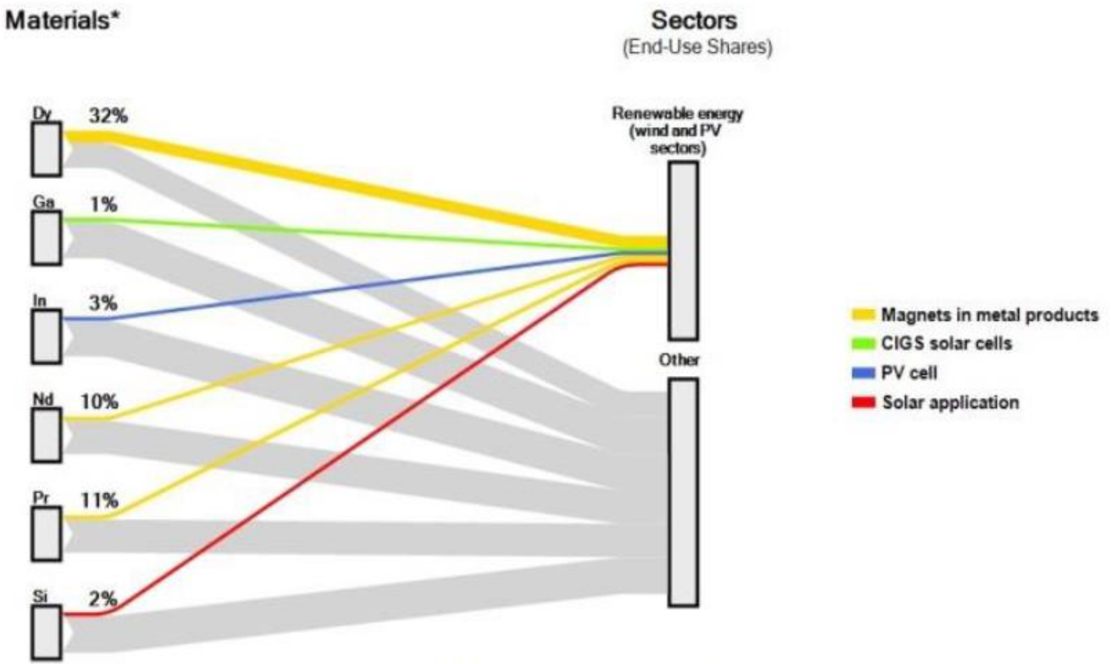
  - NSF 457 requirement on avoidance or reduction of high global warming potential gas emissions

- Exposure to silicon tetrachloride by-product
  - Production of silane and trichlorosilane
  - Reports that rapid expansion of production has resulted in pollution of rivers
  - Possibility to be used as raw material, e.g. polysilicon and fibre optics
  - More information is needed for abatement options used in the sector

Non LCA environmental impacts

Use of Critical Raw Materials

- Indium (CIGS)
- Gallium (CIGS, tandem)
- Silicon metal
- Cobalt (batteries)
- Tantalum (inverters and MLP)



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

Non LCA environmental impacts

Social and ethical issues

- Use of minerals from conflict zones, Great Lakes region of Africa
- Mining under dangerous conditions, and without sufficient maintenance of health and safety standards and in some cases by children
- Three broad types of projects,
  - General traceability systems
    - Public-Private Alliance for a responsible minerals trade
    - Solutions for Hope
  - Focus on specific minerals
    - Tin Source
    - Tantalum Initiative
  - Verification routes
    - RMAP and CFSI

Next steps?

- Circulation of slides followed by meeting minutes
- Deadline for stakeholder written comments, Wednesday 30th January

Please use BATIS to submit your comments
http://eippcb.jrc.ec.europa.eu/batis/login.jsp

BATIS Helpdesk
JRC-B5-PRODUCT-BUREAU@ec.europa.eu

Upcoming meetings

Webinar on EU Ecolabel and GPP criteria early 2019

- Criteria areas

Stakeholders meeting June 2019, Brussels

- Task 6 (Assessment of base case, design options and improvement potential)
- Task 7 (Policy scenario analysis)

Thanks for your attention

Any questions?

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Stay in touch

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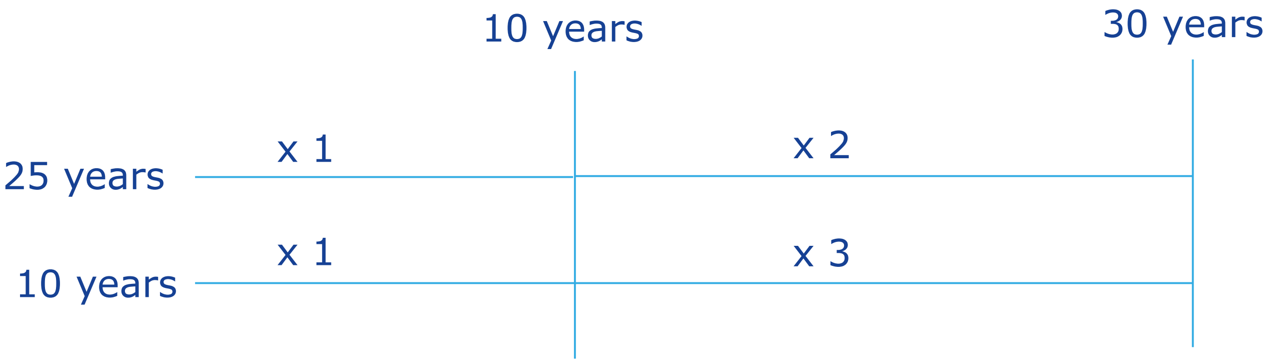
Notes

Current functional unit service life for inverters



- In order to capture the issue above, we propose to extend the functional unit service life for inverters to 30 years.
- Is the assumption of 30 years lifespan for a central inverter appropriate?
  - In that assumption there are parts assumed to be replaced, could you check the appropriateness of the assumptions?