JRC TECHNICAL REPORTS

Preparatory study for solar photovoltaic modules, inverters and systems

Draft Report Task 6: Assessment of BAT, design options and improvement potential

Dodd, Nicholas; Espinosa, Nieves – JRC B5

Van Tichelen, Paul; Peeters, Karolien; Soares Ana - VITO

Tsanakas, Ioannis; Voroshazi, Eszter - IMEC

Joint Research Centre

Contact information

Nicholas Dodd and Nieves Espinosa

Address: Edificio Expo. C/ Inca Garcilaso, 3. E-41092 Seville (Spain)

E-mail: jrc-b5-photovoltaics@ec.europa.eu

Tel.: +34 954 488 728/476

JRC Science Hub

https://ec.europa.eu/jrc

How to cite this report: Dodd, N Espinosa, N, Van Tichelen, P., Peeters, K., Soares, A., Voroshazi, E., and Tsanakas, I *Preparatory study for solar photovoltaic modules, inverters and systems – Task 6 Assessment of BAT, design options and improvement potential*

6. Task 6: Assessment of BAT, design options and improvement potential

6.0 General introduction

This task aims at identifying the design options, their monetary consequences in terms of Life Cycle Cost for the user, their economic and possible social impacts, and pinpointing the solution with the Least Life Cycle Costs (LLCC) and the Best Available Technology (BAT).

The assessment of monetary Life Cycle Costs is relevant to indicate whether design solutions might impact the total user's expenditure over the total product life (purchase, operating, end-of-life costs, etc.). The distance between the LLCC and the BAT indicates —in a case a LLCC solution is set as a minimum target— the remaining space for product-differentiation (competition).

The BAT indicates a target in the shorter term that would probably be more subject to promotion measures than to restrictive action. The BNAT indicates possibilities in the longer term and helps to define the exact scope and definition of possible measures. Any intermediate options between the LLCC and the BAT have to be described, and their impacts assessed.

6.0.1 Identification of design options and assessment of their impacts

Available design options will be identified by investigating and assessing the environmental impact and LCC of each suggested design option against each Base-Case (using the MEErP EcoReport 2014):

- The design option should not have a significant variation in the functionality, the quality of the produced products and in the primary or secondary performance parameters compared to the Base-Case and in the product-specific inputs.
- The design option must have a significant potential for improvement regarding at least one of the following ecodesign parameters without deteriorating others: the consumption of energy, water and other resources, use of hazardous substances, emissions to air, water or soil, weight and volume of the product, use of recycled material, quantity and nature of consumables needed for proper use and maintenance, ease for reuse and recycling, extension of lifetime or amounts of waste generated.
- The design option should not entail excessive costs. Impacts on the manufacturer must be investigated regarding redesign, testing, investment and/or production costs, including economy of scale, sector-specific margins and market structure, and required time periods for market entrance of the design option and market decline of the current product. The assessment of the monetary impact for categories of users includes the estimation of the possible price increase due to implementation of the design option, either by looking at prices of the product on the market and/ or by applying a production cost model with sector-specific margins.

For each of the identified design options, it must be described:

- if Member State, Community or Third Country legislation and/or standards are available regarding the design option;
- how market forces may address the design option;
- how large the disparity is in the environmental performance of the product available on the market with equivalent functionality compared to the design option.

The analysis carried out in task 5.2 also has the intention of identifying environmental 'hotspots'., If these hotspots differ from the findings of Ecoreport tool may then also be taken into account, if relevant to the extent of Ecodesign/Energy Labelling, in the analysis under task 6 and 7, provided that the life cycle cost is properly assessed.

6.0.2 Summary of how the functional unit for LCA and LCOE results has been calculated

The functional unit used for the calculation of environmental impacts and levelized cost of energy is '1 kWh of electricity generated'. The environmental impacts are expressed per kWh of electricity generated. At module level, the primary energy results do not include the electricity generated by the module. Instead the primary energy is a function of the life time energy yield. To get results per kWh produced, environmental impacts are first calculated per m^2 of module and per inverter. Then the area of modules and amount of inverters needed to generate 1 kWh electricity is calculated using module and inverter efficiencies and derate factors. Area and amount necessary per kWh are then multiplied with the environmental impact per m^2 of module

PV system yield over years is calculated in line with the transitional method under development by JRC unit C2. However, in this study more derate factors have been used. The additional derate factors made possible a more detailed differentiation between the package and system options.

The task 5 report includes an introduction to Life Cycle Costing and Levelized Cost of electricity (LCOE) (section 5.3.1). LCOE is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment (including module and inverter costs), operations and maintenance, cost of fuel and cost of capital. It is commonly applied to evaluate PV system costs[1]. The Levelized cost of electricity (LCOE) is defined for the purpose of these calculations as:

$$\mathrm{LCOE}[€/\mathrm{kWh}] = \frac{\text{net present value of sum of costs of generation over its life time}}{\textit{sum of electrical energy produced over its life time}}$$

The LCOE calculation of costs per kWh generated aligns with the functional unit defined in Task 1. In this definition the life cycle environmental impacts of the PV system or component are normalized to 1 kWh of electricity produced by the system/component.

The LCOE results present the cost of supplying each kWh to the grid. They do not present revenues for PV owners. Revenues for PV owners depend on the market/subsidy prices.

[1] https://setis.ec.europa.eu/sites/default/files/reports/Cost-Maps-for-Unsubsidised-Photovoltaic-Electricity.pdf

Table 1. Overview of design options for photovoltaic modules (the options selected for further analyses are highlighted in grey).

Design options	**Description**	**Rationale for the selection of design options for further analyses**
Option 1: Optimised multi Si	Optimized BSF modules as of today (2019): - white EVA - more busbars (6) - better glass (AR properties) - factory quality control measures Note: this is not PERC	Within BSF modules also some progress is expected compared to the base case of Task 5
Option 2: PERC	PERC cells	Expected mainstream improvement option
Option 3: Bifacial + PERC	Bifacial PERC cells and a glass backsheet	Expected to have a higher yield when applied at utility scale and moreover they do not have a halogenated back sheet
Option 4: CdTe	Thin film CdTe	Showed lower carbon footprint in the LCA review in Task 5
Option 5: CIGS	Thin film CIGS	Showed lower carbon footprint in the LCA review in Task 5
Option 6: Kerfless old	Epitaxial Si/Ribbon Si	Could reduce energy intensive wafer manufacturing
Option 7: SHJ	Silicon heterojunction	Silicon heterojunction (SHJ) cells offer high efficiencies and several advantages in the production process compared to conventional crystalline silicon solar cells (Louwen et al, 2015[2]) SHJ could minimize the use of silicon raw material that had important GWP/Primary energy impact
Option 8: MSi cleaner cell	MSi base case module	Module manufactured with a more favourable grid emissions factor for

[2] Louwen A., van Sark W.G.J.H.M., Schropp R.E.I., Turkenburg W.C., Faaij A.P.C. 2015. Life-cycle greenhouse gas emissions and energy payback time of current and prospective silicon heterojunction solar cell designs. Progress in photovoltaics: research and application. 23:1406-1428. Doi: 10.1002/pip.2540

production		electricity (EU average and best performing Member State- Sweeden)
Option 9: BNAT kerfless new	Kerfless wafer production	Could reduce energy intensive wafer manufacturing
Option 10: Back-contact	Compared to two-sides contacted solar cells, back-contact solar cells have both contact polarities on the rear side which significantly reduces optical losses at the illuminated front side both from cell metallization and cell-to-cell interconnection (task 4 report)	Not selected
Option 11: Perovskite	Perovskite based thin film PV is not yet in production, but this technology has made remarkable progress in the past few years. Because of its potential of very low-cost production, and its suitable bandgap for tandem formation with crystalline silicon, it could be (or pave the way for) a significant and disruptive technology PV energy generation (task 4 report)	Not selected: BNAT
Option 12: Perovskite/Si-tandem	The start-up Oxford PV showed that the tandem configuration has the potential to outperform single junction Si PV with efficiencies over 22%. They have acquired a production facility in Germany targeting tandem pilot production by 2019-2020 (task 4 report)	Not selected: BNAT

Table 2. Overview of design options for inverters (the options selected for further analyses are highlighted in grey).

Design options	**Description**	**Rationale for the selection of design options for further analyses**
Residential		
Option 1: more efficient	This design option represents the potential for improvement on the Euro efficiency of the base case	The focus of Ecodesign and Energy label is on the energy efficiency during the use phase
Option 2: longer life time	This design option represents the potential for extension of the design lifetime of the base case	Reducing the number of inverter replacements during the PV system lifetime will minimise environmental impacts and improve material efficiency

Option 3: repair (repaired)	This design option represents the extent to which a product is designed for repair along its lifetime	Repairing and replacing components to achieve a longer design life will minimise the environmental impacts and improve material efficiency
Option 4: monitor/smart	This design option represents the potential for monitoring to diagnose and react to faults related to firmware or hardware. It can help additionally the consumer to adjust their demand to increase self-consumption	Early fault detection and reaction can reduce downtime and maximise energy efficiency during the use phase
Option 5: Module Level Converter (MLI)	This design option represents the installation of module level inverters that may increase yield in mismatch conditions	Shifting to inversion at the module level may bring system level benefits, such as maximising energy efficiency during the use phase
Option 6: Hybrid storage worst performer	These design options represent the installation of inverter with integrated storage to either: - provide peak shaving in feed in (German EEG case). - increase hourly and quarterly self-consumption	A trend has been observed for households increasing the self-consumption by integrating battery storage. However, this may introduce losses in the total amount of renewable electricity generated which should be avoided or minimised. There is also the potential to achieve marginal emissions reduction by displacing peak power generating plants in the evening
Option 7: Hybrid storage best performer		
Commercial		
Option 8: More efficient	This design option represents the potential for improvement on the Euro efficiency of the base case	The focus of Ecodesign and Energy label is on the energy efficiency during the use phase
Option 9: Repair (repaired)	This design option represents the extent to which a product is designed for repair along its lifetime	Repairing and replacing components to achieve a longer design life will minimise the environmental impacts and improve material efficiency
Option 10: Wide band gap converter (WBG)	This design option represents the installation of inverters which transistors are completely based on new semiconductor materials with a wide band gap	Not selected – consultation of manufacturers revealed that the benefits and possible tradeoffs of this design option are not apparent at this stage
Utility		
Option 11: More efficient	This design option represents the potential for improvement on the system level efficiency of the base case	The focus of Ecodesign and Energy label is on the energy efficiency during the use phase
Option 12: More efficient plus string	This design option represents the potential for improvement on the Euro efficiency of the base case	Shifting to inversion up the string level may bring system level benefits, such as maximising energy efficiency during the use phase. However, may be a trade-off in material efficiency
Option 13: Wide band	This design option represents the installation of inverters which	Not selected – consultation of manufacturers revealed that the

gap converter (WBG)	transistors are completely based on new semiconductor materials with a wide band gap	benefits and possible tradeoffs of this design option are not apparent at this stage.

Table 3. Overview of design options for systems (the options selected for further analyses are highlighted in grey).

Design options	**Description**	**Rationale for the selection of design options for further analyses**
Residential		
System Options		
System Option 1: Multi Si optimised + best inverter (SO 1)	This option combines the best module with the best inverter	An obvious combination of all the best at component level in a system to be compared to a standard design with base case components
System Option 2: Multi Si optimised + best inverter + better design (SO 2)	This system combines the best module with the best inverter and includes a better design by installer	An obvious combination of all the best at component level in a system to be compared to a standard design with base case components Derating factors are adapted to reflect the better design
System Option 3: Multi Si optimised + best inverter + optimised O&M (SO 3)	This system combines the best module with the best inverter and includes optimized operation and maintenance routine.	This would introduce practices from the large scale segment including remote monitoring, repair response or early failure detection and cleaning routines.
Package option 1 (PO 1)	Multi Si module and reference inverter	
Package option 2 (PO 2)	Multi Si optimised module and reference inverter	
Package option 3 (PO 3)	PERC module and reference inverter	
Package option 4 (PO 4)	CIGS module and reference inverter	
Package option 5 (PO 5)	Kerfless (old) module and reference inverter	
Package option 6 (PO 6)	Silicion heterojunction module and reference inverter	
Package option 7 (PO 7)	BNAT kerfless (new) module and reference inverter	

Package option 8 (PO 8)	Multi Si module and more efficient inverter	
Package option 9 (PO 9)	Multi Si module and longer life inverter	
Package option 10 (PO 10)	Multi Si Module and inverter with repair	
Package option 11 (PO 11)	Multi Si module and inverter including monitoring	
Package option 12 (PO 12)	Multi Si module and multi-level inverter	
Package option 13 (PO 13)	Multi Si module and inverter including storage (worst case)	
Package option 14 (PO 14)	Multi Si module and inverter including storage (best case)	
Commercial		
System Options		
System Option 1: best combination and design (SO 1)	Improved design, this is combination of all the best at component level in a system including bifacial modules with a more with reflective roof surface. This option also assumes higher derating factors due to lower cable losses, shading and module mismatch because of a tailored design	This is an all best combination to be compared to a standard design with base case components PERC bifacial + higher derating factors due to lower cable losses, shading and module mismatch because of a tailored design
Package option 1 (PO 1)	Multi Si module and reference inverter	
Package option 2 (PO 2)	Multi Si optimised module and reference inverter	
Package option 3 (PO 3)	PERC module and reference inverter	
Package option 4 (PO 4)	PERC bifacial module and reference inverter	
Package option 5 (PO 5)	CdTe module and reference inverter	
Package option 6 (PO 6)	Multi Si module and more efficient inverter	
Package option 7 (PO 7)	Multi Si module and inverter with repair	
Utility		

System Options		
System Option 1: best combination and design including single axis tracker (SO 1)	System with single axis tracker, CdTe modules and energy efficient string inverter	Single axis trackers can provide higher yield at the expense of a slewing drive worm gear and motor for a series of modules
Package option 1 (PO 1)	Multi Si module and reference inverter and reference BOS	
Package option 2 (PO 2)	Multi Si optimised module and reference inverter and reference BOS	
Package option 3 (PO 3)	PERC module and reference inverter and reference BOS	
Package option 4 (PO 4)	PERC bifacial module and reference inverter and reference BOS	
Package option 5 (PO 5)	CdTe module and reference inverter and reference BOS	
Package option 6 (PO 6)	Multi Si module and more efficient inverter and reference BOS	
Package option 7 (PO 7)	Multi Si module and more efficient string inverter and reference BOS	

6.1 Overview of the selection of single design options

6.1.1 PV modules

6.1.1.1 Assumptions regarding the selected design options

Table 5 below provides the assumptions for the selected design options. The modules can be used for residential, commercial and utility scale applications. The design parameters remain identical. Table 5 also provides the estimated additional costs per Wp. A life time of 30 years has been assumed for all modules.

The Base-Case as defined in Task 5 represents a multi Si module with reference year 2016. The technology of the multi Si base case has been improved since 2016. This has been considered in the Base-Case 'optimized design multi-Si'. It is assumed that technology will further improve according to the VDMA roadmap, BSF will no longer have a relevant share and will be replaced by PERC type cells by 2020. The expected improvement measures are provided in Table 4.

Table 4: Expected improvement of the multi Si modules (year 2020 and 2025)

Production step	**Selected improvement measures**	
	Optimised BSF 2020	**Optimised BSF 2025**
Wafer production	Multi-crystalline with diamond wire sawing with larger wafer size than>156x156 mm^2 170 um wafer thickness and 80 µm of kerfless	Epitaxial wafer production with larger wafer size than>156x156 mm^2 and wafer thickness of 120 µm and no kerfless
Semi-conductor preparation e.g. passivation	Bifacial PERC cell without passivation	SHJ on n-type mono wafer
Cell metallisation	Reduced Ag to 50 mg/cell and Al to < 200 mg/cell	Reduce Ag and Pb-free cell metallization paste with 90 mg/ml and Al< 200 mg/cell
Cell stringing	Full-cells and 5BB interconnection	Half-cell, busbarless cells with copper interconnection with Pb-free soldering
Cell encapsulation	Glass-glass with 3.2 mm glass	Glass-glass with AR and anti-soiling coating with < 3.2 mm glass thickness
Module power	340 Wp for 72-cell modules	440 Wp for 72-cell modules
Degradation rate	0.7%	0.5%
Performance warranty	25 years	30 years
Factory quality inspection	Infrared+Electroluminescence/Lock in thermography	Infrared+high-resolution Electroluminescence/Lock in thermography Light/Potential Induced Degradation assessment

Table 5: Design option parameters

Acronym	Multi Si – Base Case	Multi Si optimized	PERC	PERC bifacial	CdTe	CIGS	Kerfless old	SHJ	BNAT kerfless new
Module type	Multi crystalline Si	Multi crystalline Si – optimized design	Passivated Emitter and Rear Cell (PERC)	PERC + bifacial glass backsheet	Thin film - Cadmium Telluride	Thin film – Copper Indium Gallium Selenide	Epitaxial grown Si	Silicon heterojunction mono Si cells	Kerfless manufacturing
Performance degradation rate (% per year)	0.7%	0.7%	0.5%	0.5%	1%	1%	0.7%	1%[1]	0.5%
Failure rate modules (%/year)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cells per module	60	60	60	60	/	/	60	60	60
Module power density (Wp/m^2)	147	174	196	196	180	150	147	197	196
Wafer thickness/Active layer thickness (µm)	200	170	180	180	/	/	250	180	125
Kerf thickness (µm)	100	80	100	100	/	/	0	130	0
Total silicon use in kg per m^2	0.638	0,531	0,595	0,595	/	/		0.383	0.266
Economic life time for the FU (years)	30	30	30	30	30	30	30	30	30
Cost (EUR/Wp)	0.48	0.48	0.56	0.56	0.48	0.53	0.35	0.60	0.39

6.1.1.2 Life cycle information – Bill of Materials: Modules

6.1.1.2.1 Multi Si

Material input for the multi Si module production has been taken from the data collection exercise carried out for the PEF[3]. This is considered to provide the most up to date and representative dataset for the silicon wafer-based cells, as validated by the data quality rating (DQR) contained within the PEF pilot. For this assessment, packaging materials and the end of life treatment of the production waste have been omitted.

Data for the solar cell production has been taken from the ecoinvent 3.4 database. The global dataset has been used. This dataset contained an input of both solar and electronic grade Si. The input of electronic grade Si has been changed into solar grade Si, which better resembles reality.

The PEF data provided the input of photovoltaic cells per m^2, not per kg. The weight of the photovoltaic cells has been calculated based on the wafer thickness. The wafer has a thickness of 200 micrometer. The specific weight cell weight is 0.530 kg/m^2cell. The cell area per m^2 module is 93,5% (PEF), which results in a cell weight of 0.496 kg/m^2 module.

The materials which were not available and have been added to the EcoReport tool are: multi Si photovoltaic cell, tin, lead, ethylvinylacetate, polyvinylfluoride, silicone, solar glass and tempering, tap water, hydrogen fluoride, potassium hydroxide, 1-propanol, isopropanol. The ecoinvent version 3.4 global datasets have been used to model these materials.

Energy use for module manufacturing has been added to the tool as well. The input data have been taken from the PEF life cycle inventory (LCI) file. Data from the EcoReport tool have been used to calculate the environmental impact of the energy use during module manufacturing.

The BOM is available in annex A.

6.1.1.2.2 Multi Si optimised design

To model this design option, we started from the BOM of the multi Si base case module. The wafer thickness has been adapted to 170 micrometers (200 micrometers in the base case). This means less cast silicon is needed.

For the BOM we refer to the BOM of the multi Si base case which is available in Annex A. Only the solar cell input has been changed compared to the base case.

6.1.1.2.3 PERC

The LCI for module production has been taken from the PEF LCI table for Monocrystalline silicon solar modules.

The photovoltaic cell has been taken from the ecoinvent 3.4 database. To this dataset the 'PERC rear passivation layer' process and 'PERC dielectric openings' process has been added based on the LCI information provided in Lunardi et al. (2018). Some minor modifications have been made to the report inventory because some of the inputs or outputs were not available in the ecoinvent database. In addition, electronic grade silicon has been changed into solar grade silicon, like in the multi Si cell. The considered cells are n-type cells.

The BOM in EcoReport tool format is available in annex A.

[3] Wyss F., Frischknecht R., de Wild-Scholten M., Stolz P. 2015. PEF screening report of electricity from photovoltaic panels in the context of the EU Product Environmental Footprint Category Rules (PEFCR) Pilots

6.1.1.2.4 PERC+bifacial

For this design option, we started from the PERC inventory. The PVF/PET backsheet has been replaced with a glass backsheet. The same weight as the front sheet has been assumed. No other changes have been made to the BOM compared to the PERC only design option.

The BOM in EcoReport tool format is available in annex A.

6.1.1.2.5 CdTe

The life cycle inventory for the CdTe module production has been taken from PEF. Data for the materials which were not available in the EcoReport Tool have been taken from Ecoinvent 3.4.

The BOM in EcoReport tool format is available in annex A.

6.1.1.2.6 CIGS

The life cycle inventory for the CIGS module production has been taken from PEF. Data for the materials which were not available in the EcoReport Tool have been taken from Ecoinvent 3.4.

The BOM in EcoReport tool format is available in annex A.

6.1.1.2.7 Kerfless old

This design option has been modelled using the ecoinvent record 'photovoltaic panel production, ribbon-Si RER' which is based on primary data of the production of ,modules by Evergreen's string ribbon process (ca. 2011)

The BOM in EcoReport tool format is available in annex A.

6.1.1.2.8 SHJ

The life cycle inventory for the SHJ module is a combination of data available in ecoinvent and the life cycle inventory published by Louwen et al. (2015)[Error! Bookmark not defined.][2]. Data for the materials which were not available in the EcoReport Tool have been taken from Ecoinvent 3.4.

The BOM in EcoReport tool format is available in annex A.

6.1.1.2.9 BNAT kerfless new

To model this design option, we started from the BOM of the PERC module (see 6.1.1.2.3). The wafer thickness has been adapted to 125 micrometers. There are no kerf losses.

For the BOM we refer to the BOM of the PERC module which is available in Annex A. Only the solar cell input has been changed compared to the PERC module.

The BOM in EcoReport tool format is available in annex A.

6.1.2 PV inverters

6.1.2.1 Assumptions regarding the selected design options for residential use

Table 6: Design option residential inverters (BC 1)

Acronym	Base Case - Reference	Efficient	Longer life	Repair	Monitoring	MLI	Storage (worst case)	Storage (best case)
Inverter type	String 1 phase reference inverter Transformerless	More efficient inverter	Longer life time	Repair/repaired	Monitor/Smart BC1 reference plus monitoring	Module level converter transformerless	Hybrid storage worst performer	Hybrid storage best performer
Rated power (kVA)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Euro Efficiency η_{conv}[%]	96	98	96	96	96	97	96	96
Failure rate inverters (% / year] = 1/(average life time)	10%	10%	3.86%	10% - repairs, not a full inverter being replaced	10%	10%	10%	10%
Cost (EUR/VA)	0.22	0.25	0.28	0.22	0.25	0.33	0.33	0.33

Life time assumptions for inverters:

More background on inverter failure is given in Task 3 section 3.3.1.5 and Task 4 section 4.1.4.3, as a reminder, failure rate of an inverter was defined as the linear average failure rate per year of an inverter relative to its technical life time (= 1/MTBFinv).

Table 7: BC failure rates for inverters

	BC 1 residential	**BC 2 Commercial**	**BC 3**
wear out failures = wear out + economic life time of installation			
EOL (years)	30	30	30
proxy replacement rate for EoL (%/y)	3,33%	3,33%	3,33%
note: premature failures = warrenty replacements (assumed in BOM)			
random failures = constant failure rate phase			
MTBF BAU (years)	15	15	15
constant failure rate BAU (%/y)	6,67%	6,67%	6,67%
MTBF BAT LL (years)	191	50	30
constant failure rate BAU (%/y)	0,52%	2,00%	3,33%
total inverters modelled over 30 years			
BAU total failure rate (%/y)	10,00%	10,00%	10,00%
BAT total failure rate (%/y)	3,86%	5,33%	6,67%
BAU inverter needed over 30 y life	3,00	3,00	3,00
BAT inverter needed over 30 y life	1,16	1,60	2,00

In electronics the common method applied for reliability prediction of electronic equipment are metrics, methods and data from MIL-HDBK-217, published by the US Department of Defense. It allows to calculate the failure rates [%/y] and the reciprocal value Mean Time Between Failure(MTBF). Note that these computed values in the failure rate bathtub curve (Figure 23, Task 3) relate to the constant failure rate phase only, which excludes premature failures covered under first year warranty. In the Tasks 5 and 6 modelling we assume that premature warranty failures are part of the manufacturing drop out and waste.

Based on literature[4] a 10 years average life time was proposed for the base case (see Tasks 2), hence the failure rate of 10 % was established in Task 5 as a minimum reference. However, it is understood that design lifetimes of manufacturers are now up to 20-25 years with accompanying recommendations as to repair and replacement cycles to achieve the design lifetime.

[4] See sources cited in Task 3 and 4 but also high amount of inverter failures reported by consumer organisation: https://www.which.co.uk/news/2017/08/top-five-solar-panel-problems/

Clearly as a circular economy improvement option the failure rates of products can be improved using the MIL-HDBK 217 as reference. Task 4 already reported that manufacturers today already offer inverter warranty up to 10 years and input from manufacturers together with the findings from field analysis suggest a constant failure rate of as low as 0,50 % per annum. This is added as a separate improvement option 'longer life time'.

Note that 'longer life time' is an alternative to repairing low life time products, for residential repair cost can be expensive, hence a market shift to longer life time products is likely more economic. For larger units service cost aren't a barrier and servicing is common practice.

6.1.2.2 Life cycle information – Bill of Materials: Inverters for Residential use

6.1.2.2.1 More efficient inverter

No change in BOM compared to base case (see Task 5 report).

6.1.2.2.2 Longer life time inverter

The reference case BOM for 1 inverter has been used as a starting point. The base case inverter is replaced 2 times during the life span of the system. The inverter used in this design option has a failure rate of 3.76% while the reference inverter has a failure rate of 10%.

The BOM in Ecoreport tool format is available in annex B.

6.1.2.2.3 Repair

Based on the information contained in Table 4 of the Task 4 report, the main repair events for an inverter are derived. Note that this is related to BC 1 (residential) and BC 2 (commercial) in particular.

The base case inverter is replaced 2 times during the life span of the system. For this design option, it is assumed that inverters are repaired and the damaged components are replaced proportionally to their failure rate and this occurs two times during the 30 year life span of the inverter (after 10 years and after 20 years).

Table 8 provides a proxy LCA estimate for inverter failures that have an impact on Bill-of-Materials. Based on this information the BOM for this design option has been established. The BOM of the base case has been taken from Tschumperlin et al (2016). This BOM contains several proxies and to establish the modelling of this design option further proxies have been added to it (e.g. link between BOM and the failed component), our repair estimate is accordingly.

This excludes software failures. Software failures have no impact on the BOM, only on the derate factor.

Fans are excluded as well, as the best inverter designs are without fans.

Table 8: Proxy bill of material estimate to model smaller fanless inverter failures. Source: based on table 4 from task 4 report[5]

Inverter failure area	Percentage of occurrence
Fuse/contactor	56%
Card/board	21%
Matrix/IGBT	10%
Capacitors	5%
Power supply	8%

The bill of materials is adjusted accordingly. A more detailed BOM in EcoReport format is available in annex B.

6.1.2.2.4 Monitor/smart

The impact of this design option on the BOM is unknown and therefore the BOM of the reference inverter has been used per similar rated power.

The BOM in Ecoreport tool format is available in annex B.

6.1.2.2.5 Module level inverter

The impact of this design option on the BOM is unknown and therefore the BOM of the reference inverter has been used per similar rated power.

The BOM in Ecoreport tool format is available in annex B.

6.1.2.2.6 Hybrid storage worst performer

This design option has an impact on the BOM, based on the weight of commercial available products impact has been estimated at +20 % based on total weight of commercial available solutions The BOM of the reference inverter has been used and upscaled.

The BOM in Ecoreport tool format is available in annex B.

6.1.2.2.7 Hybrid storage best performer

Due to lack of accurate data, the same bill of materials as the worst performer storage inverter was assumed.

The BOM in Ecoreport tool format is available in annex B.

---

[5] Reference table 4, taks 4 report: T. J. Formica, H. A. Khan, and M. G. Pecht, “The Effect of Inverter Failures on the Return on Investment of Solar Photovoltaic Systems,” *IEEE Access*, vol. 5, pp. 21336–21343, Sep. 2017.

6.1.2.3 Assumptions regarding the selected design options for commercial use

Table 9: Design option inverters for commercial use (BC 2)

Acronym	**Reference**	**Efficient**	**Repair**
Inverter type	3 phase reference inverter Transformerless	More efficient inverter	Repair/repaired
Rated power (kVA)	20	20	20
Euro Efficiency η_{conv}[%]	97	98	97
Failure rate inverters (% / year] = 1/(average life time)	10%	10%	10%
Cost (EUR/VA)	0.15	0.18	0.12

6.1.2.4 Life cycle information – Bill of Materials: Inverters for commercial use

6.1.2.4.1 More efficient inverter

The impact of this design option on the BOM is unknown and therefore the BOM of the reference inverter has been used per similar rated power.

The BOM in Ecoreport tool format is available in annex B.

6.1.2.4.2 Repair

To model this scenario, the BOM of the reference inverter has been modified in a similar way as in the residential case (see 6.1.2.2.3).

The BOM in Ecoreport tool format is available in annex B.

6.1.2.5 Assumptions regarding the selected design options for utility scale

Larger utility scale systems (BC 3), have already servicing of inverters in the base case, one of the most replaced components are fans and filters of the cooling system (in utility scale systems). Operation and Maintenance (O&M), including replacement of fans, is modelled in the base case (Task 5) of BC3 (utility scale). In BC 3 we consider therefore inverter O&M as a prerequisite and not an improvement option.

Table 10: Design option inverters for utility scale (BC 3)

Acronym	**Reference**	**Efficient**	**Efficient String**
Inverter type	3 phase reference inverter Transformerless	More efficient inverter	More efficient inverter with string level inverters
Rated power (kVA)	1500	1500	10 string inverters of 150 kW
Euro Efficiency η_{conv}[%]	97	98	98
Failure rate inverters (%/year = 1/(average life time)	10%	10%	10%
Cost (EUR/VA)	0.10	0.12	0.15

6.1.2.6 Life cycle information – Bill of Materials: Inverters for utility scale

6.1.2.6.1 More efficient inverter

The impact of this design option on the BOM is unknown and therefore the BOM of the reference inverter has been used per similar rated power.

The BOM in Ecoreport tool format is available in annex B.

6.1.2.6.2 Efficient string inverter

The impact of this design option on the BOM is unknown and therefore the BOM of the reference inverter has been used per similar rated power.

The BOM in Ecoreport tool format is available in annex B.

6.1.3 PV Systems

At system level, modules are combined with inverters. Also, the balance of systems has been added at system level.

6.1.3.1 Assumptions regarding the selected design options at residential scale

All the design options at residential scale include a reference balance of system, except for some of the design options in which the inverter is different.

Table 11 provides an overview of the considered design options for systems at residential scale.

6.1.3.1.1 Multi Si module and reference inverter (PO 1)

In this design option, a multi Si module has been combined with the reference inverter and a reference BOS.

6.1.3.1.2 Multi Si optimised module and reference inverter (PO 2)

This design option combines the multi Si optimized module with the reference inverter and reference BOS.

6.1.3.1.3 PERC module and reference inverter (PO 3)

This design option combines the PERC module with the reference inverter and a reference BOS.

6.1.3.1.4 CIGS module and reference inverter (PO 4)

This design option combines a CIGS module with a reference inverter and BOS.

6.1.3.1.5 Kerfless (old) module and reference inverter (PO 5)

This design option combines the kerfless (old) module with a reference inverter and BOS.

6.1.3.1.6 Silicon Heterojunction and reference inverter (PO 6)

This design option combines a silicon heterojunction module with the reference inverter and BOS.

6.1.3.1.7 BNAT kerfless (new) module and reference inverter (PO 7)

This design option combines the BNAT kerfless module with a reference inverter and BOS.

6.1.3.1.8 Multi Si module and more efficient inverter (PO 8)

This design option makes uses a more efficient inverter. The Euro Efficiency of the inverter is 98%, while 96% was assumed for the reference inverter. This more efficient inverter is combined with the reference multi Si module and a reference BOS.

6.1.3.1.9 Multi Si module and longer life inverter (PO 9)

In this design option the inverter failure rate has been changed from 10% to 0.5%. The inverter with a longer life has been combined with the reference multi Si module and a reference BOS.

6.1.3.1.10 Multi Si module and inverter with repair (PO 10)

This design option makes use of an inverter with an increased repair. The failure rate is 10%, but the failure does not lead to a full replacement of the inverter, rather a repair of the broken component has been assumed. The inverter with increased repair has been combined with the reference Si module and a reference BOS.

6.1.3.1.11 Multi Si module and inverter including monitoring (PO 11)

This design option represents a situation with improved monitoring. Derate soiling factor has been increased to 98% (compared to 96% in the reference case) and derate inverter failure downtime has been increased to 99.9% (compared to 99% in the reference case).

The inverter including monitoring has been combined with the reference multi Si module and reference BOS.

6.1.3.1.12 Multi Si module and multi-level inverter (PO 12)
In this design option a multi-level inverter is combined with a multi Si module and reference BOM. The multi-level inverter has a higher Euro Efficiency (97%) compared to the reference inverter (96%). Also, the derate shading is increased to 98% (compared to 90% for the reference inverter). The multi-level inverter is combined with the reference multi Si module and reference BOS.

6.1.3.1.13 Multi Si module and inverter including storage (worst case) (PO 13)
In this design option the Euro Efficiency of the derate module mismatch has been increased from 97% in the reference case to 98.5%. The inverter including storage is combined with a reference multi Si module and reference BOS. The extra system loss storage changes from 5% in the reference case to 30% in this design option including storage. System losses are however not modelled in the Ecoreport tool.

6.1.3.1.14 Multi Si module and inverter including storage (best case) (PO 14)
In this design option the Euro Efficiency of the derate module mismatch has been increased from 97% in the reference case to 98.5%. The inverter including storage is combined with a reference multi Si module and reference BOS. The extra system loss storage changes from 5% in the reference case to 10% in this design option including storage. System losses are however not modelled in the Ecoreport tool.

6.1.3.1.15 Multi Si optimized module and best of best inverters (SO 1)
This design option combines the best performing module with an inverter design combining the best of all investigated inverters. The multi Si optimized module is the best performing module. CIGS performs better but it was not selected due to its higher life cycle cost. This option has a derate soiling factor of 98%, the best of best inverter has a Euro Efficiency of 98%, and a derate inverter failure factor of 99.9%. The other derate factors are equal to the reference inverter. A reference BOS is added to this design option.

6.1.3.1.16 Multi Si optimized module, best of best inverters and better design (SO 2)

This design option adds a better design to the pervious design option. The better design is reflected in the higher derate module mismatch factor (98.5%), the higher derate shading factor (96%) and the higher derate cable losses (99.5%) compared to the previous design option (multi Si optimized + best of best inverter 6.1.3.1.15).

6.1.3.1.17 Multi Si optimised + best inverter + optimised O&M (SO 3)

This system combines the best module with the best inverter and includes optimized operation and maintenance routine. This introduces practices from the large scale segment including remote monitoring, repair response or early failure detection and cleaning routines. This affects the downtime, repair cycles for the modules and inverter and the derate soiling factor.

6.1.3.2 Assumptions regarding the selected design options at commercial scale

All the design options at utility scale include a reference BOS (except for the inverter which changes in some of the design options).

Table 12 provides an overview of the considered design options for both modules and inverters at commercial scale.

6.1.3.2.1 Multi Si module and reference inverter (Base Case PO 1)

In this design option, a multi Si module has been combined with the reference inverter and a reference BOS.

6.1.3.2.2 Multi Si optimized module and reference inverter (PO 2)

This design option combines the multi Si optimized module with the reference inverter and reference BOS.

6.1.3.2.3 PERC module and reference inverter (PO 3)

This design option combines the PERC module with the reference inverter and a reference BOS.

6.1.3.2.4 PERC bifacial module and reference inverter (PO 4)

This design option combines the PERC bifacial module with the reference inverter and reference BOS. The power gain due to the bifacial surface is set at 115%.

6.1.3.2.5 CdTe module and reference inverter (PO 5)

This design option combines a CdTe module with a reference inverter and reference BOS.

6.1.3.2.6 Multi Si module and more efficient inverter (PO 6)
This design option makes uses a more efficient inverter. The Euro Efficiency of the inverter is 98%, while 97% was assumed for the reference inverter. This more efficient inverter is combined with the reference multi Si module and a reference BOS.

6.1.3.2.7 Multi Si module and inverter with repair (PO 7)
This design option makes use of an inverter with an increased repair. The failure rate is 10%, but the failure does not lead to a full replacement of the inverter, rather a repair of the broken component has been assumed. The inverter with increased repair has been combined with the reference Si module and a reference BOS.

6.1.3.2.8 PERC bifacial and higher derating factors (SO 1)
This design option combines a PERC bifacial module with higher derating factors due to lower cable losses, shading and module mismatch because of a tailored design. The Euro Efficiency of the inverter is set at 98%, the derate shading is 98,5%, the derate temperature effect is 98% and the derate cable losses is 99.5%.

6.1.3.3 Assumptions regarding the selected design options at utility scale

Table 13 provides an overview of the considered design options for both modules and inverters at utility scale.

6.1.3.3.1 Multi Si module and reference inverter and reference BOS (PO 1)

In this design option, a multi Si module has been combined with the reference inverter and a reference BOS.

6.1.3.3.2 Multi Si optimized module and reference inverter and reference BOS (PO 2)

This design option combines the multi Si optimized module with the reference inverter and reference BOS.

6.1.3.3.3 PERC module and reference inverter and reference BOS (PO 3)

This design option combines the PERC module with the reference inverter and a reference BOS.

6.1.3.3.4 PERC bifacial module and reference inverter and reference BOS (PO 4)

This design option combines the PERC bifacial module with the reference inverter and reference BOS. The power gain due to the bifacial surface is set at 115%.

6.1.3.3.5 CdTe module and reference inverter and reference BOS (PO 5)
This design option combines a CdTe module with a reference inverter and reference BOS.

6.1.3.3.6 Multi Si module and more efficient inverter and reference BOS (PO 6)
This design option combines the reference multi Si module with a more efficient inverter. The Euro Efficiency of the inverter increases from 97% (reference inverter) to 98%.

6.1.3.3.7 Multi Si module and more efficient string inverter and reference BOS (PO 7)
This design option combines the reference multi Si module with a more efficient string inverter. The Euro Efficiency is 98% and the derate module mismatch is 98%.

6.1.3.3.8 CdTe module, efficient string inverter and tracking (SO 1)
This design option combines a CdTe module with an efficient string inverter and tracking. Due to the use of tracking the radiation hours increase from 1331 hours to 1465 hours (from PVGIS simulation in Strasbourg).

Table 11: Combination of design options for modules and inverters – residential scale

System		Base Case - PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	PO 13	PO 14	SO 1	SO 2	SO 3
Parameters																		
Use phase parameters Task 3 + inverter efficiency of Task 4																		
PR = DRother x DR modelled	%	74,9%	74,9%	74,9%	74,9%	74,9%	74,9%	74,9%	76,5%	74,9%	74,9%	77,2%	82,4%	76,1%	76,1%	78,8%	85,8%	77,2%
DR other	%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%	95,1%
Euro Efficiency ηconv[%]	%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	98,0%	96,0%	96,0%	96,0%	97,0%	96,0%	96,0%	98,0%	98,0%	96,0%
DR Module mismatch	%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	98,5%	98,5%	97,0%	98,5%	97,0%
DR shading	%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	98,0%	90,0%	90,0%	90,0%	96,0%	90,0%
DR temp effect	%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
DR soiling	%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	98,0%	96,0%	96,0%	96,0%	98,0%	98,0%	98,0%
DR snow	%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%
DR cable losses	%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,5%	99,0%
DR inv failure (downtime)	%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,9%	99,0%	99,0%	99,0%	99,9%	99,9%	99,9%
DR modelled	%	78,78%	78,78%	78,78%	78,78%	78,78%	78,78%	78,78%	80,42%	78,78%	78,78%	81,15%	86,67%	79,99%	79,99%	82,84%	90,18%	81,15%
reference irradiation	hours	1331	1331	1331	1331	1331	1331	1331	1331	1331	1331	1331	1331	1331	1331	1331	1331	1331,00
System yield - Yf (in year 1)		997	997	997	997	997	997	997	1018	997	997	1027	1097	1013	1013	1049	1141	1027
cleaning and maintenance cycle	#/y	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067
extra system loss storage(ESS) or grid(no ESS	%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	30,0%	10,0%	5,0%	5,0%	5,0%
Technology parameters Task 4																		
power gain for bifacial	Wp/m2	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
Rated power/m² or mod. Efficiency	Wp/m2	147	174	196	150	147	197	196	147	147	147	147	147	147	147	174	174	174
corrected rated power	Wp/m2	147	174	196	150	147	197	196	147	147	147	147	147	147	147	174	174	174
Performance degradation rate	%	0,70%	0,70%	0,50%	1,00%	0,70%	1,00%	0,50%	0,70%	0,70%	0,70%	0,70%	0,70%	0,70%	0,70%	0,70%	0,70%	0,70%
Economic System Life (Task 1)	years	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
System yield average over life	hours	902	902	928	867	902	867	928	921	902	902	930	993	916	916	949	1033	930
Failure rate modules	%/year	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,03%	0,03%	0,03%	0,03%	0,03%	0,03%	0,03%	0,20%	0,20%	0,20%
Average module replacement	%/life	6,00%	6,00%	6,00%	6,00%	6,00%	6,00%	6,00%	0,90%	0,90%	0,90%	0,90%	0,90%	0,90%	0,90%	6,00%	6,00%	6,00%
Failure rate inverters =1/MTBF	%/year	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%	3,86%	10,00%	10,00%	10,00%	10,00%	10,00%	3,86%	3,86%	3,86%
Average inverter replacements	%/life	300,0%	300,0%	300,0%	300,0%	300,0%	300,0%	300,0%	300,0%	115,7%	300,0%	300,0%	300,0%	300,0%	300,0%	115,7%	115,7%	115,7%
Installed rated power modules	Wp	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Rated Power inverter	VA	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Overall output of electricity	kWh	81215	81215	83477	78062	81215	78062	83477	82907	81215	81215	83661	89356	82471	82471	85404	92974	83661
total module area	m²	21,6	18,3	16,2	21,2	21,6	16,1	16,2	20,6	20,6	20,6	20,6	20,6	20,6	20,6	18,3	18,3	18,3
area of single modules	m²	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
total modules	#	13,5	11,4	10,1	13,3	13,5	10,1	10,1	12,9	12,9	12,9	12,9	12,9	12,9	12,9	11,4	11,4	11,4
# m2 panel per kWh	**m²/kWh**	2,66E-04	2,25E-04	1,94E-04	2,72E-04	2,66E-04	2,07E-04	1,94E-04	2,48E-04	2,54E-04	2,54E-04	2,46E-04	2,30E-04	2,50E-04	2,50E-04	2,14E-04	1,96E-04	2,18E-04
# 2.5 kVA inverter (incl repl)/kWh	**units (incl repl)/kWh**	1,23E-05	1,23E-05	1,20E-05	1,28E-05	1,23E-05	1,28E-05	1,20E-05	1,21E-05	1,23E-05	1,23E-05	1,20E-05	1,12E-05	1,21E-05	1,21E-05	1,17E-05	1,08E-05	1,20E-05
Wafer Thickness	**micrometer**	2,00E+02	1,70E+02	1,80E+02	not relevant	2,50E+02	1,80E+02	1,25E+02	2,00E+02	2,00E+02	2,00E+02	2,00E+02	2,00E+02	2,00E+02	2,00E+02	1,70E+02	1,70E+02	1,70E+02
Form factor losses silicon	**kg/m2 panel**	1,85E-01	1,55E-01	1,73E-01	not relevant	0,00E+00	1,92E-01	7,73E-02	1,85E-01	1,85E-01	1,85E-01	1,85E-01	1,85E-01	1,85E-01	1,85E-01	1,55E-01	1,55E-01	1,55E-01
Kerf losses	**micrometer**	1,00E+02	8,00E+01	1,00E+02	not relevant	ecoinvent	1,30E+02	0,00E+00	1,00E+02	1,00E+02	1,00E+02	1,00E+02	1,00E+02	1,00E+02	1,00E+02	8,00E+01	8,00E+01	8,00E+01

(PO 1): Multi Si module and reference inverter, (PO2): Multi Si optimised module and reference inverter; (PO 3): PERC module and reference inverter; (PO 4): CIGS module and reference inverter; (PO 5): Kerfless (old) module and reference inverter; (PO 6): Silicion heterojunction module and reference inverter; (PO 7): BNAT kerfless (new) module and reference inverter; (PO 8): Multi Si module and more efficient inverter; (PO 9): Multi Si module and longer life inverter; (PO 10): Multi Si Module and inverter with repair; (PO 11): Multi Si module and inverter including monitoring; (PO 12): Multi Si module and multi-level inverter; (PO 13): Multi Si module and inverter including storage (worst case); (PO 14): Multi Si module and inverter including storage (best case).

(SO 1): Multi Si optimised + best inverter; (SO 2): Multi Si optimised + best inverter + better design; (SO 3): Multi Si optimised + best inverter + optimised O&M

Table 12: Combination of design options for modules and inverters – commercial scale

System		Base Case - PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	SO 1
Parameters									
Use phase parameters Task 3 + inverter efficiency of Task 4									
PR = DRother x DR modelled	%	***82,5%***	***82,6%***	***82,6%***	***82,6%***	***82,6%***	***83,4%***	***82,6%***	***87,8%***
DR other	%	***98,2%***	***98,2%***	***98,2%***	***98,2%***	***98,2%***	***98,2%***	***98,2%***	***98,2%***
Euro Efficiency η_{conv}[%]	%	97,0%	97,0%	97,0%	97,0%	97,0%	98,0%	97,0%	98,0%
DR Module mismatch	%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	98,5%
DR shading	%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	98,0%
DR temp effect	%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
DR soiling	%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%	96,0%
DR snow	%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%
DR cable losses	%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,5%
DR inv failure (downtime)	%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%
DR modelled	%	***84,02%***	***84,10%***	***84,10%***	***84,10%***	***84,10%***	***84,97%***	***84,10%***	***89,46%***
reference irrradiation	hours	1331	1331	1331	1331	1331	1331	1331	1331
System yield - Yf (in year 1)		***1098***	***1099***	***1099***	***1099***	***1099***	***1111***	***1099***	***1169***
cleaning and maintenance cycle	#/y	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067
extra system loss storage(ESS) or grid(no ESS	%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%
Technology parameters Task 4									
power gain for bifacial	Wp/m2	100,0%	100,0%	100,0%	115,0%	100,0%	100,0%	100,0%	115,0%
Rated power/m² or mod. Efficiency	Wp/m2	147	174	196	196	180	147	147	196
Rated power	Wp/m2	147	174	196	225	180	147	147	225
Performance degradation rate	%	0,70%	0,70%	0,50%	0,50%	1,00%	0,70%	0,70%	0,50%
Economic System Life time	years	30	30	30	30	30	30	30	30
System yield average over life	hours	***994***	***995***	***1023***	***1023***	***956***	***1005***	***995***	***1088***
Failure rate modules	%/year	0,20%	0,20%	0,20%	0,20%	0,20%	0,03%	0,03%	0,20%
Average module replacement	%/life	***6,00%***	***6,00%***	***6,00%***	***6,00%***	***6,00%***	***0,90%***	***0,90%***	***6,00%***
Failure rate inverters =1/MTBF	%/year	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%
Average inverter replacements	%/life	***300,0%***	***300,0%***	***300,0%***	***300,0%***	***300,0%***	***300,0%***	***300,0%***	***300,0%***
Capacity modules	Wp	24400	24400	24400	24400	24400	24400	24400	24400
Rated Power inverter	VA	20000	20000	20000	20000	20000	20000	20000	20000
Overall output of electricity	kWh	***727478***	***728206***	***748483***	***748483***	***699929***	***735714***	***728206***	***796143***
total module area	m²	***175,9***	***148,5***	***132,0***	***114,7***	***143,8***	***167,5***	***167,5***	***114,7***
area of single modules	m²	***1,6***	***1,6***	***1,6***	***1,6***	***1,6***	***1,6***	***1,6***	***1,6***
total modules	#	***110,0***	***92,8***	***82,5***	***71,7***	***89,9***	***104,7***	***104,7***	***71,7***
# m2 panel per kWh	**m²/kWh**	***2,42E-04***	***2,04E-04***	***1,76E-04***	***1,53E-04***	***2,06E-04***	***2,28E-04***	***2,30E-04***	***1,44E-04***
# 2.5 kVA inverter (incl repl)/kWh	**units (incl repl)/kWh**	***1,37E-06***	***1,37E-06***	***1,34E-06***	***1,34E-06***	***1,43E-06***	***1,36E-06***	***1,37E-06***	***1,26E-06***
Wafer Thickness	**micrometer**	***2,00E+02***	***1,70E+02***	***1,80E+02***	***1,80E+02***	***not relevant***	***2,00E+02***	***2,00E+02***	***1,80E+02***
Form factor losses silicon	**kg/m2 panel**	***1,85E-01***	***1,55E-01***	***1,73E-01***	***1,73E-01***	***not relevant***	***1,85E-01***	***1,85E-01***	***1,73E-01***
Kerf losses	**micrometer**	***1,00E+02***	***8,00E+01***	***1,00E+02***	***1,00E+02***	***not relevant***	***1,00E+02***	***1,00E+02***	***1,00E+02***

(SO 1): best combination and design; (PO 1): Multi Si module and reference inverter; (PO 2): Multi Si optimised module and reference inverter; (PO 3):PERC module and reference inverter; (PO 4):PERC bifacial module and reference inverter; (PO 5): CdTe module and reference inverter; (PO 6):Multi Si module and more efficient inverter; (PO 7): Multi Si module and inverter with repair

Table 13: Combination of design options for modules and inverters – utility scale

System		Base Case - PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	SO 1
Parameters									
Use phase parameters Task 3 + inverter efficiency of Task 4									
PR = DRother x DR modelled	%	*82,5%*	*82,5%*	*82,5%*	*82,5%*	*82,5%*	*83,4%*	*84,3%*	*84,3%*
DR other	%	*93,2%*	*93,2%*	*93,2%*	*93,2%*	*93,2%*	*93,2%*	*93,2%*	*93,2%*
Euro Efficiency η_{conv}[%]	%	97,0%	97,0%	97,0%	97,0%	97,0%	98,0%	98,0%	98,0%
DR Module mismatch	%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	98,0%	98,0%
DR shading	%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%
DR temp effect	%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
DR soiling	%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%
DR snow	%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%	99,9%
DR cable losses	%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%
DR inv failure (downtime)	%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%	99,0%
DR modelled	%	*88,48%*	*88,57%*	*88,57%*	*88,57%*	*88,57%*	*89,48%*	*90,40%*	*90,40%*
Reference irradiation	hours	1331	1331	1331	1331	1331	1331	1331	1465
System yield - Yf (in year 1)		*1098*	*1099*	*1099*	*1099*	*1099*	*1110*	*1121*	*1234*
cleaning and maintenance cycle	#/y	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067
extra system loss storage(ESS) or grid(no	%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%
Technology parameters Task 4									
power gain for bifacial	Wp/m2	100,0%	100,0%	100,0%	115,0%	100,0%	100,0%	100,0%	100,0%
Rated power/m² or mod. Efficiency	Wp/m2	147	174	196	196	180	147	147	147
Rated power	Wp/m2	147	174	196	225	180	147	147	147
Performance degradation rate	%	0,70%	0,70%	0,50%	0,50%	1,00%	0,70%	0,70%	0,70%
Economic System Life time	years	30	30	30	30	30	30	30	30
System yield average over life	hours	*993*	*994*	*1022*	*1022*	*956*	*1005*	*1015*	*1117*
Failure rate modules	%/year	0,20%	0,20%	0,20%	0,20%	0,20%	0,03%	0,03%	0,03%
Average module replacement	%/life	*6,00%*	*6,00%*	*6,00%*	*6,00%*	*6,00%*	*0,90%*	*0,90%*	*0,90%*
Failure rate inverters =1/MTBF	%/year	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%	10,00%
Average inverter replacements	%/life	*300,0%*	*300,0%*	*300,0%*	*300,0%*	*300,0%*	*300,0%*	*300,0%*	*300,0%*
Capacity modules	Wp	1875000	1875000	1875000	1875000	1875000	1875000	1875000	1875000
Rated Power inverter	kVA	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000
Overall output of electricity	kWh	*55871867*	*55927795*	*57485081*	*57485081*	*53756002*	*56504370*	*57086890*	*62839832*
total module area	m²	*13520,4*	*11414,5*	*10140,3*	*8817,7*	*11053,9*	*12869,9*	*12869,9*	*12869,9*
area of single modules	m²	*1,6*	*1,6*	*1,6*	*1,6*	*1,6*	*1,6*	*1,6*	*1,6*
total modules	#	*8450,3*	*7134,1*	*6337,7*	*5511,0*	*6908,7*	*8043,7*	*8043,7*	*8043,7*
# m2 panel per kWh	**m²/kWh**	*2,42E-04*	*2,04E-04*	*1,76E-04*	*1,53E-04*	*2,06E-04*	*2,28E-04*	*2,25E-04*	*2,05E-04*
# 2.5 kVA inverter (incl repl)/kWh	**units (incl repl)/kWh**	*1,79E-08*	*1,79E-08*	*1,74E-08*	*1,74E-08*	*1,86E-08*	*1,77E-08*	*1,75E-08*	*1,59E-08*
Wafer Thickness	**micrometer**	*2,00E+02*	*1,70E+02*	*1,80E+02*	*1,80E+02*	*not relevant*	*2,00E+02*	*2,00E+02*	*not relevant*
Form factor losses silicon	**kg/m2 panel**	*1,85E-01*	*1,55E-01*	*1,73E-01*	*1,73E-01*	*not relevant*	*1,85E-01*	*1,85E-01*	*not relevant*
Kerf losses	**micrometer**	*1,00E+02*	*8,00E+01*	*1,00E+02*	*1,00E+02*	*not relevant*	*1,00E+02*	*1,00E+02*	*not relevant*

(SO 1): best combination and design including single axis tracker; (PO 1): Multi Si module and reference inverter and reference BOS; (PO 2): Multi Si optimised module and reference inverter and reference BOS; (PO 3): PERC module and reference inverter and reference BOS; (PO 4): PERC bifacial module and reference inverter and reference BOS; (PO 5): CdTe module and reference inverter and reference BOS; (PO 6): Multi Si module and more efficient inverter and reference BOS; (PO 7): Multi Si module and more efficient string inverter and reference BOS

6.2 Environmental impacts (results from Ecoreport tool)

6.2.1 PV modules

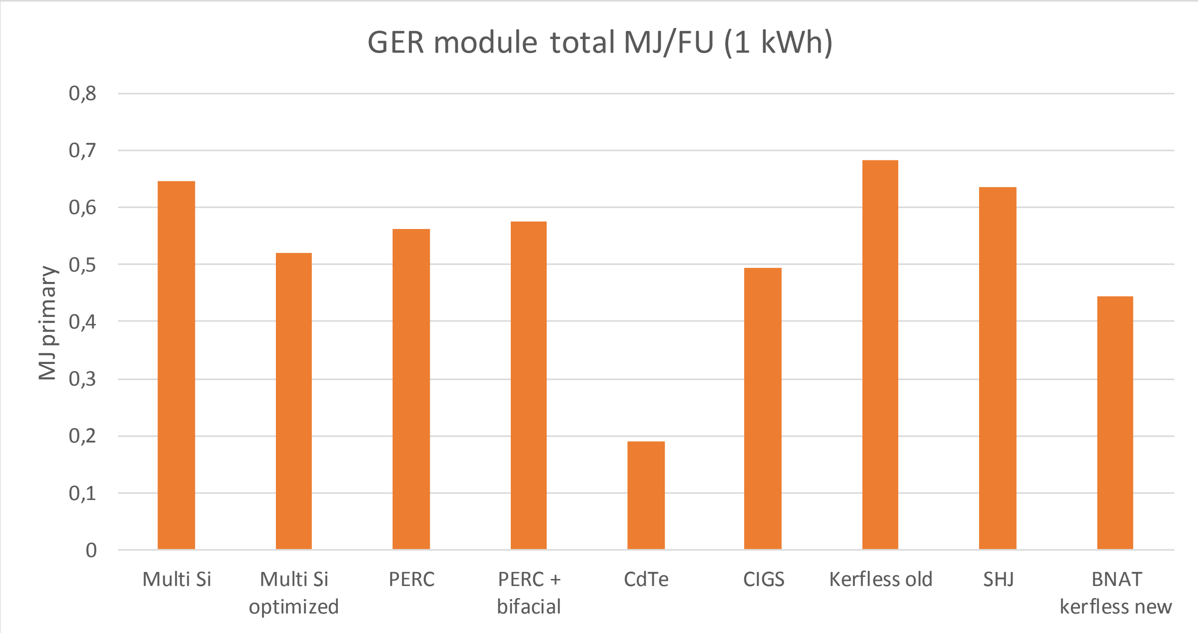
Table 14 shows the relative environmental impacts of the single design options compared to base case PV modules under real life conditions.

Figure 1 shows the results for the primary impact category 'Primary energy' per kWh for the different module types.

Table 15 shows the relative figures of the total environmental impacts of the base case (=100%) and the single design options for selected environmental impact categories.

Table 14: Life cycle impacts of PV modules design options with respect to the base case

Indicator	Base case	Multi Si optimized	PERC	PERC bifacial	CdTe	CIGS	Kerfless old	SHJ	BNAT kerfless new
Total Energy (GER)	100%	80%	87%	89%	30%	76%	106%	92%	69%
Water	100%	76%	121%	122%	11%	24%	103%	74%	99%
Waste, non-haz./ landfill	100%	81%	109%	114%	15%	27%	78%	118%	81%
Waste, hazardous/ incinerated	100%	84%	34%	34%	5%	8%	8%	36%	33%
Greenhouse Gases in GWP100	100%	81%	90%	93%	29%	76%	96%	95%	71%
Acidification, emissions	100%	81%	88%	94%	30%	64%	120%	96%	72%
Volatile Organic Compounds (VOC)	100%	84%	74%	75%	8%	13%	84%	81%	72%
Persistent Organic Pollutants (POP)	100%	82%	86%	89%	18%	45%	85%	103%	72%
Heavy Metals to air	100%	82%	83%	87%	20%	33%	94%	111%	72%
PAHs	100%	81%	72%	73%	6%	66%	90%	79%	63%
Particulate Matter (PM, dust)	100%	83%	80%	81%	63%	81%	98%	86%	73%
Heavy Metals to water	100%	84%	74%	75%	4%	26%	77%	105%	73%
Eutrophication	100%	82%	95%	99%	13%	45%	100%	124%	76%



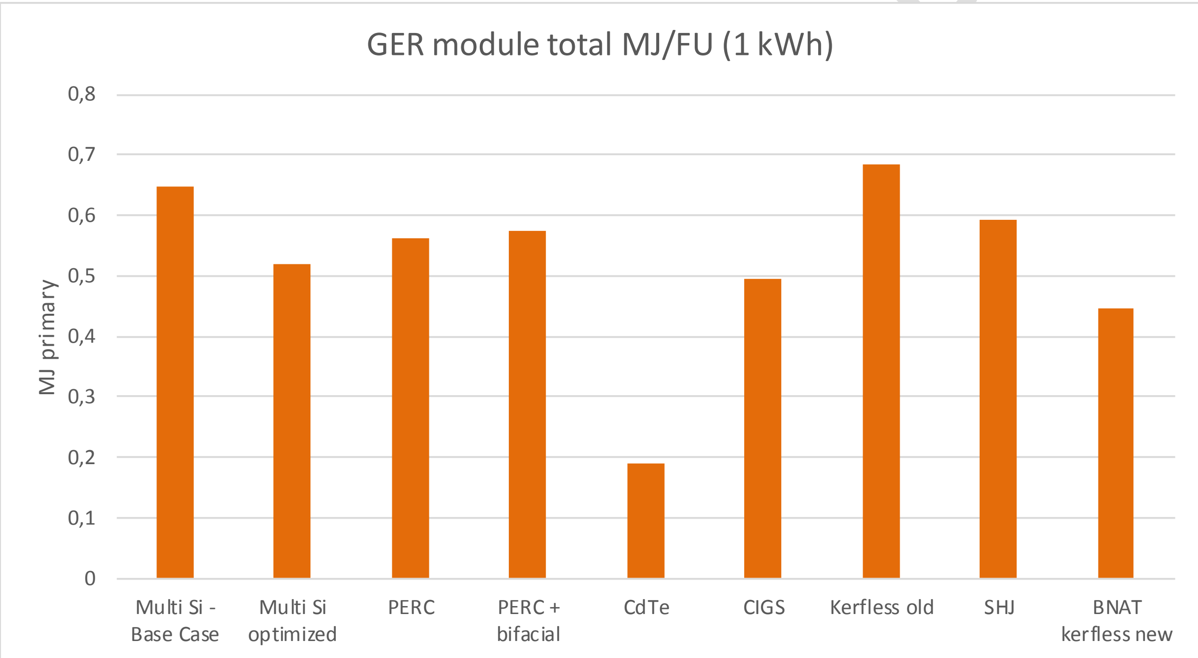


Figure 1:Primary energy results in MJ per kWh produced from modules

Table 15: Ranking of selected improvement options for PV Modules based on selected environmental indicators

Option	Total Energy (primary energy)	Secondary impact categories		
		PAH	NVOC	Heavy metals
CdTe	30%			
BNAT kerfless new	69%			
CIGS	76%			
Multi Si optimized	80%			
PERC	87%			
PERC bifacial	89%			
SHJ	92%			
Multi Si Base Case	100%			
Kerfless old	106%			

6.2.1.1 Influence of the electricity mix on the results

The main impact of the multi-Si module comes from the electricity consumed by the production of the solar cell. Therefore, electricity mix or grid factor of the location of cell production can exert an influence on the results.

To evaluate this influence, the Base Case multi-Si cell has been used. To calculate the environmental impact of this cell, the global ecoinvent data record on the production of a multi Si cell with a global market electricity mix, represents the market for solar cell production.

To account for a variation in the production location, the electricity mixes along all processes of the production of the multi Si solar cell have been changed into the Swedish electricity mix, which is known as a clean electricity mix in Europe, and the EU average electricity mix. Electricity has only been changed in the following levels of the production chain of the solar cell, which were identified as being relevant:

- Cell assembly
- Wafer production
    - Silicon carbide production
    - Silicon solar grade production

All other records (e.g. metallization pastes) remained unchanged, but were also less relevant in the environmental profile of the multi Si cell. Burning of natural gas as an energy source remained unchanged as well.

Figure 2 compares the environmental impact of a multi Si cell produced using energy mixes representing the global market multi Si cell production and the adapted records using the Swedish and the EU average electricity mix.

Figure 3 shows the results at module level. The electricity mix has been changed for the cell only, as described above. The cell is then used in the multi-Si module.

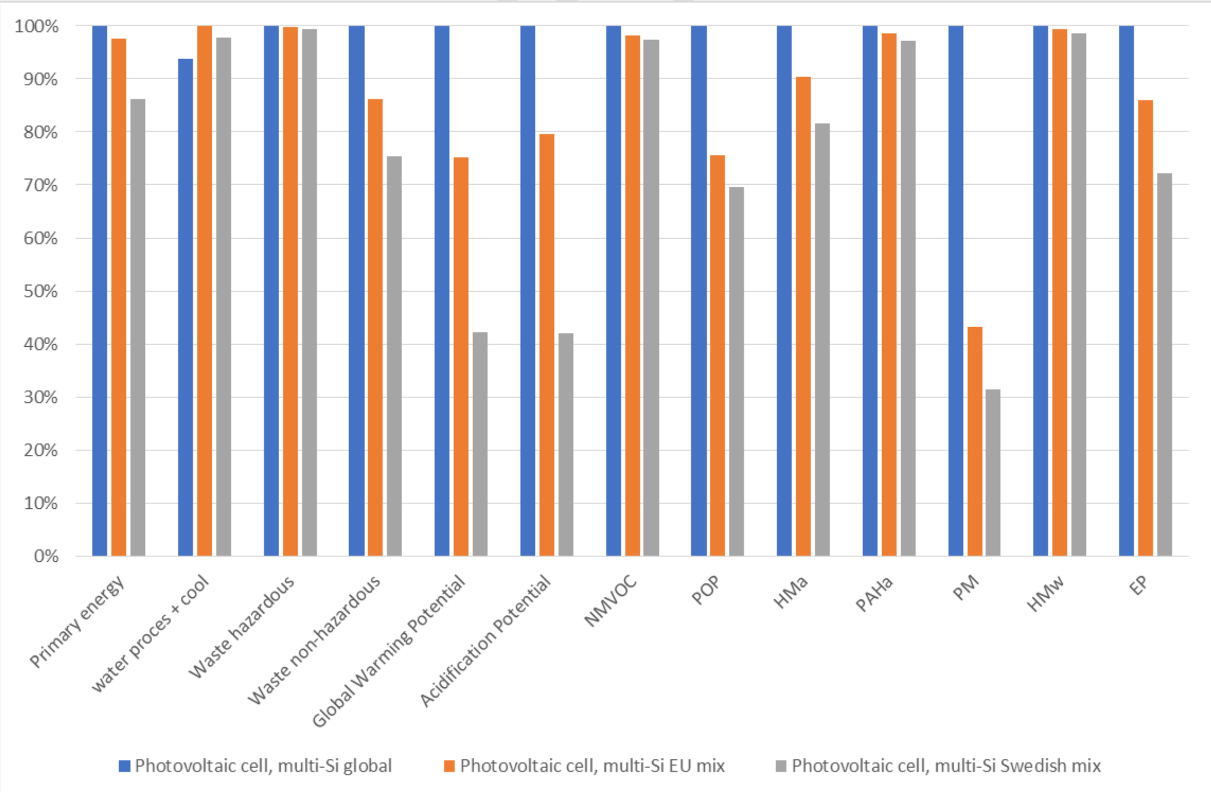


Figure 2: Comparison of environmental impact photovoltaic cell using global market mix (blue) and photovoltaic cell using Swedish mix (orange)

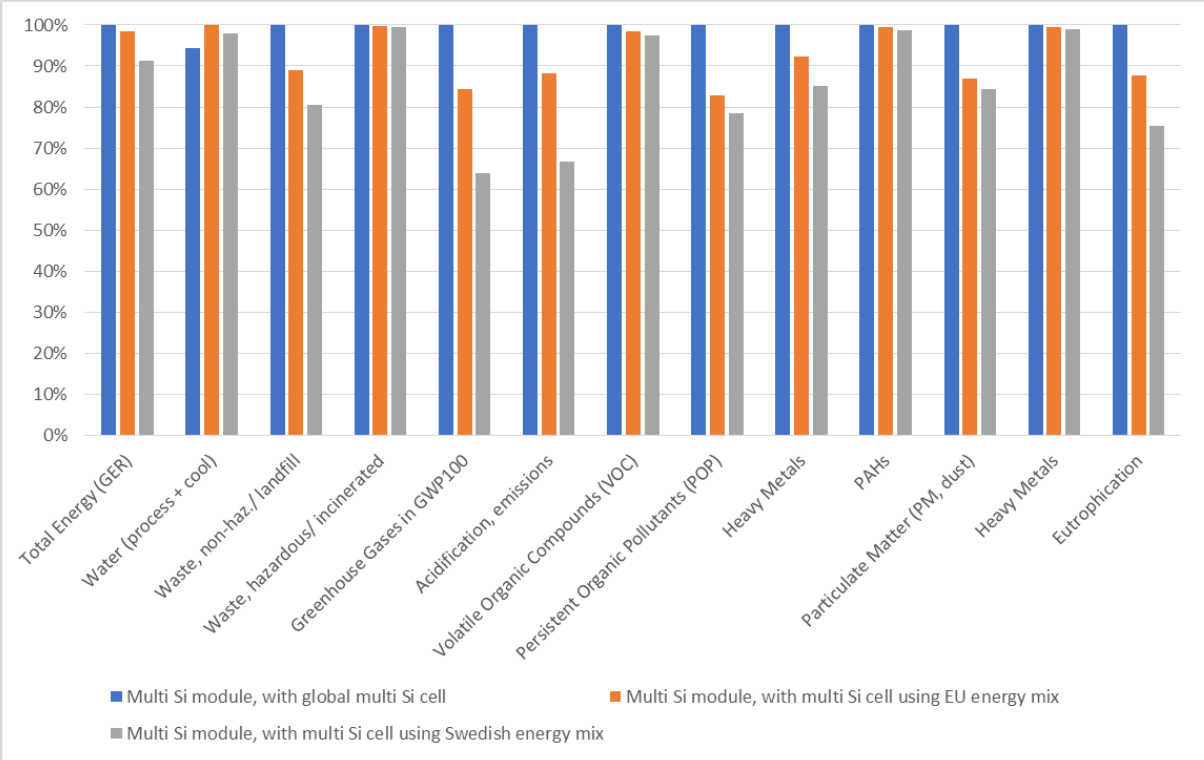


Figure 3: Comparison of the environmental impact of a multi Si module, using a cell produced according to the global market (blue) and a cell produced with the Swedish electricity mix (orange)

6.2.2 PV inverters – residential scale

Table 16 shows the relative environmental impacts of the single design options compared to base case PV inverters under real life conditions.

Figure 4 shows the results for the primary impact category 'Primary energy' per kWh for the defined inverters at residential scale.

Table 17 shows the relative figures of the total environmental impacts of the base case (=100%) and the single design options.

Table 16: Life cycle impacts of inverter design options with respect to the base case (inverters, residential scale)

Indicator	Base Case REF	Efficient	Longer life	Repair	Monitor.	MLI	Storage - worst	Storage - best
Total Energy (GER)	100%	98%	39%	46%	97%	91%	118%	118%
Water	100%	98%	39%	38%	97%	91%	118%	118%
Waste, non-haz./ landfill	100%	98%	39%	51%	97%	91%	118%	118%
Waste, hazardous/ incinerated	100%	98%	39%	47%	97%	91%	118%	118%
Greenhouse Gases in GWP100	100%	98%	39%	46%	97%	91%	118%	118%
Acidification, emissions	100%	98%	39%	46%	97%	91%	118%	118%
Volatile Organic Compounds (VOC)	100%	98%	39%	54%	97%	91%	118%	118%
Persistent Organic Pollutants (POP)	100%	98%	39%	38%	97%	91%	118%	118%
Heavy Metals to air	100%	98%	39%	54%	97%	91%	118%	118%
PAHs	100%	98%	39%	45%	97%	91%	118%	118%
Particulate Matter (PM, dust)	100%	98%	39%	52%	97%	91%	118%	118%
Heavy Metals to water	100%	98%	39%	42%	97%	91%	118%	118%
Eutrophication	100%	98%	39%	50%	97%	91%	118%	118%

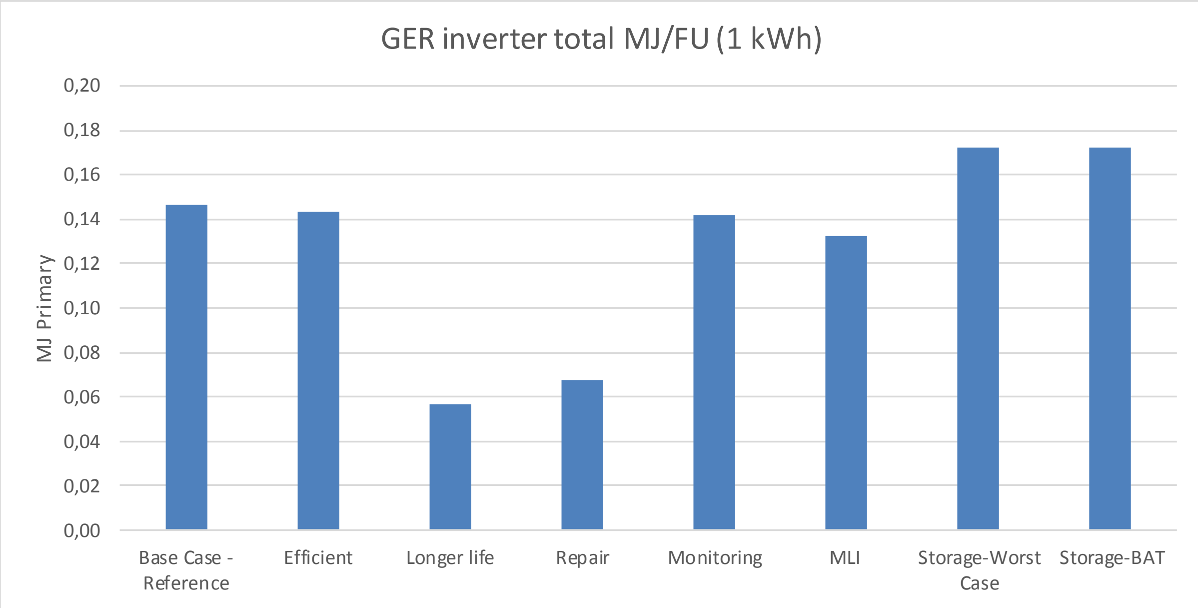


Figure 4: Primary energy results per kWh produced from inverters at residential scale

Table 17: Ranking of selected improvement options for inverters based on selected environmental indicators (inverters, residential scale)

Option	Total Energy (primary energy)	Secondary impact category		
		Photochemical ozone formation	PAH	Heavy Metals
Longer life	39%			
Repair	46%			
MLI	91%			
Monitoring	97%			
Efficient	98%			
Base Case - Reference	100%			
Storage - BAT	118%			
Storage – worst case	118%			

6.2.3 PV inverters – commercial scale

scale.

Table 18 shows the relative environmental impacts of the single design options compared to base case PV inverters under real life conditions.

Figure 5 shows the results for the primary impact category 'Primary energy' per kWh for the defined inverters at commercial scale.

Table 18: Life cycle impacts of inverter design options with respect to the base case (inverters, commercial scale)

Indicator	Reference	Efficient	Repair
Total Energy (GER)	100%	99%	48%
Water	100%	99%	36%
Waste, non-haz./ landfill	100%	99%	50%
Waste, hazardous/ incinerated	100%	99%	47%
Greenhouse Gases in GWP100	100%	99%	48%
Acidification, emissions	100%	99%	46%
Volatile Organic Compounds (VOC)	100%	99%	55%
Persistent Organic Pollutants (POP)	100%	99%	38%
Heavy Metals to air	100%	99%	53%

PAHs	100%	99%	44%
Particulate Matter (PM, dust)	100%	99%	52%
Heavy Metals to water	100%	99%	43%
Eutrophication	100%	99%	53%

Error! Not a valid bookmark self-reference. shows the relative figures of the total environmental impacts of the base case (=100%) and the single design options.

Table 19: Ranking of selected improvement options for inverters based on selected environmental indicators (inverters, commercial scale)

Option	Total Energy (primary energy)	Secondary impact category		
		Photochemical ozone formation	PAH	Heavy Metals
Repair	48%			
Efficient	99%			
Base Case - Reference	100%			

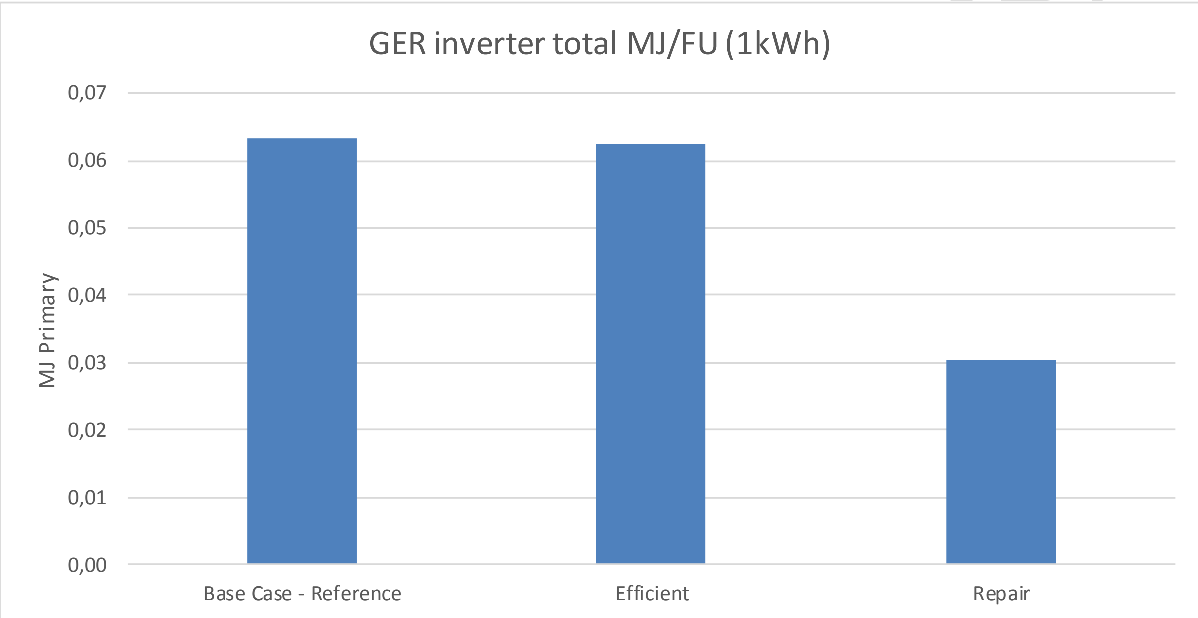


Figure 5: Primary energy results per kWh inverters commercial scale

6.2.4 PV inverters – Utility scale

Table 20 shows the relative environmental impacts of the single design options compared to base case PV inverters under real life conditions.

Figure 6 shows the results for the primary impact category 'Primary energy' per kWh for the defined inverters at utility scale.

Table 21 shows the relative figures of the total environmental impacts of the base case (=100%) and the single design options.

Table 20: Life cycle impacts of inverter design options with respect to the base case (inverters, utility scale)

Indicator	Reference	Efficient	Efficient + string
Total Energy (GER)	100%	99%	98%
Water	100%	99%	98%
Waste, non-haz./ landfill	100%	99%	98%
Waste, hazardous/ incinerated	100%	99%	98%
Greenhouse Gases in GWP100	100%	99%	98%

Acidification, emissions	100%	99%	98%
Volatile Organic Compounds (VOC)	100%	99%	98%
Persistent Organic Pollutants (POP)	100%	99%	98%
Heavy Metals to air	100%	99%	98%
PAHs	100%	99%	98%
Particulate Matter (PM, dust)	100%	99%	98%
Heavy Metals to water	100%	99%	98%
Eutrophication	100%	99%	98%

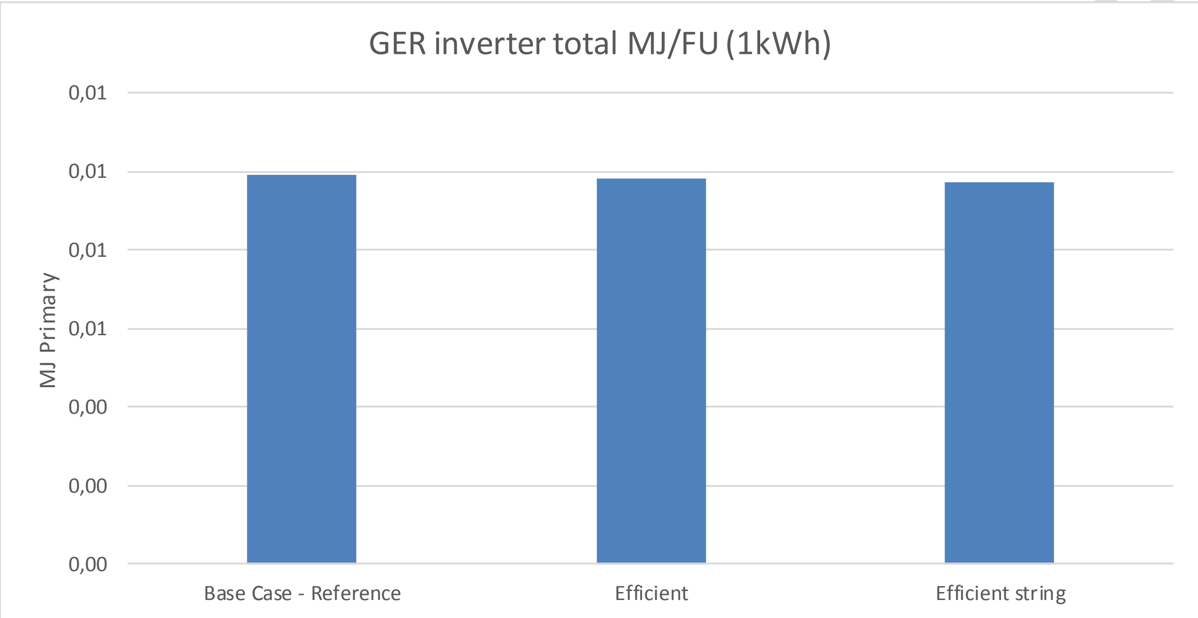


Figure 6: Primary energy results per kWh produced from inverters utility scale

Table 21: Ranking of selected improvement options for inverters based on selected environmental indicators (inverters, utility scale)

Option	Total Energy (primary energy)	Secondary impact category		
		Photochemical ozone formation	PAH	Heavy Metals
Efficient +string	98%			
Efficient	99%			
Base Case - Reference	100%			

6.2.5 PV Systems

6.2.5.1 BC 1 residential scale

To define the design options, a combination has been made of the reference inverter with the different module options and of the reference module with the different design options for the inverter (package options). In addition, optimised systems making use of the best module and best inverter have been considered as a system option. The best module available for use in a residential scale situation is the optimised multi Si module.

The different options, called package options and system options are discussed in more detail in paragraph 6.1.3.1.

The best inverter combines the benefits of the inverter with a longer life span and the inverter with monitoring.

In a final design option, the best module and inverter are combined with an optimised design.

Figure 7 shows the results (primary energy) for the defined systems. The optimised systems are the best performing systems.

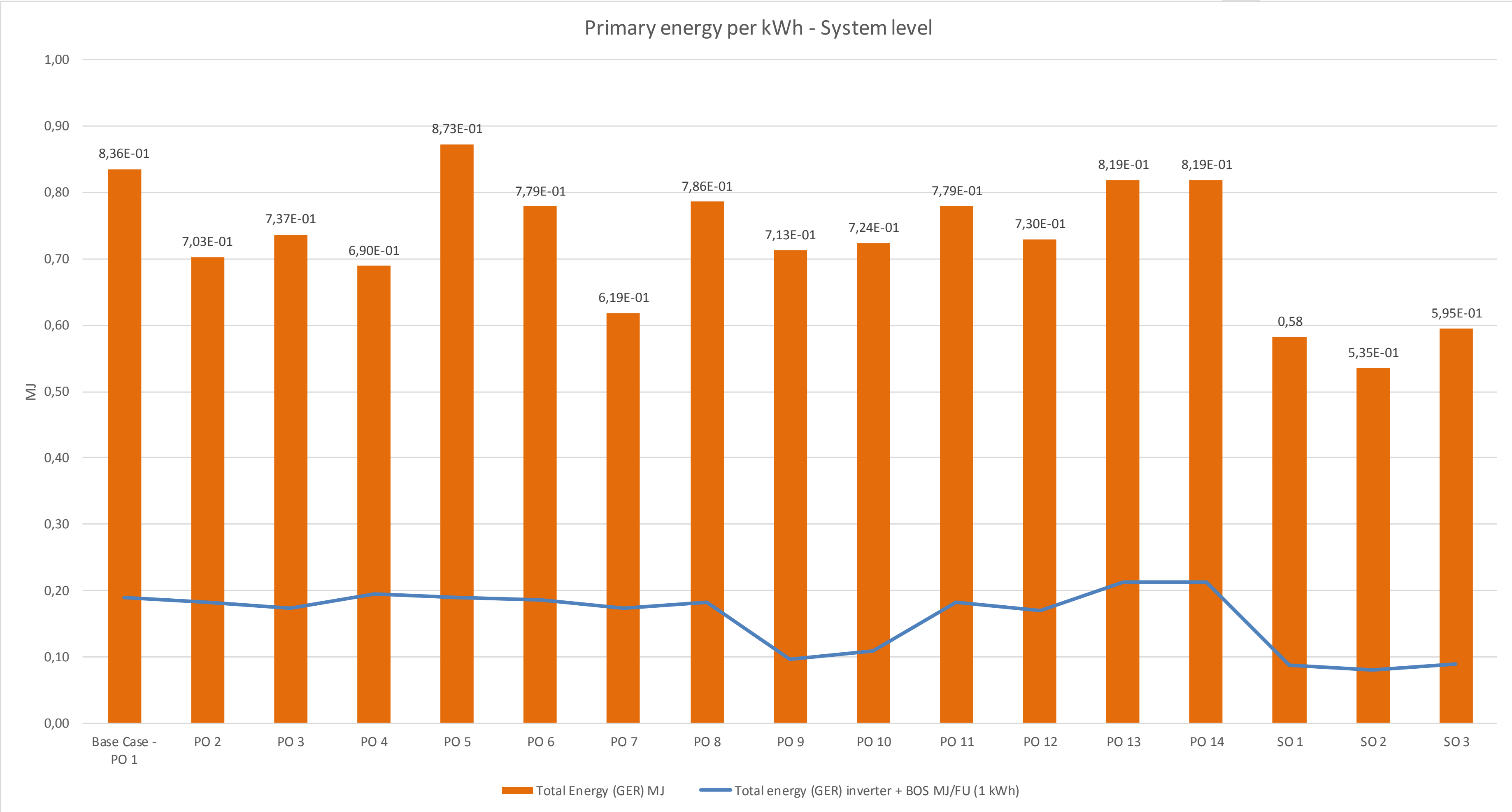


Figure 7: Primary energy at system level for different design options at residential scale

(PO 1): Multi Si module and reference inverter, (PO2): Multi Si optimised module and reference inverter; (PO 3): PERC module and reference inverter; (PO 4): CIGS module and reference inverter; (PO 5): Kerfless (old) module and reference inverter; (PO 6): Silicion heterojunction module and reference inverter; (PO 7): BNAT kerfless (new) module and reference inverter; (PO 8): Multi Si module and more efficient inverter; (PO 9): Multi Si module and longer life inverter; (PO 10): Multi Si Module and inverter with repair; (PO 11): Multi Si module and inverter including monitoring; (PO 12): Multi Si module and multi-level inverter; (PO 13): Multi Si module and inverter including storage (worst case); (PO 14): Multi Si module and inverter including storage (best case).

(SO 1): Multi Si optimised + best inverter; (SO 2): Multi Si optimised + best inverter + better design; (SO 3): Multi Si optimised + best inverter + optimised O&M

6.2.5.2 BC 2 commercial scale

Again, the considered design options are a combination of the reference inverter with the different module options and of the reference module with the different design options for the inverter. In addition, an optimized system has been defined which consist of a PERC bifacial module and the benefits of an inverter with improved repair and high efficiency. The derating factors in this system design are higher due to lower cable losses and tailored design.

Figure 8 shows the results (primary energy) for the different systems. The system with the lowest contribution to primary energy is a system combining a CdTe module with a reference inverter. The optimised system, using a bifacial PERC module and an optimised inverter has the second lowest contribution.

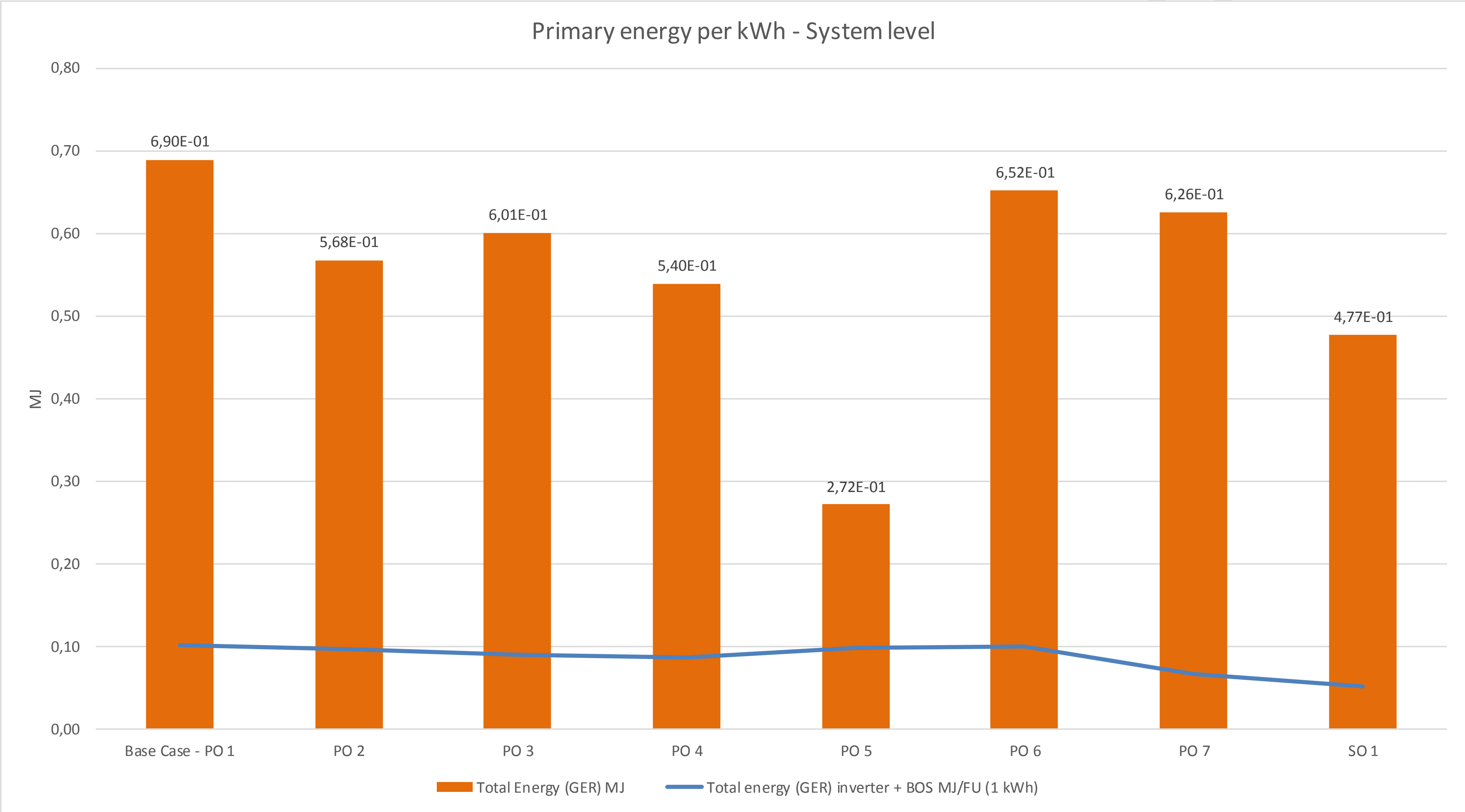


Figure 8: Primary energy at system level for different design options at commercial scale

(SO 1): best combination and design; (PO 1): Multi Si module and reference inverter; (PO 2): Multi Si optimised module and reference inverter; (PO 3):PERC module and reference inverter; (PO 4):PERC bifacial module and reference inverter; (PO 5): CdTe module and reference inverter; (PO 6):Multi Si module and more efficient inverter; (PO 7): Multi Si module and inverter with repair

6.2.5.3 BC 3 Utility scale

Also, at utility scale the considered design options are a combination of the reference inverter with the different module options and of the reference module with the different design options for the inverter. In addition, an optimised system has been defined which consists of a CdTe module and an energy efficient inverter. The system makes use of single axis tracking.

Figure 9 shows the results (primary energy) for the different systems. The system with the lowest contribution to primary energy is a system combining a CdTe module with a reference inverter. The optimised system, using tracking and an efficient string inverter has a higher contribution to the impact category primary energy compared to the system using a CdTe module in combination with a central inverter.

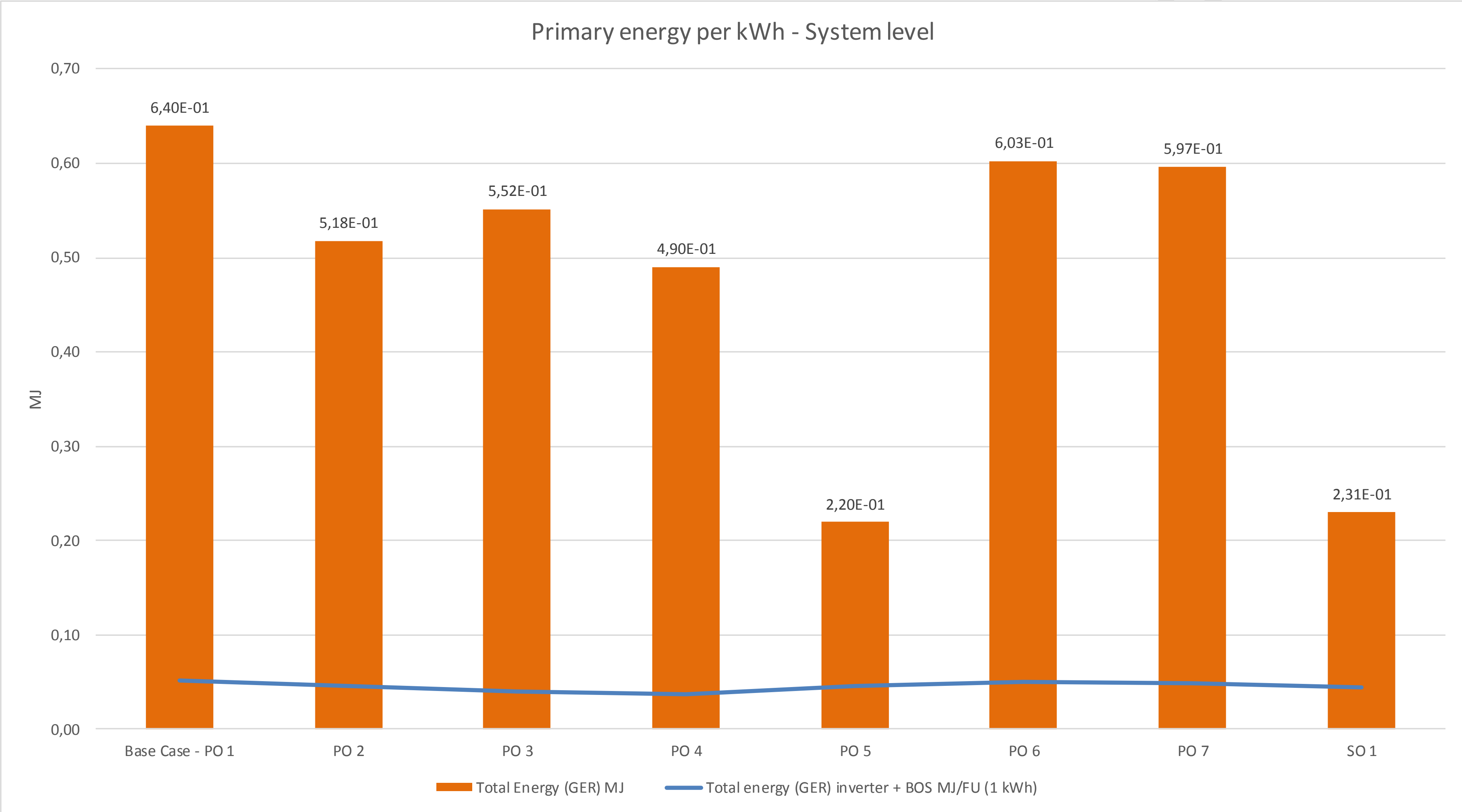


Figure 9: Primary energy at system level for different design options at utility scale

(SO 1): best combination and design including single axis tracker; (PO 1): Multi Si module and reference inverter and reference BOS; (PO 2): Multi Si optimised module and reference inverter and reference BOS; (PO 3): PERC module and reference inverter and reference BOS; (PO 4): PERC bifacial module and reference inverter and reference BOS; (PO 5): CdTe module and reference inverter and reference BOS; (PO 6): Multi Si module and more efficient inverter and reference BOS; (PO 7): Multi Si module and more efficient string inverter and reference BOS.

6.3 Analysis of BAT and LLCC

The design options identified in the technical, environmental and economic analysis in subtask 6.1 must be ranked regarding the Best Available Technology (BAT) and the Least (minimum) Life Cycle Costs. The ranking must take into account the costs both for consumers and for society. More specifically, work in this section will include:

- Ranking of the identified design options by LCC (e.g. option 1, option 2, option 3), considering possible trade-offs between different environmental impacts;
- Estimating the cumulative improvement and cost effect of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.), also taking into account 'rebound' side effects of the individual design measures;
- Ranking of the cumulative design options, drawing of a LCC-curve (Y-axis= LLCC, X-axis= options) and identifying the Least Life Cycle Cost (LLCC) point and the BAT point.

The improvement potential resulting from the ranking will be discussed, such as the appropriateness to set minimum requirements at the LLCC point, to use the environmental performance of the BAT point or benchmarks set in other countries, if manufacturers will make use of this ranking to evaluate alternative design solutions and the achieved environmental performance of the products.

6.3.1 Lead environmental impact category and supplementary parameters

Based on the results of Tasks 4/5 and the 14 impact categories that MEErP consider, GWP(CO_2eq) and the related Primary Energy(MJ) could be used as significant (see Task 5) parameter that can be optimized.

Primary energy (referred to in Ecoreport as total primary energy) has been chosen as the lead indicator. It excludes regionalized effects of process energy requirements as far as possible[6].

Other environmental parameters assessed in MEErP are listed below. They can be considered as secondary impact categories.

- Water
- Non hazardous waste
- Hazardous waste
- Acidification
- Volatile Organic Compounds
- Persistent Organic Pollutants
- Heavy Metals
- PAHs
- Particulate Matter

Using a combination of the weightings according to societal costs in Ecoreport tool and analysis of which impact categories contributions are not strongly linked to electricity generation, the following impact categories could be used as secondary indicators:

[6] Regionalized effects are assumed to be excluded in the materials which are available in the Ecoreport tool. A lot of materials had to be added to the Ecoreport tool to appropriately model the modules and inverters. The environmental impact for those materials was sourced from other databases and includes different types of energy sources and mixes.

Modules:

- Polycyclic aromatic hydrocarbons
- Volatile organic compounds
- Heavy metals

Inverters

- Photochemical ozone formation
- Polycyclic aromatic hydrocarbons
- Heavy metals

6.3.2 LCC of the design options for PV modules

Figure 10 provides the module costs in euro/Wp at residential scale.

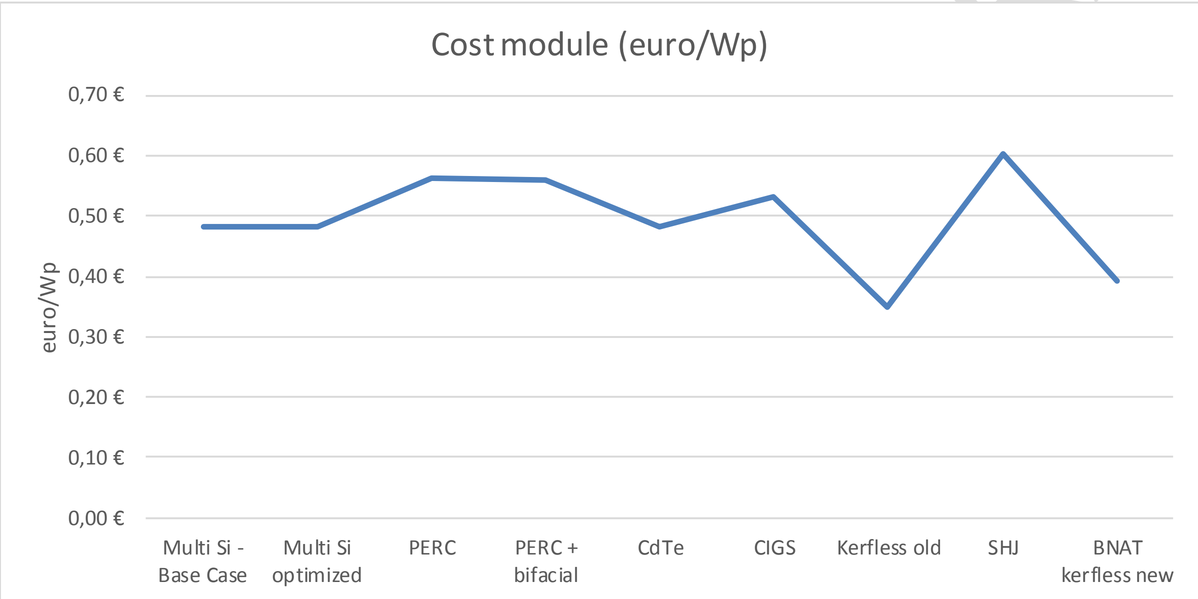


Figure 10: Module costs in euro per Wp

6.3.2.1 Residential scale (BC 1)

The CIGS module is the best available technology (BAT) from an environmental perspective (when looking at primary energy) and the Multi si optimized from a life cycle cost perspective. It is to be noted that the CIGS technology has a very low penetration rate in the residential sector. Given that the Multi Si optimized is predicted to become obsolete from the market after 2020, it is suggested that after that date, he CIGS becomes the best available technology from both environmental and cost perspectives. Figure 11 shows the results for the different modules on primary energy (per kWh) and costs (per Wp).

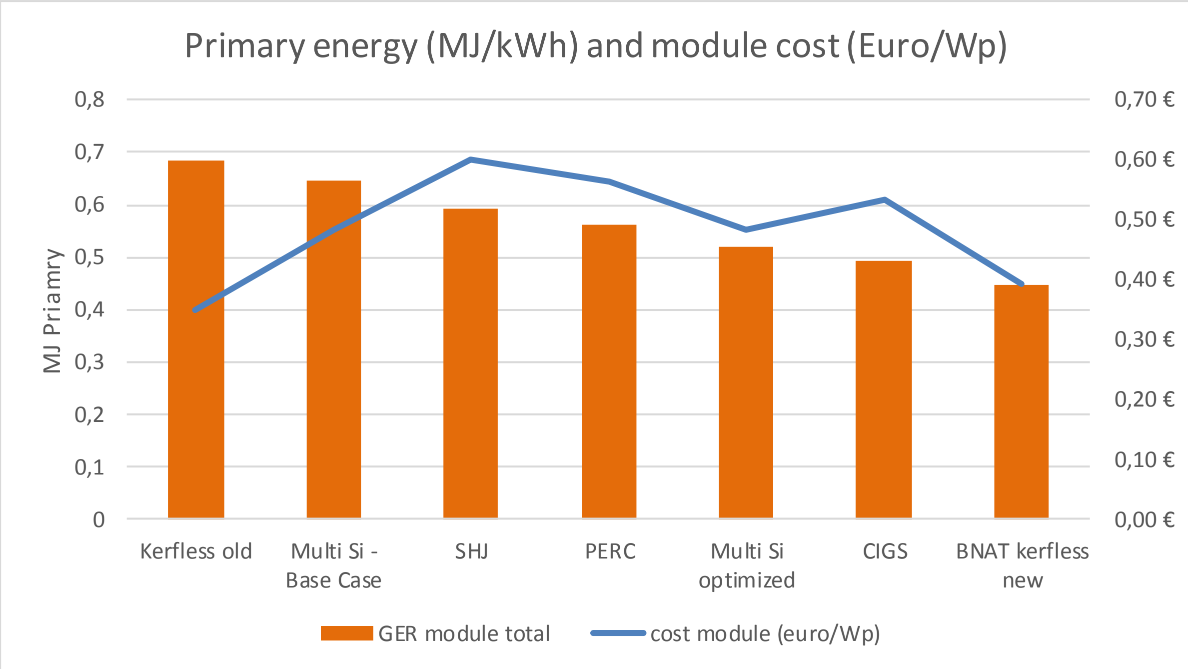


Figure 11: Modules Primary energy (MJ/kWh) and cost (per Wp) at residential scale

6.3.2.2 Commercial scale (BC 2)

The CdTe module is the best available technology (BAT) from an environmental (when looking at primary energy) and economic point of view. The multi Si reference module, the multi Si optimised module and the CdTe module all have comparable costs.

Figure 12 shows the results for the different modules on primary energy (per kWh) and costs (per Wp). Information on costs of kerfless old modules, SHJ modules and BNAT kerfless new are missing.

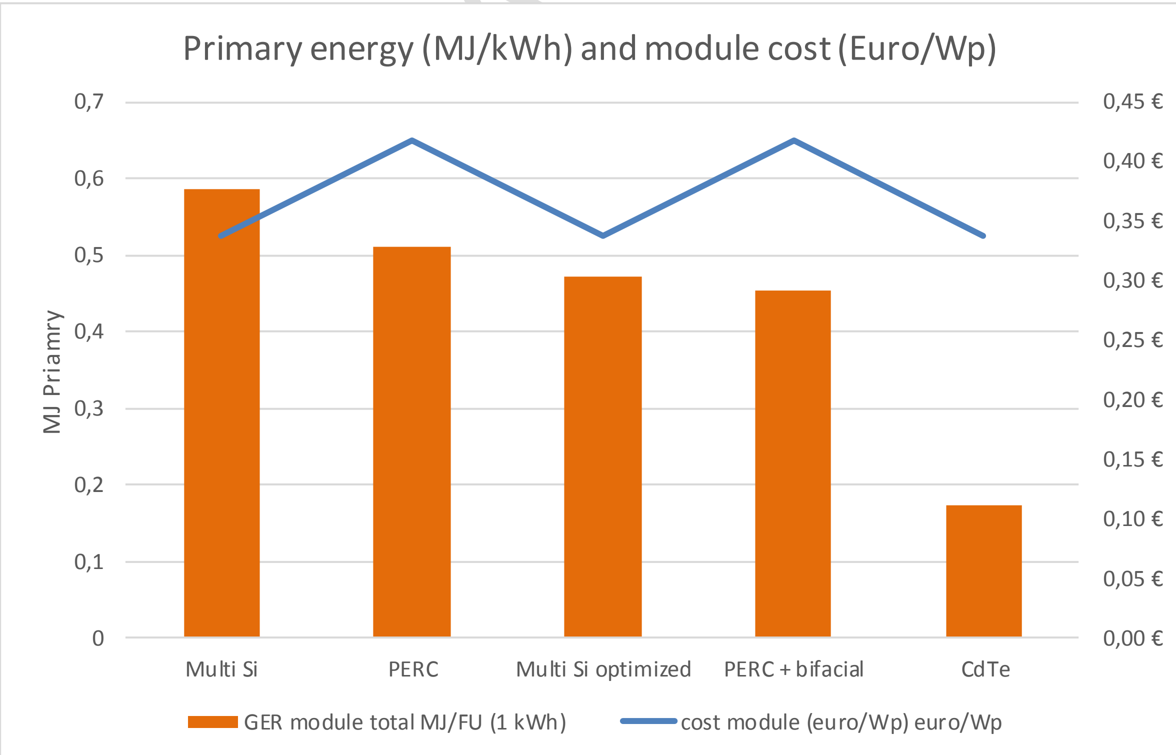


Figure 12: Modules Primary energy (MJ/kWh) and cost (per Wp) at commercial scale

6.3.2.3 Utility scale (BC 3)

The CdTe module is the best available technology (BAT) from an environmental (when looking at primary energy) and economic point of view. The multi Si reference module, the multi Si optimised module and the CdTe module all have comparable costs.

Figure 13 shows the results for the different modules on primary energy (per kWh) and costs (per Wp). Information on costs of kerfless old modules, SHJ modules and BNAT kerfless new are missing.

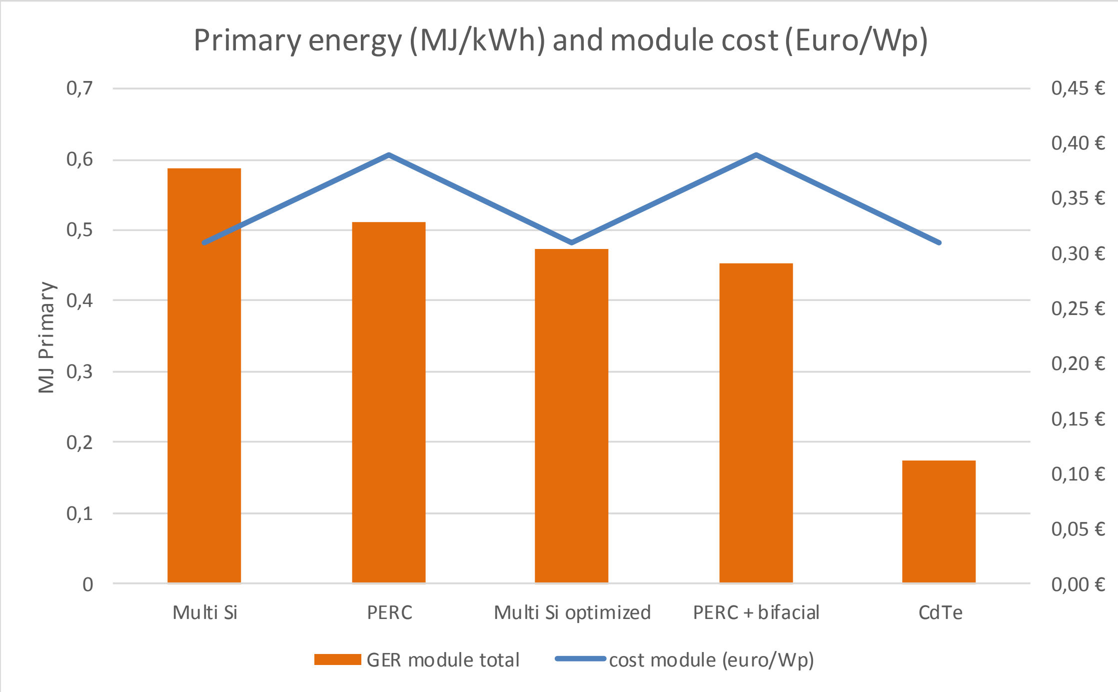


Figure 13: Modules Primary energy (MJ/kWh) and cost (per Wp) at utility scale

6.3.3 LCC of the design options for the inverters

6.3.3.1 Residential scale (BC 1)

Figure 14 provides the inverter life cycle cost in euro per Watt.

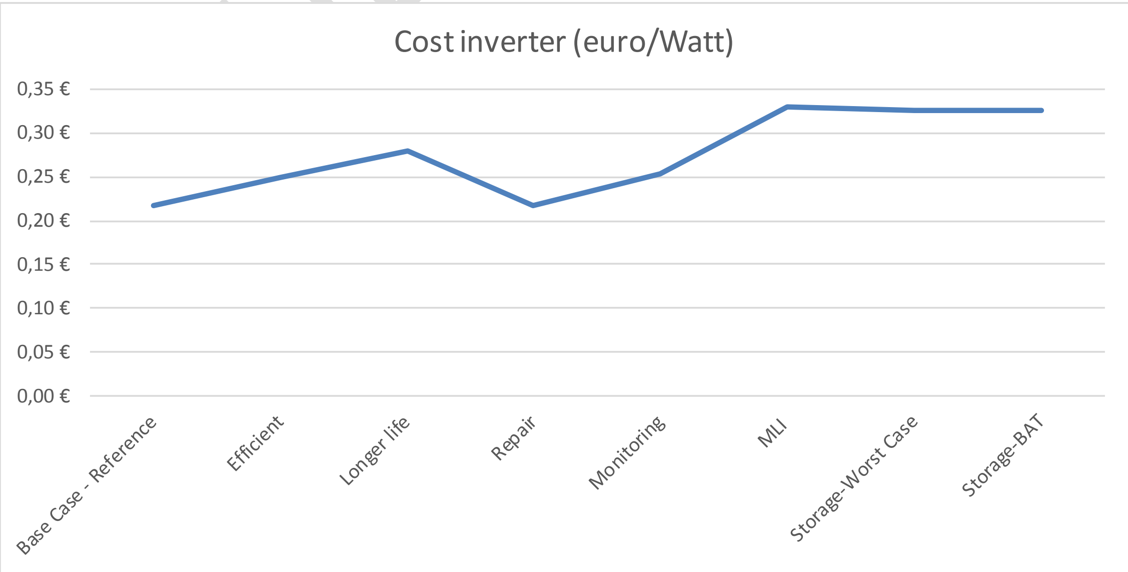


Figure 14: Inverter life cycle cost in Euro per Watt – residential scale

6.3.3.2 Commercial scale (BC 2)

Figure 15 provides the inverter life cycle cost in euro per Watt.

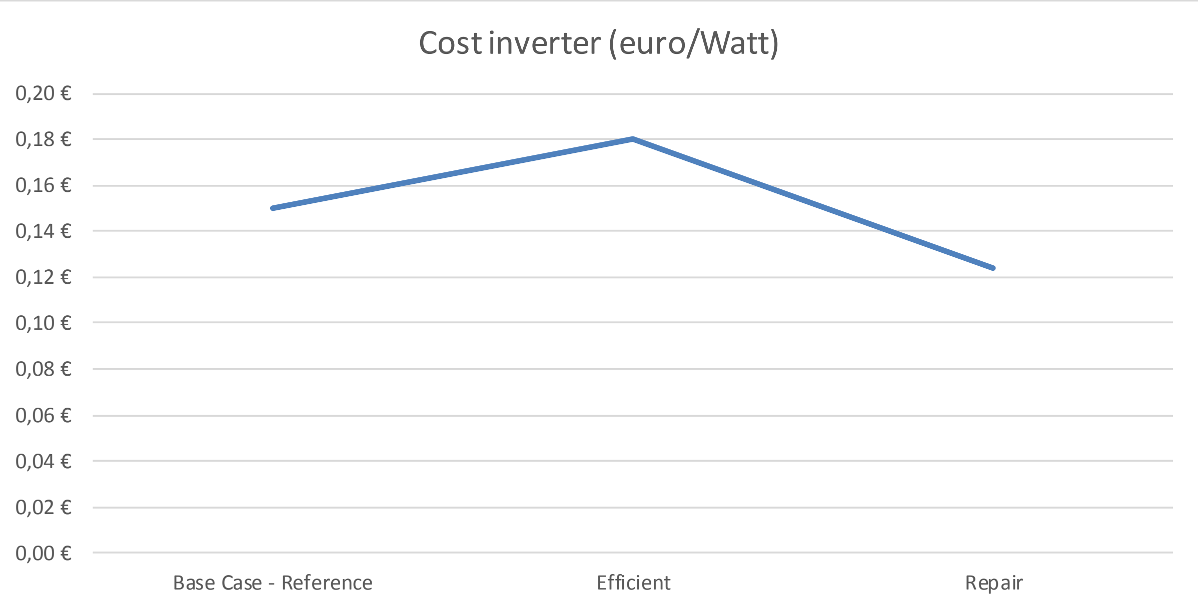


Figure 15: Inverter life cycle cost in Euro per Watt – commercial scale

6.3.3.3 Utility scale (BC 3)

Figure 16 provides the inverter life cycle cost in euro per Watt.

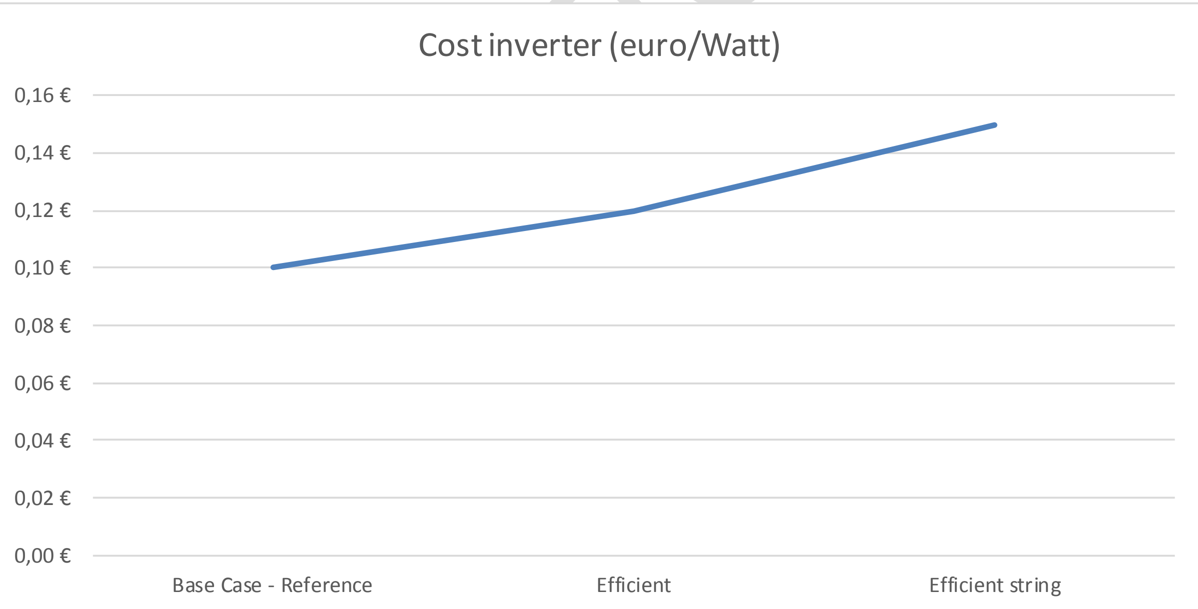


Figure 16: Inverter life cycle cost in Euro per Watt – utility scale

6.3.4 Best available and Least LCC options of inverters

6.3.4.1 Residential scale (BC 1)

The best available technology from an environmental point of view (primary energy only) is the inverter with a longer life span. Form an economic point of view, the costs are lower for the reference inverter and repaired inverter. The benefits of the repair option could only be achieved if the ongoing servicing was provided to the household installing the inverter.

Figure 17 shows the results for the different inverters on primary energy (per kWh) and costs (per Watt)

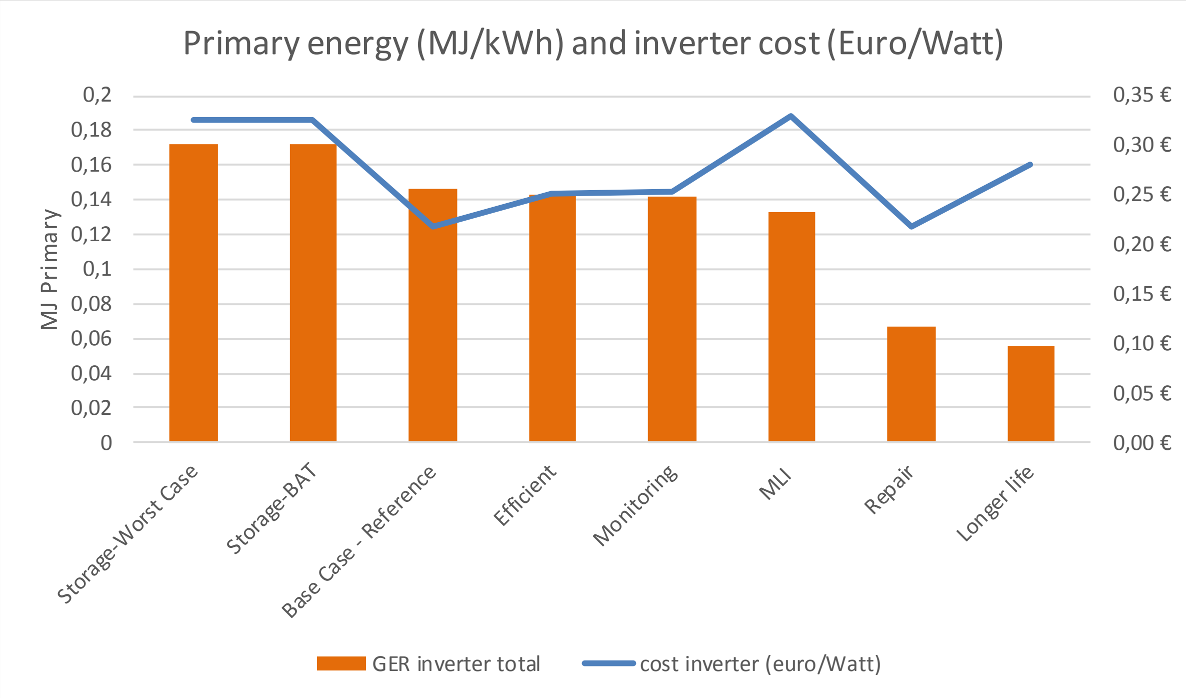


Figure 17: Inverters primary energy and cost – residential scale

6.3.4.2 Commercial scale (BC 2)

The best available technology from an environmental point of view (primary energy only) is the inverter with repair, also the costs are lowest for this design option.

Figure 18 shows the results for the different inverters on primary energy (per kWh) and costs (per Watt)

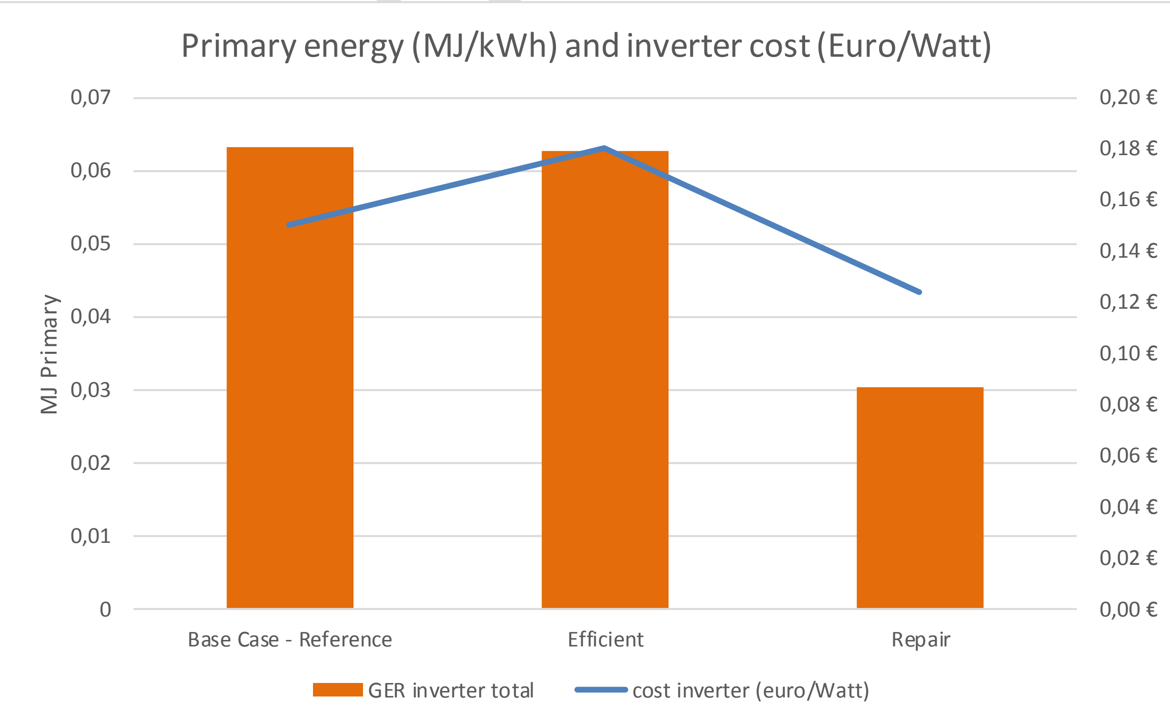


Figure 18: Inverters primary energy and cost – commercial scale

6.3.4.3 Utility scale (BC 3)

The best available technology from an environmental point of view (primary energy only) is the efficient string inverter. However, the difference in primary energy is marginal (note the scale) while the cost is relatively higher. The inverter with the lowest cost per Watt is the reference inverter.

Figure 19 shows the results for the different inverters on primary energy (per kWh) and costs (per Wp)

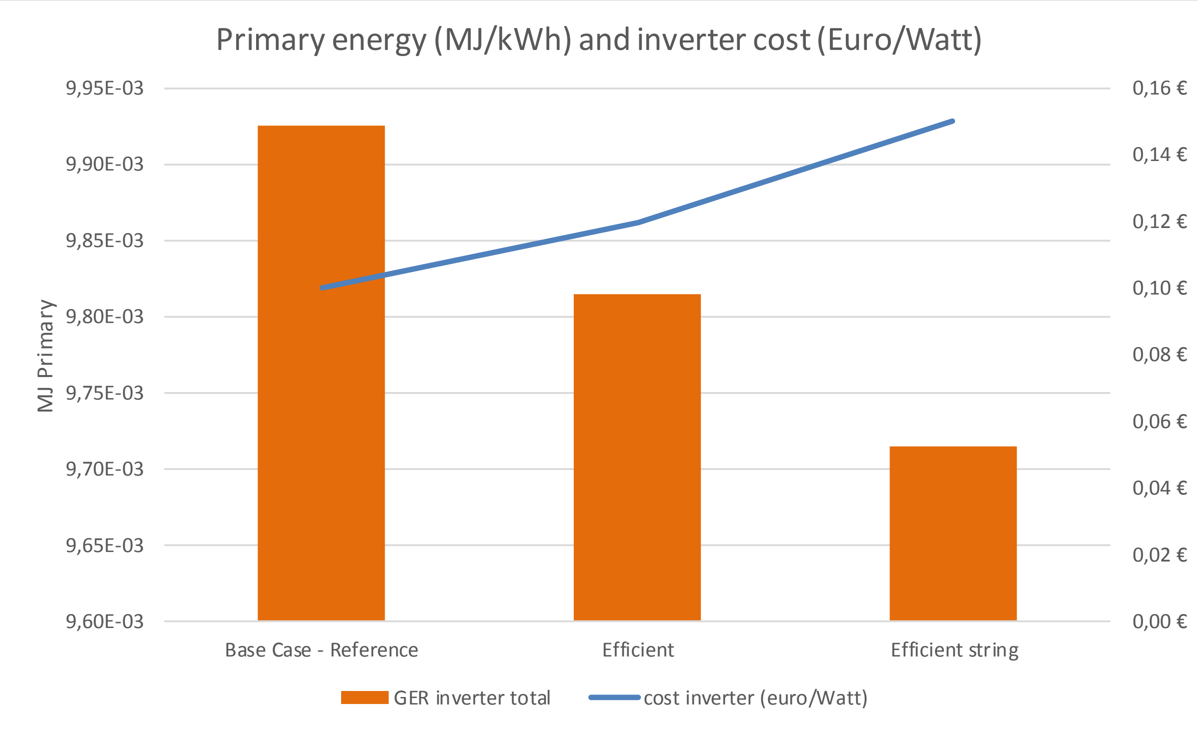


Figure 19: Inverters primary energy and cost – utility scale

6.3.5 Best available and Least LCC options of PV systems

6.3.5.1 Residential scale

The best available technology from an environmental point of view (primary energy) and life cycle cost point of view is the Multi Si optimized + best of best inverter + better design.

Figure 20 shows the primary energy use and LCOE per kWh for the different design options in base case 1, residential scale.

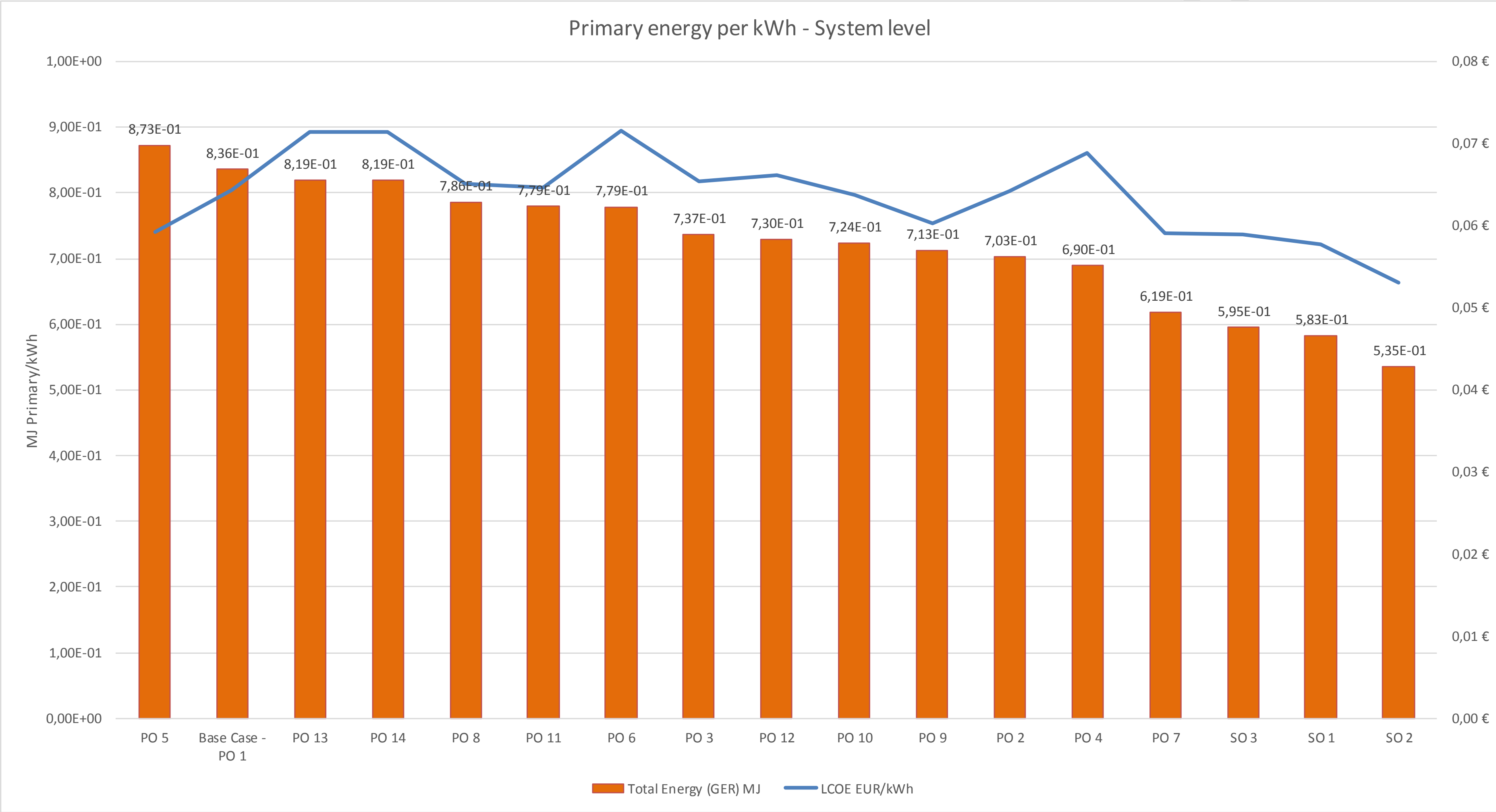


Figure 20: MJ primary energy and LCOE per kWh – residential scale

(PO 1): Multi Si module and reference inverter, (PO2): Multi Si optimised module and reference inverter; (PO 3): PERC module and reference inverter; (PO 4): CIGS module and reference inverter; (PO 5): Kerfless (old) module and reference inverter; (PO 6): Silicion heterojunction module and reference inverter; (PO 7): BNAT kerfless (new) module and reference inverter; (PO 8): Multi Si module and more efficient inverter; (PO 9): Multi Si module and longer life inverter; (PO 10): Multi Si Module and inverter with repair; (PO 11): Multi Si module and inverter including monitoring; (PO 12): Multi Si module and multi-level inverter; (PO 13): Multi Si module and inverter including storage (worst case); (PO 14): Multi Si module and inverter including storage (best case).

(SO 1): Multi Si optimised + best inverter; (SO 2): Multi Si optimised + best inverter + better design; (SO 3): Multi Si optimised + best inverter + optimised O&M

6.3.5.2 Commercial scale

The best available technology from an environmental point of view (primary energy) is the CdTe system. From the life cycle cost point of view the optimised design using a PERC bifacial module and a tailored design is the best option, being also the second in the ranking in terms of primary energy.

Figure 21 shows the primary energy use and LCOE per kWh for the different design options in base case 2, commercial scale.

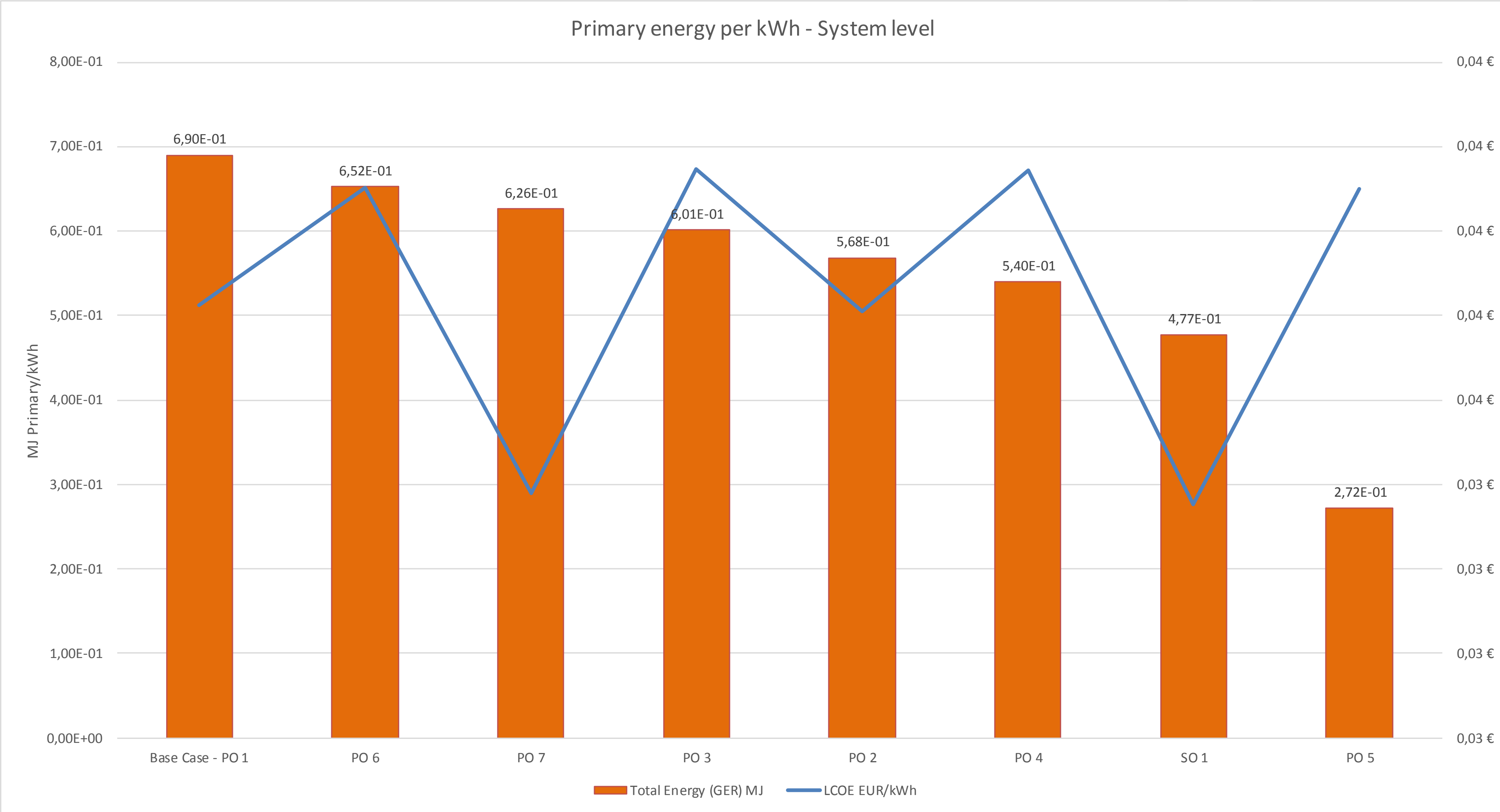


Figure 21: MJ primary energy and LCOE per kWh – commercial scale

(SO 1): best combination and design; (PO 1): Multi Si module and reference inverter; (PO 2): Multi Si optimised module and reference inverter; (PO 3):PERC module and reference inverter; (PO 4):PERC bifacial module and reference inverter; (PO 5): CdTe module and reference inverter; (PO 6):Multi Si module and more efficient inverter; (PO 7): Multi Si module and inverter with repair

6.3.5.3 Utility scale

The best available technology from an environmental point of view (primary energy) is the system using CdTe modules. Note that the addition of a single axis tracker to the system does not appear to compensate the additional cost. The system 'multi Si optimised + reference inverter + reference BOS' has the lowest LCOE but close to the BAT, while it doubles the primary energy of the BAT.

Figure 22 shows the primary energy use and LCOE per kWh for the different design options in base case 3, utility scale.

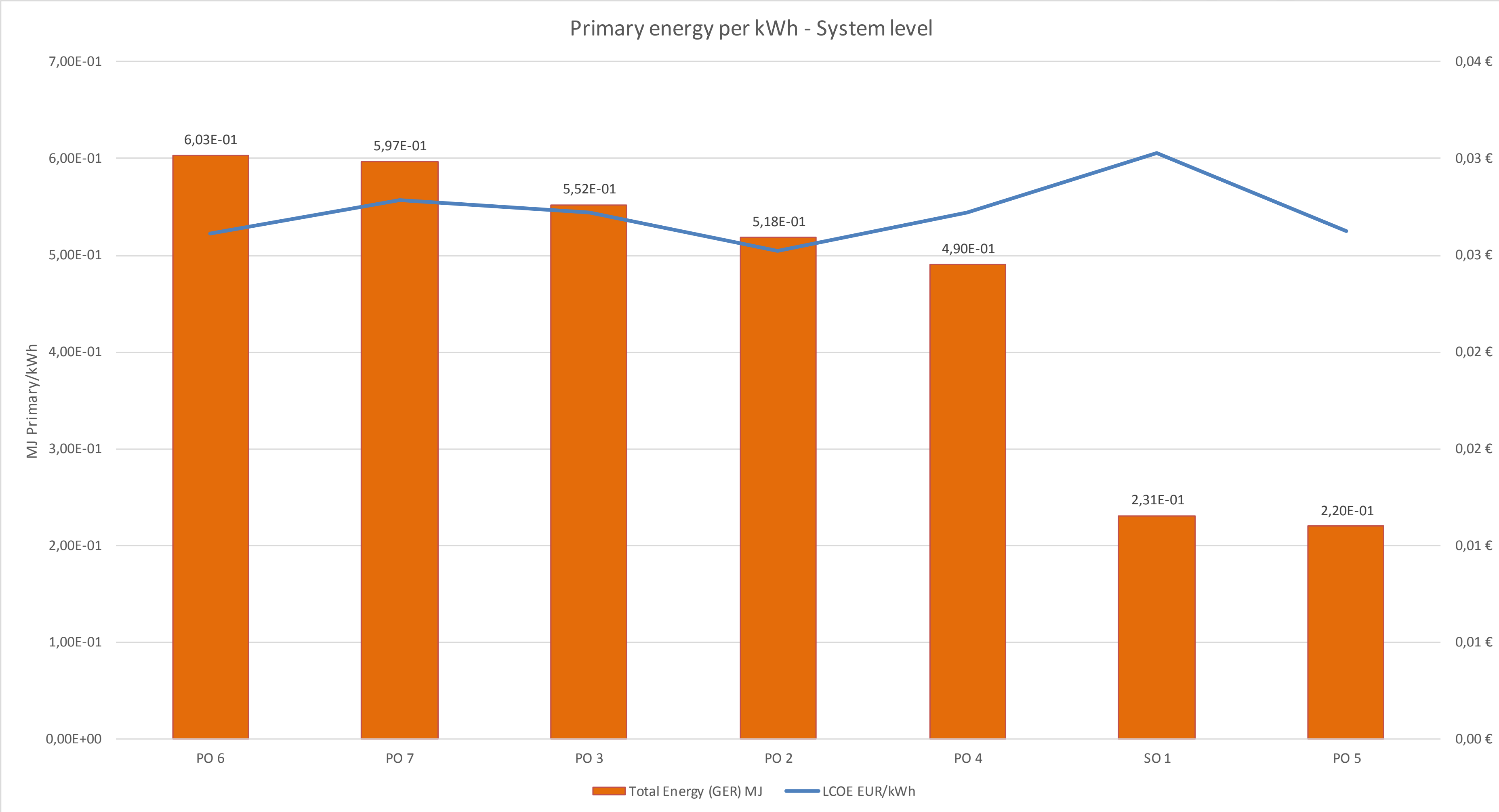


Figure 22: MJ primary energy and LCOE per kWh – utility scale

(SO 1): best combination and design including single axis tracker; (PO 1): Multi Si module and reference inverter and reference BOS; (PO 2): Multi Si optimised module and reference inverter and reference BOS; (PO 3): PERC module and reference inverter and reference BOS; (PO 4): PERC bifacial module and reference inverter and reference BOS; (PO 5): CdTe module and reference inverter and reference BOS; (PO 6): Multi Si module and more efficient inverter and reference BOS; (PO 7): Multi Si module and more efficient string inverter and reference BOS.

6.4 Long term potential (BNAT) & systems analysis

This section deals with the long-term technical potential within existing product system, including whether there is sufficient scope for product differentiation beyond the BAT and the LLCC options

6.4.1 BNAT analysis for modules

Candidates for the Best Not Yet Available Technology (BNAT) for modules consisted of crystalline silicon wafers created by lift-off or epitaxial growth with in-situ growth of the pn junction– thereby reducing silicon waste - or where the crystalline silicon cell is in a tandem formation with perovskite (or other) thin films – offering a further improvement in cell efficiency. In the modelling carried out both of these options are subject to uncertainty as to when they will reach commercial scale production and as to their cost.

However, the potential to reduce the energy consumption of crystalline wafers created by lift-off or epitaxial growth to substitute sliced polysilicon wafers could be significant and would not require a substantial change in downstream production technology.

This technology could be particularly important for the residential scale where the large scale deployment of the identified BAT (CIGS) is not yet demonstrated due to small market penetration. This should therefore be taken into consideration in the design of any policy interventions.

6.4.2 BNAT analysis for inverters

The main candidates for the Best Not Yet Available Technology (BNAT) are inverter designs based on wider band gap semi-conductors (MOSFET). Whilst some products are understood to have entered the market in 2018 – suggesting that they could eventually be candidates for BAT. Information is still lacking on their potential benefits and trade-offs in relation to changes in the bill of materials, their performance under higher temperature conditions.

Given the significance of thermally induced failures in inverters, this technology could be particularly important in warmer climates if benefits were to be confirmed.

Annex A: Bill of Materials in EcoReport format for modules

Multi-Si: reference

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS

Assessment of Environmental Impact

Nr	multi Si panel 1 kWh	Date	Author
	Products		vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process Recyclable? select Category first !
1	**materials**			
2	**photovoltaic cell**			
3	photovoltaic cell, multi-Si	1,32E-01	8-Extra	102-Photovoltaic cell, multi-Si wafer per kg
4				
5	**interconnection**			
6	Tin	3,44E-03	8-Extra	103-Tin {GLO}| market for | Cut-off, U
7	Lead	1,93E-04	8-Extra	104-Lead {GLO}| primary lead production from
8	Copper	2,74E-02	4-Non-ferro	30 -Cu wire
9				
10	**encapsulation**			
11	Ethylvinylacetate, foil	2,33E-01	8-Extra	105-Ethylvinylacetate, foil {GLO}| market for | C
12				
13	**backsheet**			
14	Polyvinylfluoride film	2,98E-02	8-Extra	106-Polyvinylfluoride {GLO}| market for | Cut-o
15	Polyethylene terephthalate	9,22E-02	1-BlkPlastics	10 -PET
16				
17	**pottant & sealing**			
18	Silicone product	3,25E-02	8-Extra	107-Silicone product {GLO}| market for | Cut-o
19				
20	**frame**			
21	Aluminium alloy, AlMg3	5,67E-01	4-Non-ferro	27 -Al sheet/extrusion
22				
23	**glass**			
24	Solar glass, low-iron & Tempering, flat glass	2,35E+00	8-Extra	108-solar glass and tempering - GLO
25				
26	**junction box**			
27	Diode, unspecified	7,48E-04	6-Electronics	47 -IC's avg., 5% Si, Au
28	Polyethylene, HDPE	6,34E-03	1-BlkPlastics	2 -HDPE
29	Glass fibre reinforced plastic, polyamide, injection mouldin	7,86E-02	2-TecPlastics	19 -E-glass fibre
30				
31	**Auxilaries**			
32	Tap water	1,34E+00	8-Extra	109-Tap water {GLO}| market group for | Cut-o
33	Hydrogen fluoride	1,66E-02	8-Extra	110-Hydrogen fluoride {GLO}| market for | Cut-
34	Potassium hydroxide	1,37E-02	8-Extra	111-Potassium hydroxide {GLO}| market for | Cu
35	1-propanol	4,24E-03	8-Extra	112-1-propanol {GLO}| market for | Cut-off, U
36	Isopropanol	3,92E-05	8-Extra	113-Isopropanol {GLO}| market for | Cut-off, U
37				
38				
39				
40				

Multi-Si optimized design

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS **Assessment of Environmental Impact**

Nr	multi Si optimized panel 1 kWh	Date	Author
	Products		vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**materials**				
2	**photovoltaic cell**				
3	photovoltaic cell, multi-Si-adapted wafer thickness	8,38E-02	8-Extra	102-Photovoltaic cell, multi-Si wafer per kg	
4					
5	**interconnection**				
6	Tin	2,90E-03	8-Extra	103-Tin {GLO}| market for | Cut-off, U	
7	Lead	1,63E-04	8-Extra	104-Lead {GLO}| primary lead production from	
8	Copper	2,32E-02	4-Non-ferro	30 -Cu wire	
9					
10	**encapsulation**				
11	Ethylvinylacetate, foil	1,97E-01	8-Extra	105-Ethylvinylacetate, foil {GLO}| market for | C	
12					
13	**backsheet**				
14	Polyvinylfluoride film	2,52E-02	8-Extra	106-Polyvinylfluoride {GLO}| market for | Cut-o	
15	Polyethylene terephthalate	7,78E-02	1-BlkPlastics	10 -PET	
16					
17	**pottant & sealing**				
18	Silicone product	2,74E-02	8-Extra	107-Silicone product {GLO}| market for | Cut-o	
19					
20	**frame**				
21	Aluminium alloy, AlMg3	4,79E-01	4-Non-ferro	27 -Al sheet/extrusion	
22					
23	**glass**				
24	Solar glass, low-iron & Tempering, flat glass	1,98E+00	8-Extra	108-solar glass and tempering - GLO	
25					
26	**junction box**				
27	Diode, unspecified	6,31E-04	6-Electronics	47 -IC's avg., 5% Si, Au	
28	Polyethylene, HDPE	5,35E-03	1-BlkPlastics	2 -HDPE	
29	Glass fibre reinforced plastic, polyamide, injection moulding	6,63E-02	2-TecPlastics	19 -E-glass fibre	
30					
31	**Auxilaries**				
32	Tap water	1,13E+00	8-Extra	109-Tap water {GLO}| market group for | Cut-o	
33	Hydrogen fluoride	1,40E-02	8-Extra	110-Hydrogen fluoride {GLO}| market for | Cut-	
34	Potassium hydroxide	1,16E-02	8-Extra	111-Potassium hydroxide {GLO}| market for | Cu	
35	1-propanol	3,58E-03	8-Extra	112-1-propanol {GLO}| market for | Cut-off, U	
36	Isopropanol	3,31E-05	8-Extra	113-Isopropanol {GLO}| market for | Cut-off, U	
37					
38					
39					
40					

PERC

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

Document subject to a legal notice (see below)

EcoReport 2014: INPUTS

Assessment of Environmental Impact

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

Nr	PERC panel 1 kWh	Date	Author
	Products		vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**materials**				
2	**photovoltaic cell**				
3	photovoltaic cell	8,90E-02	8-Extra	102-photovoltaic cell per kg	
4					
5	**interconnection**				
6	Tin	2,51E-03	8-Extra	103-Tin {GLO}| market for | Cut-off, U	
7	Lead	1,41E-04	8-Extra	104-Lead {GLO}| primary lead production from	
8	Copper	2,00E-02	4-Non-ferro	30 - Cu wire	
9					
10	**encapsulation**				
11	Ethylvinylacetate, foil	1,70E-01	8-Extra	105-Ethylvinylacetate, foil {GLO}| market for | C	
12					
13	**backsheet**				
14	Polyvinylfluoride film	2,18E-02	8-Extra	106-Polyvinylfluoride {GLO}| market for | Cut-o	
15	Polyethylene terephthalate	6,72E-02	1-BlkPlastics	10 - PET	
16					
17	**pottant & sealing**				
18	Silicone product	2,37E-02	8-Extra	107-Silicone product {GLO}| market for | Cut-o	
19					
20	**frame**				
21	Aluminium alloy, AlMg3	4,14E-01	4-Non-ferro	27 - Al sheet/extrusion	
22					
23	**glass**				
24	Solar glass, low-iron & Tempering, flat glass	1,71E+00	8-Extra	108-solar glass and tempering - GLO	
25					
26	**junction box**				
27	Diode, unspecified	5,46E-04	6-Electronics	47 - IC's avg., 5% Si, Au	
28	Polyethylene, HDPE	4,63E-03	1-BlkPlastics	2 - HDPE	
29	Glass fibre reinforced plastic, polyamide, injection moulding	5,73E-02	2-TecPlastics	19 - E-glass fibre	
30					
31	**Auxilaries**				
32	Tap water	9,78E-01	8-Extra	109-Tap water {GLO}| market group for | Cut-o	
33	hydrogen fluoride	1,21E-02	8-Extra	110-Hydrogen fluoride {GLO}| market for | Cut-	
34	potassium hydroxide	9,99E-03	8-Extra	111-Potassium hydroxide {GLO}| market for | Cu	
35	1-propanol	3,09E-03	8-Extra	112-1-propanol {GLO}| market for | Cut-off, U	
36	Isopropanol	2,86E-05	8-Extra	113-Isopropanol {GLO}| market for | Cut-off, U	
37					
38					
39					
40					

PERC + bifacial

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014			Document subject to a legal notice (see below)
ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS	EcoReport 2014: INPUTS Environmental Impact		Assessment of

Nr	PERC + bifacial panel 1 kWh Products	Date	Author vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**materials**				
2	**photovoltaic cell**				
3	photovoltaic cell	8,90E-02	8-Extra	102-photovoltaic cell per kg	
4					
5	**interconnection**				
6	Tin	2,51E-03	8-Extra	103-Tin {GLO}| market for | Cut-off, U	
7	Lead	1,41E-04	8-Extra	104-Lead {GLO}| primary lead production from	
8	Copper	2,00E-02	4-Non-ferro	30 - Cu wire	
9					
10	**encapsulation**				
11	Ethylvinylacetate, foil	1,70E-01	8-Extra	105-Ethylvinylacetate, foil {GLO}| market for | C	
12					
13	**backsheet**				
14	Solar glass, low-iron & Tempering, flat glass	1,71E+00	8-Extra	108-solar glass and tempering - GLO	
15					
16					
17	**pottant & sealing**				
18	Silicone product	2,37E-02	8-Extra	107-Silicone product {GLO}| market for | Cut-o	
19					
20	**frame**				
21	Aluminium alloy, AlMg3	4,14E-01	4-Non-ferro	27 - Al sheet/extrusion	
22					
23	**glass**				
24	Solar glass, low-iron & Tempering, flat glass	1,71E+00	8-Extra	108-solar glass and tempering - GLO	
25					
26	**junction box**				
27	Diode, unspecified	5,47E-04	6-Electronics	47 - IC's avg., 5% Si, Au	
28	Polyethylene, HDPE	4,63E-03	1-BlkPlastics	2 - HDPE	
29	Glass fibre reinforced plastic, polyamide, injection mouldin	5,73E-02	2-TecPlastics	19 - E-glass fibre	
30					
31	**Auxilaries**				
32	Tap water	9,78E-01	8-Extra	109-Tap water {GLO}| market group for | Cut-o	
33	hydrogen fluoride	1,21E-02	8-Extra	110-Hydrogen fluoride {GLO}| market for | Cut-	
34	potassium hydroxide	9,99E-03	8-Extra	111-Potassium hydroxide {GLO}| market for | Cu	
35	1-propanol	3,09E-03	8-Extra	112-1-propanol {GLO}| market for | Cut-off, U	
36	Isopropanol	2,86E-05	8-Extra	113-Isopropanol {GLO}| market for | Cut-off, U	
37					
38					
39					
40					

CdTe

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS Assessment of Environmental Impact

Nr	CdTe panel 1 kWh	Date	Author
	Products		vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**materials**				
2	Solar glass and tempering	1,99E+00	8-Extra	102-solar glass and tempering - GLO	
3	Flat glass (uncoated)	1,85E+00	8-Extra	103-Flat glass, uncoated {GLO}| market for | Cu	
4	Copper	2,61E-03	4-Non-ferro	30 - Cu wire	
5	Cadmium sulphide	7,98E-04	8-Extra	104-Cadmium sulfide, semiconductor-grade {G	
6	Cadmium telluride	5,38E-03	8-Extra	105-Cadmium telluride, semiconductor-grade	
7	Ethylene vinyl acetate (EVA)	1,10E-01	8-Extra	106-Ethylvinylacetate, foil {GLO}| market for | C	
8	Glass fibre reinforced plastic	2,45E-02	2-TecPlastics	19 - E-glass fibre	
9	Silicone	6,96E-04	8-Extra	107-Silicone product {GLO}| market for | Cut-o	
10	Silica sand	1,06E-02	8-Extra	108-Silica sand {GLO}| market for | Cut-off, U	
11	Tap water	4,51E+01	8-Extra	109-Tap water {GLO}| market group for | Cut-o	
12	Nitrogen	1,66E-02	8-Extra	110-Nitrogen, liquid {RER}| market for | Cut-off,	
13	Helium	8,25E-03	8-Extra	111-Helium {GLO}| market for | Cut-off, U	
14	Nitric acid	1,30E-02	8-Extra	112-Nitric acid, without water, in 50% solution s	
15	Sulphuric acid	8,90E-03	8-Extra	113-Sulfuric acid {GLO}| market for | Cut-off, U	
16	Hydrogen peroxide	3,78E-03	8-Extra	114-Hydrogen peroxide, without water, in 50%	
17	Sodium hydroxide	1,12E-02	8-Extra	115-Sodium hydroxide, without water, in 50% s	
18	Sodium chloride	1,03E-02	8-Extra	116-Sodium chloride, powder {GLO}| market fo	
19	Isopropanol	4,71E-04	8-Extra	117-Isopropanol {GLO}| market for | Cut-off, U	
20	Chemicals organic	2,21E-03	8-Extra		
21	Chemicals inorganic	8,51E-03	8-Extra		
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					

CIGS

Version 3.06 VHK for European Commission 2011,
modified by IZM for european commission 2014

Document subject to a legal notice (see below)

EcoReport 2014: INPUTS

Assessment of Environmental Impact

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

Nr	CIGS panel 1 kWh	Date	Author
	Products		vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**materials**				
2	**Laminate**				
3	Solar glass and tempering	2,09E+00	8-Extra	102-solar glass and tempering - GLO	
4	Flat glass (uncoated)	1,43E+00	8-Extra	103-Flat glass, uncoated {GLO}| market for | C	
5	Aluminium	1,21E-02	4-Non-ferro	27 -Al sheet/extrusion	
6	Copper wire	2,65E-03	4-Non-ferro	30 -Cu wire	
7	Tin	3,34E-03	8-Extra	104-Tin {GLO}| market for | Cut-off, U	
8	Zinc oxide	2,47E-03	8-Extra	105-Zinc oxide {GLO}| market for | Cut-off, U	
9	Molybdenum	1,65E-03	8-Extra	106-Molybdenum {GLO}| market for | Cut-off, U	
10	Indium	7,66E-04	8-Extra	107-Indium {GLO}| market for | Cut-off, U	
11	Gallium	2,44E-04	8-Extra	108-Gallium, semiconductor-grade {GLO}| ma	
12	Selenium	1,52E-03	8-Extra	109-Selenium {GLO}| market for | Cut-off, U	
13	Cadmium sulphide	7,31E-05	8-Extra	110-Cadmium sulfide, semiconductor-grade {G	
14	Diode	3,92E-04	6-Electronics	49 -SMD/ LED's avg.	
15	Flux	3,34E-03	8-Extra	111-Flux, for wave soldering {GLO}| market for |	
16	Ethylene vinyl acetate (EVA)	2,04E-01	8-Extra	112-Ethylvinylacetate, foil {GLO}| market for | C	
17	Polyvinyl butyral (PVB)	5,13E-02	8-Extra	113-Polyvinyl Butyral Granulate (PVB) | polyme	
18	Polyethylene terephthalate (PET)	9,13E-02	1-BlkPlastics	10 -PET	
19	High-density polyethylene (HDPE)	1,31E-02	1-BlkPlastics	2 -HDPE	
20	Polyphenylene sulphide (PPS)	2,33E-02	1-BlkPlastics	5 -PS	
21	Silicone	1,10E-01	8-Extra	114-Silicone product {GLO}| market for | Cut-o	
22	Nitrogen	4,26E+00	8-Extra	115-Nitrogen, liquid {RER}| market for | Cut-off,	
23	Argon	5,16E-03	8-Extra	116-Argon, liquid {GLO}| market for | Cut-off, U	
24	Ammonia	2,52E-02	8-Extra	117-Ammonia, liquid {RER}| market for | Cut-off	
25	Urea	3,12E-04	8-Extra	118-Urea, as N {GLO}| market for | Cut-off, U	
26	Hydrogen peroxide	6,27E-03	8-Extra	119-Hydrogen peroxide, without water, in 50%	
27	Sodium hydroxide	9,07E-03	8-Extra	120-Sodium hydroxide, without water, in 50% s	
28	Hydrochloric acid	2,70E-02	8-Extra	120-Hydrochloric acid, without water, in 30% s	
29	Sulphuric acid	8,99E-03	8-Extra	120-Sulfuric acid {GLO}| market for | Cut-off, U	
30	Hydrogen sulphide	5,19E-02	8-Extra	120-Hydrogen sulfide {GLO}| market for | Cut-c	
31	Butyl acrylate	2,74E-02	8-Extra	120-Butyl acetate {GLO}| market for | Cut-off, U	
32	Diborane	5,46E-05	8-Extra	120-Diborane {GLO}| market for | Cut-off, U	
33					
34	**Panel**				
35	Aluminium alloy	5,97E-01	4-Non-ferro	27 -Al sheet/extrusion	
36	Glass fibre reinforced plastic	1,09E-02	2-TecPlastics	19 -E-glass fibre	
37					
38					
39					
40					

Kerfless old

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS **Assessment of Environmental Impact**

Nr	epitaxial Si panel 1 kWh	Date	Author
	Products		vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**materials**				
2					
3	Photovoltaic cell, ribbon-Si {GLO}| market for |	1,77E-01	8-Extra	102-Photovoltaic cell, ribbon-Si {GLO}| market	
4	1-propanol {GLO}| market for | Cut-off, U	2,17E-03	8-Extra	112-1-propanol {GLO}| market for | Cut-off, U	
5	Acetone, liquid {GLO}| market for | Cut-off, U	3,45E-03	8-Extra	103-Acetone, liquid {GLO}| market for | Cut-off	
6	Aluminium alloy, AlMg3 {GLO}| market for | Cu	7,00E-01	4-Non-ferro	27 - Al sheet/extrusion	
7	Brazing solder, cadmium free {GLO}| market fo	2,33E-03	8-Extra	104-Brazing solder, cadmium free {GLO}| mark	
8	Copper wire	3,00E-02	4-Non-ferro	30 - Cu wire	
9	Ethylvinylacetate, foil {GLO}| market for | Cut-c	2,67E-01	8-Extra	105-Ethylvinylacetate, foil {GLO}| market for | C	
10	Glass fibre reinforced plastic, polyamide, injec	5,00E-02	2-TecPlastics	19 - E-glass fibre	
11	Lubricating oil {GLO}| market for | Cut-off, U	4,28E-04	8-Extra	105-Lubricating oil {GLO}| market for | Cut-off,	
12	Methanol {GLO}| market for | Cut-off, U	5,74E-04	8-Extra	106-Methanol {GLO}| market for | Cut-off, U	
13	Nickel, 99.5% {GLO}| market for | Cut-off, U	4,34E-05	8-Extra	107-Nickel, 99.5% {GLO}| market for | Cut-off,	
14	Polyethylene terephthalate, granulate, amorph	9,93E-02	1-BlkPlastics	10 - PET	
15	Polyvinylfluoride, film {GLO}| market for | Cut-c	2,94E-02	8-Extra	106-Polyvinylfluoride {GLO}| market for | Cut-o	
16	Silicone product {GLO}| market for | Cut-off, U	3,25E-02	8-Extra	107-Silicone product {GLO}| market for | Cut-o	
17	Solar glass, low-iron and tempering	2,68E+00	8-Extra	108-solar glass and tempering - GLO	
18	Tap water {RER}| market group for | Cut-off, U	5,67E+00	8-Extra	109-Tap water {GLO}| market group for | Cut-o	
19	Vinyl acetate {GLO}| market for | Cut-off, U	4,38E-04	8-Extra	108-Vinyl acetate {GLO}| market for | Cut-off, U	
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					

SHJ

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

Document subject to a legal notice (see below)

EcoReport 2014: INPUTS

Assessment of Environmental Impact

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

Nr	SHJ panel 1 kWh	Date	Author
	Products		vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**materials**				
2	**photovoltaic cell**				
3	photovoltaic cell	9,04E-02	8-Extra	102-photovoltaic cell per kg	
4					
5	**interconnection**				
6	Tin	2,67E-03	8-Extra	103-Tin {GLO}| market for | Cut-off, U	
7	Lead	1,50E-04	8-Extra	104-Lead {GLO}| primary lead production from	
8	Copper	2,13E-02	4-Non-ferro	30 -Cu wire	
9					
10	**encapsulation**				
11	Ethylvinylacetate, foil	1,81E-01	8-Extra	105-Ethylvinylacetate, foil {GLO}| market for | C	
12					
13	**backsheet**				
14	Polyvinylfluoride film	2,32E-02	8-Extra	106-Polyvinylfluoride {GLO}| market for | Cut-o	
15	Polyethylene terephthalate	7,15E-02	1-BlkPlastics	10 -PET	
16					
17	**pottant & sealing**				
18	Silicone product	2,52E-02	8-Extra	107-Silicone product {GLO}| market for | Cut-o	
19					
20	**frame**				
21	Aluminium alloy, AlMg3	4,40E-01	4-Non-ferro	27 -Al sheet/extrusion	
22					
23	**glass**				
24	Solar glass, low-iron & Tempering, flat glass	1,82E+00	8-Extra	108-solar glass and tempering - GLO	
25					
26	**junction box**				
27	Diode, unspecified	5,81E-04	6-Electronics	47 -IC's avg., 5% Si, Au	
28	Polyethylene, HDPE	4,92E-03	1-BlkPlastics	2 -HDPE	
29	Glass fibre reinforced plastic, polyamide, injection mouldin	6,10E-02	2-TecPlastics	19 -E-glass fibre	
30					
31	**Auxilaries**				
32	Tap water	1,04E+00	8-Extra	109-Tap water {GLO}| market group for | Cut-o	
33	hydrogen fluoride	1,29E-02	8-Extra	110-Hydrogen fluoride {GLO}| market for | Cut-	
34	potassium hydroxide	1,06E-02	8-Extra	111-Potassium hydroxide {GLO}| market for | Cu	
35	1-propanol	3,29E-03	8-Extra	112-1-propanol {GLO}| market for | Cut-off, U	
36	Isopropanol	3,04E-05	8-Extra	113-Isopropanol {GLO}| market for | Cut-off, U	
37					
38					
39					
40					

BNAT kerfless new

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

Document subject to a legal notice (see below)

EcoReport 2014: INPUTS Assessment of Environmental Impact

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

Nr	PERC BNAT kerfless panel 1 kWh	Date	Author
	Products		vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**materials**				
2	**photovoltaic cell**				
3	photovoltaic cell	6,66E-02	8-Extra	102-photovoltaic cell per kg	
4					
5	**interconnection**				
6	Tin	2,51E-03	8-Extra	103-Tin {GLO}| market for | Cut-off, U	
7	Lead	1,41E-04	8-Extra	104-Lead {GLO}| primary lead production from	
8	Copper	2,00E-02	4-Non-ferro	30 - Cu wire	
9					
10	**encapsulation**				
11	Ethylvinylacetate, foil	1,70E-01	8-Extra	105-Ethylvinylacetate, foil {GLO}| market for | C	
12					
13	**backsheet**				
14	Polyvinylfluoride film	2,18E-02	8-Extra	106-Polyvinylfluoride {GLO}| market for | Cut-o	
15	Polyethylene terephthalate	6,72E-02	1-BlkPlastics	10 - PET	
16					
17	**pottant & sealing**				
18	Silicone product	2,37E-02	8-Extra	107-Silicone product {GLO}| market for | Cut-o	
19					
20	**frame**				
21	Aluminium alloy, AlMg3	4,14E-01	4-Non-ferro	27 - Al sheet/extrusion	
22					
23	**glass**				
24	Solar glass, low-iron & Tempering, flat glass	1,71E+00	8-Extra	108-solar glass and tempering - GLO	
25					
26	**junction box**				
27	Diode, unspecified	5,46E-04	6-Electronics	47 - IC's avg., 5% Si, Au	
28	Polyethylene, HDPE	4,63E-03	1-BlkPlastics	2 - HDPE	
29	Glass fibre reinforced plastic, polyamide, injection moulding	5,73E-02	2-TecPlastics	19 - E-glass fibre	
30					
31	**Auxilaries**				
32	Tap water	9,78E-01	8-Extra	109-Tap water {GLO}| market group for | Cut-o	
33	hydrogen fluoride	1,21E-02	8-Extra	110-Hydrogen fluoride {GLO}| market for | Cut-	
34	potassium hydroxide	9,99E-03	8-Extra	111-Potassium hydroxide {GLO}| market for | Cu	
35	1-propanol	3,09E-03	8-Extra	112-1-propanol {GLO}| market for | Cut-off, U	
36	Isopropanol	2,86E-05	8-Extra	113-Isopropanol {GLO}| market for | Cut-off, U	
37					
38					
39					
40					

Annex B: Bill of Materials in EcoReport format for inverters.

BC1 – reference + efficient + monitoring + MLI

As the Bill of materials are expressed per kWh they differ slightly per design option as the generated kWh are different per design option and a consequence also the number of inverters necessary per kWh. The BOM below is for the reference inverter.

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS Environmental Impact

Assessment of

Nr	1500 W inverter - 3 units	Date	Author
	Products		Vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click&select	Material or Process select Category first !	Recyclable?
1	**individual components**				
2	aluminium, production mix, cast alloy, at plant	1,76E-01	4-Non-ferro	28 -Al diecast	
3	aluminium alloy, AlMg3, at plant	7,82E-03	4-Non-ferro	28 -Al diecast	
4	copper, at regional storage	7,04E-02	4-Non-ferro	31-Cu tube/sheet	
5	steel, low-alloyed, at plant	3,34E-02	3-Ferro	22 -St sheet galv.	
6	polypropylene, granulate, at plant	3,25E-02	1-BlkPlastics	4 -PP	
7	polycarbonate, at plant	7,45E-03	2-TecPlastics	13 -PC	
8	cable, connector for computer, without plugs, at plant	4,83E-03	4-Non-ferro	30 -Cu wire	
9	inductor, ring core choke type, at plant	3,21E-02	8-Extra	111-Inductor, ring core choke type, at plant/GL	
10	integrated circuit, IC, logic type, at plant	2,44E-03	6-Electronics	47 -IC's avg., 5% Si, Au	
11	ferrite, at plant	1,29E-03	3-Ferro	25 -Ferrite	
12	plugs, inlet and outlet, for network cable, at plant	1,10E-03	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
13	glass fibre reinforced plastic, polyamide, injection moulding, at plant	4,83E-03	2-TecPlastics	12 -PA 6	
14	**printed board assembly**				
15	printed wiring board, surface mount, lead-free surface, at plant	1,21E-02	6-Electronics	51-PWB 6 lay 4.5 kg/m2	
16	tin, at regional storage	3,54E-04	8-Extra	109-Tin {GLO}| market for | Cut-off, U	
17	connector, clamp connection, at plant	8,99E-04	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
18	inductor, ring core choke type, at plant	4,83E-03	8-Extra	111-Inductor, ring core choke type, at plant/GL	
19	inductor, miniature RF chip type, MRFI, at plant	4,06E-05	8-Extra	104-Inductor, miniature radio frequency chip {(	
20	integrated circuit, IC, logic type, at plant	5,71E-03	6-Electronics	47 -IC's avg., 5% Si, Au	
21	integrated circuit, IC, memory type, at plant	6,89E-05	6-Electronics	47 -IC's avg., 5% Si, Au	
22	transistor, unspecified, at plant	7,08E-04	6-Electronics	48 -IC's avg., 1% Si	
23	transistor, SMD type, surface mounting, at plant	1,54E-03	6-Electronics	47 -IC's avg., 5% Si, Au	
24	diode, glass-, SMD type, surface mounting, at plant	7,41E-05	6-Electronics	47 -IC's avg., 5% Si, Au	
25	light emitting diode, LED, at plant	5,31E-07	6-Electronics	49 -SMD/ LED's avg.	
26	capacitor, film, through-hole mounting, at plant	6,12E-03	8-Extra	105-Capacitor, film type, for through-hole mou	
27	capacitor, electrolyte type, > 2cm height, at plant	9,47E-03	8-Extra	106-Capacitor, electrolyte type, > 2cm height {	
28	capacitor, electrolyte type, < 2cm height, at plant	2,47E-04	8-Extra	107-Capacitor, electrolyte type, < 2cm height {	
29	capacitor, SMD type, surface-mounting, at plant	4,90E-05	8-Extra	112-Capacitor, SMD type, surface-mounting, a	
30	resistor, wirewound, through-hole mounting, at plant	4,13E-05	8-Extra	108-Resistor, wirewound, through-hole mount	
31	resistor, SMD type, surface mounting, at plant	1,68E-04	8-Extra	110-Resistor, SMD type, surface mounting, at p	
32	ferrite, at plant	9,40E-07	3-Ferro	25 -Ferrite	
33	transformer, low voltage use, at plant	1,48E-03	8-Extra	111-Inductor, ring core choke type {GLO}| mark	
34	plugs, inlet and outlet, for network cable, at plant	1,03E-02	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
35	glass fibre reinforced plastic, polyamide, injection moulding, at plant	9,44E-04	2-TecPlastics	12 -PA 6	
36	cable, ribbon cable, 20-pin, with plugs, at plant	8,85E-06	4-Non-ferro	30 -Cu wire	
37					
38					
39					
40					

BC 1 – longer life

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014		Document subject to a legal notice (see below)
ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS	EcoReport 2014: INPUTS Environmental Impact	Assessment of

Nr	1500 W inverter - 1,156 units Products	Date	Author Vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click&select	Material or Process select Category first !	Recyclable?
1	**individual components**				
2	aluminium, production mix, cast alloy, at plant	6,78E-02	4-Non-ferro	28 -Al diecast	
3	aluminium alloy, AlMg3, at plant	3,01E-03	4-Non-ferro	28 -Al diecast	
4	copper, at regional storage	2,71E-02	4-Non-ferro	31-Cu tube/sheet	
5	steel, low-alloyed, at plant	1,29E-02	3-Ferro	22 -St sheet galv.	
6	polypropylene, granulate, at plant	1,25E-02	1-BlkPlastics	4 -PP	
7	polycarbonate, at plant	2,87E-03	2-TecPlastics	13 -PC	
8	cable, connector for computer, without plugs, at plant	1,86E-03	4-Non-ferro	30 -Cu wire	
9	inductor, ring core choke type, at plant	1,24E-02	8-Extra	111-Inductor, ring core choke type, at plant/GL	
10	integrated circuit, IC, logic type, at plant	9,39E-04	6-Electronics	47 -IC's avg., 5% Si, Au	
11	ferrite, at plant	4,96E-04	3-Ferro	25 -Ferrite	
12	plugs, inlet and outlet, for network cable, at plant	4,25E-04	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
13	glass fibre reinforced plastic, polyamide, injection moulding, at plant	1,86E-03	2-TecPlastics	12 -PA 6	
14	**printed board assembly**				
15	printed wiring board, surface mount, lead-free surface, at plant	4,68E-03	6-Electronics	51-PWB 6 lay 4.5 kg/m2	
16	tin, at regional storage	1,36E-04	8-Extra	109-Tin {GLO}| market for | Cut-off, U	
17	connector, clamp connection, at plant	3,47E-04	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
18	inductor, ring core choke type, at plant	1,86E-03	8-Extra	102-Inductor, ring core choke type {GLO}| mar	
19	inductor, miniature RF chip type, MRFI, at plant	1,56E-05	8-Extra	104-Inductor, miniature radio frequency chip {(	
20	integrated circuit, IC, logic type, at plant	2,20E-03	6-Electronics	47 -IC's avg., 5% Si, Au	
21	integrated circuit, IC, memory type, at plant	2,66E-05	6-Electronics	47 -IC's avg., 5% Si, Au	
22	transistor, unspecified, at plant	2,73E-04	6-Electronics	48 -IC's avg., 1% Si	
23	transistor, SMD type, surface mounting, at plant	5,92E-04	6-Electronics	47 -IC's avg., 5% Si, Au	
24	diode, glass-, SMD type, surface mounting, at plant	2,86E-05	6-Electronics	47 -IC's avg., 5% Si, Au	
25	light emitting diode, LED, at plant	2,05E-07	6-Electronics	49 -SMD/ LED's avg.	
26	capacitor, film, through-hole mounting, at plant	2,36E-03	8-Extra	105-Capacitor, film type, for through-hole mou	
27	capacitor, electrolyte type, > 2cm height, at plant	3,65E-03	8-Extra	106-Capacitor, electrolyte type, > 2cm height {	
28	capacitor, electrolyte type, < 2cm height, at plant	9,53E-05	8-Extra	107-Capacitor, electrolyte type, < 2cm height {	
29	capacitor, SMD type, surface-mounting, at plant	1,89E-05	8-Extra	112-Capacitor, SMD type, surface-mounting, a	
30	resistor, wirewound, through-hole mounting, at plant	1,59E-05	8-Extra	108-Resistor, wirewound, through-hole mount	
31	resistor, SMD type, surface mounting, at plant	6,49E-05	8-Extra	110-Resistor, SMD type, surface mounting, at p	
32	ferrite, at plant	3,62E-07	3-Ferro	25 -Ferrite	
33	transformer, low voltage use, at plant	5,70E-04	8-Extra	111-Inductor, ring core choke type, at plant/GL	
34	plugs, inlet and outlet, for network cable, at plant	3,96E-03	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
35	glass fibre reinforced plastic, polyamide, injection moulding, at plant	3,64E-04	2-TecPlastics	12 -PA 6	
36	cable, ribbon cable, 20-pin, with plugs, at plant	3,41E-06	4-Non-ferro	30 -Cu wire	
37					
38					
39					
40					

BC 1 – increased repair

The table below combines failures into groups (see color coding).

Table 4 on inverter failure from task 4		
Inverter failure area	% of tickets	% of kWh lost
no-fault-found failures = software update	28,00%	15,00%
Card/board	13,00%	22,00%
AC Contactor	12,00%	13,00%
Fan(s)	6,00%	5,00%
Matrix/IGBT	6,00%	6,00%
Power supply	5,00%	5,00%
AC Fuses	4,00%	12,00%
DC Contactor	4,00%	1,00%
Surge Protection	3,00%	1,00%
GFI Components	3,00%	2,00%
Capacitors	3,00%	7,00%
Internal Fuses	3,00%	4,00%
Internal Relay/Swithces	3,00%	2,00%
DC Input Fuses	2,00%	1,00%
Other	5,00%	2,00%

The table below shows the number of tickets per group. A total of 61% of the tickets has been allocated to the different groups. Software failures have no implications on the BOM. Fans are not used anymore in new inverters. Also, the tickets under 'other' could not be allocated to a component of the bill of materials.

Translate task 4 data into input for task 6 report:	% tickets	rescale to 100%
Fuse/contactor	34%	56%
Card/board	13%	21%
Matrix/IGBT	6%	10%
Capacitors	3%	5%
Power supply	5%	8%
Total	61%	100%

In a next step a link has been made between the failure of the different components and the available bill of materials (see table below).

BOM Task 5 report - based on Treeze publication on LCA of inverters		infuence on BOM
individual components	**match with table task 4**	
aluminium, production mix, cast alloy, at plant		1
aluminium alloy, AlMg3, at plant		1
copper, at regional storage		1
steel, low-alloyed, at plant		1
polypropylene, granulate, at plant		1
polycarbonate, at plant		1
cable, connector for computer, without plugs, at plant		1
inductor, ring core choke type, at plant	Fuse/contactor	BOM*(1+(2*0,56))
integrated circuit, IC, logic type, at plant		1
ferrite, at plant		1
plugs, inlet and outlet, for network cable, at plant	Fuse/contactor	BOM*(1+(2*0,56))
glass fibre reinforced plastic, polyamide, injection moulding, at plant		1
printed board assembly		
printed wiring board, surface mount, lead-free surface, at plant	card/board	BOM*(1+(2*0,21))
tin, at regional storage		1
connector, clamp connection, at plant	card/board	BOM*(1+(2*0,21))
inductor, ring core choke type, at plant	card/board	BOM*(1+(2*0,21))
inductor, miniature RF chip type, MRFI, at plant	card/board	BOM*(1+(2*0,21))
integrated circuit, IC, logic type, at plant	card/board	BOM*(1+(2*0,21))
integrated circuit, IC, memory type, at plant	card/board	BOM*(1+(2*0,21))
transistor, unspecified, at plant	Matrix/IGBT	BOM*(1+(2*0,1))
transistor, SMD type, surface mounting, at plant	Matrix/IGBT	BOM*(1+(2*0,1))
diode, glass-, SMD type, surface mounting, at plant	card/board	BOM*(1+(2*0,21))
light emitting diode, LED, at plant	card/board	BOM*(1+(2*0,21))
capacitor, film, through-hole mounting, at plant	card/board	BOM*(1+(2*0,21))
capacitor, electrolyte type, > 2cm height, at plant	capacitors	BOM*(1+(2*0,05))
capacitor, electrolyte type, < 2cm height, at plant	capacitors	BOM*(1+(2*0,05))
capacitor, SMD type, surface-mounting, at plant	card/board	BOM*(1+(2*0,21))
resistor, wirewound, through-hole mounting, at plant	card/board	BOM*(1+(2*0,21))
resistor, SMD type, surface mounting, at plant	card/board	BOM*(1+(2*0,21))
ferrite, at plant	card/board	BOM*(1+(2*0,21))
transformer, low voltage use, at plant	power supply	BOM*(1+(2*0,08))
plugs, inlet and outlet, for network cable, at plant		1
glass fibre reinforced plastic, polyamide, injection moulding, at plant		1
cable, ribbon cable, 20-pin, with plugs, at plant		1

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014				Document subject to a legal notice (see below)
ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS		EcoReport 2014: INPUTS Environmental Impact		Assessment of

Nr	1500 W inverter - 1 unit incl repair	Date	Author
	Products		Vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**individual components**				
2	aluminium, production mix, cast alloy, at plant	5,86E-02	4-Non-ferro	28 - Al diecast	
3	aluminium alloy, AlMg3, at plant	2,61E-03	4-Non-ferro	28 - Al diecast	
4	copper, at regional storage	2,35E-02	4-Non-ferro	31-Cu tube/sheet	
5	steel, low-alloyed, at plant	1,11E-02	3-Ferro	22 - St sheet galv.	
6	polypropylene, granulate, at plant	1,08E-02	1-BlkPlastics	4 - PP	
7	polycarbonate, at plant	2,48E-03	2-TecPlastics	13 - PC	
8	cable, connector for computer, without plugs, at plant	1,61E-03	4-Non-ferro	30 - Cu wire	
9	inductor, ring core choke type, at plant	2,27E-02	8-Extra	111-Inductor, ring core choke type, at plant/GL	
10	integrated circuit, IC, logic type, at plant	8,12E-04	6-Electronics	47 - IC's avg., 5% Si, Au	
11	ferrite, at plant	4,29E-04	3-Ferro	25 - Ferrite	
12	plugs, inlet and outlet, for network cable, at plant	7,80E-04	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
13	glass fibre reinforced plastic, polyamide, injection moulding, at plant	1,61E-03	2-TecPlastics	12 - PA 6	
14	**printed board assembly**				
15	printed wiring board, surface mount, lead-free surface, at plant	5,75E-03	6-Electronics	51-PWB 6 lay 4.5 kg/m2	
16	tin, at regional storage	1,18E-04	8-Extra	109-Tin {GLO}| market for | Cut-off, U	
17	connector, clamp connection, at plant	4,26E-04	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
18	inductor, ring core choke type, at plant	2,29E-03	8-Extra	111-Inductor, ring core choke type, at plant/GL	
19	inductor, miniature RF chip type, MRFI, at plant	1,92E-05	8-Extra	104-Inductor, miniature radio frequency chip {(	
20	integrated circuit, IC, logic type, at plant	2,70E-03	6-Electronics	47 - IC's avg., 5% Si, Au	
21	integrated circuit, IC, memory type, at plant	3,26E-05	6-Electronics	47 - IC's avg., 5% Si, Au	
22	transistor, unspecified, at plant	2,83E-04	6-Electronics	48 - IC's avg., 1% Si	
23	transistor, SMD type, surface mounting, at plant	6,15E-04	6-Electronics	47 - IC's avg., 5% Si, Au	
24	diode, glass-, SMD type, surface mounting, at plant	3,51E-05	6-Electronics	47 - IC's avg., 5% Si, Au	
25	light emitting diode, LED, at plant	2,51E-07	6-Electronics	49 - SMD/ LED's avg.	
26	capacitor, film, through-hole mounting, at plant	2,90E-03	8-Extra	105-Capacitor, film type, for through-hole mou	
27	capacitor, electrolyte type, > 2cm height, at plant	3,47E-03	8-Extra	106-Capacitor, electrolyte type, > 2cm height {	
28	capacitor, electrolyte type, < 2cm height, at plant	9,07E-05	8-Extra	107-Capacitor, electrolyte type, < 2cm height {	
29	capacitor, SMD type, surface-mounting, at plant	2,32E-05	8-Extra	112-Capacitor, SMD type, surface-mounting, a	
30	resistor, wirewound, through-hole mounting, at plant	1,95E-05	8-Extra	108-Resistor, wirewound, through-hole mount	
31	resistor, SMD type, surface mounting, at plant	7,97E-05	8-Extra	112-Capacitor, SMD type, surface-mounting, a	
32	ferrite, at plant	4,45E-07	3-Ferro	25 - Ferrite	
33	transformer, low voltage use, at plant	5,72E-04	8-Extra	111-Inductor, ring core choke type, at plant/GL	
34	plugs, inlet and outlet, for network cable, at plant	3,43E-03	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
35	glass fibre reinforced plastic, polyamide, injection moulding, at plant	3,15E-04	2-TecPlastics	12 - PA 6	
36	cable, ribbon cable, 20-pin, with plugs, at plant	2,95E-06	4-Non-ferro	30 - Cu wire	
37					
38					
39					
40					

BC2 – reference + efficient

As the Bill of materials are expressed per kWh they differ slightly per design option as the generated kWh are different per design option and a consequence also the number of inverters necessary per kWh. The BOM below is for the reference inverter.

Version 3.06 VHK for European Commission 2011,
modified by IZM for european commission 2014

Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS Environmental Impact

Assessment of

Nr	20 kW inverter - 3 units	Date	Author
	Products		Vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**individual components**				
2	aluminium, production mix, cast alloy, at plant	8,08E-02	4-Non-ferro	28 - Al diecast	
3	aluminium alloy, AlMg3, at plant	3,59E-03	4-Non-ferro	28 - Al diecast	
4	copper, at regional storage	3,24E-02	4-Non-ferro	31-Cu tube/sheet	
5	steel, low-alloyed, at plant	1,54E-02	3-Ferro	22 - St sheet galv.	
6	polypropylene, granulate, at plant	1,50E-02	1-BlkPlastics	4 - PP	
7	polycarbonate, at plant	3,43E-03	2-TecPlastics	13 - PC	
8	cable, connector for computer, without plugs, at plant	2,23E-03	4-Non-ferro	30 - Cu wire	
9	inductor, ring core choke type, at plant	1,48E-02	8-Extra	102-Inductor, ring core choke type {GLO}| mar	
10	integrated circuit, IC, logic type, at plant	1,12E-03	6-Electronics	47 - IC's avg., 5% Si, Au	
11	ferrite, at plant	5,94E-04	3-Ferro	25 - Ferrite	
12	plugs, inlet and outlet, for network cable, at plant	5,07E-04	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
13	glass fibre reinforced plastic, polyamide, injection moulding, at plant	2,21E-03	2-TecPlastics	12 - PA 6	
14	**printed board assembly**				
15	printed wiring board, surface mount, lead-free surface, at plant	5,59E-03	6-Electronics	51-PWB 6 lay 4.5 kg/m2	
16	tin, at regional storage	1,62E-04	8-Extra	109-Tin {GLO}| market for | Cut-off, U	
17	connector, clamp connection, at plant	4,12E-04	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
18	inductor, ring core choke type, at plant	2,21E-03	8-Extra	102-Inductor, ring core choke type {GLO}| mar	
19	inductor, miniature RF chip type, MRFI, at plant	1,87E-05	8-Extra	104-Inductor, miniature radio frequency chip {(	
20	integrated circuit, IC, logic type, at plant	2,64E-03	6-Electronics	47 - IC's avg., 5% Si, Au	
21	integrated circuit, IC, memory type, at plant	3,18E-05	6-Electronics	47 - IC's avg., 5% Si, Au	
22	transistor, unspecified, at plant	3,25E-04	6-Electronics	48 - IC's avg., 1% Si	
23	transistor, SMD type, surface mounting, at plant	7,09E-04	6-Electronics	47 - IC's avg., 5% Si, Au	
24	diode, glass-, SMD type, surface mounting, at plant	3,40E-05	6-Electronics	47 - IC's avg., 5% Si, Au	
25	light emitting diode, LED, at plant	2,44E-07	6-Electronics	49 - SMD/ LED's avg.	
26	capacitor, film, through-hole mounting, at plant	2,82E-03	8-Extra	105-Capacitor, film type, for through-hole mou	
27	capacitor, electrolyte type, > 2cm height, at plant	4,37E-03	8-Extra	106-Capacitor, electrolyte type, > 2cm height {	
28	capacitor, electrolyte type, < 2cm height, at plant	1,14E-04	8-Extra	107-Capacitor, electrolyte type, < 2cm height {	
29	capacitor, SMD type, surface-mounting, at plant	2,26E-05	8-Extra	112-Capacitor, SMD type, surface-mounting, a	
30	resistor, wirewound, through-hole mounting, at plant	1,90E-05	8-Extra	108-Resistor, wirewound, through-hole mount	
31	resistor, SMD type, surface mounting, at plant	7,75E-05	8-Extra	110-Resistor, SMD type, surface mounting, at p	
32	ferrite, at plant	4,33E-07	3-Ferro	25 - Ferrite	
33	transformer, low voltage use, at plant	6,80E-04	8-Extra	102-Inductor, ring core choke type {GLO}| mar	
34	plugs, inlet and outlet, for network cable, at plant	4,74E-03	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
35	glass fibre reinforced plastic, polyamide, injection moulding, at plant	4,33E-04	2-TecPlastics	12 - PA 6	
36	cable, ribbon cable, 20-pin, with plugs, at plant	4,07E-06	4-Non-ferro	30 - Cu wire	
37					
38					
39					
40					

BC2 – repair

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS | EcoReport 2014: INPUTS Environmental Impact | Assessment of

Nr	Products	Date	Author
	20 kW inverter - 1 unit incl repair		Vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**individual components**				
2	aluminium, production mix, cast alloy, at plant	2,69E-02	4-Non-ferro	28 - Al diecast	
3	aluminium alloy, AlMg3, at plant	1,19E-03	4-Non-ferro	28 - Al diecast	
4	copper, at regional storage	1,08E-02	4-Non-ferro	31-Cu tube/sheet	
5	steel, low-alloyed, at plant	5,12E-03	3-Ferro	22 - St sheet galv.	
6	polypropylene, granulate, at plant	4,98E-03	1-BlkPlastics	4 - PP	
7	polycarbonate, at plant	1,14E-03	2-TecPlastics	13 - PC	
8	cable, connector for computer, without plugs, at plant	7,42E-04	4-Non-ferro	30 - Cu wire	
9	inductor, ring core choke type, at plant	1,04E-02	8-Extra	102-Inductor, ring core choke type {GLO}| mar	
10	integrated circuit, IC, logic type, at plant	3,74E-04	6-Electronics	47 - IC's avg., 5% Si, Au	
11	ferrite, at plant	1,98E-04	3-Ferro	25 - Ferrite	
12	plugs, inlet and outlet, for network cable, at plant	3,58E-04	1-BlkPlastics	8 - PVC	
13	glass fibre reinforced plastic, polyamide, injection moulding, at plant	7,37E-04	2-TecPlastics	12 - PA 6	
14	**printed board assembly**				
15	printed wiring board, surface mount, lead-free surface, at plant	2,64E-03	6-Electronics	51-PWB 6 lay 4.5 kg/m2	
16	tin, at regional storage	5,41E-05	8-Extra	109-Tin {GLO}| market for | Cut-off, U	
17	connector, clamp connection, at plant	1,95E-04	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
18	inductor, ring core choke type, at plant	1,05E-03	8-Extra	102-Inductor, ring core choke type {GLO}| mar	
19	inductor, miniature RF chip type, MRFI, at plant	8,83E-06	8-Extra	104-Inductor, miniature radio frequency chip {(	
20	integrated circuit, IC, logic type, at plant	1,25E-03	6-Electronics	47 - IC's avg., 5% Si, Au	
21	integrated circuit, IC, memory type, at plant	1,50E-05	6-Electronics	47 - IC's avg., 5% Si, Au	
22	transistor, unspecified, at plant	1,30E-04	6-Electronics	48 - IC's avg., 1% Si	
23	transistor, SMD type, surface mounting, at plant	2,83E-04	6-Electronics	47 - IC's avg., 5% Si, Au	
24	diode, glass-, SMD type, surface mounting, at plant	1,61E-05	6-Electronics	47 - IC's avg., 5% Si, Au	
25	light emitting diode, LED, at plant	1,15E-07	6-Electronics	49 - SMD/ LED's avg.	
26	capacitor, film, through-hole mounting, at plant	1,33E-03	8-Extra	105-Capacitor, film type, for through-hole mou	
27	capacitor, electrolyte type, > 2cm height, at plant	1,60E-03	8-Extra	106-Capacitor, electrolyte type, > 2cm height {	
28	capacitor, electrolyte type, < 2cm height, at plant	4,17E-05	8-Extra	107-Capacitor, electrolyte type, < 2cm height {	
29	capacitor, SMD type, surface-mounting, at plant	1,07E-05	8-Extra	112-Capacitor, SMD type, surface-mounting, a	
30	resistor, wirewound, through-hole mounting, at plant	8,97E-06	8-Extra	108-Resistor, wirewound, through-hole mount	
31	resistor, SMD type, surface mounting, at plant	3,67E-05	8-Extra	110-Resistor, SMD type, surface mounting, at p	
32	ferrite, at plant	2,05E-07	3-Ferro	25 - Ferrite	
33	transformer, low voltage use, at plant	2,63E-04	8-Extra	102-Inductor, ring core choke type {GLO}| mar	
34	plugs, inlet and outlet, for network cable, at plant	1,58E-03	8-Extra	103-Plugs, inlet and outlet, for network cable, a	
35	glass fibre reinforced plastic, polyamide, injection moulding, at plant	1,44E-04	2-TecPlastics	12 - PA 6	
36	cable, ribbon cable, 20-pin, with plugs, at plant	1,35E-06	4-Non-ferro	30 - Cu wire	
37					
38					
39					
40					

BC3 – reference + efficient + efficient string

As the Bill of materials are expressed per kWh they differ slightly per design option as the generated kWh are different per design option and a consequence also the number of inverters necessary per kWh. The BOM below is for the reference inverter.

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014				Document subject to a legal notice (see below)
ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS		EcoReport 2014: INPUTS Environmental Impact		Assessment of
Nr	1500 kW inverter - 1 unit incl repair Products	Date	Author Vito	

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**individual components**				
2	Alkyd paint, white, without solvent, in 60% solution state	1,18E-03	8-Extra	103-Alkyd paint, white, without solvent, in 60%	
3	Aluminium, cast alloy	7,03E-03	4-Non-ferro	28 -Al diecast	
4	Capacitor, electrolyte type, > 2cm height	4,12E-05	8-Extra	109-Capacitor, electrolyte type, > 2cm height {	
5	Capacitor, film type, for through-hole mounting	5,49E-05	8-Extra	108-Capacitor, film type, for through-hole mou	
6	Capacitor, tantalum-, for through-hole mounting	3,70E-06	8-Extra	104-Capacitor, tantalum-, for through-hole mo	
7	Copper	1,80E-02	4-Non-ferro	31-Cu tube/sheet	
8	Diode, glass-, for through-hole mounting	7,57E-06	6-Electronics	49 -SMD/ LED's avg.	
9	Electric connector, wire clamp	7,64E-03	8-Extra	106-Plugs, inlet and outlet, for network cable, a	
10	Fleece, polyethylene	1,61E-05	1-BlkPlastics	2 -HDPE	
11	Glass fibre reinforced plastic, polyamide, injection moulded	3,81E-03	2-TecPlastics	12 -PA 6	
12	Glass fibre reinforced plastic, polyester resin, hand lay-up	2,36E-03	1-BlkPlastics	10 -PET	
13	Inductor, ring core choke type	5,65E-05	8-Extra	114-Inductor, ring core choke type {GLO}| mark	
14	Integrated circuit, logic type	4,51E-06	6-Electronics	47 -IC's avg., 5% Si, Au	
15	Lubricating oil	4,73E-02	8-Extra	102-Lubricating oil {GLO}| market for | Cut-off,	
16	Polyethylene, high density, granulate	1,18E-03	1-BlkPlastics	2 -HDPE	
17	Polystyrene foam slab	8,59E-05	1-BlkPlastics	5 -PS	
18	Printed wiring board, for through-hole mounting, Pb containing surface	5,90E-05	6-Electronics	51-PWB 6 lay 4.5 kg/m2	
19	Printed wiring board, for through-hole mounting, Pb free surface	0,00E+00	6-Electronics	51-PWB 6 lay 4.5 kg/m2	
20	Resistor, metal film type, through-hole mounting	8,05E-07	8-Extra	111-Resistor, wirewound, through-hole mountin	
21	Steel, low-alloyed, hot rolled	7,72E-02	3-Ferro	22 -St sheet galv.	
22	Transistor, wired, small size, through-hole mounting	6,12E-06	6-Electronics	48 -IC's avg., 1% Si	
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					