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Preparatory study for solar photovoltaic modules, inverters and systems

(Draft) Task 7 Report: Policy scenario analysis

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7. Task 7: Policy scenario analysis

This task looks at suitable policy means to achieve the identified potential improvement. This could include implementing LLCC as a minimum requirement, the environmental performance of BAT or BNAT as a benchmark, using dynamic aspects, legislative or voluntary agreements, standards, labelling or incentives, relating to public procurement or direct and indirect fiscal instruments.

Under this task scenarios will be drawn up quantifying the improvements that can be achieved versus a Business-as-Usual scenario and comparing the outcomes with EU environmental targets, the societal costs if the environmental impact reduction would have to be achieved in another way, etc. The impact on users (purchasing power, societal costs) and industry (employment, profitability, competitiveness, investment level, etc.), will be estimated explicitly describing and taking into account the typical design cycle (platform change) in a product sector.

In addition, an analysis will be made of which significant impacts may have to be measured under possible implementing measures, and what measurement methods would need to be developed or adapted.

This Task should be read in conjunction with the draft JRC Technical Report '*Transitional methods for PV modules, inverters and systems in an Ecodesign Framework*'.

7.1. Policy analysis

In this section the policy options to be modelled are identified and analysed considering the outcomes from the previous six tasks. This includes consideration of:

- Stakeholder's positions
- Market and legislative barriers
- The pros and cons of different policy measures
- Existing standards and measurement requirements
- Self-regulation and sectoral benchmarking
- Installation and user information requirements

The options to arise are then further analysed and modelled in the subsequent sections.

7.1.1. Stakeholder positions

A number of distinct stakeholder positions have emerged along the Preparatory Study, both during the two meetings held to date and in subsequent written consultation round. These positions are briefly identified and summarised in this section before being taken into consideration in the identification of policy options:

- Impact on achievement of EU climate and renewable energy targets: solar PV is expected to make a substantial contribution to achieving the EU 2030 targets, implying an expansion of the market after several years of decline following the financial crisis and with the scaling back of major subsidy regimes. At the same time concern has been raised that any intervention in the market could prejudice the deployment of solar PV technology. In particular it is considered that:
  - The major benefit of solar photovoltaic technology is the electricity it generates in the use phase and the associated reduction in environmental impacts from displacement of 'brown' electricity.
  - Even solar PV systems that are not optimised – for example, by focussing on the Performance Ratio as a metric and minimising derate factors – will have a role to play in meeting medium to long range targets.

  - Policy measures should aim at achieving growth ‘above business as usual’ and they should not be too complex for SMEs.

- Importance of product quality and durability: The proposal in 2015/16 for an EU Ecolabel for modules was based on the premise that the quality of some products being placed on the EU market were of a lower quality and that ongoing work in the sector to establish standards and test routines could form the basis for criteria. Moreover, from a life cycle perspective performance degradation and lifetime are considered the use phase parameters that have biggest influence on the life cycle environmental impacts of solar PV.
- Address Critical Raw Materials (CRM) and hazardous substances: These two aspects have been highlighted by EU Ecolabel consortium members as an additional area of focus for the differentiation of module performance. The presence of hazardous substances restricted by the RoHS Directive are of specific interest as, although modules have an overall exclusion from its requirements, some manufacturers make product claims of compliance or for the absence of certain substances. The presence of certain CRMs and hazardous substances in PV module technologies such as CdTe and CIGS should be carefully considered as growth in their production could have trade-offs and/or present supply risks that would constrain their future contribution to increasing solar PV capacity.
- Transfer of best practices to the residential market segment: Whilst the design and operation of large scale PV systems and commercial PV systems is understood in most cases to be optimised to ensure they are bankable and to minimise risks, this is not necessarily the case in the residential market segments. There is understood to be significant scope to promote the transfer of best practices from the large scale and commercial market segments.
- NSF 457 leadership standard and the PEFCR as the basis for the EU Ecolabel: These two initiatives are understood to have received a high level of engagement by manufacturers. The former is to be adopted by the US Green Electronics Council as a reference standard for the EPEAT label and it is anticipated that criteria for inverters will be added in 2020. Their suitability as the basis for EU Ecolabel criteria, as evaluated in a separate supporting feasibility report, have limitations because the NSF standard largely consists of process-based criteria whereas the EU Ecolabel has to be based on pass/fail performance based criteria. Following on from the Footprint method pilot it is unclear at present what the next step may be in terms of Product Category Rules for photovoltaic modules.
- Opportunity to stimulate EU industry: Any intervention in the market should be used to stimulate the capacity of EU manufacturing to deliver high quality modules and inverters with a lower environmental impact. This arises from wider discussions within the sector about the potential for a renaissance in EU manufacturing, with a focus on knowledge intensive R&D and manufacturing processes, in part as a response to concerns about the quality of some low cost imports.
- The EU Taxonomy on sustainable activities: A regulation on the establishment of a framework to facilitate sustainable investment. is currently undergoing Impact Assessment [1] and accompanying technical screening criteria for economic activities, including renewable electricity generation, are currently under development and are currently proposed as including a requirement to disclose to investors the life cycle CO_2 emissions of solar PV systems. This initiative will have lasting implications for access to and the cost of capital for green investments, as well as due diligence requirements.

[1] Commission legislative proposals on sustainable finance, 24th May 2018, https://ec.europa.eu/info/publications/180524-proposal-sustainable-finance_en#investment

7.1.2. Market and legislative barriers and opportunities for measures

7.1.2.1. Macro trends on the global market

According to the insight from the trends given in Task 2, the main EU and global trends are identified and categorised as relating to:

- the structure of global module production and supply will be subject tofurther rationalisation: the larger manufacturers could push lower cost-quality products from the market, reducing the potential impact of mandatory cut-off measures.
- the type of the financial incentives and market arrangements that will be used by Member States to support further market growth: the phase out of subsidies is leading to a greater importance for the auction of capacity at the larger end of the markets.
- the relationship of utilities with their consumers and their extent of their role in providing solar PV systems: a range of business models could emerge ranging from third party ownership to off-site PV generation projects.
- the extent to which self-consumption models will shape system designs in the future: a number of models including battery storage, AC modules, collective self-consumption could be important in the residential and commercial market segments.
- a diversification in the range of digital and operational support services available to system owners: this could bring a range of benefits including the smart operation of systems and their components, the enabling of better or more responsive O&M as well as greater self-consumption by households and businesses.

The seven main trends identified from four authoritative market analysis reports, together with a qualitative assessment of their time horizon and uncertainty, are summarised in Table 7-1 below.

Table 7-1. Overview of meta trends in the Global photovoltaic market

Market trend	**Time horizon**	**Degree of uncertainty**
Continued overcapacity in global module production	Short term	Medium
Digitalisation of PV systems and components	Short term	Low
Phasing out of financial support schemes	Medium term	Low
Increased use of solar auctions to drive down prices	Medium term	Low
An increase in Corporate Power Purchase Agreements for solar energy	Medium term	Low
An increased focus on operation & maintenance services	Medium term	Medium
An increase in the number of utilities that provide solar PV services	Medium term	High
An increase in self-consumption by system owners	Medium term	Medium to high

Sources: developed from IEA PVPS (2017), GTM (2018), PV Market Alliance (2018)

7.1.2.2. Opportunities and barriers in the EU grid connected market

Following those trends an analysis of the market opportunities and legislative barriers that measures on Ecodesign and or Energy label would have on photovoltaics sector is presented below:

<u>High upfront-cost for PV systems, access to and the cost of capital</u>

One of the main barriers of the PV systems is often the high upfront cost relative to the long-term revenue combined with the cost for capital to invest in a PV project. It can also explain why investors sometimes prefer low price and low life time products over high price high quality products or ultimately they do not want to invest in PV but prefer more rewarding other options.

Implication: Interventions would need to ensure that cost structure reductions are not reversed or that the impacts remain on niche products. Quality factors may play a role as well in insuring/reducing cost of capital.

Uncertainties in support policies

The PV development has been powered up to now by the deployment of support policies, aiming at reducing the gap between PV's cost of electricity and the price of conventional electricity sources over the last ten years. In many countries the debate on the financing of support schemes is ongoing creating uncertainty for investors.

Commercial and large-scale segments tend to auctions, while the residential sector sees a weaker growth relying on grid parity.

Implication, Weak support could affect effectiveness of measures, diminished demand for higher performance products. There could be opportunities for novel market interventions e.g. reverse auctions

Uncertainties in future energy prices

Apart from the support schemes part of the return on investment will come from the value of the solar produced electricity per KWh. When looking to the market value of electricity it is important to discriminate the wholesale market price from the retail price. Retail prices can be significantly much higher compared to wholesale market price therefore they can provide an important driver for investing in PV systems and in particular for self-consumption.

Implication: Smart technology could facilitate yield maximisation and increased self-consumption to obtain retail prices. However, because the PV investments are long term investments and design tools/data have variable uncertainty.

Market access and metering schemes for small producers

The way countries deal with the grid access and monitoring of energy locally generated from PV panels is not the same.

Implication: the lack of access arrangements could affect effectiveness of measures, and diminish the demand for higher performance products.

Lack of knowledge or skilled subcontractors

The deployment, repair and maintenance of PV systems requires skilled technicians which should demonstrate some form of certification attesting their qualification. Across Europe these schemes may vary or might even be inexistent in some countries, even though training for PV installers might exist (PVTRIN, 2013). Still, different eligibility requirements and qualifications may exist for the training courses.

Implication: this could affect the potential for performance improvement of design options that rely on overall system design optimisation, particularly in the residential sector.

Repair frameworks may not be supported particularly in residential segment

The complexity or lack of clear consumer distribution channels limits the potential for an on-going relationship between the installer and the customer in order to maintain the performance of the system along its lifetime.

Implication: for system or package label implementation could be affected, also for voluntary instruments.

Opportunities to increase self-consumption

Onto the opportunities that can be created, next to the existing solutions, measures in photovoltaics can create opportunities for batteries and Demand Response Management (DRM). Mainly, in the residential sector, there is a mismatch between PV production and the typical demand which opens up the way to energy storage. There are also emerging arrangements that can facilitate communities of local self-consumption.

Implication: self-consumption could be moreover facilitated by smart requirements and guidelines for auctions/fund establishment (GPP).

Opportunities for public authorities to support residential installations

One approach to elimination of barriers to residential deployment is the concept of a 'reverse auction'. This concept is currently being demonstrated by the 'Solar Together London' initiative of the Mayor of London in the UK. It consists of a two-part group buying process that is managed by the public authority – it starts with the registration of households interested in installing a system on their home then followed by a supplier shortlisting and tender process to select an installation company that can service the registered households.

Implication: exploiting the potential economies of scale, the auction process has as a principle objective a reduction in the unit price of each system. A price reduction of 35% on market rates has been claimed for the first auction round based on installations for approximately 4,000 households.

Opportunities to use auctions to drive quality systems and components

The Chinese "top runner program" referred to in Task 1 is an auction based tender program for projects using high efficiency modules and advanced technologies The programme has directed project developers to adopt the latest technology, increasing module efficiency (e.g. minimum requirements for multi Si modules ≥17% or for mono Si modules ≥17.8%) and reducing LCOE. By the end of 2016 and largely as a result of the programme, the average cell efficiency of mono Si produced in Mainland China had increased to 20.5%.

The French auction process has also been notable for containing award criteria that reward modules with a higher quality and lower estimated production stage CO_2 emissions. The most recent calls for tender include a specific award threshold expressed in kg eq CO_2/kWp.

Implication: for larger systems there is evidence that the incorporation of requirements to tender specifications can be used to drive improvement in quality and performance, whilst at the same time reducing the LCOE.

7.1.3. Identification of policy options

In this section the policy options to be modelled are selected and defined based on a combination of the policy instruments to be considered by the Preparatory Study and the possible requirements that could be set on modules, inverters and/or systems.

7.1.3.1. The potential for self-regulation

The Ecodesign Directive 2009/125/EC states that priority should be given to alternative courses of action such as self-regulation via the establishment of voluntary agreements before contemplating regulatory interventions and in cases:

> *'…where such action is likely to deliver the policy objectives faster or in a less costly manner than mandatory requirements.'*

The solar photovoltaic industry is well represented by trade organisations such Solar Power Europe. These organisations benefit from the active engagement of leading module and inverter manufacturers.

At the time of drafting this Task report (June 2018), no proposals of voluntary agreements have been tabled by any (industrial) stakeholder. However, in order to inform discussions the current activity of private initiatives in support of the introduction of performance standards that could form the basis for self-regulation is briefly summarised below:

Module performance:

- Existing private schemes or initiatives for addressing quality and /reliability
  - The PV QAT International Photovoltaic Quality Assurance Task Force (PVQAT) initiative serves as a frame platform for the development of new quality and reliability standards.
  - The DNV reliability module reliability scorecard is based on a series of durability tests applied to the products of leading manufacturers,
  - The Photon module and inverter performance test programme provides data on the energy yield, product defects and degradation effects for modules. An efficiency metric is also tested for inverters. It is not understood to be supported by all parts of the industry due to concerns because of economic motivations.
- Labelling of front runners:
  - The NSF/ANSI 457 standard offers a potential starting point for a first multi-criteria set for modules. The Green Electronics Council (GEC) and TUV are currently developing criteria for inverters.
  - The Ecolabel consortium – a combination of French and German test institutes, together with manufacturer interest led in 2015/16 a consortium to propose modules as an EU Ecolabel product group.
- Development of EPD category rules
  - The Product Environmental Footprint (PEF) pilot has now concluded and there is the option to take forward the Product Category Rules that have been developed.

System performance:

A number of project standards and certifications have been developed, primarily driven by the needs of investors for due diligence and to ensure the 'bankability' of proposals:

- DNV system 'Project certification of photovoltaic power plants' – this certification includes system and component quality and performance requirements
- VDE 'Quality Tested mark for Photovoltaic Power Plants' - this certification is designed to provide information to investors.

In addition the accompanying standards review carried out by the JRC has identified that an IECRE conformity assessment scheme for PV systems is currently under development.

Whilst less activity has been possible to identify for inverters, the PV QAT International Photovoltaic Quality Assurance Task Force (PVQAT) initiative is also active in the development of new standards for inverters and it is to be noted that there are a small number of large EU manufacturers who have captured a significant share of the market, estimated in Task 2 to account for more than 50% of EU shipments in 2016. This could potentially facilitate self-regulatory measures, whereas in the case of modules the lead manufacturers are located in third countries outside the EU and Task 2 highlighted that the EU is no longer the most significant market for these manufacturers.

7.1.3.2. The role of the four EU policy instruments

The focus of the Preparatory study is on the feasibility of employing four individual policy instruments, either individually or in combination. Each instrument has distinct characteristics and requirements that must be taken into consideration when deciding whether an intervention in the market is required. They are each briefly summarised in Table 7-2.

As was identified in section 7.1.2 there could also be the potential to explore other policy instruments that have been successfully applied in other countries to drive improvements in module and system quality and performance – for example, the inclusion of technical requirements in the auction tender specifications in China and France.

Table 7-2. Product policy instruments.

Policy Instrument	Stringency	Scope	Life cycle stage	Verification
Ecodesign	Mandatory	Products, packages of products	Requirements can be set on tested use stage product performance, although material efficiency requirements relating to other life cycle stages have been implemented as both requirements and information requirements. Annex V of the Directive also allows for a management system for design through manufacturing to be used for conformity assessment.	Market surveillance is carried out at member state level.
Energy label	Mandatory	Products, packages of products	The chosen Energy Efficiency Index (EEI) shall address performance in the use stage. It is not clear if the EEI can be applied to other life cycle stages.	Market surveillance is carried out at member state level.
EU Ecolabel	Voluntary	Can be products or services	Criteria can be set on any life cycle stage and can include manufacturing sites as well as tested product performance.	Member State Competent Bodies verify compliance evidence and award the label.
Green Public Procurement (GPP)	Voluntary	Can be products or services	Criteria can be set on any life cycle stage and can include manufacturing sites as well as tested product performance. The criteria must always link to the subject matter.	Verification is through evidence from tenderers provided during the procurement process.

7.1.3.3. Policy option specification

In this section the detailed proposals for the policy options are specified based on the results of the analysis from Task 6. Unless specified each policy option is modelled in isolation in order to estimate the environmental benefits and societal costs and benefits. For some options there are multiple variants so that the results for different areas of improvement or performance metrics can be compared and contrasted.

Policy option 1: Business as usual (BAU)

The assumptions forming the basis for the Business As Usual (BAU) stock model are summarised in this section. The main references for the model are the sources of market intelligence that were compiled in the Task 2 report. These include data sourced from the Becquerel Institute, the IEA PVPS programme, PV Market Alliance, Solar Power Europe, GTM and VDMA. The European Reference Scenario for 2016 and subsequent modelling variants has also been used as the main basis for the medium to long term projections[2].

[2] European Reference Scenario 2016, https://ec.europa.eu/energy/en/data-analysis/energy-modelling/eu-reference-scenario-2016

Module stock model BAU assumptions

The module stock for the EU has been estimated for the reference year 2016. The reference module capacity per technology and segment is shown in Table 7-3. The values have been taken from the ITRPV Roadmap[3], which tracks the module rated power for different cell technologies. For CdTe the power is modelled on the products of the market leader at the time, Series 4 from First Solar. CIGS module power is modelled on the manufacturers that at the time had the largest market shares. High efficiency modules' power is modelled on the products of Panasonic (Heterojunction technology) and Sunpower (IBC back contact technology). The following generalised trends also inform the stock estimate:

- Multi-crystalline is less expensive than mono-crystalline on a Wp basis but on an LCOE basis within a system the latter can deliver a better performance by increasing output and reducing BoS costs.
- Until 2015 multi crystalline was dominant at utility-scale but since then prices for mono-crystalline have declined and production has expanded.
- High-efficiency mono-crystalline has been used in all segments even if the residential segment has seen a higher penetration of that technology. But their share is difficult to measure over time.
- Cadmium Telluride has been used almost exclusively for utility-scale applications. Their use in other segments was extremely small.
- Copper Indium Gallium Selenide CI(G)S has been used in all segments, even if there is limited data to translate their application into a segmentation. An indicative share between segments is assumed.
- The share of amorphous silicon technology for residential applications has been very low due to space constraints.
- High efficiency technologies are defined as those achieving efficiencies indicatively greater than 22% with present technology, which may include modules based on heterojunction, back contact and bifacial cell structures. BNAT variations and combinations of these cell technologies are not reflected in the modelling.

Then the number of installed units in EU can be calculated from the technology shares per market segment that were provided in Task 2 (shown in Table 7-4)

Table 7-3. Reference size in Wp of modules installed per segment and technology in 2016.

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

[3] VDMA (2019) *International Technology Roadmap for Photovoltaic (ITRPV) – 10TH Edition* , http://www.itrpv.net/Reports/Downloads/

Table 7-4. Number of installed units (thousands) of modules per technology and segment estimated from the reference size and the stock of modules for the reference year 2016

	Multi-Si	Mono-Si	CdTe	CIGS	HighEff	Total
Residential	2,898	1,580	-	256	283	5,018
Commercial	4,255	2,455	-	434	361	7,505
Utility-scale	3,861	2,047	1,159	-	262	7,329
Total	11,014	6,082	1,159	690	906	19,852

Quality and technical lifetime

The technical lifetime for the module component of a system is expected to differ more and more from the economic lifetime. PV modules conceived decades ago showed that, apart from the degradation of performance due to aging semiconductors, they could often last much more than 30 years. Since then the onset of mass production has raised concerns about manufactured quality and the lifespan of newer designs and bills of materials.

Once the current quality issues that are addressed in several studies (IEA PVPS task 13 for instance) and which are currently the subject of intense interest within the industry are solved, PV modules should be capable of providing electricity for more than 20 years. However, the economic lifetime depends on business choices and it is considered that 25-30 years will become a corresponding intended service lifetime for most PV modules.

Evolution of the module stock through to 2030

The following assumptions have been developed as the starting point for the modelling. The VDMA roadmap has been used as a starting point and then been cross-referenced with a range of other sources as referred to in the Task 2 report. It has not been considered possible to make predictions beyond 2030 for the technology because of a lack of foresight as to how it may develop.

Modelled design options and BAT

- The global market share for PV modules is dominated by crystalline silicon wafer-based cell types for the reference year 2016 accounting for 94% of modules placed on the market with the starting assumption that this percentage remains constant until 2030.
- In terms of the market split between multi and mono crystalline wafer-based technology, this is estimated to shift from multisilicon dominating with a 65% share in 2016 and falling to below 10% by 2030. Only multi-silicon p-type PERC/PERL cells are predicted to remain by 2030 (see also the section below on BNAT).
- The PERx family of silicon wafer-based cell structures [4] has quickly entered the market, starting in 2016 with approximately 20% market share and being projected to account for a market share of greater than 70% by 2030. This is based on an average of 3.5% percentage point growth in market share each year. It is important to note that the bifacial market share should be deducted from the PERx market share as all bifacial products are based on PERx technology.
- Bifacial PERC cell types are projected to grow steadily, reaching approximately 20% market share by 2021, driven largely by large rooftop and utility scale system installations. They could reach 50-60% market share by 2030. This is based on 3.5% percentage point growth in market share each year.
- Heterojunction (HIT/HJT) cells are expected to gain a market share from 2% in 2016 to 10% in 2025 and 15% by 2030.

[4] This includes PERC, PERL and PERT silicon wafer-based cell structures

- The share for back contact cells is not expected to gain significant market share: rising from 3% in 2016 to approximately 10% in 2030.
- The initial market shares for the predominant thin film technologies – namely CdTe and CIGS – were 3.1% and 1.3% in 2016. CdTe is anticipated to make gains from silicon wafer-based technologies in the large-scale PV system market segment and CIGS in residential and commercial market segments. These market gains have not been possible to estimate and it is also possible that the supply risk associated with tellurium, indium and gallium may have a future influence on pricing and growth.

BNAT candidates

Based on the technology analysis made in Task 4, four 'lead' BNAT candidates can be identified and are presented here in notional descending order of proximity to market:

- TOPCon passivated contact cells: This technology is based on the application of an additional thin oxide passivation layer across the whole front of a silicon wafer. The technology is estimated to increase efficiencies by up to 23%. The first mass market application of this technology is projected to be n-type PERT multi crystalline cells, with over 1.5 GWp of production capacity anticipated to convert [5]. In China application to p-type crystalline cells, albeit more challenging, have already formed part of solutions entered into the Top Runner auction programme [6].
- Silicon wafer material and energy efficiency: The production of silicon wafers by alternative processes that are more efficient in their use of energy and silicon, such as epitaxial growth, are currently identified as BNAT, although in reality this will represent an optimisation of BAT designs that previously entered the market in the period 1999 – 2014 [7]. This type of wafer could potentially be introduced into multi-silicon module production lines, which in 2016 accounted for around 65% of the crystalline portion of the market, which at the present time is expanded from BSF cells to also now includes some PERx cell variants (PERC/PERL on p-type material). However, this portion is projected to decline to around 10% by 2030, when only multicrystaline PERC/PERL cells may remain, so the scope to bring process efficiency gains into the market may be constrained unless the associated modules are more competitively priced.
- Tandem perovskite cells: Perovskite technology is anticipated to first enter the market at a commercial scale in the form of tandem layered cells. The application of perovskite layers to monocrystalline wafers is currently being planned at commercial scale for 2020/21 by at least one company worldwide. The claimed benefit would be an increase in the overall efficiency of each cell from 20-22% to up to 30%. There is however a question mark over the potential lifetime of the perovskite layer, given the continuing challenges faced in seeking to achieve acceptable levels of stability. Pilot production modules incorporating tandem cells have already been certified to have passed IEC 61215 design approval.
- Back contact silicon heterojunction cells: The integration of the two technologies with some of the highest recorded commercial efficiencies and yields has been the subject of research under the Horizon 2020 programme [8]. The aim has been to achieve 26% cell efficiencies and 22% module efficiencies.

A further option has been identified that has passed the prototyping stage and has entered small-scale production so can be considered intermediate to BNAT and BAT:

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[5] PV Magazine, *TOPCon: The next big thing after PERC*, October 8th 2018, https://www.pv-magazine.com/2018/10/08/topcon-the-next-big-thing-after-perc/

[6] PV Magazine, *TOPCon boosts demand for EU equipment*, 15th December 2018, https://www.pv-magazine.com/2018/12/15/the-weekend-read-topcon-boosts-demand-for-eu-equipment/

[7] Manufacturers includes RWE-Schott, Astropower and Evergreen

[8] NextBase project: *The next generation baseline for solar modules*, https://nextbase-project.eu/

- Crystalline module redesign for recycling: Currently the majority of module designs present various difficulties at the moment of seeking to dismantle them to recovery materials for recycling. Once the junction box and aluminium frame (if present) have been removed the main difficulty is to separate the encapsulated components as well as the soldered connections and tabbing of the cells. This requires destructive thermal and mechanical processes to be used, which result in low grade, cross contaminated material recovery. Alternative module designs have been developed to pre-commercial stage that have eliminated the polymer encapsulants and laminates as well as the metal soldering that hinder dismantling [9]. Pilot production modules have already been certified to have passed IEC 61215 design approval.

Inverter stock model BAU assumptions

The inverter stock for the EU has been estimated for the reference year 2016. The reference inverter capacity per technology and segment is shown in Table 7-5. The values have been taken from the market research by GTM and Becquerel Institute, which tracks the inverter capacities for different technologies.

Then the number of installed units in the EU can be calculated from the technology shares per market segment that were provided in Task 2 (shown in Table 7-6.)

Table 7-5. Reference size of inverters installed per segment and technology.

	Micro	**String 1 phase**	**String 3 phase**	**Central**
Rated power residential (W)	250	3000	1000.00	n/a
Rated power commercial (kW)	n/a	n/a	25.00	n/a
Rated power utility (kW)	n/a	n/a	n/a	1,500

Table 7-6. Number of installed units (thousands) of modules per technology and segment estimated for the reference year 2016

	Micro	**String 1 phase**	**String 3 phase**	**Central**
Residential	345,713	365,060	687,517	n/a
Commercial	n/a	n/a	83,338	n/a
Utility- scale	n/a	n/a	n/a	1,056

Evolution of the inverter stock through to 2022

The following assumptions have been developed as the starting point for the modelling. The starting point is the market data and commentary provided by GTM. This has then been cross-referenced with a range of other sources which were referenced in Task 2. With the exception of micro-inverters, it has not been considered possible to make predictions beyond 2022 for the technology because of a lack of foresight as to how the market may develop.

Modelled design options and BAT

- In 2016 the split between single and three-phase in the residential segment was 35:65. All commercial installations are assumed to have used three phase inverters.

[9] Einhaus et al, *Recycling and reuse potential of NICE PV-modules* (2016)

- The string 1 phase share is estimated to reduce from 16% to 13% by 2022.
- The string 3 phase share is estimated to maintain a market share of 60% until 2022.
- In the last years, the cost decrease and capacity increase of string inverters (now up to 125 kW) has allowed to them to now be used in utility-scale plants instead of central inverters. No data could be found to estimate the substitution of central inverters/solutions.
- Most utility-scale PV plants are using central inverters which in 2016 accounted for 23% of the market, with a small increase to 26% by 2022 estimated.
- Micro-inverters attached to the module itself are less common but have experienced some market development in the last years. These are almost exclusively used in the residential market. In 2016 they accounted for around 1.3% and this is estimated to grow to 1.6% by 2022. Their share could grow to 10% by 2030.

BAU assumptions of the system stock model

At the system level, and in agreement with the previous sections for the estimation of modules and inverter sales, the system sales have been estimated and equated to the added system capacity (see Table 7-7.).

Table 7-7. Number of installed units of systems per segment estimated for the reference year 2016

	Residential	**Commercial**	**Utility**
Average capacity (kW)	3	24.4	1875
Total capacity (MW)	1339	2541	2334
Units	446480	104130	1245

Additional assumptions that underpin the model are detailed here:

- Residential PV systems won't be decommissioned unless the roof requires replacing. While loss of performance will happen through, for example, degradation mechanisms, it is not a reason to consider decommissioning. It is assumed that the system lifetime will correspond to that of the modules, which is assumed to be as a minimum the subsidy contract period available in a member state – up to 30 years. It is assumed that some house owners may decide to replace their system with new panels (repowering) but the probability of this occurring cannot easily be estimated. It is therefore assumed that this may occur after a period of 30 years. It could be considered to include in the assumptions a repowering rate for the stock installed from the outset of major subsidy schemes in Germany , Spain, Italy, UK and France.
- For residential systems across all Member States it is assumed that up to 47% of electricity generated is self-consumed and the remaining 53% of electricity is exported to the grid.
- Commercial and industrial systems may be constrained by other factors such as the lifespan of the building itself on the site. However, assumptions that can be made from a PV system perspective are not readily available. A 30-year lifetime shall be taken as an initial assumption, but this may also be influenced by typical building lifespans. For example, industrial buildings may have a shorter service life than that of the PV system.
- Utility-scale systems have mostly been developed based on 13 to 25 years incentives. It can reasonably be considered that they will be either decommissioned or repowered after 20 years on average. It could be possible to refine this assumption by looking at the proportion of PV systems financed in each country under specific incentive schemes.

Evolution of the system stock through to 2023, 2030 and 2050

Forecasts for the future PV system installations are fundamental in order to also develop stock models for modules and inverters, but a broad range of assumptions must be made and adjusted depending on the time horizon. The following assumptions for short, medium and long-term forecasts are presented as the starting point for discussion:

Short term (until 2023)

Short term forecasts are based on bottom-up market analysis, including Member State policies supporting PV and the general trends in PV development. The data from Solar Power Europe has been used as the starting point. Starting from 115 GW in 2017, the installed capacity in 2023 could reach between 196 - 318 GW according to the three scenarios developed.

Medium term (2023-2030)

The EU's re-cast renewable energy directive sets the target for the 2030 share of renewables in gross final energy consumption at 32%. To achieve this, the EU needs to increase its use of renewables in the power sector by a much higher amount and a significant part of this will come from solar systems.

For the period until 2025, a mix has been used of the starting point provided by the Solar Power Europe scenarios and the European Reference Scenario 2016 afterwards. The forecast is heavily dependent on EU policy as the Reference Scenario was remodelled to reflect the more ambituous targets in the EU 2030 energy and climate change policies.. Development of the policy assumptions is explained further in the box below. Residential scenarios developed for a recent study by DG Justice are referred to as they are estimated by member state based on take up rates and the proportion of remaining capacity to 2030 (see Table 7-8).

Major factors influencing that post 2023 situation relate to the political willingness in Europe to fulfil climate change commitments and the expected PV market developments due to price competitiveness (parity) in most European countries. At an EU level a new binding renewable energy target for the EU for 2030 has been established of at least 32%, with a clause for a possible upwards revision by 2023.

An assumption has been made that the ratio between wind and PV contributing to targets could be higher than 2:1. Also most other renewable technologies won't grow as fast until 2030 given the competitiveness of wind and solar in the electricity sector. The low scenario of Solar Power Europe corresponds well as a starting point with the 2023/4 projection in the EUCO3232.5 model. By applying a linear annual growth rate of 2.9% through to 2030 this could translate into around 323 GW for photovoltaics, slightly higher than the 295 GW and 305 GW in the EU 2016 and EUCO3232.5 scenarios respectively.

Long term (2030-2050)

The main policy driver is likely to be the decarbonisation of the energy mix in Europe under the more ambitious version of the Reference Scenario 2016, referred to previously as EUCO3232.5. Because of long range uncertainty a greater possible divergence in the outcomes has been assumed.

The same methodology has therefore be applied as described for 2023-30. The Reference Scenario estimates a nuclear production of 737 TWh in 2050, which leaves 3124 TWh to be produced with RES-E electricity, of which a contribution of 429 TWh is predicted for solar PV. By applying a linear annual growth rate of 2.5% referred to in the original EU Reference Scenario for the period 2030-50 a high end capacity projection of 843 GW is the result, compared to the original projection of 428.5 GW.

Table 7-8. Projected residential solar PV capacity to 2030 for EU and EEA countries

	Residential solar PV capacity in 2015 (MW)	Residential solar PV capacity in 2030 (MW)	Growth rate, 2017-2030 (% pa)	Share of total potential residential solar PV capacity (2030)	solar PV prosumers as a share of all households (2030)
Belgium	1,976.9	3,255	3.5%	29.0%	8.2%
Bulgaria	8.9	40.6	10.2%	1.4%	0.5%
Czech Rep.	95.0	106.3	0.8%	2.6%	0.7%
Denmark	454.1	838.1	4.2%	18.7%	6.8%
Germany	5,240.5	9,137.8	3.8%	39.5%	5.8%
Estonia	1.1	5.6	8.2%	1.7%	0.2%
Ireland	1.1	12.4	15.3%	0.4%	0.2%
Greece	350.0	950.2	4.4%	27.4%	6.7%
Spain	48.6	57.9	1.2%	0.4%	0.1%
France	1,049.0	2,622.7	6.3%	6.6%	2.6%
Croatia	12.1	30.3	6.3%	1.2%	0.5%
Italy	2,640.0	5,614.1	5.1%	22.6%	5.9%
Cyprus	20.6	55.7	6.7%	7.6%	3.1%
Latvia	0.4	5.6	14.9%	1.5%	0.3%
Lithuania	19.7	31.2	3.1%	3.9%	1.1%
Luxembourg	33.6	80.6	6.0%	14.1%	5.0%
Hungary	60.5	282.8	10.0%	5.0%	2.3%
Malta	19.7	23.6	1.3%	13.0%	3.6%
Netherlands	1,086.0	3,684.0	8.1%	26.4%	9.5%
Austria	377.5	684.2	4.3%	16.4%	5.1%
Poland	10.2	151.2	16.5%	1.0%	0.4%
Portugal	147.1	382.9	6.5%	7.5%	4.1%
Romania	13.3	18.7	2.3%	0.3%	0.2%
Slovenia	1.8	13	12.9%	1.1%	0.5%
Slovakia	5.9	40.4	12.5%	1.9%	0.6%
Finland	4.0	24.5	12%	0.7%	0.2%
Sweden	52.0	257.6	9.4%	3.4%	1.1%
UK	2,499.0	3,539.9	2.1%	13.1%	3.5%
Iceland	-	-	-	0.0%	0.0%
Norway	11.3	25.6	5.5%	0.4%	0.3%

Source: DG JUST study "Residential Prosumers in the European Energy Union' (2017)

Policy option 2: Ecodesign requirements on modules and inverters

Description: Requirements would be set that would apply to individual modules and inverter products placed on the EU market.
Rationale: To foster innovation in module and inverter design, with a focus on life cycle yield, circularity and smart readiness, and to prevent imports that are of low quality. An approach focussed on the two key components is considered to be justified because they are business to business components of all PV systems in general in the case of modules without intended end-use. The intervention would therefore cut off products at the point of being placed on the market to distributors, retailers and installer. It does not require consumer visibility. From a market surveillance perspective it is more appropriate to place requirements on these components.
Evidence: ○ Modules: The BAT and LLCC options identified in Task 6 show that there is scope within the market to improve the overall performance of modules, both in terms of primary energy and cost. Moreover, requirements on the quality and durability of products over time could further contribute to lower environmental impacts. ○ Inverters: The BAT and LLCC options identified in Task 6 show that whilst potential efficiency gains are more modest a focus on extending the lifetime of inverters and ensuring that they are readily repairable can contribute to significant reductions in their environmental impact.
Expected benefits: ○ Product efficiency will be driven up overall. ○ The cost differential is predicted based on spot prices to be less than 20% between the different design options at the low performance end of the market meaning that a cut-off could be introduced without strongly impacting on the total pricing of systems whilst at the same time increasing their yield. ○ Information requirements could be used to drive a focus on quality and circular aspects that have been demanded by industry, as well as contributing to EU policy actions. ○ Requirements could for inverters drive a focus on repairability and customer support and promote their role as a digital gateway to system performance monitoring.
Possible drawbacks: ○ Requirements could create a supply constraint if they take lower cost/lower end products off the market ○ High performance products can have higher life cycle impacts e.g. SHJ modules. Any increase in the sale of high efficiency modules would only focus on predicted use stage performance – care would therefore need to be taken in how this would be accounted for. ○ For inverters there is limited differentiation between products using the Euro Efficiency metric. Account would need to be taken of other beneficial operating characteristics such as under mismatch conditions and design to operate at higher temperatures.

Proposed Ecodesign module requirements under Policy Option 2

Two sets of requirements are proposed for PV modules that each address specific aspects of performance:

1. The first set has the objective of removing those module products with the lowest electricity efficiency or yield.
2. The second set has the objective of ensuring that all modules meet minimum requirements for their quality, durability and circularity.

For the purpose of modelling this allows for the distinct improvements of each aspect of performance to be analysed. These two sets may also be combined into one set of requirements and this combination has also been modelled (see section 7.2). Also for both options some minimum information requirements are proposed.

Scope of the product group

In line with the findings reported in the Task 1 report, the product scope is proposed below. BIPV was initially considered for inclusion with the potential to focus on the performance of the cells used. However, this would still not fully address the diversity of products that are also largely specialist B2B and construction products, whereas the focus of Ecodesign is on consumer products in the market.

Proposed Ecodesign product scope

Modules

The scope shall correspond to photovoltaic modules intended for use in photovoltaic systems for grid-connected electricity generation.

Specifically excluded from this scope are:

- Module level power electronics, containing micro-inverters and power optimisers
- Modules with a DC output power of less than 50 Watts under Standard Test Conditions (STC)
- Building Integrated Photovoltaic (BIPV) products that incorporate solar photovoltaic cells
- Modules intended for mobile applications or integration into consumer electronic products.

Inverters

The scope shall correspond to the following inverters that are intended for use in grid connected electricity generation:

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

Specifically excluded from this scope are:

- Central inverters that are packaged with transformers (sometimes referred to as central solutions) as defined in Commission Regulation (EU) No 548/2014 on Ecodesign requirements for small, medium and large power transformers.

Module option 2.1: Performance requirements on efficiency and life time electricity yield

This initial Ecodesign option would introduce a cut-off based on the potential of module products to generate electricity. The results of Tasks 5 and 6 have shown that increased electricity generation is a determinant in reducing the life cycle primary energy per kWh generated. Moreover, from a market perspective the efficiency of the base case module is an average. The standard products of major manufacturers are currently situated in the range of 16-17% and evidence suggests that less efficient products are still being placed on the EU market [10]. These largely comprise products imported into the EU.

For the BAT module product (CIGS) the reported results, which show the selected model having an advantage over crystalline designs because of their lower production primary energy use, can only be achieved by maximising their efficiency and yield. If yield is also taken into account then the mono PERC 2020 and optimised mono PERC design options also both demonstrate low production primary energy use and high yield.

Two options have been identified for the performance requirements (see also Table 7-9):

1. Power rating (IEC 61853-1): A simplified option based on measurement of the efficiency of a module in converting solar radiation into DC electricity under Standard Test Conditions and,
2. Energy rating (IEC 61853-3): A more complex, but more representative option based on applying performance coefficients to the module efficiency under STC, the estimated yield of a module under reference conditions and in a reference climate zone.

Whilst option 1 is a standard metric used for declaration of the power rating of a module by manufacturers, the standardised test method to support option 2 takes into account more performance corrections in the field and could therefore provide a more representative comparison of product performance. It is however a more complex method that is not yet widely reported on in product datasheets since the yield calculation takes into account specific climate zone conditions as well as PV module performance characteristics such as coefficients for spectral response under low light conditions and the loss of performance at high temperatures.

For option 1 a threshold of 14% rising to 16% is proposed based on the performance of the LLCC option (the mono PERC 2020 module) and the best performing models available in the market for the BAT (the CIGS module). The main assumption underpinning this option is that the Base case and low performing modules would be removed progressively form the market, moving largely towards modules with a higher power output. Care, however, would need to be taken in the application of such a requirement to emerging technologies. Cases such as CIS/CIGS thin films show that although a technology may initially not be able to demonstrate high performance they may subsequently improve as a result of progressive investment in Research & Development.

For the energy output (yield) performance two options are presented. The first (option 2) would be an information requirement, given that this performance metric is not yet as widely declared as the module power rating and the accompanying standard was only introduced in 2018., The second (option 3) would be a minimum requirement but no specific threshold can be proposed yet because of a lack of market data. It could be possible to initially set this based on the power density, spectral response and temperature co-efficient of a selected module representative of the BAT (CIGS).

[10] The ENF solar directory identified that of the 16.020 multi-crystalline module models >50 Wp listed as being available on the world market, there are 1.741 with an efficiency in the range of 9 - 14%. These include module products supplied to the major PV markets in Germany, Italy, France and Spain.

Table 7-9. Module policy option 2.1: Efficiency and yield requirements

Performance aspect	**Detailed proposed requirements**
Option 1: Module efficiency	Require a minimum module efficiency 16% measured according to IEC 61853-1 under Standard Test Conditions. This threshold could alternatively be tiered starting at 14% and rising to 16%.
Option 2: Module energy yield	An information requirement to declare the module energy output (yield) expressed in kWh/kWp and calculated according to IEC 61853-3 and for a reference climate zone.
Option 3: Module energy yield	Tier 1: Require a minimum module energy output (yield) expressed in kWh/kWp and calculated according to IEC 61853-3 and for a reference climate zone.
	Tier 2: The minimum module energy output (yield) in kWh/kWp to be time averaged over 30 years to reflect the declared linear degradation rate of the product.

Module option 2.2: Performance requirements on quality, durability and circularity

This further Ecodesign option would introduce a more stringent set of quality and durability tests for module products. It would also seek to ensure that modules were possible to disassemble and dismantle in order to facilitate repairing and recycling. The proposed set of requirements are presented in Table 7-10.

Quality and durability

The optimised monocrystalline PERC module was identified in Task 6 as the LLC option. Contributing to its performance are a number of factory quality tests and material specifications that are understood to be applied to module products in order to reduce failures at the infant, mid-life and wear out phases of a module product, as well as to reduce performance degradation along a product's lifetime. These were selected based on literature reporting the findings from field analysis of the most common factory defects as well as defects to emerge in the field and manufacturers design and testing responses.

Using IEC 61215 [11] as a starting point for conformity assessment of quality and material specifications, a set of factory and durability test requirements have been specified which complement or extend the currently specified test methods. This would have the effect of focussing attention on specific tests as it appears that although for the largest manufacturers of solar modules who account for approximately 65% of the market it is considered a market entry requirement only a small proportion of module *models* that are available on the world market are currently formally certified to IEC 61215 (in the range of 10-20%). It appears that there are a range of smaller manufacturers for whom design type approval and factory quality control is less comprehensive – as evidenced by a high degree of variation in the findings from factory quality audits [12].

Some other aspects, related to IEC 61215, should be noted in this context:

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[11] IEC, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements* (2016)

[12] Confidential analysis carried out by STS (9.4 GWp production, 39 manufacturers) and Exergy (sample of 195.000 modules before and after quality audit procedure)

- Experience from factory quality inspection in China strongly suggests that it is not sufficient to require only a design type approval, as later on in the move to full scale manufacturing there may be:
  - changes in material quality,
  - small changes and deviations may occur from the design and
  - there may not be the same precision manufacturing.

  A complementary focus on implementation of a factory quality standard is therefore recommended to ensure that the design quality is replicated at mass production scale. The standard IEC TS 62941 and linked to that the accompanying IECRE Operational Documents for audits (IECRE OD 405 series).

- As analysed in detail in the draft report 'Transitional methods for PV modules, inverters and systems in an Ecodesign Framework', there are various tests of the IEC 61215 sequence which show clear commonalities (until a certain extent, at least), with the EN IEC 61730. EN IEC 61730 is the harmonised standard for compliance of photovoltaic modules/installations with the provisions of the Low Voltage Directive 2014/35/EU, therefore it can be expected that the tests foreseen under this standard are already commonly executed by manufacturers. This should be taken into account, to avoid overburdening/duplications in terms of costs for testing.
- The indicative cost for the full test sequence of (8) modules, as foreseen in IEC 61215, is in the order of (at least) 30000-35000 Euro.
- Industry stakeholders note that a shortcoming of the current standard is that tests are not applied simultaneously to each module sample, thereby representing tests closer to real life conditions.

As a result and based on the analysis in Tasks 4 to 6 a small number of selected tests rather than the whole IEC 61215 test sequence could be used to focus attention on the following performance aspects:

- Micro-cracks: Module quality testing can be specified to include electroluminescence inspections to detect inactive cell areas in the semi-conductor which may have the potential to propagate over time and at different rates depending on climatic conditions [13]. They can be minimised by careful handling practices.
- Degradation mechanisms: These mechanisms are complex but state of the art analysis based on field observation suggests that they are mostly strongly contributed to by:
  - UV exposure over time,
  - progressive water ingress into a module, and
  - high operating (system) voltages.

  The semi-conductor materials also have different degradation mechanisms. Given that a standardised test for the long-term degradation of performance of all technologies is not available it is considered necessary to complement an overall declaration of the module degradation rate (see below) with UV preconditioning test, water ingress and Potential Induced Degradation (PID) tests. Specific concerns have also been documented in relation to possible severe short term degradation of the new generation of PERx modules, although there is evidence of recovery over time [14]. A test for Light and elevated Temperature Induced Degradation (LeTID) would be preferable as a way of screening out the worst performing products but does not currently have a standardised basis. The introduction of a test into IEC 61215 or as separate technical recommendation is currently under discussion

[13] 3-7% power loss in standard modules is possible as a result of micro-cracks according to analysis under IEA PVPS Task 13. Although a relatively high defect rate (16%) was reported by STS from large scale Chinese factory inspections in 2013, quality is claimed to have improved since then and in 2018 an average reject rate of 1.5% has been reported.

[14] An LeTID test study of 10 commercially available PERx modules for Photon International performed by PI Berlin yielded degradation of some models relative output power by ≥5% and in some of these cases the degradation curve did not appear to have reached saturation. Some degree of recovery has been observed but the extent that can be expected in the short to medium term is not clear.

Other factory quality problems identified include on the material side silicon and silver impurities, and in relation to assembly processes badly aligned tabbing [15]. It is also claimed that, linked to these types of defects, the efficiency of modules can be negatively affected. Based on the results from the implementation of factory quality improvements across a range of production aspects, an increase in the Wp rating of modules of between 1% and 7% is claimed.

Performance requirements associated with these tests could be complemented by an overall information requirement to declare the lifetime degradation rate over a notional service life of 30 years. This is an important measure of the long term performance of a solar module and strongly influences the overall life cycle impacts. However, despite widespread unsupported declarations in marketing literature and on datasheets of rates and, linked to these rates, performance warranties, there is no standardised experimental basis for estimating a rate. The declaration of the degradation rate would therefore need to clearly state whether the rate was unvalidated (based solely on laboratory tests and models, to be specified by the manufacturer) or validated (based on field observations). The latter would need to follow the Transitional Method for minimum field observed degradation data collection as proposed by the JRC:

- The data should cover at least 5 (five) consecutive years.
- The experimental data shall cover all the climatic profiles that are considered in the calculation of the annual energy yield of PV modules.
- The data shall be collected from at least 2 (two) separate geographic locations in each climatic zone.
- It should contain open rack ground-mounted, roof-mounted and building added and or building integrated systems (at least 2 of the four options must be included).
- The assigned degradation rate shall be the average of all collected degradation rates from above.

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

As a consequence of the application of this policy option, it is expected that durability is improved for some key performance aspects. The main assumption for this option is that the Base case and low performing modules would be removed progressively form the market, moving largely towards modules with an optimised performance.

Circularity requirments

In addition to the identified durability requirements, it is important to address two key aspects of circular design, namely disassemblability to facilitate repair and dismantleability to facility recycling.

In respect to disassembly the failure rate for modules was reported in Task 4 to be low, at around 0.5%. The junction box and bypass diodes were identified as a point of attention for ease of repair. There is a trend towards soldered instead of plug-in diodes which may prevent replacement. Stakeholders also noted that the sealing of the junction box to improve the IP rating can prevent access. In the case of access and diode replacement being hindered it should be possible to replace the whole junction box.

In respect to dismantling, a BNAT module designed for recycling has been identified. The main feature of the design is that the components and their means of assembly allows for an easier separation of the components and materials, including ease of access to the cells without breakage. Materials are carefully selected in order to allow for recycling. In the case of current module designs, which are more problematic to achieve a clean separation of materials, materials choices may hinder recovery processes.

[15] Personal communicationwith Thomas Sauer, Exergy

It is therefore proposed to have information on the design and material content of modules. The purpose would be to facilitate future end of life recovery of valuable raw materials and to identify appropriate recovery routes, for example in the case of encapsulant and backsheet materials where the presence of fluorinated materials could create a processing hazard. It can be envisaged that with the right incentives, bifacial glass to glass module designs, which are predicted to account for 50-60% of the market by 2030, could evolve to adopt some features of the BNAT module designed for recycling.

Table 7-10. Module policy option 2.2: Quality, durability and circularity requirements

Performance aspect	**Detailed proposed requirements**
Performance requirements	
Option 1 2.2.1 Comprehensive durability product test sequence	Each model shall be certified to have passed the comprehensive product test sequence required for qualification under IEC 61215. *To ensure conformity this requirement could be further extended to require factory quality controls and auditing according to IEC TS 62941 and IECRE OD 405.*
Option 2 2.2.2 Specifc durability tests	Component degradation - *UV pre-conditioning:* MQT10 of IEC 61215 over four cycles of 60 kWh/m^2 in the two stipulated UV wavelength ranges, followed by visual inspection and a pass/fail based on no detectable browning of the encapsulant/laminate. - *Damp heat:* MQT 13 of IEC 61215 extended to 2500 hours of exposure divided into four separate cycles followed by application of the pass criteria. - *Potential Induced Degradation:* Testing according to IEC 62804 shall result in no more than a 5% power loss after 192 hours at 1000V. - . Water ingress - *Junction box:* Achievement of an Ingress Protection rating of at least IP67, category 1 according to EN 60529. Cell integrity - The inactive cell area shall be no more than 8% upon optical inspection using electroluminescence imaging[16].
Information requirements	
2.2.4 Lifetime performance degradation	The manufacturer shall declare the average linear degradation rate expected over a notional service lifetime of 30 years. This shall be the same rate that is used as the basis for the power warranty (if offered). The declaration shall be clearly identified as being either: – *Validated:* The manufacturer's claim shall be an average derived from a series of field observations made according to the Transitional Method, in regard to the number, geographical coverage and the time series. – *Unvalidated:* on the manufacturer shall report on the basis for their claimed rate with reference to accelerate life testing methods and modelling..

2.2.5 Repairability	The manufacturer shall report on: – the possibility to access and replace the bypass diodes in the junction box [17], – the possibility to replace the whole junction box of the module *Note: the possibility exists to include semi-quantitative criterion if a product specific standard is developed in accordance with the forthcoming horizontal standard for repairability prEN 45554.*
2.2.6 Dismantlability	The manufacturers shall report on: – the possibility to separate and recover the solar cells or semi-conductor material from the module. – Design measures to prevent breakage and a clean separation of the cells and/or to maximize the purity of the recovered semi-conductor material. *Note: the possibility exists to include semi-quantitative criterion if a product specific standard is developed in accordance with the forthcoming horizontal standard for recyclability prEN 45555.*
2.2.7 Material disclosure	The manufacturer shall declare the content in grams of the following materials in the product: – Antimony – Cadmium – Gallium – Indium – Lead – Silicon metal – Silver – Tellurium For the encapsulant and backsheet the manufacturer shall also declare the type of polymers used (including if it is fluorinated or contains fluorinated additives) and the content in grams.

[17] This is the main option available for the repair of a module in order to minimise yield loss during the lifetime of the product.

Proposed Ecodesign inverter requirements under Policy Option 2

Two sets of requirements are proposed for PV inverters that each address specific aspects of performance:

1. The first set that has the objective of removing the remaining poor performing products and ensuring that inverters in the residential market segment in particular support smart monitoring of PV systems.
2. The second set that has the objective of ensuring that all inverters meet minimum requirements for their quality and durability.

This allows for these two distinct aspects of performance to be analysed and modelled. These two sets may also be combined into one set of requirements and this combination has also been modelled (see section 7.2).

Inverter option 2.3: Performance requirements on efficiency

This initial Ecodesign option would introduce a cut-off based on the Euro Efficiency of the inverter product. Whilst the results of Task 4 and 6 suggested that there is a limited potential for further improvement based on the Euro Efficiency and Task 2 reported that the digitalisation of inverters has raised their overall efficiency significantly, there is evidence that a small number of less efficient products are still being placed on the EU market, some of which have an efficiency as low as 93% [18]. These include both products imported into and manufactured in the EU. The proposed requirements are presented in Table 7-11.

Additional requirements are proposed to support the *'smart readiness'* of PV systems. The inverter can integrate monitoring features capable of supporting the advanced yield monitoring and fault diagnosis of PV systems. This improvement aims to facilitate system level improvements in the residential segment and is supported by the two best performing PV system design options in Task 6, which rely on monitoring and fault diagnosis to support repair response and maintenance.

Minimum hybrid inverter energy efficiency requirements

In order to facilitate self-consumption, some consumers are choosing to integrate inverters and battery storage. However, the process of charging and discharging power from the battery introduces the potential for significant losses.[19] It is therefore proposed to include an overall hybrid system efficiency requirement.

The measurement of the efficiency is proposed as being based on the method that has been developed by the Effibat project, which has led to the publication of "Effizienzleitfaden 2.0[20]. The standard measures the DC/DC and DC/AC conversion efficiencies at different steps in a system design – covering AC coupled, DC coupled and generator coupled systems. It also addresses standby losses. Although this is a relatively new private standard it may soon be adopted as a DIN (Deutsches Institut für Normung) national standard in Germany. is based on the laboratory testing of the hybrid products of a range of major inverter manufacturers and so could inform a transitional method and, at this stage, form the basis for an information requirement.

Minimum inverter smart readiness

[18] The ENF solar directory identified that of the 4108 on-grid inverter models listed on the world market, there are 458 with a euro efficiency performance in the range of 93 - 96%. These include micro, string and central inverter products supplied to the major PV markets in Germany, Italy and Spain.
[19] A base case system model for the Effibat project indicates possible losses of income of about 13%
[20] BVES, *Effizienzleitfaden für PV-Speichersysteme v. 2.0.1*, July 2019, https://www.bves.de/effizienzleitfaden_2/

Inverters can play a key role in providing the in-line data required to achieve these improvements but to date smart monitoring capabilities have largely only been integrated into the specifications of large inverters targeted at commercial and large scale systems. According to inverter manufacturers a Class C monitoring capability according to IEC 61724-1 would be sufficient to support both home owner and installer remote monitoring/call out response. This would also reflect current best practice for residential equipment, therefore being suitable for Ecodesign as a minimum functionality.

Linked to this it could be considered to establish a requirement for the data transfer protocol. The focus should be on the system communication protocol rather than the internet protocol. There are a number of common industry protocols for smart metering (Mbus) and for SCADA systems (Modbus, fieldbus, LonWorks, Bacnet). Cable and wireless connected inverters generally use Fieldbus or Modbus and a variant of the latter called Modbus Sunspec. They are both open platforms which originate from industry with a basis in IEC standards, namely IEC 61158 (withdrawn) and IEC 61784. ,. Modbus appears to be the appropriate protocol for residential scale.

Table 7-11. Inverter policy option 2.3: Efficiency requirements

Performance aspect	**Detailed proposed requirements**
2.3.1 Euro Efficiency requirement *Option 1* Euro efficiency minimum requirement for PV inverters without storage	Require a minimum efficiency at Tier 1 of 94% and Tier 2 at 96% measured according to EN 50530. *Allowances shall be provided for micro-inverters and hybrid inverters to offset for their other benefits.*
Option 2 Euro Efficiency declaration and supporting information requirement	Declaration of the Euro Efficiency measured according to EN 50350. In addition the following supporting information shall be provided: - The efficiency values shall be presented in a tabulated form. - An annual temperature derating factor for the climate zones defined in IEC 61853-4 and calculated relative to 25ºC
2.3.2 Efficiency requirements for PV inverters with possibility to connect storage or with integrated storage	Require a minimum system efficiency of 90% at 25% of nominal power,at minimum MPP voltage with the battery at around 50% state of charge. Measurement to be made according 'Effizienzleitfaden 2.0'.
2.3.3 Smart readiness	Manufacturers shall ensure that the inverter supports class C data monitoring according to IEC 61724-1. The inverter shall have physical and/or wireless connectivity and be capable of communicating with other devices using the Modbus data transfer protocol in accordance with IEC 61158. –

Inverter option 2.4: Performance requirements on quality, durability and circularity

This further Ecodesign option would introduce a more stringent set of quality and durability tests for inverter products, as well as addressing the potential for their repair. The results of Task 6 showed that the inverters designed for repair and a longer lifetime were closely matched for the BAT and LLCC options. This is largely because of the anticipated reduction in the failure rate and the number of product replacements.

Quality and durability

Taking IEC 62093, IEC 60529-1 and in IEC 62109-1 as a starting point for conformity assessment, design qualification tests have been specified for inverters that are intended to located outside. The tests are selected from the IEC 62093 standard and address thermal stress and water ingress, with the main aim being to minimise mid-life failures. These are the two main (outdoor) environmental conditions understood from analysis of inverters in the field to provoke failures. Design qualification according to these tests will contribute towards a more durable inverter product. Whilst the design type approval standard IEC 62093 as a whole could be specified as a main requirement it is not clear the extent to which it is already implemented.

Stakeholders also emphasised that a complementary focus on the implementation of a factory quality standard would ensure that the design quality is replicated at mass production scale. The relevant standard is IEC TS 63157 and an accompanying IECRE Operational Documents for audits is pending development.

Circularity requirements

Based on feedback from manufacturers the approach needs to distinguish between small and large scale inverters, and by market segment. In the residential segment it appears that the practice for products under warranty is to provide on-site response with substitution of the faulty device. Devices taken off site would then be taken to a repair workshop and may be refurbished. The main common repair that may be carried out on site is the replacement of circuit boards. It appears therefore that a requirement could focus on the ease of replacement of circuit boards and their availability, out of warranty.

For larger string and central inverters, it appears that a more common practice is to provide a documented preventative maintenance and repair cycle for an anticipated design lifetime. This would identify components and include recommended timings for their replacement, thereby allowing owners of the product/model to ensure they follow practices recommended to extend the life of the product.

The materials disclosure included within the Ecodesign proposal 2.2 for modules, which combined hazardous materials and Critical Raw Materials, has been adapted to also include as an information requirement in the 2.4 proposal.

Table 7-12. Inverter policy option 2.4: Quality, durability and circularity requirements

Performance aspect	**Detailed proposed requirements**
Option 1 2.4.1 Comprehensive durability product test sequence	Each model shall be certified to have passed the comprehensive product test sequence required for qualification under IEC 62093. *To ensure conformity this requirement could be further extended to require factory quality controls and auditing according to IEC TS 63157 and the associated IECRE OD [pending a code].*
Option 2 2.4.2 Specific durability tests (for outdoor applications)	*Thermal cycling:* For outdoor conditions, the IEC 62093 Test 6.4 subjected to conditions of -40oC to +85oC for 400 cycles followed by the specified functionality test.
	Operating temperature: Capacitors, inductors and transformers used within inverters shall be selected so that under the most severe rated operating conditions, the temperatures do not exceed the temperature limits specified in IEC 62109-1 Table 1 minus 20 °C (10 °C for capacitors)
	Water ingress: Achievement for outdoor conditions an Ingress Protection rating of at least IP65, category 1 according to EN 60529.
Additional information requirements	
2.4.3 Repairability requirements for inverters <30 kW	The manufacturer shall identify which of the circuit boards can be replaced by an on-site repair service.
2.4.4 Repairability requirements for inverters >30 kW	Manufacturers shall provide a preventative maintenance and replacement cycle. This shall include a list of parts that may be replaced and the timing of preventative measures to achieve a declared intended design technical lifetime (as required in IEC TS 63157). *Note: the possibility exists to include semi-quantitative criterion if a product specific standard is developed in accordance with the forthcoming horizontal standard for repairability prEN 45554.*
2.4.5 Material disclosure	The manufacturer shall declare the content in grams of the following materials in the product as a whole and in the replaceable circuit boards: – Cadmium – Gallium – Indium – Lead – Silicon carbide – Silver – Tantalum

Ecodesign option 2.5: Provision of life cycle GER and GWP performance data

This additional overarching Ecodesign option would establish a standardised basis for the collection, analysis and presentation of module and inverter life cycle data and Life Cycle Assessment (LCA) results in the EU. The initial focus would be on two impact categories – primary energy (GER) and Global Warming Potential (GWP). The latter is also sometimes referred to as a carbon footprint or embodied CO_2 emissions. The initial proposal is presented in Table 7-13.

Manufacturers would be required to provide LCA results obtained in conformity with the standard for construction product Environmental Product Declarations EN 15804 and/or with reference to the PEF Category Rules for photovoltaic modules. This would represent a first step towards ensuring that good quality, verified life cycle performance data was available for all products on the market, and would serve the dual purpose of supporting the building sector and the energy sector. Given that a period of time would be required for manufacturers to prepare declarations a tiered approach could be adopted.

Given that the majority of solar photovoltaic applications are anticipated to be building attached, and that in particular for Nearly Zero Energy Buildings (NZEB) solar PV is the renewable energy technology of choice for building designers [21], it is considered appropriate to align the requirement with the EN standard for construction product Environmental Product Declarations. Whilst in some EU countries the availability of EPD's for construction materials is generally good, the availability of EPDs for technical building systems is poorer, resulting in the need to use default data in building LCAs.

In most cases the results would need to be verified and registered with an EPD scheme [22], such as INES (France), Oekobaudat (Germany) or Environmental Profiles (UK). The process for obtaining such LCA results would consist of a combination of 1) carrying out an LCA according to the relevant Product Category Rules and 2) verifying and registering each model EPD.

Table 7-13. Ecodesign policy option 2.5: Life cycle data

Performance aspect	**Detailed proposed requirements**
Information requirement	
2.5.1 Life cycle GER and GWP product declaration	At the latest by [*delayed year of introduction*] and for a representative product from each module series placed on the market, an Environmental Product Declaration (EPD) for, as a minimum, life cycle primary energy (GER) and GWP shall be developed and provided. *For further discussion: options are for the EPD to be in conformity with EN 15804 or the PEFCR and to have been registered with a Type III Product Category Rule operator.*
Note: In order for this proposal to be made 'operational' within an Ecodesign implementing regulation, a dedicated check on the legal feasibility of such a requirement in the framework of the Ecodesign Directive should be carried out.	

[21] Check Concerted Action reference

[22] Eco Platform, *Established EPD programmes*, https://www.eco-platform.org/the-eco-epd-programs.html

Policy option 3: Energy labelling requirements for residential PV systems

Description:

Requirements would be set that would apply to either the weighted efficiency of a package consisting of a module type and an accompanying inverter type or, alternatively, the calculated energy yield of a whole system design.

Rationale:

The aim is to enable consumers to make an informed choice based on the performance of system packages or system designs offered by retailers and installers. It is not considered to be desirable or practical to have component level requirements because they are B2B products.

A package approach is proposed as one option, combining the module(s) and the inverter(s) performance information. An extension of this approach to label system designs could also be considered whereby other derate factors are taken into account. The Energy Efficiency Index (EEI) would be based on the derating of the module power rating or CSER with the inverter efficiency. A declaration would be needed for 3 climate zones in order to capture variations in the module performance, for example due to temperature dependency.

The Energy Efficiency Index (EEI) for the system approach is proposed as being based on the module and inverter performance expressed as an overall calculated yield in each of the three climatic zones identified from IEC 61853-4, normalised to the system rating and area. The yield calculation would also take intoaccount the predicted module degradation rate over a fixed lifetime of 30 years.

Evidence:

- Modules: The BAT and LLCC options identified in Task 6 show that there is scope within the market to improve the overall performance of modules, both in terms of lifetime primary energy, use phase yield and cost. Taking into account other factors that can affect long term energy yield, such as temperature co-efficient, spectral response and performance degradation could further allow for differentiation of product performance.
- Inverters: The BAT and LLCC options identified in Task 6 show that whilst potential euro efficiency gains are more modest further derating losses may be minimised according to the package design and the intended end-use – for example, reduced mismatch losses by using micro-inverters, reduced temperature dependency by using inverters based on new semi-conductor materials.
- Systems: Evidence from selected Member States suggests that the distribution curve of system performance ratios of the stock has the potential to be shifted positively through:
  - better design to take into account of site-specific conditions,
  - learning applied to installation practices
  - reduced losses due to equipment, cabling and maintenance practices.

  A combination of both the repowering of old systems and the optimisation of new system has the potential to contribute.

Expected benefits:

A focus on the point of sale to consumers is expected to increase the visibility of better performing combinations of products or system designs. Clients are particularly interested in yield and performance, hence the focus on these two aspects in selecting the EEI. Moreover, if a Performance Ratio was to be included this could be later monitored after installation.

Calculation of a yield and Performance Ratio is understood to be current practice for designers and installers when estimating system yield and analysing risk mitigation measures. It allows for multiple variables to provide an indication of a system's efficiency. Some countries already have specified PR targets in their subsidy regimes.

Possible drawback:

Labelling is a new concept for PV system packages or system designs. Care would need to be taken with consumer perceptions, as all new solar PV capacity can be considered advantageous and it would be important not to dissuade consumers. The format of the labelling scale would therefore need to be considered, so as not to portray systems with site constraints in a negative light e.g. a residential roof with an east-west orientation.

Verification of the components within packages could prove to be difficult depending on how often they change based on supplier relationships and pricing. It may not be possible to label a system until the design decisions have been made or, in order to offer different performances, a reduced number of parameters may need to be considered in order to simplify the process.

Not all life cycle performance aspects can be covered within an EEI. As a result a focus on maximising use phase yield could lead to trade-offs if high efficiency components which require more primary energy to manufacture them are selected.

NOTE: the present analysis deals with techo-economic aspects. In parallel, a check is ongoing on the legal feasibility of an Energy labelling scheme for PV products/system, in the form of a delegated act in the framework of Regulation 2017/1369[23].

[23] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU

Proposed Energy Labelling package and system performance requirements under Policy Option 3

In this policy option the Energy Label could be used to introduce energy classes in order to provide information to retail customers. The results of Tasks 5 and 6 have shown that increased electricity generation for modules, a higher euro efficiency for inverters and a high Performance Ratio for PV systems are key determinants in reducing the life cycle primary energy/kWh generated.

Two options can be considered for the Energy Efficiency Index (EEI) on which the label classes could be based:

1. A package approach: This would combine either the module power rating or the CSER energy rating with a derating based on the Euro Efficiency of the inverter.

A system approach: This would entail the modelling of a PV system design's yield and performance ratio, taking into account more parameters that are specific to the installation, for example, shading, inclination, orientation.The labelling would be the responsibility of those at the point of sale – i.e. installers that have direct contact with retailers and end-retailers of systems.

It has already been noted that, based on initial feedback from a cross section of stakeholders, care would need to be taken with consumer perceptions of such a label and the possible impact on consumer confidence, as all new solar PV capacity can be considered advantageous and it would be important not to dissuade consumers. The format of the labelling scale would therefore need to be considered, so as not to portray systems that are constrained by site conditions in a negative light e.g. a residential roof with an east-west orientation and shading caused by chimneys and parapets.

In regard to specific references within the Energy Labelling regulation to solar technology, there is already a labelling classification that includes the contribution of solar thermal panels to domestic water heating systems as an improvement upon class A, which is the maximium a fossil fuelled system can achieve:

> *(17) Energy labelling of space and water heating products was introduced only recently and the rate of technological progress in those product groups is relatively slow. The current labelling scheme makes a clear distinction between conventional fossil fuel technologies that are at best class A, and technologies that use renewable energy, [...] for which classes A+, A++ and A+++ are reserved.*

In terms of the corresponding colour coding of the classes it could therefore be possible to start from B (orange) so as to indicate a constrained and sub-optimal location and then to label more optimal orientations and system designs A through to A+++ with the coding in different shades of green (see Figure 7-1).

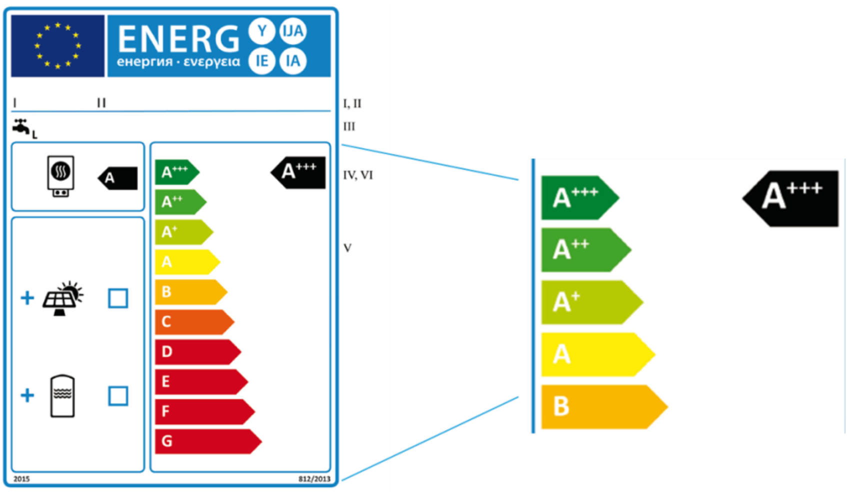

Figure 7-1: Annual. Water heaters label format, incorporating solar water heater scaling

Scope of the product group

In line with the findings reported in the Task 1 report and following on the stakeholder consultation on the preliminary evaluation, the product scope is proposed below. BIPV has been included within the scope as it is considered that the CSER for a product can be obtained and, based on feedback from stakeholders, yield information should also be provided for BIPV arrays. The diversity of BIPV products should in this case not pose an issue because only the yield is of concern and not other environmental impacts that may be influenced by the integration design. The issue of operating temperature will require attention within the yield calculation as BIPV products may not be as well ventilated.

Proposed Energy Label product scope

Modules (as part of a package)

The scope shall correspond to photovoltaic modules selected for use in photovoltaic systems for grid-connected electricity generation. This shall include Building Integrated Photovoltaic (BIPV) products.

Specifically excluded from this scope are:

- Modules with a DC output power of less than 50 Watts under Standard Test Conditions (STC)
- Modules intended for mobile applications or integration into consumer electronic products.

Inverters (as part of a package)

The scope shall correspond to inverters selected for use in photovoltaic systems for grid-connected electricity generation.

Specifically excluded from this scope are:

- Central inverters that are packaged with transformers (sometimes referred to as central solutions) as defined in Commission Regulation (EU) No 548/2014 on Ecodesign requirements for small, medium and large power transformers.

Systems

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

The scope is limited to grid connected systems installed on residential buildings and with low voltage connections that facilitate self-consumption of the electricity generated by the occupants. This shall include Building Integrated Photovoltaic (BIPV) systems made up of one discrete array consisting of a homogenous PV product.

Residential package energy label option 3.1: Simplified approach based on component efficiency

This first option is simpler to calculate as for both components it is proposed to be based on efficiency standardised rating or efficiency metric. The Energy Efficiency Index (EEI) could be based on the module efficiency (based on the power rating) or yield (energy rating) derated by the euro efficiency. This EEI would server as a proxy for improved yield.

Table 7-14. Energy label policy option 3.1: Efficiency-based EEI

Performance aspect	**Detailed proposed requirements**	**Modelling assumptions**
3.1 Package Efficiency-based approach	The package provider shall combine either: 1. the module power rating measured according to IEC 61853-1 under Standard Test Conditions and expressed as an efficiency, or 2. the module energy rating calculated according to IEC 61853-3 for the reference climate described in IEC 61853-4, with The Euro Efficiency is to be measured according to	The label is modelled to 2030 and that increasing numbers of package combinations achieve ratings of A+ and A++.

	EN 50530.	

In this scenario, a new label class differentiation could be created with five energy classes ranging from B to A+++. Bands of efficiency are then assigned to label classes based on a combination of the performance of the module and inverter models selected to form part of a package offered to consumers. An issue to take into account when establishing the number of label classes are the performance tolerance levels. According to the ENF Solar database the majority of module models had a tolerance of approximately +/- 5%.[24] Because of this relatively wide possible tolerance the number of label classes would be limited to approximately five.

Error! Reference source not found. shows an indicative energy label class distribution, together with an indication, per each class, of the typical values of inverter and module efficiency. In practice the energy class of the package would be derived from a derating of the module efficiency by the inverter efficiency, therefore combinations other than those of the table are also possible.

Table 7-15. Indicative Energy Label class distribution

Label class	Combined performance	Indicative module efficiency	% Models	Indicative inverter euro efficiency	% Models	Indicative technology packages
A+++		*>21.5%*	0%	*Empty*	0%	Tandem perovskite + MOSFET
A++	>19.6 – 21.6%	>19 – 21.5%	4%	>98%	11.6%	SHJ, bifacial + MOSFET
A+	15.3 – 19.6%	>16.5 – 19%	40.6%	>96 – 98%	55.5%	Mono PERC/PERT +String Central
A	12.2 - 15.3%	>14 – 16.5%	43.7%	>94 – 96%	16.4%	BSF, CIGS, CdTe +Micro-inverters
B	8.5% - 12.2%	9-14%	10.9%	<94%	16.3%	BSF, A-Si

Residential system energy label option 3.2: Yield and performance ratio based approach

This option is more complex to calculate but would have the benefit of accommodating a wider range of product performance characteristics, reflecting site specific conditions in the field. It would also allow for system designers to tailor yield estimations to the specific parameters of the installation and to reflect the quality of the electrical design, including the use of low-loss wiring. There would be the potential to later certify the calculated energy rating of the 'as-installed' design, in a similar way to building Energy Performance Certificates (EPCs).

Task 1 identified previous attempts by labels to establish system design and yield criteria. One of the main problems encountered was the need for agreement on a common calculation method which could be used by all actors in the market. Within the frame of the transitional methods under development a simplified tool for modelling and reporting on a system yield is therefore proposed. This would include default values for a number of derate factors within the Performance Ratio of a system. System and site specific values could be entered by designers.

Whilst the main information on the label could be calculated for a reference EU climate, there are distinct variations in performance between module products in different climate zones. For example, some modules have

[24] The ENF solar directory identified that of the 34,405 models of PV modules listed as being supplied in the EU, there are 27113 that have a tolerance between +/-5%. This represents 80% of the modules.

a lower temperature co-efficient and will perform better in a warmer climate. Design choices specific to the site and the electrical configuration would also be taken into account.

For the calculation of the system yield and performance a ratio it is proposed that the following design and derate factors are factored into the yield calculation:

- The solar radiation for the location,
- The orientation and inclination of the module array,
- the energy rating (CSER) and yield calculation for the modules, which includes for temperature dependency and spectral response,
- the degradation rate of the modules,
- the Euro efficiency of the inverter(s),
- System losses from:
    - module mismatch,
    - AC and DC wiring,
    - Diodes and connectors
    - Inverter temperature derating
    - Shading,
    - soiling.

For certain input parameters data would be needed from the module and inverter manufacturer, whereas for others either prescribed or site specific values could be used. It is anticipated that this Energy Label option would have the effect of encouraging the selection of modules and inverters to achieve higher yields, as well as system designers and installers to offer to clients design options that are optimised to site conditions and which have lower Performance Ratios.

Table 7-16. Energy label policy option 3.2: System yield-based EEI

Performance aspect	**Detailed proposed requirements**
3.2 System yield-based approach	The system provider shall follow instructions for the calculation of the overall yield derived from the Performance Ratio for the system design. In addition: – The calculation shall be representative of a notional 30 year service life. – The derate factors to be considered, together with prescribed (default) values, are to be provided in the Implementing Regulation. – The potential to report the PR for a reference location and up to 3 other representative EU climate zones shall be considered. The EEI shall be expressed in units of MWh/kWp.m^2. *Note: useful supporting information would be an average hourly energy output [kWh] profile per month to support calculating a building's energy consumption and to enable accounting for self-consumption.*
3.2.1 Module DC Performance Ratio input variable to the system EEI	The system provider shall calculate and normalise the module yield to kWh/m^2 for the system. The yield shall be derived from the CSER calculated according to IEC 61853-3. In addition: – The module yield shall be adjusted to take into account the declared linear degradation rate over 30 years. – The degradation rate shall be either the prescribed (default) value for the module technology or a field validated rate in accordance with the requirements in the Transitional Method.
3.2.2 Inverter AC input variable to the system EEI	The package provider shall use the inverter Euro Efficiency calculated according to EN 50530.

Various possible locations and configurations for a PV system should be reflected in the label. This is proposed as being achieve by including a yield calculation for the following three climate zones, as defined in IEC 61853-4:

- subtropical arid,
- temperate coastal, and
- temperate continental.

The PV system provider would have the option to choose between the use of prescribed (default) and user defined PV system configuration factors. in the calculated yield along a notional 30 year service lifetime would then be normalised to kWh/kW.m^2 as indicated in the example in

Table 7-17. For more details on the calculation, please see the separate calculator tool which forms part of the supporting Annex on Transitional Methods [25].

[25] Joint Research Centre, *Transitional methods for PV modules, inverters and systems in an Ecodesign Framework, Technical Report, 2019*

Table 7-17. Draft indicative lifetime PV system AC Energy yield (kWh/kW.m²)

	PV system configuration		**Energy Label**	
Climates	Default	User defined	**Default**	**User defined**
Subtropical arid	2159	3325	**D**	**B**
Temperate coastal	942	1450	**D**	**B**
Temperate continental	1216	1873	**D**	**B**

Taking into account the consideration of perception and the potential to use the approach applied to solar water heaters, an indicative label scale and the sensitivity by climate zone is shown in Table 7-18.

Table 7-18. Draft energy label classes classified by the lifetime energy yield of a PV system in three different climate zones

	Lifetime AC Energy yield (MWh/kW.m²)		
Energy Label	**Subtropical arid**	**Temperate coastal**	**Temperate continental**
A+++	> 3.61	> 1.58	> 2.04
A++	[3.61 - 2.93)	[1.58 - 1.28)	[2.04 - 1.65)
A+	[2.93 - 2.24)	[1.28 - 0.98)	[1.65 - 1.27)
A	[2.24 - 1.55)	[0.98 - 0.68)	[1.27 - 0.88)
B	< 1.55	< 0.68	<0.88

As for other product categories that are covered under Energy label requirements, a QR matrix barcode could be addedwhich would refer to the European Product Database for Energy Labelling (EPREL), where the main input parameters for selected module and inverters could be gathered.

To date, there are already a few examples of energy labels on packages/systems, in particular on water heaters, space heaters and solid fuel boilers[26]. Guidelines have been prepared in order to clarify the responsibilities of manufacturers, dealers and installers[27]. Comments from stakeholders on this kind of label, gathered in the context of the ongoing review study on the Ecodesign and Energy Labelling measures on space and combination heaters (task 1, in particular[28]), highlighted some areas for potential improvement, summarised as follows:

- potential user groups are not familiar with the label or do not recognise its benefits,
- enforcement (i.e. market surveillance) is considered insufficient,
- installers rarely use this label, which, on the contrary, is mainly used by manufacturers to show the higher rating of the package of heater, temperature control, heat pump and/or solar device.

[26] See Commission Delegated Regulation (EU) No 811/2013, Commission Delegated Regulation (EU) No 812/2013 and Commission Delegated Regulation (EU) No 2015/1187

[27] https://ec.europa.eu/energy/sites/ener/files/documents/guidelinesspacewaterheaters_final.pdf

[28] https://www.ecoboiler-review.eu/downloads/20190326_Boiler%20TASK%201%20draft%20final%20report%20Mar%202019.pdf

Policy option 4: EU Ecolabel criteria set

Description:
A criteria set would be established that would apply to a combination of a package placed on the EU market and the related system design and installation service offered to consumers.

Rationale:
To foster green innovation in module and inverter design and improve the environmental performance and quality of photovoltaic installations. A dual focus not just on yield improvements, but also on long term durability, repairability and dismantleability to support recycling and reuse, is considered important because of the projected mass deployment of photovoltaic systems. It is therefore important to signal which aspects of design and operation should be the focus of attention in order to avoid future environmental problems that can be anticipated to arise from management of the stock of modules and inverters.

An approach focussed on the two key components of a system is considered to be justified because they are business to business (B2B) components of all PV systems and so the criteria could support the choice of products with a superior environmental performance at the point of being placed on the market to distributors, retailers and installer. Modules and inverters could therefore be labelled as intermediate products, allowing installers and designers to choose EU Ecolabelled components to offer as part of an EU Ecolabel PV system service 'offer'. Moreover, aspects of the system 'offer' are important in the delivery of a long lasting, high performance system to consumers.

Evidence:

- PV market: Projections for PV deployment continue to be revised upwards and as yet only a small proportion of the market potential has been realised. Long-term issues arising from design quality, performance degradation, short replacement cycles and end of life handling can be addressed through better product design,
- Modules: both the Task 5 LCA review and Task 6 results show that there is margin to reduce the life cycle primary energy use by choosing the best products currently available in the market. Moreover, in locations with lower solar resource there is the need to minimise it in order to have a better energy payback time. A further distinction can be made by referring to life cycle GWP. This allows for the level of decarbonisation of the energy networks where products are manufactured to be differentiated.
- Inverters: the results of Task 6 showed that the most significant opportunity to improve the life cycle performance of inverters is by extending their life time and ensuring they are repairable. They can also play an important role in supporting better system performance if they include smart monitoring and, in the case of larger systems, fault diagnosis capabilities.
- Service/system design: a review of literature on minimising LCOE was made in the preliminary report for the EU Ecolabel and GPP. This revealed the importance of the staff training and capabilities in the following aspects when providing a service:
  - surveying and simulating the installation conditions,
  - electrical engineering in solar energy systems, and
  - protocols for the handling and transport of modules.

Expected benefits:

- Benchmarks would be established in the market for products with reduced environmental performance along their life cycle and for the quality of services provided to consumers.
- A focus on the whole life cycle, hazardous substances and circular aspects, including durability, that have been requested by a broad cross section of stakeholders.
- The criteria could, for inverters, drive a focus on repairability and customer support – particularly for the sub-20 kW market segment – and promote their role as a digital gateway to system performance monitoring.

Possible drawbacks:

- If the criteria were not compatible with the EPEAT Photovoltaic Modules and Inverters Product Category criteria there could be duplicated efforts to establish labels with different criteria.
- Whilst there appears to be interest from the sector, there is a risk with a multi criteria set that no one

product can comply with all criteria.

- It is not clear that there is a consumer demand for the higher environmental performance of modules, inverters or services, as opposed to a higher yielding and more profitable photovoltaic system.

Proposed EU Ecolabel criteria set under Policy Option 4

Scope of the product group

In line with the findings reported in the Task 1 report and following on the stakeholder consultation on the preliminary evaluation, the product scope and definition are proposed as follows:

Proposed EU Ecolabel product scope

Modules (as part of a package)

The scope shall correspond to photovoltaic modules selected for use in photovoltaic systems for grid-connected electricity generation.

Specifically excluded from this scope are:

- Modules with a DC output power of less than 50 Watts under Standard Test Conditions (STC)
- Building Integrated Photovoltaic (BIPV) products that incorporate solar photovoltaic cells
- Modules intended for mobile applications or integration into consumer electronic products.

Inverters (as part of a package)

The scope shall correspond to inverters selected for use in photovoltaic systems for grid-connected electricity generation.

Specifically excluded from this scope are:

- Central inverters that are packaged with transformers (sometimes referred to as central solutions) as defined in Commission Regulation (EU) No 548/2014 on Ecodesign requirements for small, medium and large power transformers.

Systems

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

The scope is limited to grid connected systems installed on residential buildings and with low voltage connections that facilitate self-consumption of the electricity generated by the occupants.

Findings of the feasibility evaluation

The background preliminary evaluation of the feasibility of having EU Ecolabel criteria was published in a separate document in support of the Preparatory Study[29]. Section 7 of the preliminary report presented the findings of an LCA hot spot analysis which, together with the other requirements established by the Ecolabel Regulation (EC) 66/2010 including a review of existing standards and ecolabels, was used to identify a set of possible first criteria areas.

A qualitative evaluation, which was made with reference to DG Environment's criteria for establishing new product groups, found there to be feasibility but indicated some areas of uncertainty. A summary as presented to the EU

[29] Draft options and feasibility evaluation for the EU Ecolabel and GPP, 10/04/19, JRC evaluation report, http://susproc.jrc.ec.europa.eu/solar_photovoltaics/docs/190410_PV_Prep_study_Ecolabel_and_GPP_Preliminary_Consultation_Draft.pdf

Ecolabel Board is provided in *Table 7-19*. An important linked issue identified by stakeholders would be the need to complement performance metrics and requirements used in any mandatory policy measures brought forward, with the EU Ecolabel extending or making stricter those requirements.

Table 7-19. Summary findings from the EU Ecolabel preliminary feasibility evaluation

Evaluation criteria	Finding	Observations
1. Feasibility of definition and scope	To check	Possible focus on kits/packages for residential systems (<5-10 kW) and service offer, but the point of award would need clarification
2. Existence of other ecolabels and schemes	Uncertain	Three standards/labels have criteria that could be reflected in an EU Ecolabel criteria but, to date only one has been awarded to a PV product.
3. Market significance	Uncertain	No specific products can be identified that would achieve all of the identified improvement potential. A points system could allow for flexibility in award.
4. Visibility	Positive	A high profile green product but the degree of visibility for the EU Ecolabel may depend on the point of sale for the PV system or components
5. Potential uptake	To be seen	An industry consortium made a proposal for PV modules in 2015/6. This suggests there are potential verifiers and some manufacturers interested/ready to bring products forward for labelling.
6. Alignment with legislation and standards	Positive	Moderate>strong contributing role was identified in implementating some of the main objectives of energy, construction, electrical equipment and circular economy.
7. Environmental impacts analysis	Variable	There is the potential for performance improvement. There is a lack of performance metrics, performance benchmarks and/or standardised methods for several of the possible criteria areas.

Options for broad criteria areas

Based on this preliminary work, an approach is proposed that is mainly targeted at residential systems of <10 kWp. Taking into account the need for prior verification of products or services by EU Ecolabel Competent Bodies in a selected Member State, two options are proposed for consideration for a multi-criteria set:

1. Package approach: There would be criteria for modules and inverters. The criteria would extend the focus of policy options 2 and 3 on life cycle hot spots, hazardous substances and circular design, introducing more demanding criteria and performance thresholds.
2. Service approach: There would be criteria for the main components of a PV system (i.e. modules and inverters) together with criteria covering aspects of the service provided by system installers. Service aspects could include:
    - the system design factors taken into account, including factors influencing the Performance Ratio
    - the protocols used for the transport/handling of modules;
    - the installation of monitoring capabilities, and
    - the provision of maintenance/aftercare services

It is proposed to combined the benefits of the two approaches. Thefirst would allow for the specifics of the two 'hot spot' components of a residential system to be addressed, whilst the service is considered to represent a more consumer-facing aspect that could create added value for installers using the label.

Findings from Task 6 and the LCA hot spot analysis

The Task 6 results for PV modules have shown that on the lead indicator used, primary energy, the margin for reduction between the best product and the base case, is 31%. For the BAT, CIGS, the margin for reduction is 24%. It is important to note, however, that performance of the mono PERC 2020 and optimised mono PERC deliver a result that is within the margin of error of the BAT, whilst having a higher life cycle electricity yield (see the discussion below relating production and use stages).

It is notable that even with a lower module efficiency and a higher degradation rate the CIGS product still performs better overall when considering the whole life cycle. Secondary indicators were also identified – namely PAH, POP and heavy metals to air and water – that can be reduced by material efficiency in component and system design. However, the improvement from specific changes in specification – for example, to lead-free solder – have only a limited overall impact because of the inherent trade-offs in substituting them with other materials.

The LCA hot spot analysis carried out in Task 5 highlighted the important influence of the module cells, inverter circuit boards and, in the case of ground mounted systems, mounting structures, on the overall life cycle impacts. They also highlighted the impact of the long-term performance degradation rate on the life cycle primary energy use for some technologies. Indicatively an increase in the degradation rate from 0.5% to 0.7% would lower the energy yield by 7% meaning that environmental impacts would rise proportionally another 7%. Comparing a base case (30y, 0.5% degradation) to a case where lifetime is 30 years and the degradation rate increases to 0.7%), the environmental impacts would be 15 % higher compared to the base case. Criteria to minimise long-term performance degradation should therefore be considered.

The results of the hot spot analysis have also shown that it is important to consider the relationship between the life cycle impacts in the use phase and life cycle benefits of the energy generated by a PV system in the use stage. This relationship is not yet well accounted for or standardised in the LCA studies reviewed or in LCA standards such as the PEFCR or EN 15804. A number of methods exist to express this relationship, either on a relative basis (Energy Payback Time) or absolute basis (Energy Return on Investment) [30].

The ratio of the production phase primary energy investment and the electricity generated in the use phase can vary considerably between locations, and thereafter between products and systems. For multi-silicon module-based systems this Energy Return on Investment (EROI) ratio can be 1:4 or 1:7 if the modules are installed in Helsinki or Madrid respectively. There is therefore significant margin to reduce the EROI in climates with less solar resource.

For inverter, the results of Task 6 showed that the inverters designed for repair and a longer lifetime were closely matched in terms of the BAT and LLCC options. This is largely because of the anticipated reduction in the failure rate and the number of product replacements that would be needed.

Other areas of improvement identified by the LCA hot spot analysis that apply to both modules and inverters include the potential to reduce the content of metals such as copper and aluminium that contribute significantly to toxicity impact categories. As already noted, hazardous substances such as lead and cadmium contribute overall less strongly as well as bulk materials such as copper and aluminium. While requirements under the RoHS Directive don't currently apply to modules, the EU Ecolabel could include criteria controlling their presence and ensuring proper end of life treatment.

[30] IEA Methodological guidelines

The potential benefits of advanced yield monitoring and fault diagnosis for PV systems are also highlighted by the system results in Task 6. The two best performing PV system options rely on monitoring and fault diagnosis to support repair response and maintenance. Inverters can play a key role in providing the in-line data required to achieve these improvements but to date smart monitoring capabilities, such as SCADA integration and via field or modbus communication protocols, have largely only been integrated into the specifications of large inverters targeted at commercial and large-scale systems.

EU Ecolabel criteria set option 4.1: Residential package with services

A first possible set of criteria has been configured based on the Preparatory Study findings to date, the draft evaluation report and feedback from stakeholders. The criteria address the key environmental hot spots for both modules and inverters – the manufacturing and life cycle management of module cells and inverter circuit boards - as well as addressing supporting services that could be offered by designers and installers which have the potential to address priority areas for improvement identified in Task 4 – including site specific design to optimise yield, and electrical design and ongoing maintenance to minimise losses.

It is proposed that the products scope for the package with services approach is the residential market segment, although the scope shall be written in such a way that the collective or community purchase of solar PV systems shall be included. In addition it shall be possible to use the criteria for GPP purposes.

Because the EU Ecolabel is a voluntary instrument it is difficult to estimate the possible impact of this proposed criteria set. The assumption used for the modelling is the achievement of an annual take-up of 5% of new residential systems by 2030. The improvement potential is assumed to be based on a comparison with the base case 3 kWp residential system and base case module and inverter components.

Table 7-20. Ecolabel criteria set for modules, inverters and services

Performance aspect	**Detailed requirements**
4.1 Energy and CO_2 criteria	
4.1.1 Energy return on investment	The EU Ecolabel applicant shall calculate the energy return on investment for the module and inverter package. The EROI should be below [*to be determined*]. *The production and use stage primary energy use shall be derived using the method set out in the corresponding Ecodesign information requirement, which is proposed as being based on EN 15804 and the PEFCR.*
4.1.2 Life cycle GWP	The EU Ecolabel applicant shall calculate the life cycle GWP for the module and inverter package. The kg/CO_2.kWh shall not exceed [*to be determined*]. *The life cycle impacts shall estimated according to method set out in Ecodesign, which is based on EN 15804 and the PEFCR.* *Note:* there is an option to provide default values in tabular form as has been done by the French Government for the national PV capacity auction process.
4.2 Hazardous substances criterion This criterion will require the formal 'derogation' under Articles 6(6)/6(7) of the EU Ecolabel Regulation (EC) No. 99/2010 of a number of substances that may be present in modules and inverters.	
4.2.1 Candidate list substances	The IEC 62474 substance declaration shall be used to declare that Candidate list substances are not present at >0.1%

4.2.2 Lead and cadmium	The content of lead and cadmium in modules and inverters shall be less than 0.1% and 0.01% respectively. By weight or by Wp The cadmium level may be >0.01% if recovery of the semi-conductor can be demonstrated as part of a take back service provided.
4.2.3 Fluorinated backsheets	Module products shall be manufactured without fluorinated backsheet materials.
4.2.4 Glass additives	Antimony and arsenic in glass shall each not be present at >50 ppm
4.2.5 Flame retardants and pthalates	*The hazard restrictions of the personal computer product group on cables and main circuit boards shall apply*.
4.3. Circular economy criterion	
4.4.1 Module durability and quality	Design type approval proposed as an Ecodesign requirement shall be implemented by an audited factory quality control system in accordance with IEC TS 62941 and IECRE OD 405.
4.3.2 Module degradation rate	Declaration of the rate shall be validated by the Transitional Method for Ecodesign and demonstrate an average performance degradation rate over a 30 year time period of 0.6%
4.4.3 Module design for recycling	The manufacturer shall document and report the sequence of steps and tools required to dismantle the module and recover the solar cells or semi-conductor material. *Note: the possibility exists to base this criterion on product specific standard if developed in accordance with the forthcoming horizontal standard for recyclability prEN 45555.*
4.4.4 Inverter on-site repair service	The installer shall ensure that a responsive repair service is provided for inverters, with on-site replacement of the main circuit boards forming part of the service.
4.4.5 Repairability requirements for inverters	<30 kW: The manufacturer shall ensure that the power, filter and communications circuit boards, as well as firmware updates, shall be made available for a minimum period of 7 years. >30 kW: Manufacturers shall ensure that replacement parts and firmware updates are made available in line with the recommended replacement cycle. *Note: the possibility exists to base this criterion on a product specific standard if developed in accordance with the forthcoming horizontal standard for repairability prEN 45554.*
4.5 System service criteria	
4.5.1 Optimised design	The system design shall be optimised taking into account the specific local conditions of the installation. The service provider shall demonstrate that the system design software used takes into account, as a minimum: – Orientation and possible shading, – Local climatic conditions, including temperature dependency – Exposure/access to the inverter

4.5.2 Handling and installation protocols	The contractors used to install the system shall follow a protocol designed to minimise any breakages to modules during transport to and handling on site.
4.5.3 Monitoring and maintenance	The service shall include, for a minimum of 10 years, the monitoring of the system for faults and a responsive repair and maintenance service designed to optimise performance. This shall include, as a minimum: – Fault diagnosis, – Repair and replacement cycles for major components, and – Cleaning of the modules.

Policy option 5: Green Public Procurement (GPP) criteria

Description: A criteria set would be established that would apply to the process of procuring a solar PV system, from contractor selection through to decommissioning. Additional options would be for a public authority to play a role in boosting solar PV installations either in the residential sector by acting as an intermediary or by contracting new capacity via Power Purchase Agreements.
Rationale: The public sector has a substantial stock of buildings and land on which solar PV could potentially be installed. Once a decision has been made to procure solar PV systems a public authority can in most cases exert an influence on the competencies of contractors, the design of systems, the specification of components and this influence is direct in most cases. In the case of reverse auctions or the procurement of electricity this influence can be extended to third party, installations.
Evidence: o Modules: both Task 5 LCA review and Task 6 results show that there is margin to reduce the life cycle primary energy use by choosing the best products currently available in the market. Moreover, in locations with lower solar resource there is the need to minimise production stage impacts in order to have a better energy return on investment. o Inverters: the results of Task 6 showed that the most significant opportunity to improve the life cycle performance of inverters is by extending their life time and ensuring they are repairable. They can also play an important role in supporting better system performance if they include smart monitoring and fault diagnosis capabilities. o Service/system design: a review of literature on minimising LCOE was made in the preliminary report showing the importance of the capacity of contractors in the following aspects when providing a service: surveying and simulating the installation conditions, in the electrical engineering of solar energy systems and having protocols for the handling and transport of module.
Expected benefits: o Guidance will be provided that any public authority could use in order to procure competent contractors, quality components and high quality systems with a good yield and performance ratio. It would also support the monitoring of the performance of systems upon installation. o The criteria could address both life cycle environmental impacts and the cost and value of installing a PV system. The criteria can be structured to minimise life cycle cost, minimise exposure to unexpected failures and maximise electricity revenue. o Local residential installations could be boosted by acting to bring down the costs (indicatively by 20-30%, based on 0.1-0.3% household annual installation rate) of each installation and by increasing confidence in the service and components.
Possible drawbacks: o Public authorities may prefer to procure solar electricity rather than engage in the installation of systems and the associated cost and risk. o Public authorities may not use the criteria because of pressure to focus only on minimising initial capital cost rather than life cycle cost. o As a voluntary criteria set only the easier criteria may be used so that only some of the expected benefits would be realised. The overall criteria set may only therefore be used by a limited number of front runners.

Scope of the product group

In line with the findings reported in the Task 1 report and following on the stakeholder consultation on the preliminary evaluation, the product scope and definition are proposed as follows:

Proposed GPP solar photovoltaic system scope

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

The scope is limited to grid connected systems at all scales. This shall include the provision of energy generated by solar PV systems as a service via arrangements such as Power Purchase Agreements. . It shall also include street furniture that incorporates solar photovoltaic cells

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

- For integration with street lighting and electric vehicles
- Systems in which there are modules with DC output power of less than 50 Watts under Standard Tests Conditions (STC)
- Substations and transformers for power conditioning

Findings of the feasibility evaluation

The background evaluation for possible Green Public Procurement (GPP) criteria was published in a separate document in support of the Preparatory Study[31]. Section 7 presented the findings of an LCA hot spot analysis which, together with a focus on Life Cycle Cost (LCC), required as part of GPP criteria development, was used to identify a set of possible criteria areas. A specific focus on minimising the Levelised Cost of Electricity (LCOE) of electricity generated by systems installed by public authorities is proposed.

A qualitative evaluation made with reference to DG Environment's criteria for establishing new product groups, found there to be broadly feasibility. A summary is provided in Table 7-21. An important linked issue identified by stakeholders would be the need to complement performance metrics and requirements used in any mandatory policy measures brought forward, with the GPP extending or making stricter those requirements. Reference is also usually made to EU Ecolabel criteria when establishing the ambition level for Comprehensive GPP criteria.

Table 7-21 Summary findings from the GPP preliminary feasibility evaluation

Evaluation criteria	**Finding**	**Summary**

[31] Draft options and feasibility evaluation for the EU Ecolabel and GPP, 10/04/19, JRC evaluation report, http://susproc.jrc.ec.europa.eu/solar_photovoltaics/docs/190410_PV_Prep_study_Ecolabel_and_GPP_Preliminary_Consultation_Draft.pdf

Step 1: Contribution to objectives	Positive	• Support **greater deployment** and **yield optimisation** • Reduce or **manage environmental impacts along the life cycle** of solar PV systems and components • Contribute towards **achievement of grid parity** for the LCOE of solar electricity
Step 2: Determine the added value of GPP to existing policy instruments	Positive	Potential to play a strong role in promoting **better systems and components** – with a focus on quality, hazardous substances and circular design - but also through **novel procurement routes**
Step 3: Determine if GPP is the most effective instrument to achieve the objectives	Positive	Public sector has a substantial stock of buildings and land on which solar PV could potentially be installed: • the potential influence on the design and specification of components is **direct** in most cases • reverse auctions or the procurement of electricity could **extend this influence** to: - third party, citizen installations – new solar capacity under PPAs
Step 4: Determine the best form of GPP implementation	See draft proposal	A combined focus on **product** (e.g. quality), **works** (e.g. protocols) and **services** (e.g. maintenance) is proposed.

GPP criteria option 5.1: Improved PV system life cycle performance

The GPP policy option is based on the same environmental analysis presented in support of the EU Ecolabel criteria under policy option 4. In addition a focus is introduced on the project management of a PV system installation. This could extend from contractor selection through to decommissioning. An overview of the proposed criteria set is presented in Table 7-22.

As well as an overall focus on minimising the life cycle environmental impact of a solar PV system, the criteria would also be based on the findings of recent studies of solar PV projects that have analysed strategies to minimise LCOE and 'mitigation' risk. In Tasks 3 and 4 and in the EU Ecolabel and GPP evaluation report specific prioritised actions were identified to manage solar PV system procurement processes in order to:

- optimise the site specific potential to generate solar power,
- minimise risks to loss of income from quality issues that may arise related to equipment and the installation itself,
- minimise the LCOE along the life cycle of a project.

From the analysis made by a number of studies priority mitigation measures can be identified based on Cost Priority Number (CPN) analyses and insurance claims, and based on this evidence, the potential impact on LCOE and bankability. These measures can be grouped into preventative and corrective measures. The combined effect can be estimated to have the potential to reduce annual potential economic losses (measured as CPN) by more than 80%. The evidence from insurance claim analysis also suggests that exposure to internally and externally caused damage can also be minimised, with the cost of incidents having the potential to be in the range of 40-100 €/kWp in year 1 of operation, rising to between 140-150 €/kWp in year 10 [32]. The cost and time incurred in remedial work can also have a dramatic impact on projected payback period for projects.

The modelling assumptions for take up of these voluntary criteria are based on the public sector installation rate for solar PV systems. No distinction is made at this stage between core/comprehensive GPP criteria. It is initially

[32] Insurance claim research report reference to be inserted

estimated that 4% of annual system capacity is accounted for by public buildings to which 20% could have criteria applied to it by 2022, 40% by 2024 and 80% by 2026 onwards. These assumptions could be revised upwards if retrofit installations on public housing stock were to be included in relevant countries.

Table 7-22. GPP criteria set for PV system procurement

Performance aspect	**Detailed proposed requirements**
Module and inverter factory quality and performance testing	
5.1.1 Design quality of modules and inverters	*Technical requirement for design qualification and factory quality*: – Core: Design type approval of each model deployed according to IEC 61215 and IEC 62941 – Comprehensive: Factory quality controls and auditing according to IEC TS 63157 and the associated IECRE OD *[pending a code*].
5.1.2 Module degradation rate	*Award criteria based on declared module degradation rate.* Points shall be awarded based on the validated performance degradation rate period expressed as the average annual % loss over a 30 year time. The transitional method shall be used as the basis for verification.
Design and yield estimation	
5.1.3 Energy return on investment	*Award criteria based on declared system EROI.* The EU Ecolabel applicant shall calculate and declare the energy return on investment for the system. *The production and use stage primary energy use for the modules and inverters specified shall be derived from the method set out in the corresponding Ecodesign information requirement, which is proposed as being based on EN 15804 and the PEFCR.*
5.1.4 Life cycle GWP	The EU Ecolabel applicant shall calculate the life cycle GWP for the system. The kg/CO_2.kWh shall not exceed *[threshold tbd*]. *The life cycle impacts shall estimated according to method set out in Ecodesign, which is based on EN 15804 and the PEFCR.* *Note:* there is an option to provide default values in tabular form as has been done by the French Government for the national PV capacity auction process.
5.1.4 System energy yield	*Award criteria based on an estimate of the system yield (with reference to the Energy Label EEI)* The system provider shall make a design estimate of the system yield based on the methodology for calculating the Energy Label EEI. The EEI shall be expressed in units of MWh/kWp.m^2. The contractor shall also declare a target plant Performance Ratio. Under a contract performance clause the yield and target plant performance ratio the installed system shall then be monitored according to IEC 61724.
Installation/ construction	
5.1.5 Handling and installation protocols	*Selection Criteria evidencing the use of such protocols and/or Technical Specification requiring specific actions within a protocol.* The contractors used to install the system shall follow a protocol designed to minimise any breakages to modules during transport to and handling on site.

5.1.6 Commissioning test	*Contract performance clause based on the target plant Performance Ratio* A commissioning test shall be carried out according to IEC 61724 in order to evaluate the Performance Ratio of the system. The commissioning PR shall be compared with the target plant Performance Ratio declared at bid stage.
Operation & Maintenance	
5.1.7 Inverter preventative repair cycle	*Technical Specification based on planning to respond to inverter manufacturers recommended repair cycle* In order to use a longer inverter lifetime than the default for the life cycle GWP calculation manufacturers shall provide a recommended preventative maintenance cycle. This shall include a list of parts recommended to be replaced and preventative measures to achieve an intended design technical lifetime.
5.1.8 Monitoring	*Technical Specification/Award Criteria for the granularity of monitoring system* Manufacturers shall ensure that the system design supports class [*B or C*] data monitoring according to IEC 61724-1. The system shall have physical and/or wireless connectivity capable of communicating with remote monitoring systems using a recognised data transfer protocol.
5.1.9 Maintenance	*Technical Specification/Award Criteria for the provision of aftercare services* The service shall include, for a mínimum of [*award*] years, a repair and maintenance service designed to optimise performance. This service shall include, as a minimum: – Fault diagnosis, – Responsive repair and planned replacement cycles for major components, and – Cleaning of the modules.

GPP criteria option 5.2: Facilitating increased residential system installations

As was highlighted in the draft evaluation report the GPP criteria set could also be used to boost residential deployment by promoting and providing a framework and criteria for 'reverse auctions'. A reverse auction process would see the public authority establishing criteria for the performance of installation services offered to local residents. This option consists of a two part group buying process that is managed by the public authority:

1. the registration of households interested in installing a system on their home, followed by
2. a subsequent supplier shortlisting and tender process to select an installation company on the basis of price and service offers for the registered households.

The public tender for the service may include quality specifications for the systems offered to households, including monitoring systems and an extended guarantee for each system. The auction process also has as a principle objective a reduction in the unit price of each system, with indicatively a price reduction of 35% on market rates obtained in the reference case analysed in the preliminary evaluation. This reduction is anticipated to decline in subsequent procurement rounds. The quality criteria are envisaged as mirroring some of those of the GPP proposal outlined in policy option 5.1, addressing both PV system components and the service provided.

The modelling assumptions for increased residential take-up are based on use of this process by those cities taking part in the Covenant of Mayors for climate and energy initiative. Of the EU local authorities that are signatories 23% (2,156) have established monitored initiatives on the ground [33]. For a small city of 50,000 inhabitants an initial take-up in the first round of 30 homes could be assumed, increasing to 60 and then 120 in subsequent 6 monthly procurement rounds[34]. If this were to be extrapolated to 400 of the 800 local authorities in the EU with a population greater than 50,000 this would approximate to 288 MW of new capacity per annum from 2022 onwards.

GPP criteria option 5.3: Using electricity purchasing to support new capacity

Stakeholders highlighted the potential to use the electricity purchasing power of public authorities to support the installation of new solar PV capacity. Whilst recent research for DG ENV in support of revised EU GPP green electricity criteria cast doubt on the additionality from criteria that request green certificates as a form of verification, there could be potential for new installations to be tied to bilateral solar Power Purchase Agreements (PPAs). This could also be linked to the provision by the public authority of the sites and/or roofs where the PV systems can be installed.

The subject matter of tenders would be the purchase of electricity generated by new solar photovoltaic system capacity. The scope to include further criteria on how the electricity is to be generated – for example, the environmental performance of the modules or inverters used - would require further investigation, as it may be beyond the legal scope of such a call for tender.

Modelling assumptions have not been developed yet at this stage pending discussions on the legal potential of this type of criteria.

[33] Covenant of Mayors for climate and energy initiative, Accessed 2019 https://www.covenantofmayors.eu/about/covenant-initiative/covenant-in-figures.html

[34] This assumption is based on the London reverse auction where out of the 12 boroughs involved the first round achieved 4000 registrations of which 1000 were converted into installations.

Policy option 6: Combined policy options

It could be considered to combine a number of options that have been evaluated, given that each of them can act in a different way to achieve different improvements in the market. Some of the possible synergies that could be achieved are briefly analysed in Table 7-23. The two combined options have been taken forward for modelling as the synergies between the mandatory and voluntary instruments are considered to be an important aspect.

Table 7-23. Evaluation of policy combinations

Policy combination	**Advantages**	**Disadvantages**
Mandatory Ecodesign (mandatory) + Energy Label (mandatory)	• The Ecodesign requirements can provide a performance metrics and test methods that act as uniform criteria for products entering the market • The Energy Label can help consumers to choose more efficient system design offers in the market and to expect more from system providers. • The metrics established for Ecodesign would provide input data for the Energy Label EEI	• The Energy Label would have to carefully designed so as not to impact on confidence in the market and the number of installations • Care would also need to be taken with the Ecodesign thresholds not to prevent emerging technologies from entering the market
Voluntary EU Ecolabel (voluntary) + GPP (voluntary)	• EU Ecolabel criteria usually provides the basis for comprehensive GPP criteria • Both criteria sets can address the full life cycle performance of the products including any trade-off between yield and GER • GPP might enhance the take-up of the EU Ecolabel products	• A low take-up of the EU Ecolabel may limit the number of pre-verified products meeting ambitious environmental criteria • Both instruments have a degree of uncertainty as to the take-up
Combined option 1 (COM 6.1) Ecodesign (mandatory) + Energy Label (mandatory) + GPP (voluntary)	• The metrics established for Ecodesign and the Energy Label would provide metrics and benchmarks for used in GPP • Enables procurers to follow the recommendations in the Energy Efficiency directive to use labelled products • Enables procurers to relate the yield of a PV system to the energy payback time •	• May result in conflicting information if a high performing system has components that cannot meet the GPP module/inverter criteria
Combined option 2 (COM 6.2) Ecodesign (mandatory) + EU Ecolabel (voluntary) + GPP (voluntary)	• Complementarity – ecodesign would cut off the worst performing products whilst the other would reward the best performers and extend the minimum requirements. • The Ecodesign requirements can provide a performance metrics and test methods for criteria within the EU Ecolabel • The voluntary instruments would address broader life cycle aspects of performance •	• Ecodesign does not provide a basis for criteria at system level.- • Both instruments have a degree of uncertainty as to the take-up

Further potential policy options using other EU policy instruments

In addition to the four policy instruments that are the focus of this Preparatory Study, the potential to use other existing policy instruments to act on aspects of solar PV performance has also been identified. This could be considered for inclusion within future revisions of two important Directives that were identified as being of relevance in Task 1 – the Renewables Directive and the Energy Performance of Buildings Directive. One important possible role for these instruments could be to encourage the entry of BNAT technologies into the market that offer improved life cycle performance.

Policy option 7.1: Renewables Directive member state capacity auction requirements

Module and inverter quality and/or performance requirements could be considered for inclusion in any public PV capacity auction process that takes place in member states. This approach has been applied in China and now in France. It is understood that one of the main drivers for the rapid entrance of module improvements such as PERx variants and TOPCon onto the global market has been the Chinese Top Runner requirements, to the extent that the EU now benefits from these products, both in terms of their performance and the manufacturing lines that EU companies supply to the Chinese to deliver the improved module performance.

Policy option 7.2 Energy Performance of Buildings technical systems requirements

Use of provisions within the EPBD that require member states to establish minimum performance requirements for major building renovations and technical building systems could be explored as a means to promote new performance and/or quality requirements. The 2010 EPBD states Article 8 that:

> *'Member States shall, for the purpose of optimising the energy use of technical building systems, set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings.'*

As was noted in Task 1 solar PV is included within the scope of technical building systems for which a simplified calculation method is provided as an extension to the harmonised method EN 52000. The current scope of technical building systems could be considered for extension to address performance aspects of solar PV systems.

7.2. Scenario analysis

The objective of this section is to set up a stock model (2015-2030) and calculate the impact of different policy scenarios regarding Primary Energy which was the leading parameter from Task 6, consumer expenditure and employment depending on the market evolution of PV modules, inverters and systems. The different policy options have already been identified and possible technical performance criteria and requirements outlined in section 7.1 above.

Modelling scenarios for assessing the impacts of the policy options taken are further described below. The calculated impacts for the different scenarios are indicative and are subject to the simplifications made in previous Tasks 5 and 6 to model the market and improvement options. Proxies are used to map the improvements modelled in Tasks 5 and 6 onto policy options and scenarios.

The analyses on the previous tasks have been extended to the defined scenarios in comparison with the Base case definitions in Task 5 and the Best Available Technologies (BAT) and Least Life cycle cost (LLCC) options identified in Task 6.

7.2.1. Scenarios overview

Different scenarios have been defined to illustrate quantitatively the improvements that can be achieved at the EU level by 2050 with suitable policy actions against the Business-as-Usual (BAU) scenario.

It is also important to mention that a fixed lifetime of 30 years has been assumed for the equipment. During this lifetime, repairs can be done, for example the replacement of inverters.

The reference case and main technical improvement option scenarios based on the findings of Task 6 are defined as follows:

- **Business as Usual (BAU) scenario:** the products placed on the EU market have the same level of performance as the Base Cases defined in Task 4 and market assumptions from Task 2 which were categorized according to their application field: 1 string inverter (residential segment), 3 string inverter (commercial segment) and central inverter (utility scale segment). The system base cases proposed are representative for the market segments of residential (3 kW), commercial (20 kW) and utility scale (1.5 MW), see Task 5. These BAU scenarios are also linked to module technologies modelled in Task 2, they are: Back Surface Field multicrystalline silicon (the 2016 base case), an updated base case to reflect the 2019/20 position, PERx silicon, PERx silicon bifacial, thin film modules (CIGS/CdTe), Hetero-junction(HJT/BJT) and back contact monocrystalline silicon.
- **The Task 6 Best Available Technology and system (BAT) scenario:** It is a proxy scenario that implements all the potential improvements possible from maximum uptake of BAT technologies as identified in Task 6, thereby estimating the policy impact at both product level and system level. This scenario is set up to provide a benchmark of use as a basis for the EU Ecolabel and GPP scenarios, which are strongly based on promoting BAT. This scenario combines greater deployment of the BAT module technologies (CIGS for residential and CdTe for commercial/large scale), BAT inverter technology (longer life products) and BAT systems (design optimisation with improved operation & maintenance).
- **Ecodesign scenarios for modules and inverters:** Taking into account the time needed to elaborate and implement any regulation, the regulation is assumed to enter into force in 2022 under the scenario. Within the Regulation two policy Tiers are considered:
  - Tier 1 policy in place in 2022 and will assume effect in the scenario calculations from 2023 onwards
  - Tier 2 policy in place in 2022 and will assume effect in the scenario calculations from 2025 onwards

  The four variants of the Ecodesign scenario (2.1-2.4) have been modelled separately and in combination for the products, with each having effect on various performance aspects for the two sub-products. The module design option ‘further optimisation of BoM’ and the inclusion of additional benefits from the ‘design for recycling’ of future PERC bifacial module designs are used as proxies in order to account for improvements resulting from new designs and material selections. Option 2.5 was proposed as an information requirement only.

- The Ecodesign performance requirements on modules on life time yield scenario (MOD 2.1): It is a proxy scenario for the proposed Ecodesign policy options (2.1) on modules.
- The Ecodesign performance requirements on module performance on quality, durability and circularity (MOD 2.2): It is a proxy scenario for the proposed Ecodesign policy options (2.2) on modules.
- The Ecodesign requirements on inverters efficiency and life time electricity yield scenario option 2.3 (INV 2.3): It is a proxy scenario for the proposed Ecodesign policy options (2.3) on inverters.
- The Ecodesign requirements on inverters on quality, durability and circularity scenario option 2.4 (INV 2.4): It is a proxy scenario for the proposed Ecodesign policy options (2.4) on inverters.

- **The simple residential package energy package label option 3.1 (LAB 3.1 and 3.1++):** It is a proxy scenario for a simple label based on component efficiency for the residential market to model policy option 3.1.
- **The system residential energy label option 3.2 (LAB 3.2):** It is a proxy scenario for an installers label based on encouraging higher yields from residential system designs under policy option 3.2.
- **The advanced residential EU Ecolabel criteria for packages and services option 4.1 (LAB 4.1 and LAB 4.1++):** It is a proxy scenario for an advanced label to model policy option 4.1.
- **The GPP scenario options 5 (5.1):** It is a proxy scenario for a combination of BAT for modules, inverters and systems. A simple estimate of the possible increase in residential stock is also separately modelled for 5.2.
- **The combined effect of mandatory and voluntary options (COM 6.1 and 6.2):** It is a representation of how the policies could be combined to achieve synergetic effects in the market.

Module option 2.1 is expected to have a tiered introduction from 2023, taking full effect from 2025.

Modelling of these scenarios is done by linking the market model based on Task 2 to improvement options that were calculated in Task 6. These options are used as proxies for substitutions in the stock relative to the base included in Annex **Error! Reference source not found.**. Additional assumptions have in some cases had to be applied in order to adjust the results to account for, for example, improvements as a result of factory quality systems. Label scenarios LAB 3.1, LAB 3.2 and LAB 4.1 combine the substitution of product combinations with other market effects as described below:

- LAB 3.1 + assumes a combined effect with MOD 2.1 and INV 2.3affecting the performance distribution curve of market, thereby enabling more systems to enter class A. Also it assumes a substitution of other less efficient module products by more efficient products (2020 revised base case by PERC, PERC by SHJ or back contact IBC), but without an increase in installed capacity, i.e. less modules are installed to achieve the same 3 kWp system rating. The model therefore represents the combined effects of 2.1 and 3.1.
- LAB 3.1++ is a more optimistic LAB 3.1 scenario that assumes that modules are substituted in a “like for like” fashion and there is therefore an increase in the installed capacity using the same roof area and with a resulting increase in energy yield of approximately 18% (in the residential sector). This is based on the proxy of the 2020 revised base case module technology being substituted by PERC, SHJ or back contact IBC module technology, as the driver of consumer choices would be based on yield.
- LAB 3.2 is similar to the LAB 3.1 scenario in that it assumes that modules are substituted in a “like for like” fashion and there is therefore an increase in the installed capacity using the same roof area and with a resulting increase in energy yield of approximately 18% (in the residential sector). System proxies with a higher Performance Ratio (>80) become more prevalent in the stock model. Because some of the

building stock will have inherent constraints such as east-west orientation, chimneys and parapets an assumption has been made that 50% of the systems installed would be restricted to B class.

- LAB 4.1 assumes a gradual uptake of the module and inverter BAT technologies, together with system design option elements in the residential market segment. The take-up is conservative, assuming 5% of new systems annually by 2030.
- LAB 4.1++ is a more optimistic LAB 4.1 scenario that assumes both a gradual uptake of the BAT combinations in the residential market segment from 5% in 2024 rising to 30 % by 2030 and also the installation of more generation capacity on roofs as a result (as per 3.1++).

In addition the GPP scenario 5.1 is described as follows:

- LAB 5.1 is a similar scenario to LAB 4.1 to model GPP policy option 5.1, it assumes an uptake of BAT options and that 12% of commercial stock (BC2) is affected and that BAT would be applied to 20% of stock by 2022, then 40% by 2024 and 60% by 2026.

7.2.2. Scenario analysis (unit stock/sale & environmental)

Policy option 1: Business as Usual (BAU)

A Business as Usual (BAU) scenario was built upon the market input data, using the assumptions described in section 7.1.3.3 (Policy option 1) and data from Annex A. The model is subdivided by market segment (residential, commercial and large scale) and per module technology in MWp of annual sales, see Figure 7-2for the overall market projections. It is important to note that the PV market is fast moving and already the stock model includes some uptake of Task 6 design options which may weaken the potential impact arising from the proposed policy options in the medium to long term. The diffusion of BNAT options into the market is also uncertain and could be a further disruptive influence on the stock model.

The annual build-up of stock is based on the best available assumptions for specific periods in time rather than a continuous time series. In the juncture between each period changes in policy are assumed which result in a staggered change in PV system annual sales. The initial period to 2023 is the result of the projected end of large scale subsidies in a number of major Member States. 2030 is a key milestone for EU and Member State target setting.

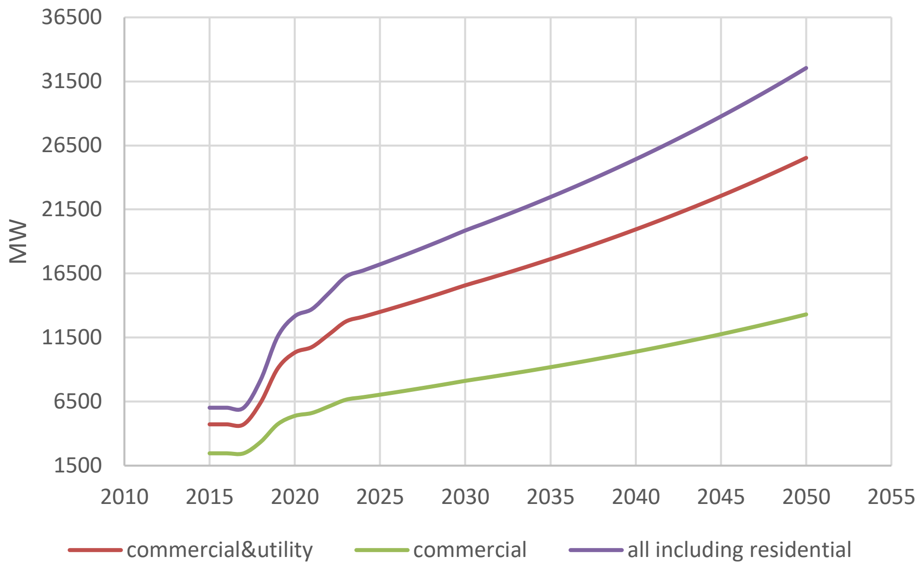

Figure 7-2: Annual new stock MWp per market segment

For the purpose of this study a tailored scenario calculation spreadsheet was developed taking into account the impact from all life cycle stages that was derived from the Ecoreport tool from Task 6. It is based on the leading parameter selected in Task 6, which is Gross Energy Requirement (GER) from an LCA perspective. It therefore enables also extra waste streams to be added at the End-of-Life and during the life time (per year), e.g. for the replacement of inverters and/or the repair of components.

The approach to the modelling of inverter lifetime is intended to be compatible with the typical failure metrics for electronics (e.g. MIL-HDBK-217), which are based on failure rates [%/y] or its reciprocal value expressed as Mean Time Between Failure (MTBF). It approximately models the failure rate 'bathtub' (Weibull) distribution curve (Figure 23, Task 3) by using constant failure rates which are midlife failures occurring in between premature failures and wear out failures. Premature or warranty failures are herein assumed to be similar to manufacturing drop out and End of Life wear out. In this study a fixed life time of 30 year is assumed in line with the functional unit proposed in Task 1 and also the proposed economic system life time.

The model also allows for the calculation of the Capital Expenditure (CAPEX) and the Operational Expenditure (OPEX) per respective year. All cost values are discounted to the reference year of 2016. The model always assumes that a full photovoltaic system is presented, meaning that when a module improvement is added the impact of this improvement option is always analysed in the context of a reference system environment. As a result, the interpretation of the scenarios should be made relative to the BAU rather than to the absolute value when considering a particular policy option. The values for all calculated scenarios are in Annex C

For calculating the improvement potential both the Annual Yield (TWh) and the Gross Energy Requirement (GER) were calculated for all scenarios. When looking to the scenarios it is important to look at the impacts on both the Yield and GER, because the forecasted impact is a combination of effects between which there may be trade-offs. Improvements in performance efficiency are mostly reflected in greater yield so that the GER per functional unit is reduced correspondingly along the lifetime.

Improvements in the production stage performance are mostly reflected in a reduction in GER per functional unit, but in some cases can affect the long term yield either positively or negatively, e.g. a module may be BAT but have lower efficiency than other design options, a module performance degradation improvement will increase lifetime yield in turn reducing the GER per functional unit. Ideally a third metric is required that links together these variables – for example, Energy Return on Investment (EROI) – and is proposed to be used in the context of the two voluntary instruments.

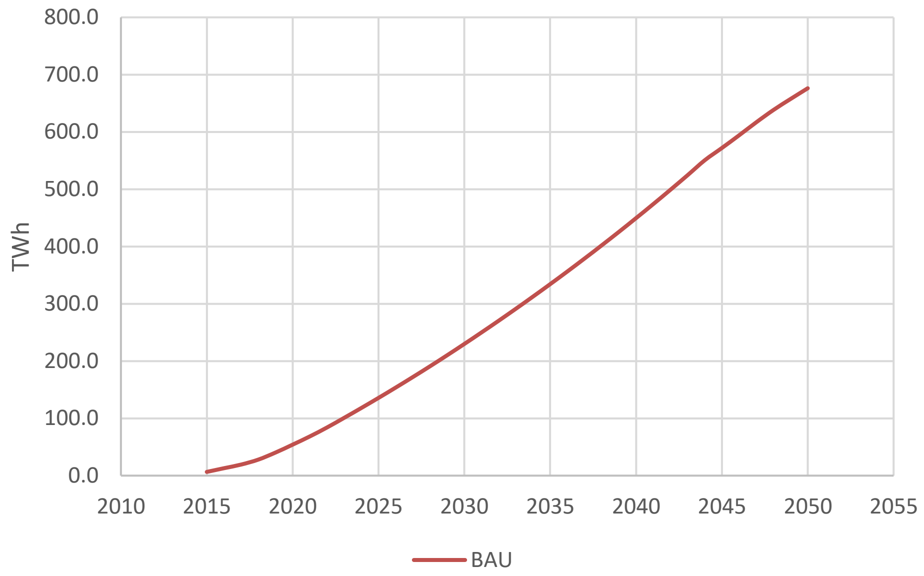

Figure 7-3 and Figure 7-4 presents the annual yield (TWh) and the GER (TWh) (Gross Energy Requirements) for the BAU. Herein 1 TWh GER equals 3600 TJ. The scenario forecasts about 120 TWh additional electricity generated in 2030 due to the stock increase of PV systems between 2015 and 2030. It is therefore not the total annual yield from PV in the EU which is higher due to stock of PV installed before 2015; but this is left out of the scenarios because with the performance of pre-existing stock cannot be significantly influenced by future policy unless specific repowering assumptions were to be applied from 2035/40 onwards. Worth noting is that the primary energy or GER for manufacturing in 2016 (

Figure 7-4) is 1.500.000 TJ or 41,7 TWh which is 6.4 times the power generated in 2016 (6,48 TWh) from the installed PV systems, this indicates that there is an initially energy investment required before there is a break-even point.

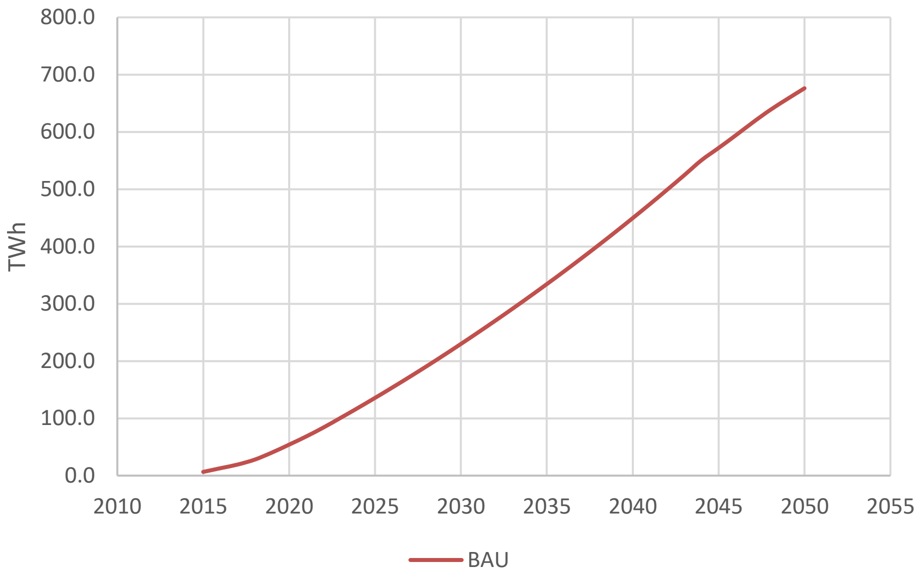

Figure 7-3: Annual yield for BAU PV systems

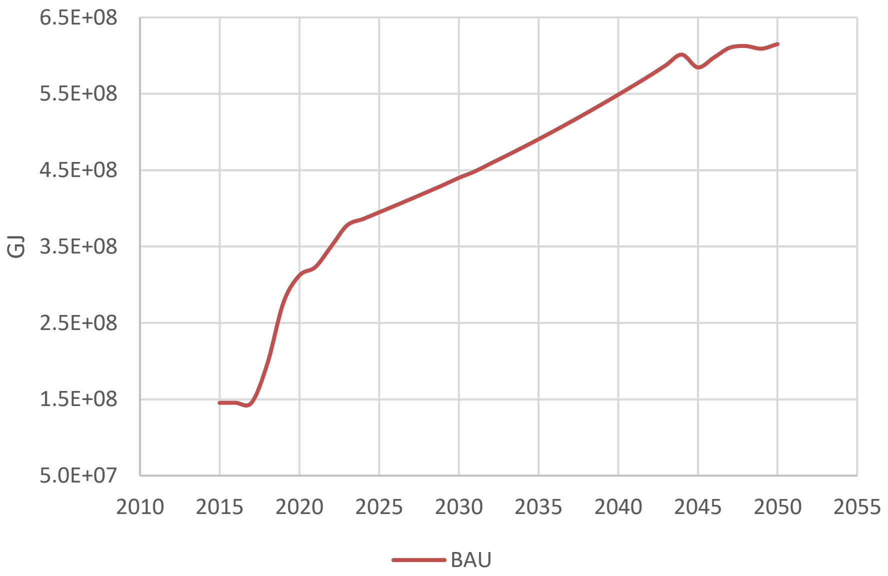

Figure 7-4: Gross energy requirements for the BAU for modules, inverters and systems

Policy option 2: Ecodesign requirements

The proposed scenarios for modules **MOD 2.1** and **MOD 2.2** (Figure 7-5 and Figure 7-6) apply to all market segments and the results show the improvement upon the overall system stock performance but with a change only in the module component. The results have a relatively weak but increasing long-term impact because they remove a small underperforming proportion of the market (see Annex C) and because a threshold for reduce degradation is not specified, only an information requirement. No appreciable change in yield can be seen because the installed capacity is assumed to remain the same. The yield result is likely an underestimate because only modules with the base case efficiency (16%) has been substituted in the stock model, whereas models with a performance as low as 9% are on sale.

In contrast **MOD 2.1++** assumes a modest increase in yield as higher power modules replace standard modules on a like for like m^2 basis, resulting in more installed capacity. Values for this scenario are in Annex C.

The policy options MOD 2.1. and MOD 2.2 are combined in MOD COM 2.1/2. Because of an overlap between the technology options in regards to the two types of performance improvement the effects is not as great as a summation of the improvement potential from MOD 2.1 and MOD 2.2 (see Figure 7-5 and Figure 7-6).

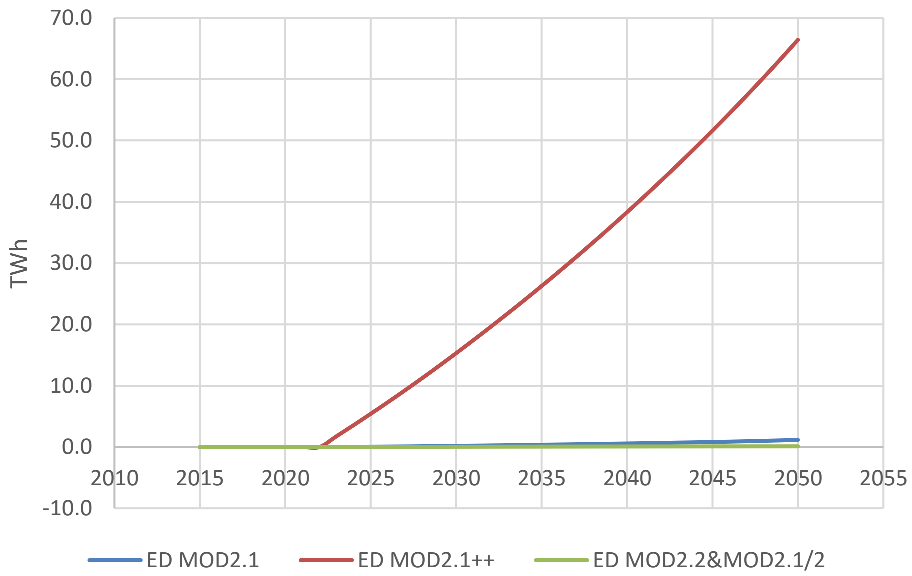

Figure 7-5 Annual Yield relative to the BAU for Ecodesign module policy options

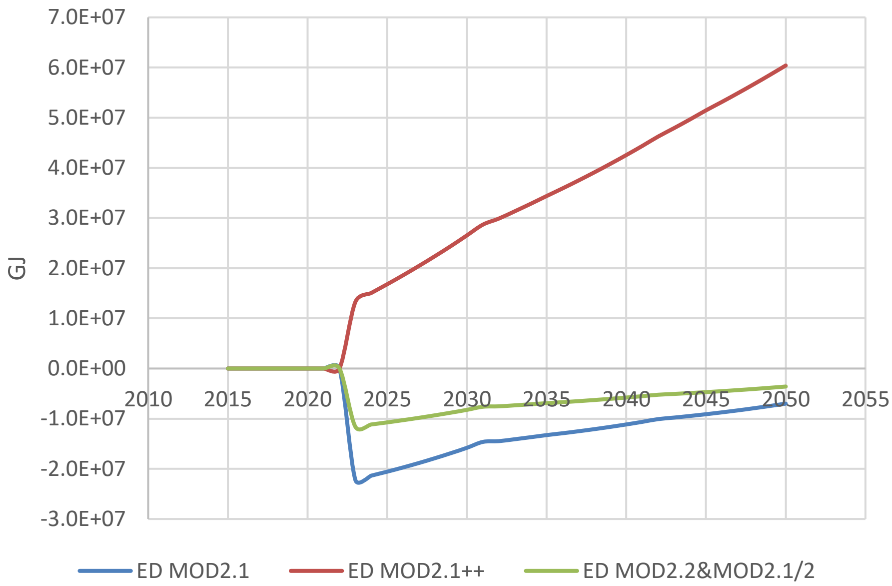

Figure 7-6 Gross Energy Requirement (GER) relative to the BAU for Ecodesign module policy options

The scenario with Ecodesign requirements on **inverter efficiency INV 2.3**, see

Figure 7-7 and Figure 7-8; applies to all market segments and the results show the improvement upon the overall system stock performance but with a change only in the module component. No appreciable increase in the yield can be seen as the substitution of lower Euro Efficiency products only achieves a minor improvement in yield because of the small overall the margin for improvement. A minor decrease in GER can be seen, due to a reduction in the inverter capacity needed. The yield result is likely an underestimate because only inverters with the base case efficiency (96%) have been substituted in the stock model, whereas models with a performance as low as 93% are on sale.

The Ecodesign requirements on the **quality, durability and circularity of inverters INV 2.4**, see

Figure 7-7 and Figure 7-8; has been applied only to the residential sector because the improvement potential was mainly identified in this segment and because the design options are already commonplace in the other segments. The results show a decrease in the GER due to less need for inverter components but the impact is relatively low because in the full system, inverters have a lower proportional contribution to GER impact relative to modules (see Task 6). Values for this scenario can be found in Annex C.

The policy options INV 2.3. and INV 2.4 are combined in **INV COM 2.3/4**, with the effects summing up those obtained individually for each option, see

Figure 7-7and Figure 7-8.

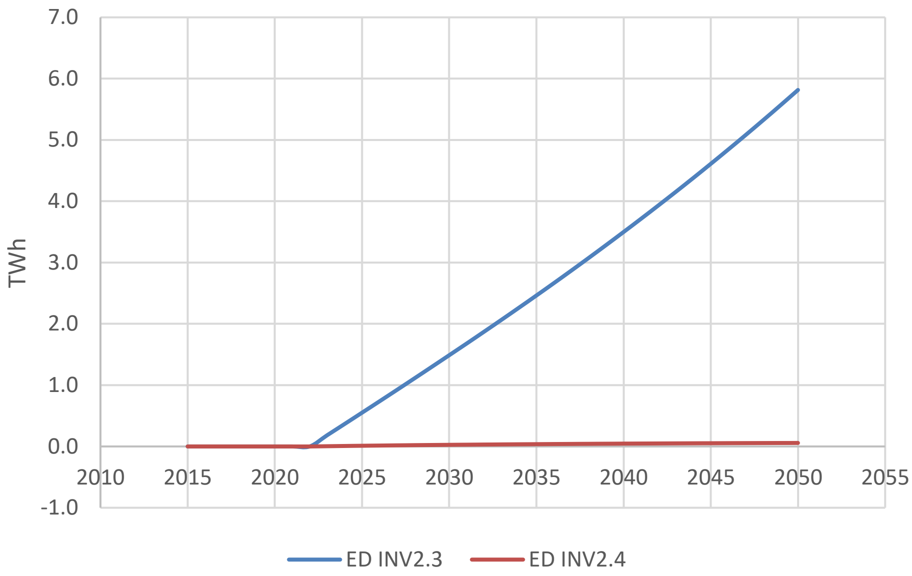

Figure 7-7 Annual Yield relative to the BAU for Ecodesign inverter policy options

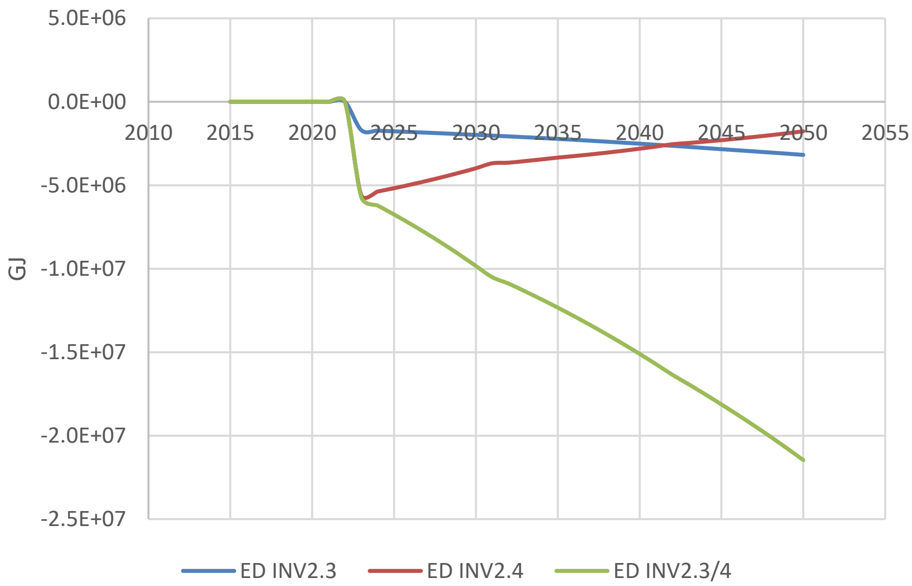

Figure 7-8 Gross Energy Requirement (GER) relative to the BAU for Ecodesign inverter policy options

Policy option 3: Energy Label

The **package energy label LAB 3.1** applied to the residential market segment is included in Figure 7-9 (3.1- and 3.1). The figures show a moderate impact because it was assumed to phase out class B only in the LAB 3.1- scenario and because lower performance modules are not assumed to be substituted on the same like for like area (m^2) basis, so it is likely a conservative estimate of its impact. No appreciable change in the yield can be seen for LAB 3.1 and LAB 3.1- because only a reduction in the module stock area in m^2 to deliver the same MWp is assumed. LAB 3.1 has combines the effect of the Ecodesign cut offs in MOD 2.1 and INV 2.3 with assumptions about a modest market shift to module products in higher label classes (Reference base case>PERC, PERC>SHJ/back contact).

The effects of a more optimistic scenario for the energy label LAB3.1++ is applied as well to the residential market, as also shown in Figure 7-9 and

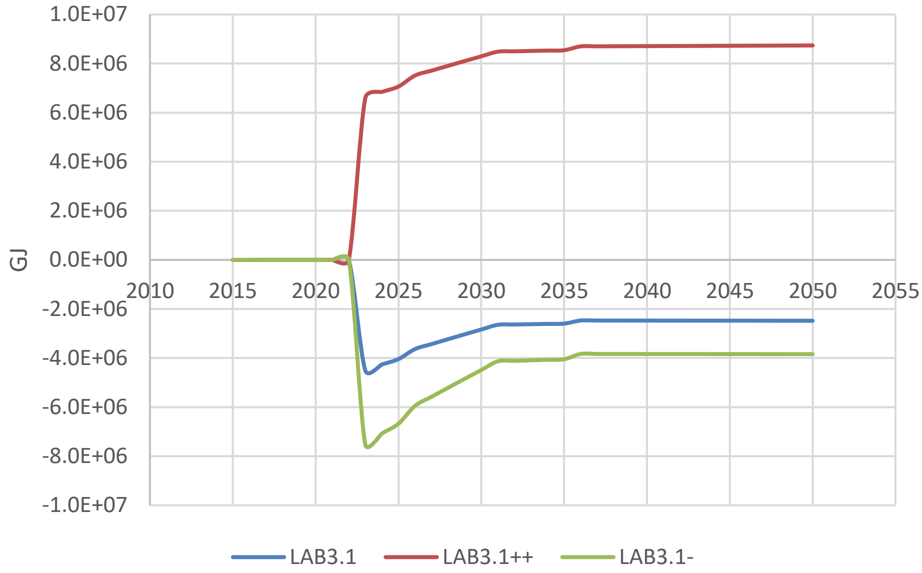

Figure 7-10. This assumes an increase in yield as higher power modules replace standard modules on a like for like area (m2) basis, resulting in more installed MWp capacity (e.g. 3 kWp system with BSF modules substituted by mono PERC modules increases to 3.5 kWp with an 18% yield increase).

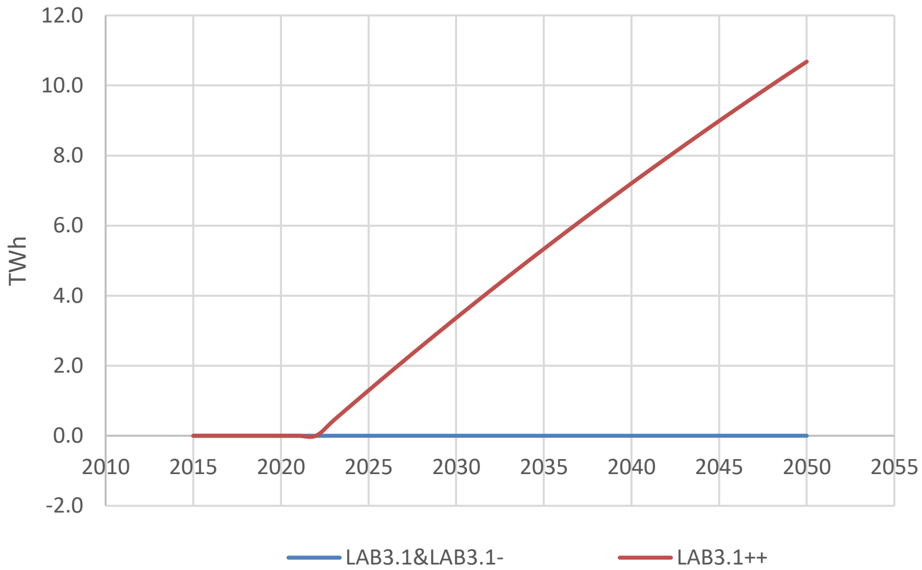

Figure 7-9 Annual Yield relative to the BAU for Energy Label policy option 3.1

It is noteworthy that the effect of the increased yield in LAB3.1++ is to increase the GER for the stock above the BAU. This is because the higher power modules that would fill the higher scales of the energy label have a greater GER per functional unit (see Task 6).

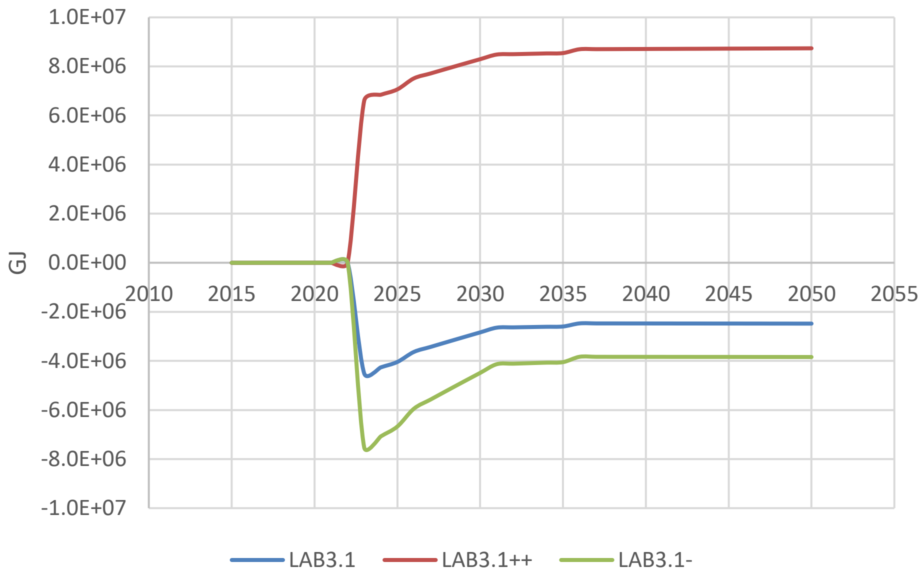

Figure 7-10 Gross Energy Requirement (GER) relative to the BAU for Energy Label policy 3.1

The impact of policy option **system energy label LAB 3.2** as applied to systems is similar to that of 3.1, but with a stronger improvement in yield in the case of the optimistic scenario LAB 3.2++ (see Figure 7-11). This is in part due to assumptions related to the use of higher yield modules with lower temperature co-efficients, such as SHJ designs, as well as a shift in the distribution curve for stock system Performance Ratios. The same trade-off can be seen in the GER, with higher yield and greater deployment increasing associated production stage impacts (see Figure 7-12).

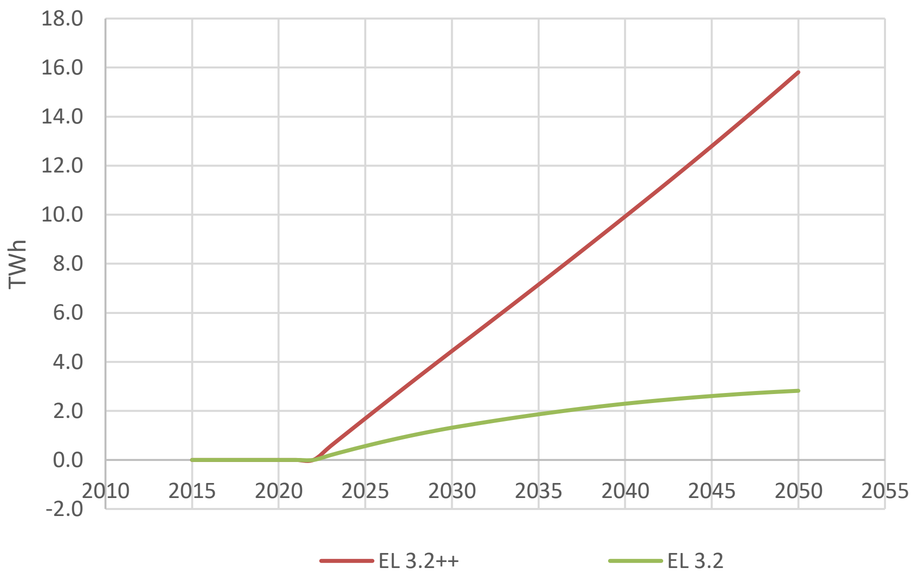

Figure 7-11 Annual Yield relative to the BAU for Energy Label policy option 3.2

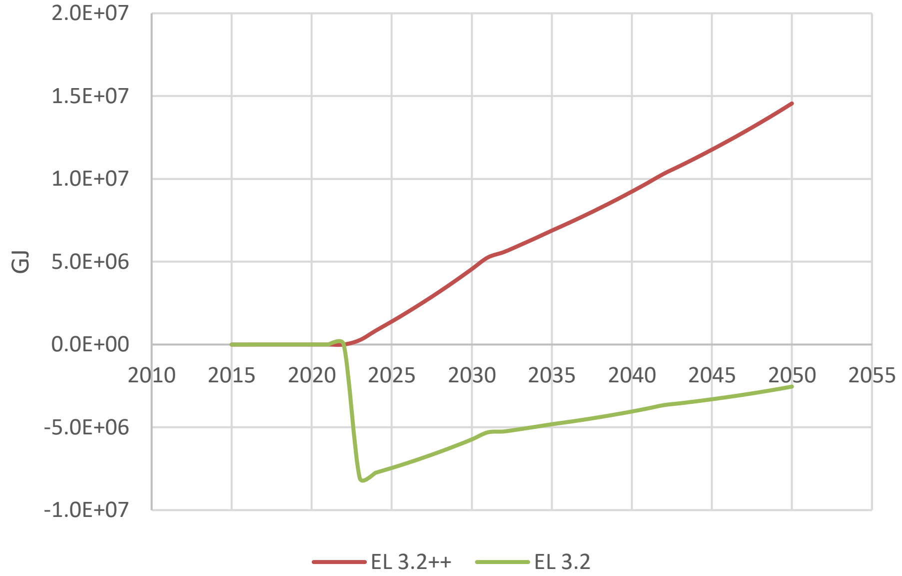

Figure 7-12 Gross Energy Requirement (GER) relative to the BAU for Energy Label policy 3.2

Policy option 4: EU Ecolabel

The **residential EU Ecolabel criteria for residential packages and services LAB 4.1** assumes a relative low uptake of the EU Ecolabel (up to 5% annually after 10 years). As explained in the introduction also a more optimistic scenario LAB 4.1++ has been modelled that assumes a drive in the market created by the EU Ecolabel (up to 15% annually after 10 years) and a resulting installation of more capacity. Values for this scenario can be found in Annex C.

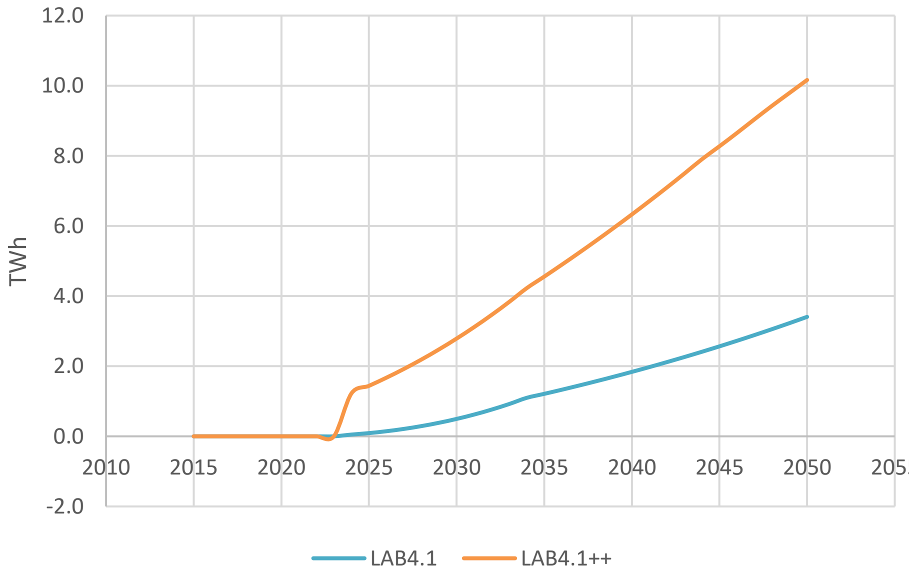

Figure 7-13 Gross Energy Requirement (GER) relative to the BAU for EU Ecolabel policy options

Notably the increase in market confidence and consequently yield associated with option LAB 4.1++also results in an increase in GER. In order to understand whether this trade-off would still deliver an overall environmental benefit the Energy Return on Investment (EROI) requires analysis. The criteria proposal for an EROI threshold could, moreover, be used to minimise the trade-off.

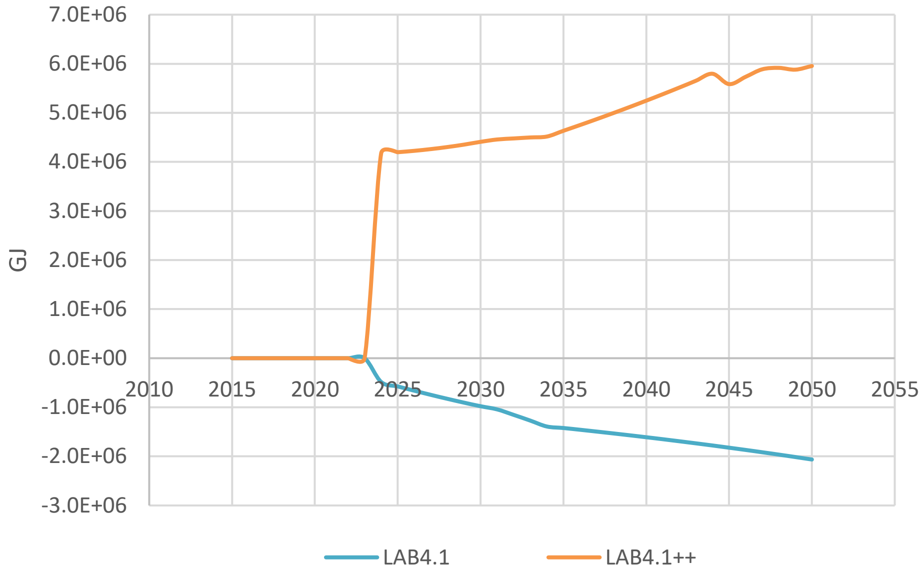

Figure 7-14 Gross Energy Requirement (GER) relative to the BAU for EU Ecolabel policy options

Policy option 5: Green Public Procurement

The projected results for the public solar PV systems GPP 5.1 policy option are in Figure 7-15 and Figure 7-16 It is built on the commercial market segment and the uptake of BAT by the public sector within this segment (12 % of annual installation capacity).

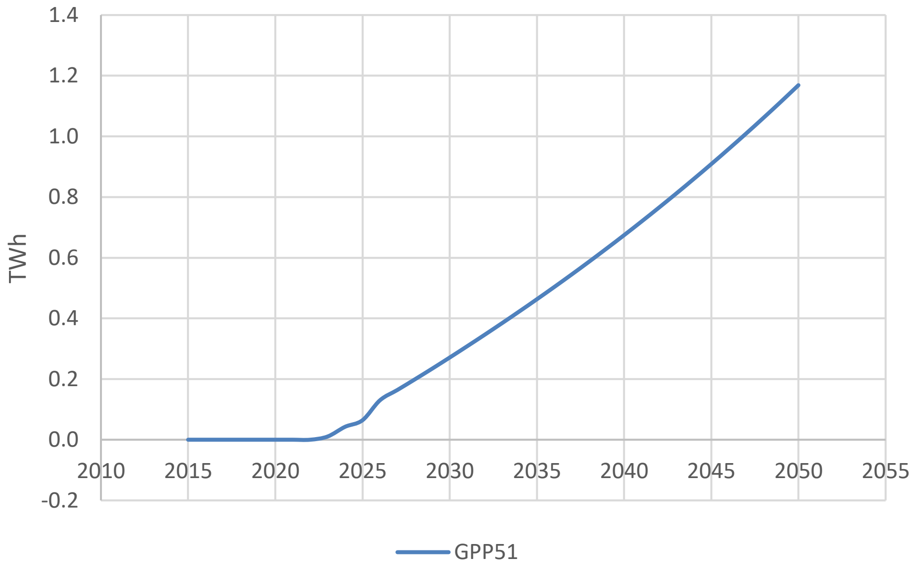

Figure 7-15 Annual Yield relative to the BAU for the GPP 5.1 policy option

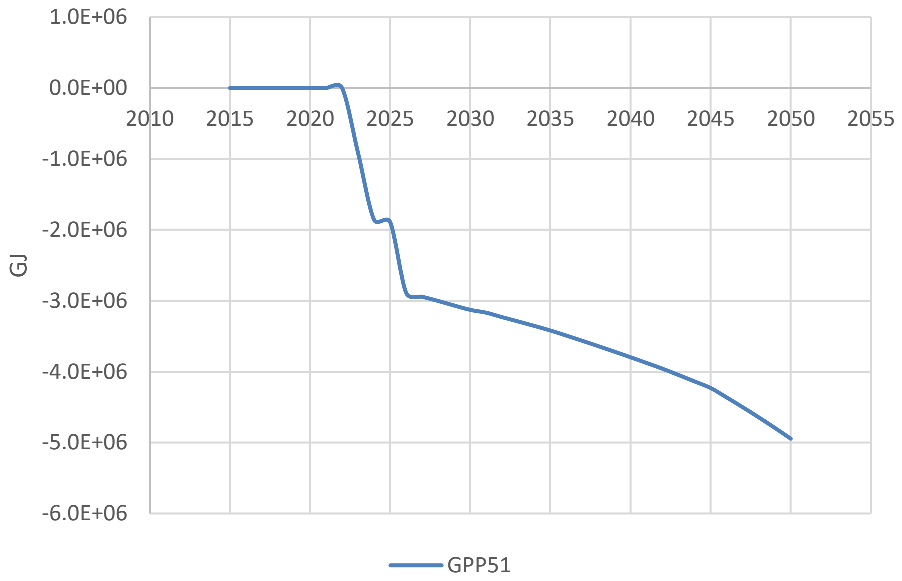

Figure 7-16 Annual Gross Energy Requirement (GER) relative to the BAU for the GPP5.1 policy option

For the further policy option GPP 5.2, only a simplified scenario for the possible increase in stock is shown in order to illustrate the potential impact on the market (Figure 7-17). Even with the modelling being based on relatively conservative assumptions (see Section 7.1.3.3, Policy option 5) the potential impact could be significant, representing an increase in the annual stock additions of approximately 30% in 2023 falling to 20% by 2050.

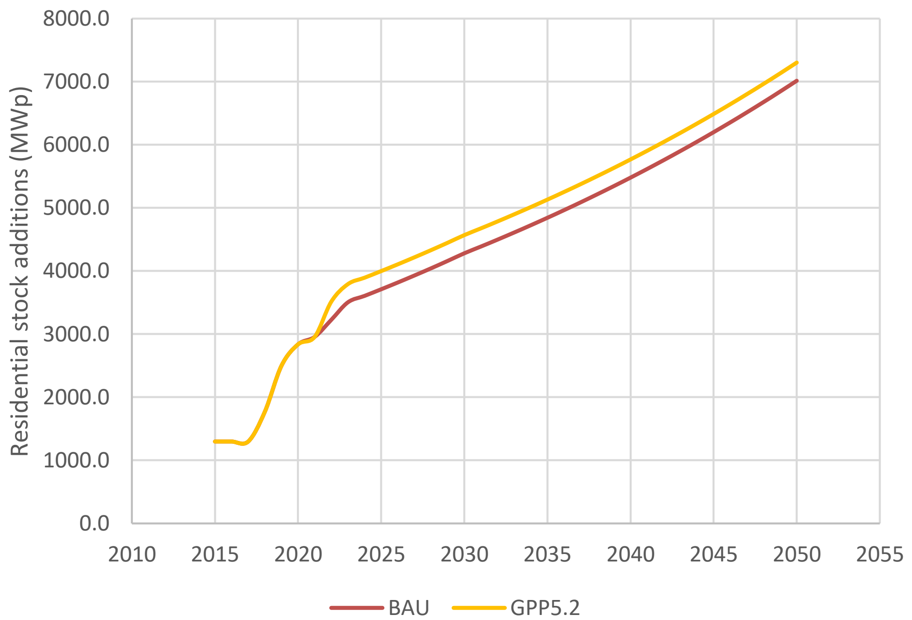

Figure 7-17 Annual stock for the GPP 5.2 policy option in comparison with the BAU stock

Combined policy options 6

One of the aims of considering both mandatory and voluntary policy instruments within the frame of the Preparatory Study has been to analyse the potential for synergies between them. Two combined policy options have therefore been modelled in order to determine the improvement potential. The two combined options are:

- **COM 6.1 (ED+EL+GPP)** would be led by implementation of the two mandatory instruments, namely Ecodesign and Energy Labelling, to be complemented by voluntary Green Public Procurement criteria.
- **COM 6.2 (ED+GPP+EU Ecolabel)** would be led by implementation of the two voluntary instruments, namely the EU Ecolabel and Green Public Procurement, backed by the mandatory instrument Ecodesign.

The annual yield projections for the combined options are presented in Table 7-24 and Figure 7-18. It can be seen that COM 6.1 is estimated to provide the greatest improvement in yield until 2050, initially providing an uplift of 3.4% in 2025 rising to as much as 7.7% by 2035, versus an uplift of 2.4% in 2025 and 5.4% in 2035 for COM 6.2 The difference is accounted for assumptions made in COM 6.1 about efficiency gains and improved system yields driven primarily by substitution effects in the market from the Energy Label option 3.2.

More modest assumptions about similar effects that could be driven by the EU Ecolabel criteria set still drive up yield in COM 6.2 but not to the extent of the Energy Label 3.2 option and in fact the assumptions about market confidence made for the EU Ecolabel can be considered to have a higher level of uncertainty due to it being a voluntary instrument. This could therefore increase the gap between the performance of the two options. Note also that the potential for an increase in residential deployment, as modelled in option 5.2, is not included in COM 6.1 or 6.2.

The annual GER projections are presented in Table 7-24 Evolution of Improvements in annual yield relative to the BAU for the COM 6.1 and 6.2 policy options and Figure 7-19. The most beneficial for yield is COM 6.1 whilst the most beneficial for GER is COM 6.2. Here it can be seen that COM 6.2 achieves the greatest improvement, providing a benefit of up to 21% on the BAU by 2035. This improvement is largely driven by the mandatory Ecodesign part of the option, supported by the EU Ecolabel. The more modest improvement of 4-5% achieved by COM 6.1 is the result of a trade-off between the higher yield it achieves and, in order to achieve this yield, the deployment of module technologies that have a higher GER.

Table 7-24 Evolution of Improvements in annual yield relative to the BAU for the COM 6.1 and 6.2 policy options

	Scenario COM 6.1 (ED+EL+GPP)		**Scenario COM 6.2 (ED+GPP+EU Label)**	
Year	**Stock yield (TWh)**	**Improvement against the BAU (TWh)**	**Stock yield (TWh)**	**Improvement against the BAU (TWh)**
2015	6.5	0.0	6.5	0.0
2020	54.1	0.0	54.1	0.0
2025	140.4	4.8	139.0	3.3
2030	244.1	14.3	239.8	9.9
2035	360.1	25.8	352.3	18.1
2040	489.2	39.7	477.5	28.0
2045	628.1	56.2	611.9	40.0
2050	751.0	74.9	729.6	53.6

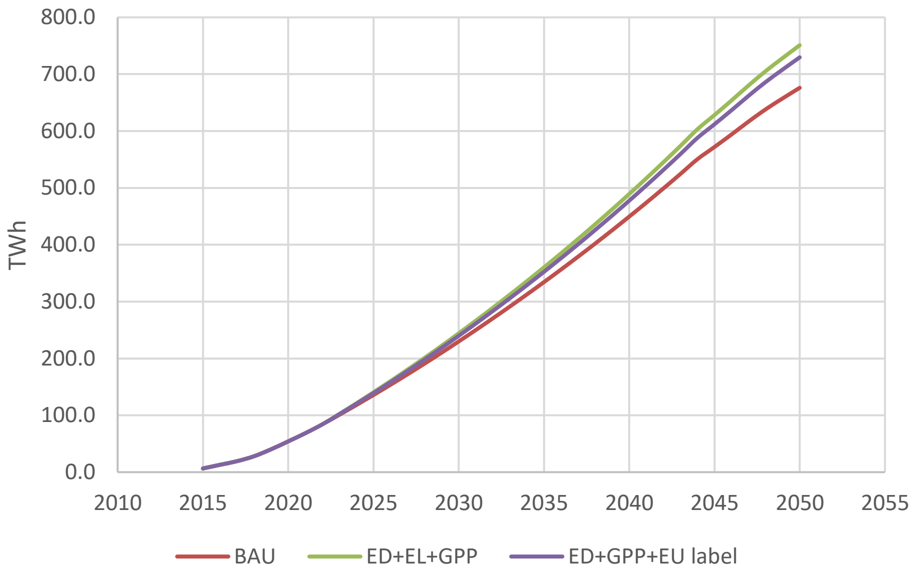

Figure 7-18 Annual Yield relative to the BAU for the COM 6.1 and 6.2 policy options

Table 7-25 Evolution of Improvements in the GER relative to the BAU for the COM 6.1 and 6.2 policy options

	Scenario COM 6.1 (ED+EL+GPP)		Scenario COM 6.2 (ED+GPP+EU Label)	
Year	**Stock GER (MJ)**	**Improvement against the BAU (MJ)**	**Stock GER (TWh)**	**Improvement against the BAU (MJ)**
2015	1.454E+08	0.000E+00	1.454E+08	0.000E+00
2020	3.121E+08	0.000E+00	3.121E+08	0.000E+00
2025	3.751E+08	-1.962E+07	3.136E+08	-8.116E+07
2030	4.211E+08	-1.879E+07	3.468E+08	-9.300E+07
2035	4.715E+08	-1.888E+07	3.867E+08	-1.037E+08
2040	5.292E+08	-1.958E+07	4.317E+08	-1.170E+08
2045	5.640E+08	-2.055E+07	4.524E+08	-1.321E+08
2050	5.925E+08	-2.261E+07	4.588E+08	-1.563E+08

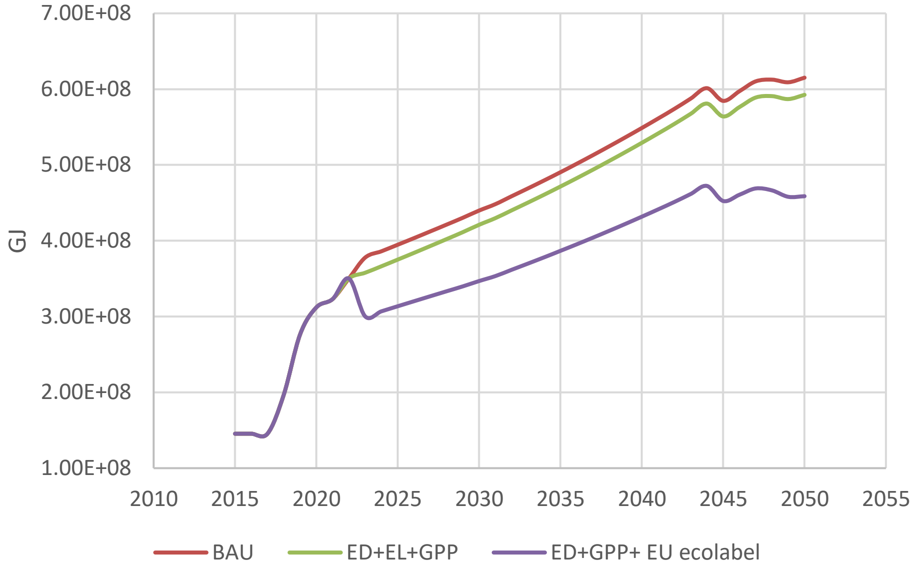

Figure 7-19 Annual Gross Energy Requirement (GER) relative to the BAU for the COM 6.1 and 6.2 policy options

Consideration of BNAT technologies

These scenarios were largely built on the BAT technologies but as discussed in Task 4 and 6 there are still **BNAT** technologies under development that could further improve performance relative to the BAU and previous scenarios in the upcoming years. The most promising currently include, with their suggested production status:

Commercially available, limited lines

- TOPCon passivated contact silicon cells
- Inverters based on wide bandwidth semi-conductors

Pre-production scale

- Epitaxial or 'kerfless' silicon wafer production
- Tandem perovskite:silicon cells

Prototyping

- Back contact (IBC) silicon heterojunction cells

The near BAT design for recycling of silicon modules is also noteworthy given that stakeholders have emphasised the need to consider the end of life scenarios for a rapidly increasing module stock.

In respect to inverters the benefits of the next generation of wide bandwidth inverters – for example, the potential for higher euro efficiencies and lower temperature induced failure - is as yet unclear. Hence the impact is likely underestimated and potentially an ambitious label can support driving the market to those BNAT. Therefore it could be recommended to support related R&D and to reconsider the proposed policy options at more ambitious levels after a notional period. An additional option is to consider a broader scope of mandatory policy instruments, as suggested under options 8.1 and 8.2 in section 7.1.3.3.

7.3. Socio-economic impact analysis

The aim of this section is to estimate the economic impact of the policy options. It therefore runs a stock model scenario 1990-2030 (2050) for EU-28 on running costs & consumer expenditure, as well as establishing multipliers for employment by upstream and downstream activity and market segment.

7.3.1. Estimated impact on income and expenditure

Based on the previous stock model and Task 6 economic modelling, the total EU annual long term expected impact on expenditure was calculated (see Figure 7-20). For the Ecodesign policy scenarios MOD and INV a limited economic impact arises from the computation, meaning that the proposed measures have a positive impact and are anticipated to entail minimal additional cost. All values are discounted relative to 2016.

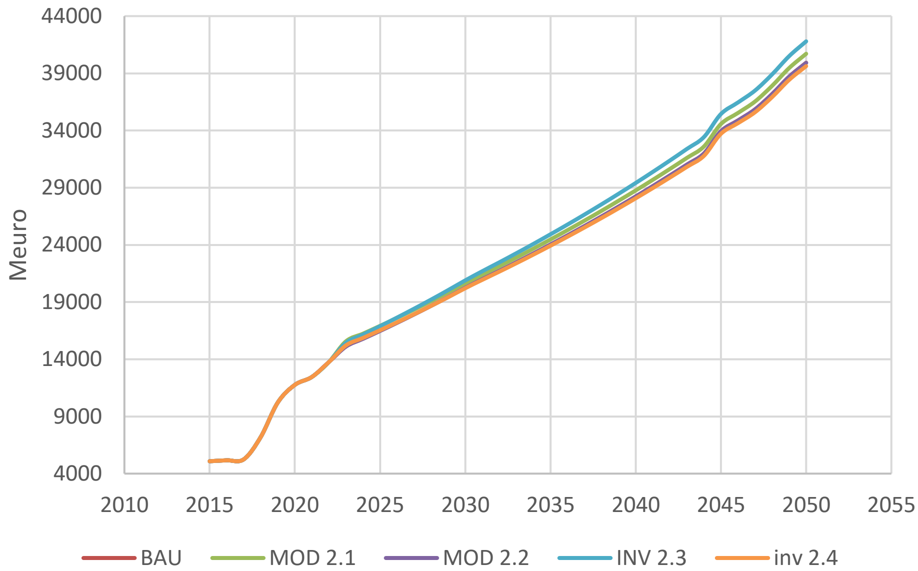

Figure 7-20

Calculated total annual expenditure for different scenarios (Discounted to reference year 2016)

As opposed to typical energy consuming products there is for photovoltaics no trade-off between running energy cost and capital expenditure. Therefore for photovoltaics it is proposed to compare the annual expenditures relative to the expected economic value of generated electricity, based on the average expected 85.5 Euro/MWh for 2035 from the PRIMES model (see Table 7-26).

Table 7-26 PRIMES projected electricity prices to 2050 (source: PRIMES[35])

	2015	2020	2025	2030	2035	2040	2045	2050
Decomposition of electricity generation costs and prices (6)								
Average cost of electricity generation (Euro'13 per MW	95,1	105,2	103,0	101,0	96,0	92,5	91,3	87,7
Annual capital cost	45,4	50,5	44,6	40,8	**33,5**	30,5	30,3	30,3
Fixed O&M cost	19,5	20,6	19,3	19,6	**19,7**	18,5	18,3	18,1
Variable non fuel cost (7)	1,6	1,7	1,8	1,9	**1,9**	2,0	2,4	3,2
Fuel cost	23,9	26,1	28,8	28,8	**30,4**	31,3	29,5	26,6
Tax on fuels and ETS auction payments	4,7	6,3	8,4	10,0	10,4	10,1	10,7	9,5
Additional supply costs (Euro'13 per MWhe)	28,1	26,6	32,9	37,9	46,8	50,0	49,6	52,0
Transmission, distribution and sales costs	27,4	25,9	31,9	36,8	45,6	48,7	48,2	50,3
Other costs	0,7	0,7	0,9	1,1	1,2	1,3	1,4	1,7
Estimation of RES supporting costs passed on to cor	20,0	24,2	23,2	19,0	11,8	4,7	1,7	1,3
Average price of electricity (pre-tax) (Euro'13 per MWhe)	123,1	131,9	135,9	138,9	142,8	142,5	140,9	139,6
Excise tax and VAT on electricity (Euro'13 per MWhe)	17,7	18,0	18,2	18,6	19,1	19,2	19,2	19,2
Average price of electricity (after tax) (Euro'13 per MWhe)	140,8	149,9	154,1	157,6	161,9	161,6	160,0	158,8
	0	0	0	0	0	0	0	0
(8) extra costs due to renewable recovery which are passed on to consumers								
average used for this study (euro/MWh)					**85,5**			

As can be seen comparing total societal expenditure from Figure 7-20 with the economic benefits in Figure 7-21, the revenues outperform the calculated costs but with some delay. This is due to the high upfront capital cost and the associated long term return on investment.

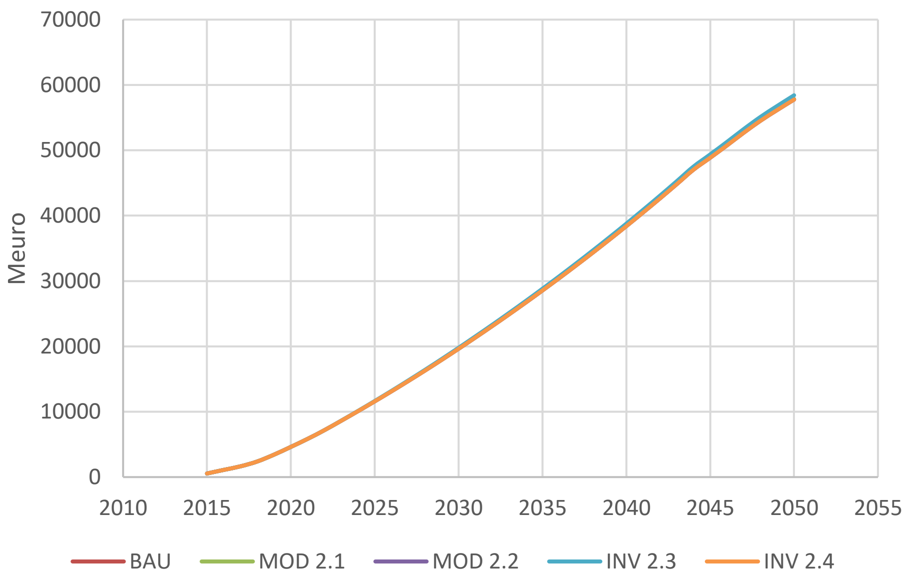

Figure 7-21 Value of generated electricity per year

The previous expenditure calculation allows for the estimation of the impact on employment which is assumed to be proportional to expenditures by market segment. The impact on EU employment on a macroeconomic scale is difficult to assess as most of the upstream cell and module manufacturing takes place outside Europe (see Task 2).

35

7.3.2. Assumptions for the economic impact analysis

In this section the base assumptions used within the economic impact analysis on the economy and employment are compiled. These include the potential response of the market, supply chain impacts and learning rates.

7.3.2.1. Price and response of the market

The elasticity of demand for PV systems, and their associated modules and inverters, is complex to determine because the market has to date been heavily reliant on subsidy programmes that act in a very punctuated way. Moreover, capital investment in residential solar PV systems is different from other consumer products studied under Ecodesign because of the significantly higher upfront investment required into a 'non-essential', long life asset on which consumer decisions may be easily postponed relative to spending decisions on 'essential' items.

Programmes in Spain, Italy and the UK have triggered very fast responses from the market because of a high latent demand for solar PV installations and because the economic returns that can be achieved from a PV system were intentionally adjusted by setting subsidy levels at appropriate rates. The projections developed in Task 2 and which form the basis for the Business as Usual stock model suggest that post 2020 the EU solar PV market will move to a more stable growth pattern based on price parity with conventional forms of electricity generation that it will therefore be less dependent on subsidy regimes.

Analysis of price elasticity in local PV markets has been made in the USA. Modelling for the residential sector suggests a price elasticity in the range of -0.4 and -1.2 [36] [37]. If this assumption is used then the demand price for PV systems is likely to be relatively inelastic to change. This would also accord with solar PV systems being a non-essential, long life asset. Market interventions that go beyond price support may therefore need to be considered in order to stimulate greater take-up.

7.3.2.2. **Upstream and downstream economic impacts**

As was described in Task 2 the value chain for the PV sector within the EU can be split between upstream and downstream activities.

- Upstream activities to manufacture system components: manufacturing of multi-silicon, wafers, cells, modules, inverters, mounting and tracking systems and electrical components (Balance of System).
- Downstream activities that provide services related to PV systems: engineering/studies/administration, installation, operations & maintenance and decommissioning.

In the reference year 2016 the total number of Full Time Equivalent (FTE) jobs created by the EU PV sector were 81,319, projected to rise to 174,682 by 2021[38]. The latter estimate is based on the medium growth market scenario defined by the PV Market Alliance.

In order to model the potential impact of any change in the quantum or nature of demand for modules or inverters the upstream and downstream supply chain for PV technologies and services can be further sub-divided

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[36] Rogers E, Sexton S. 2014. *Effectiveness of subsidies for residential rooftop solar adoption: Lessons from California*. North Carolina State University Working Paper

[37] Hughes JE, Podolefsky M. 2015. *Getting green with solar subsidies: Evidence from the California solar initiative*. Journal of the Association of Environmental and Resource Economists 2: 235–275.

[38] Ernst & Young and Solar Power Europe, *Solar PV - jobs and valued added in Europe*, November 2017

into the constituent activities that add value to the delivery of a PV system to a client. Table 7-27applies a percentage split of activities to the EU employment figures for the reference year of 2016 and an estimate for 2021 based on the medium PV Market Alliance scenario, which can be equated to policy scenario 1 'business as usual' (BAU).

It can be seen that upstream employment accounts for a lesser proportion of the total employment with modules in particular projected to decline further whilst Balance of System is projected to increase. These trends reflect the culmination of a trend towards the loss of EU module and inverter manufacturing as large scale production has necessitated the establishment of lower cost factories outside of the EU.

An important feature of the EU PV industry's current employment structure is the significance of the downstream activities. This is particularly important to consider when analysing the impact of policy scenarios because actions that influence the deployment of PV systems will have a disproportionate impact on EU employment. A survey of the skill profile of downstream actors in the German PV market suggested that the majority of employees completed vocational training (60%), a high proportion had a university degree (35%) and that only a small proportion having no vocational training (6%) [39].

The three main downstream activities support the project life cycle for PV system installation and by necessity the employment is located in local EU markets. Related to these activities, existing upstream EU competencies in other BoS components such as cabling, mounting structures and control systems are projected to generate an increase in employment in function of the further increase in PV system installations and associated downstream employment.

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[39] German Federal Ministry for the Environment (2012) *Renewably employed – short and long term impacts of the expansion of renewable energy on the German labour market*.

Table 7-27 EU employment supported by the PV industry in the reference year and 2021 (BAU)

Supply chain	**Activity**	**Employment (% FTE, FTE/MWp)**					
		2016			**2021 (BAU projected)**		
Upstream	Silicon	1%	813	0.1	1%	1747	0.2
	Wafer	3%	2440	0.4	2%	3494	0.4
	Cells	3%	2440	0.4	2%	3494	0.4
	Modules	5%	4066	0.7	3%	5241	0.6
	Inverters	2%	1626	0.3	2%	3494	0.4
	BoS components	11%	8945	1.5	15%	26202	2.9
	Total	*25%*	*20330*	*3.4*	*25%*	*43671*	*4.9*
Downstream	Engineering studies	23%	18703	3.1	31%	54151	6.1
	Installation	16%	13011	2.2	22%	38430	4.3
	Operation & Maintenance	36%	29275	4.9	22%	38430	4.3
	Total	*75%*	*60989*	*10.1*	*75%*	*131012*	*14.7*

Adapted from Ernst & Young (2017)

The potential impact of the policy options on the upstream and downstream activities are analysed qualitatively in Table 7-28 The intention is to identify which supply chain activities each policy option acts upon more strongly. For example, policy option 2 would be anticipated to have a direct impact on upstream module and inverter manufacturing with the majority of manufacturers having their production capacity located extra-EU, whereas in contrast the procurement of system services within the frame of public tenders would directly impact on downstream service providers in local markets within the EU. Only an increase in the demand for installation services is assumed to generate an impact on employment otherwise there is only anticipated a change in the nature of the services called upon by clients e.g. if the energy label places requirements on system performance this may require more attention on system designs by existing installers.

Table 7-28 Qualitative analysis of upstream and downstream economic impacts for the main policy options

Policy options	Upstream impacts	Downstream impacts
1. Business as usual	Continued decline in EU module and inverter manufacturing.	Projected growth in engineering studies, installation services and O&M services.
2. Ecodesign requirements on module and inverters	Direct (external) impact on imported module and inverter products.	Indirect price internal impact on the pricing of low end performance module and inverter products.
3. Energy label requirements for residential packages **3.1/2 Package approach**	Positive consumer choices may have a direct impact on better performing products, including EU module and inverter designs and manufacturing equipment.	Greater confidence in packages could foster residential demand across all three service activities.
3.3 System approach		Greater confidence in system designs could foster residential demand across all three service activities.
4. EU Ecolabel criteria: residential package with services	Positive choices may have a direct impact on better performing products, including EU module and inverter designs and manufacturing equipment.	Improved information on module, inverter and system performance could foster increased consumer confidence.
5. Green Public Procurement criteria: PV systems ***5.1 Public buildings***	Quality specifications may have a direct impact on imported module and inverter products (core criteria). Life cycle specifications may have potential to support EU module and inverter designs and manufacturing equipment (comprehensive criteria).	Greater call for life cycle management to optimise LCOE and performance could foster demand for extended O&M services.
5.2 Reverse auctions	Quality specifications may have a direct impact on better performing products, including EU module and inverter designs and manufacturing equipment.	Growth in residential demand from novel procurement routes could foster all three service activities.

Key to the colour coded evaluation of potential impact

Business as Usual	Minimal or unknown	Moderate	Significant	Very significant

Another important feature of the EU PV industry's current employment structure are the system market segments that have been analysed by this study – namely residential, commercial and large scale (utility). These are also important to consider when analysing the impact of policy scenarios because actions that influence the deployment of smaller scale roof mounted PV systems will result in a disproportionately greater impact on EU employment.

It can be seen in Figure 7-22: that the large scale ground mounted systems, which accounted for 31% of the installed capacity in 2016, accounted for 27,400 FTE (33%) whilst roof mounted residential and commercial systems accounted for 56,340 FTE (67%). A clear shift towards roof mounted installations is then projected under the medium to long-term market scenarios described under the Business as Usual (BAU) policy option. The large scale ground mounted and roof mounted segments are projected to rise to 30,335 FTE (17%) and 145,179 FTE (83%) respectively by 2021.

In the BAU policy scenario future EU employment is projected to be dominated by activities related to roof mounted systems, which will include BoS components that are distinct to those of large scale ground mounted systems. As was identified in Tasks 2 and 3 further opportunities also exist to develop the (downstream) demand for systems in the residential sector and related to this the demand for system design/quotation studies, installation services and the operation & maintenance service offer.

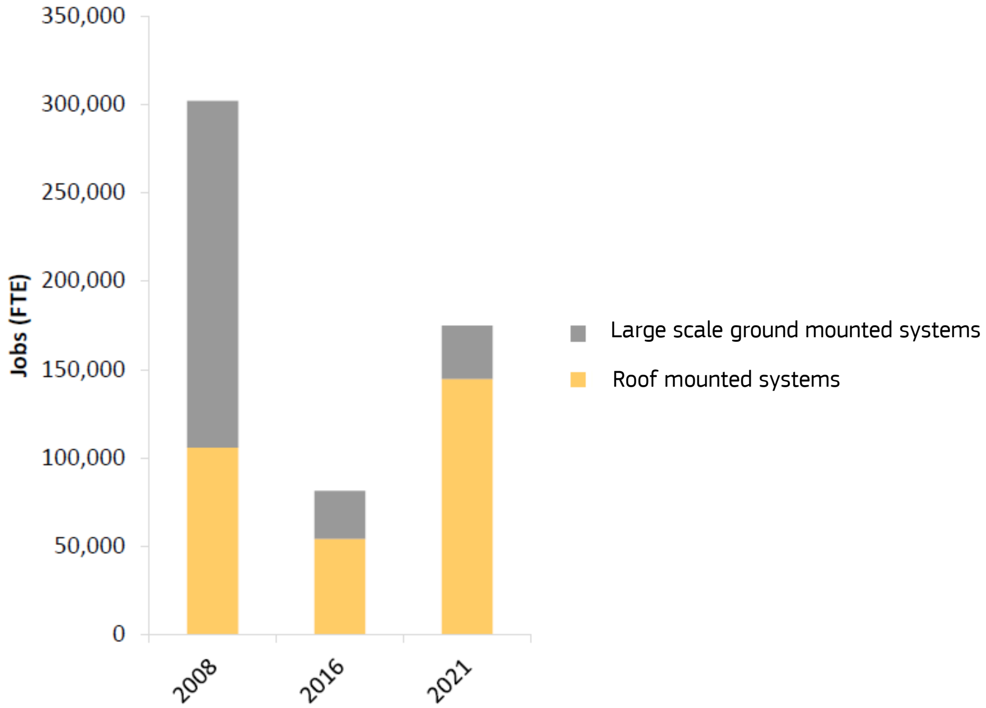

Figure 7-22: Upstream and downstream employment supported by EU PV system installations

Source: Ernst & Young (2017)

7.3.2.3. Residential system cost structure

In order to support modelling for the residential market segment, which in previous tasks has been identified as the segment with the greatest potential for growth and the implementation of BAT measures, an indicative cost structure has been defined (see Table 7-29) This cost structure is based on installations in a mature PV market (Germany) and the module and inverter costs have been updated to reflect the reference year 2016. From this cost structure the person hours involved in implementing an installation and the unit costs per kWp of capacity can be estimated and scaled. Maintenance and operation are not currently accounted for in this cost structure.

Table 7-29 Indicative cost structure for a residential solar PV system installation

Cost item		**Person hours**	**Cost (Euro)**	**Unit cost (Euro/kWp)**	**% of total cost**
Components	Modules	n/a	1500	500	37%
	Inverter	n/a	234.6	78.2	6%
	Mounting structure	n/a	420	140	10%
	Cabling	n/a	60	20	1%
	Total	*n/a*	*2214.6*	*738.2*	*55%*
Installation	Customer acquisition	5	105	35	3%
	Permitting	0.67	13.8	4.6	0%
	Grid connection	1.5	31.8	10.6	1%
	Installation	45	945	315	24%
	Commissioning	2.5	52.8	17.6	1%
	Marketing	-	43.2	14.4	1%
	Overheads & profit	-	595.8	198.6	15%
	Total	*54.7*	*1787.4*	*595.8*	*45%*

Adapted from Strupeit.L and Neij.L (2017)

An additional factor to take into account in the cost structure is the Weighted Cost of Capital (WACC). At retail loan interest rates of between 5% and 7% this can account for between 30% and 35% of the life cycle cost of a PV system.

The channel to market also has an influence on the cost structure, with large national installers, utilities and DIY chains able to reduce supply chain costs and overheads. Group purchasing structures of the kind described in Policy Option 5 can also achieve similar reductions in the overall cost.

7.3.2.4. Module manufacturing cost structure

Despite a >97% decrease in costs since 1980 and an average learning rate of 21% [40] [41], modules still account for a significant proportion of the cost of PV systems – typically within the range of 30-50% depending on the market segment. The potential response of module manufacturers to policy instruments that act specifically on module performance characteristics is therefore important to analyse.

On one hand analysts suggest that the scope for further cost reduction within existing crystalline silicon technology platforms may be constrained [42]. This is because the technology is characterised by high capital costs, long lead times in reacting to changing demand and, based on current pricing, relatively small operating margins. These factors have recently led to oversupply and may in the future pose problems for sustaining growth in output , reflected in the Minimum Sustainable Price (MSP) for modules. Expert analysis suggests that the MSP may lie between 0.14 and 0.36 Euro/Wp although spot market prices are for some mainstream products

[40] Fraunhofer ISE (2015) *Current and Future Cost of Photovoltaics. Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems*. Study on behalf of Agora Energiewende.
[41] Kavlak et al, *Evaluating the causes of cost reduction in photovoltaic modules*, Energy Policy 123 (2018) 700–710
[42] Powell et al, *The capital intensity of photovoltaics manufacturing: barrier to scale and opportunity for innovation*, Energy & Environmental science, Royal Society of Chemistry, 2015, 8, 3395

are already within this price window [43]. Figure 7-23 illustrates an indicative cost structure for a module manufacturing plant and associated expenditure related to upstream processes.

On the other hand existing production platforms have, according to the experts consulted, proved flexible in responding to demand for new crystalline cell technologies such as PERx that can be integrated into the existing module production lines and form factors. Thin film products such as CdTe have also been able to demonstrate the scaling up and optimisation of manufacturing lines. The capability of existing production platforms to respond appears therefore to be an important consideration if mandatory Ecodesign or Energy Labelling measures are used to require the substitution of existing products.

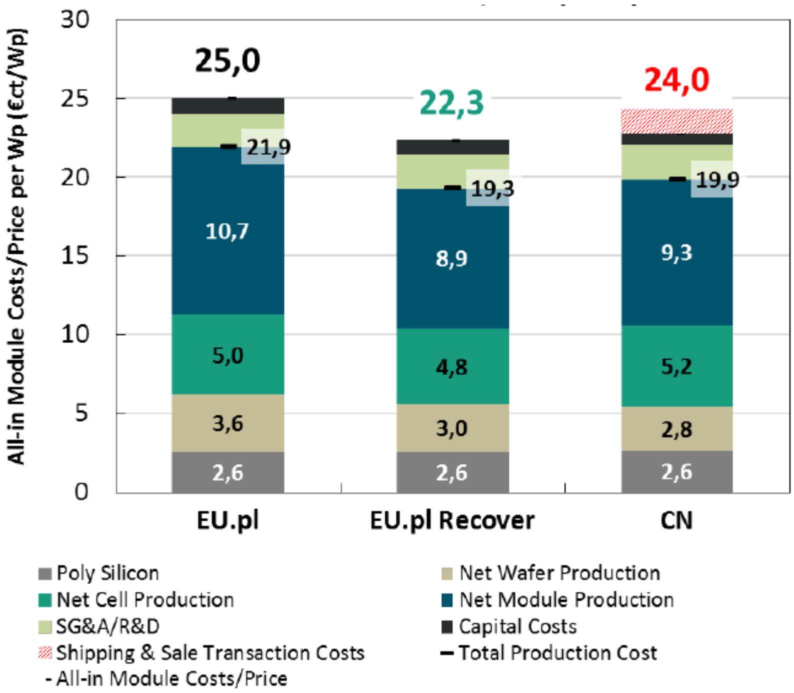

Figure 7-23: Indicative cost structure for a crystalline module manufacturing plants in Europe and China (CN)

Source: Fraunhofer ISE (2019)

7.4. Sensitivity analysis

The aim of this section is to establish the basis for a sensitivity analysis of the policy scenario modelling, covering the relevant factors (such as the price of energy or other resources, production costs, discount rates). In particular, a sensitivity analysis is proposed for the BAT and LLCC design options from Task 6 that have been mapped onto Ecodesign policy options in section 7.1.3.

Reference studies that analysed the sensitivity of solar PV system LCOE (PVTP 2015, Vartiainen et al 2019) have highlighted the relative importance of the climate zone, the Weighted Cost of Capital, Operational expenditure and Capital expenditure as having greater significance than technical parameters such as lifetime and degradation (see Figure 7-24).

[43] See footnote 40

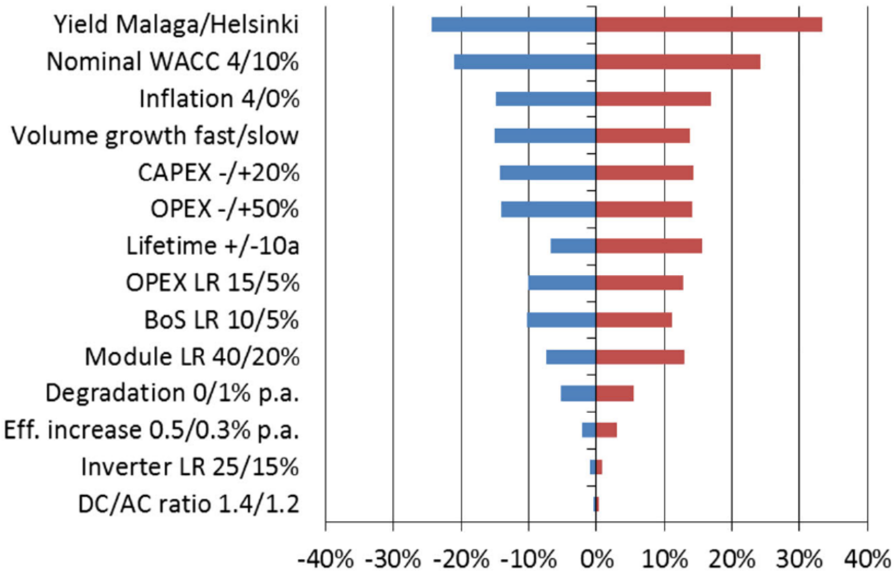

Figure 7-24: Sensitivity analysis of LCOE (%)

Source: Vartiainen et al (2019)

Considering Tasks 1 to 6 and the proposed policy options the following parameters are judged relevant in the context of this study for a sensitivity analysis:

A. In Task 1 the economic life time of a PV system for the functional unit was set at 30 years, it is proposed to analyse +/- 5 years.
B. In Task 3 the reference yield (Yr) was defined as corresponding to a reference central EU location (Strasbourg) which formed the basis for the Task 6 modelling. Yield is climate sensitive and therefore it is proposed to analyse 3-4 additional locations that are representative of broad climate zones in the EU.
C. Task 4 suggested that there are some uncertainties associated with modelling the prices (euro/Wp) for HJT/BJT, CIGS/CdTE and epitaxial-wafer based modules, therefore it is proposed to vary module prices with +/- 20 %. Price varies in different market segments as a function of volume, either through direct supply or via distributors.
D. Task 2 and the MEErP methodology proposed a discount rate of 4 % to be applied but this can have a strong impact on the calculated Life Cycle Cost (LCC) or LCOE. The rate could be geared to market segment, for example the large scale ground mounted segment could, indicatively, be tested at 8-12% (private capital rates), the residential segment at 5-6% (personal loan rates) and the public sector segment at 2-3%.

A further sensitivity could focus on the efficiency of modules given that an absolute figure was used to model each technology, whereas in reality a series of models with different efficiencies are offered (e.g. CIGS 13.8 – 16%).

It is also important to note that much of the Life Cycle Inventory (LCI) data used as the basis for the LCA analysis in Tasks 5 and 6 has a large degree of uncertainty but it is not deemed useful and possible to apply a sensitivity analysis on this.