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Preparatory study for solar photovoltaic modules, inverters and systems

(Draft) Task 7 Report: Policy scenario analysis

Dodd, Nicholas; Espinosa, Nieves – JRC B5

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

Tsanakas, Ioannis; Voroshazi, Eszter - IMEC

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Contact information
Nicholas Dodd and Nieves Espinosa
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-b5-photovoltaics@ec.europa.eu
Tel.: +34 954 488 728/476

JRC Science Hub
https://ec.europa.eu/jrc

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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 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 certain PV module technologies should be carefully considered as growth in their production could have negative consequences.
- 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 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 2019. Following on from the Footprint method pilot it is unclear 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, in part as a response to concerns about the quality of some low cost imports.

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;=: further rationalisation of 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 the Table 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
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
Digitalisation of PV systems and components	Short term	Low

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.

<u>Uncertainties in support policies</u>

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 – the registration of households interested in installing a system on their home followed by a subsequent supplier shortlisting and tender process to select an installation company that can service the registered households.

Implication: based on the economies of scale, the auction process also 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 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, the average cell efficiency of mono Si produced in Mainland China 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 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.
- 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
  - Although the PEF pilot has concluded the level of commitment to take forward Product Category Rules as envisaged by DG Environment is as yet unclear.

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 IEC RE qualification standard 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 on the Preparatory study is 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 7.1-2.

As was identified in section 7.1.2 there could also be the potential to explore other policy instruments that have been successfully used in other countries to drive improvements in module and system quality and performance – for example, the use of auction requirements 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.
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 has also been used for the medium to long term projections[1].

[1] 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 7-2. The values have been taken from the ITRPV Roadmap[2], which tracks the module rated power for different cell technologies. For CdTe the power is taken form the popular module at the time, Series 4. CIGS modules power is taken from the main manufacturers with largest market shares. High efficiency modules power refers to Panasonic modules, LG and Sunpower. The following generalised trends also inform the stock estimate:

- Multi-crystalline is less expensive than mono-crystalline.
- 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 probably 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.

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 7-3.)

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**

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

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

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 mentioned 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 more than 20 years. However, the economic lifetime depends on business choices and it is considered that 25 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 starting point is the VDMA roadmap which has then been cross-referenced with a range of other sources. 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 [3] 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.
- 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.

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

BNAT candidates

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. 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.

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 7-4. 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 7-5.)

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	3,000	3000.00	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. 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 it 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.
- 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 7-6.).

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 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 amount of PV systems financed in each country under specific incentive schemes.

Evolution of the system stock through to 2030

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 2020)

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 the PV Market Alliance has been used as the starting point. The relative stability of European policies for PV in the last two years indicate that until 2020, little changes can be expected. Starting from 107 GW in 2017, the installed capacity in 2020 could reach up to 137,5 GW according to the reference scenario and up to 146 GW according to the PV Market Alliance high scenario.

Medium term (2020-2030)

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 PV Market Alliance scenarios until 2022 and the European Reference Scenario 2016 afterwards. The forecast is heavily dependent on EU policy. 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 2020 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. In general on this basis it is estimated that the development of the PV market will continue, driven in part by the declining prices of PV systems, and its emerging competitiveness with wholesale market prices in several key countries.

An assumption has been made that the ratio between wind and PV contributing to targets could be 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. By 2030 this could translate into between 193 and 392 GW.

Long term (2030-2050)

The main driver is likely to be decarbonisation of the energy mix in Europe under the Reference Scenario 2016 and a more ambitious one that is provided. The same methodology could be applied as described for 2020-30. To reach 95% of decarbonisation in the electricity sector by 2050, based on the reference scenario, the additional amount of RES-E electricity compared to 2030 is calculated based on an assumed consumption of 4064 TWh in 2050. The reference scenario estimates nuclear production of 737 TWh in 2050, which leaves 3124 TWh to be produced with RES-E electricity. Or compared to 2030, an additional 900 TWh. This could translate into between 315 and 622 GW by 2050.

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

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 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 and so the intervention would 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: o 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. o 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: o Product efficiency will be driven up overall. o 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. o 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 on Critical Raw Materials. o Requirements 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: o Requirements could create a supply constraint if they take lower cost/lower end products off the market o 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. o 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 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 and durability.

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 prop osed first.

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/kWh generated Moreover, from a market perspective the efficiency of the base case module is an average. A significant number of less efficient products are still being placed on the EU market [4]. These largely include 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.

Two options have been identified for the performance requirements:

1. Power rating (IEC 61583-1): 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 optimised BSF module) and the best performing models available in the market for the BAT (the CIGS module). 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 a higher power output.

[4] The ENF solar directory identified that of the 16020 multi-crystalline module models >50 Wp listed as being supplied in the EU, there are 1741 with an efficiency in the range of 9 - 14%. These include module products supplied to the major PV markets in Germany, Italy and Spain.

For the yield performance in option 2, no specific threshold is proposed yet since it would need to be based on the power density, spectral response and temperature co-efficient of the BAT (CIGS).

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	Tier 1: Require a minimum module energy yield expressed in kWh/kWp calculated according to IEC 61853-3 and for a reference climate zone.
	Tier 2: The minimum module energy yield in kWh/Wp to be time averaged over 30 years to reflect the declared degradation rate of the product.

Module option 2.2: Performance requirements on quality and durability

This further Ecodesign option would introduce a more stringent set of quality and durability tests for module products. For this option tiered introduction could be considered in order to allow manufacturers to improve their worst performing products.

The optimised multicrystalline BSF 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 [5] 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 only a small proportion of module models that are available in the EU are currently formally certified to IEC 61215 (in the range of 10-20%). Two other aspects, related to IEC 61215, should be noted in this context:

- 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

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

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.

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 [6].
- 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[7]. A test for Light Induced Degradation (LID) is therefore also proposed as a safety net to cut off the worst performing products.

Performance requirements associated with these tests would be complemented by an overall information requirement to declare the estimated lifetime degradation rate over a notional service life of 30 years. The declaration would need to clearly state whether the rate was unvalidated (based solely on laboratory tests) 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.

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 (optimised BSF).

In addition to the identified durability requirements, it is important to have information on the 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.

[6] 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.

[7] 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.

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

Performance aspect	**Detailed proposed requirements**
Performance requirements	
2.2.1 Component degradation	*UV pre-conditioning:* MQT10 of IEC 61215 over four cycles of 15 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. *Potential Induced Degradation:* Testing according to IEC 62804 shall result in no more than a 5% power loss after 192 hours at 1000V. *Light Induced Degradation:* Testing according to IEC 63202-1 shall result in an efficiency loss of no more than 2.5% .
2.2.2 Water ingress	*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..
	Junction box: Achievement of an Ingress Protection rating of at least IP67, category 1 according to EN 60529.
Information requirements	
2.2.3 Cell integrity	The inactive cell area shall be no more than 8% upon optical inspection using electroluminescence imaging[8].
2.2.4 Lifetime performance degradation	The manufacturer shall declare the average linear degradation rate expected over a notional service lifetime of 30 years. The declaration shall be clearly identified as being either: – *Validated:* Based on minimum number and time series of field observations made according to the Transitional Method. – *Unvalidated:* Based on accelerate life testing methods carried out in a laboratory.
2.2.5 Repairability	The manufacturer shall report on: – the possibility to access and replace the bypass diodes in the junction box [9], – the possibility to replace the whole junction box of the module
2.2.6 Dismantlability	The manufacturers shall report on the potential to separate and recover the semi-conductor from the frame, glass, encapsulants and backsheet. Design measures to prevent breakage and enable a clean separation of the glass and internal layers during the operations shall be detailed.

[8] The inactive area can be quantified via EL testing. Cell cracks may lead to isolation/separation of semiconductor material and this, in turn, to inactive "dark" areas in the EL image.

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

2.2.7 Material disclosure	The manufacturer shall declare the content in grams of the following materials in the product: – Lead – Cadmium – Silicon metal – Silver – Indium – Gallium – Tellurium For the encapsulant and backsheet the manufacturer shall also declare the type of polymers used (inlcuding if it is fluorinated or contains fluorinated additives) and content in grams.

Proposed Ecodesign inverter requirements under Policy Option 2

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

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 some minimum inverter energy efficiency requirements are discussed first.

Inverter option 2.3: Performance requirements on efficiency and life time electricity yield

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% [10]. These include products both imported into and manufactured in the EU.

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. 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.

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.[11] 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[12]. This could inform a transitional method.

[10] The ENF solar directory identified that of the 4108 on-grid inverter models listed as being supplied in the EU, 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.
[11] A base case system model for the Effibat project indicates possible losses of income of about 13%
[12] https://www.bves.de/effizienzleitfaden_2/

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

Performance aspect	Detailed proposed requirements
2.3.1a Euro efficiency for PV inverters without storage	Require a minimum efficiency of 96% measured according to EN 50530. Allowances shall be provided for micro-inverters and hybrid inverters to offset for their other benefits.
2.3.1b Efficiency requirements for PV inverters with possibility to connect storage or with integrated storage	Require a minimum efficiency of 90% at 25% of nominal power and at minimum MPP voltage and battery around 50% state of charge. Measurement according 'Effizienzleitfaden 2.0'.
2.3.2 Smart readiness (monitoring system features)	Manufacturers shall to ensure that the inverter supports class A data monitoring according to IEC 61724-1, including: – Basic system performance assessments; – System loss analyses; – Electricity network interaction assessment; – Fault localisation; – System degradation measurements.

Inverter option 2.4: Performance requirements on quality and durability

This further Ecodesign option would introduce a more stringent set of quality and durability tests for inverter products. 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.

Using IEC 62093, IEC 63157 and in IEC 62109-1 as a starting point for conformity assessment, design qualification tests have been specified that 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.

In addition, and reflecting best practice for larger string and central inverters, a requirement is proposed to provide a documented preventative maintenance and repair cycle. This shall identify components and recommended timing for their replacement, thereby allowing owners of the product/model to ensure they follow practices recommended to extend the life of the product.

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

Performance aspect	**Detailed proposed requirements**
2.4.1 Quality and durability	*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 IP67, category 1 according to EN 60529.
Additional information requirements	
2.4.2 Preventative repair cycle	Manufacturers shall provide a preventative maintenance and replacement cycle. This shall include a list of parts recommended to be replaced and the timing of the replacement as a preventative measure to achieve the intended design technical lifetime.
	Manufacturers shall ensure that replacement parts and firmware updates are made available in line with the recommended replacement cycle.
2.4.3 Technical design life declaration	Manufacturers shall declare based on internal design parameters and qualification testing the design technical lifetime of the inverter. This declaration shall include a Mean Time Between Failure (MTBF) calculation.

Policy option 3: Energy labelling requirements for residential PV systems

Description: Requirements would be set that would apply to a package consisting of a module type and an accompanying inverter type or 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 instead based on combining only 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) for the package approach is proposed as being based on the module and inverter performance expressed as an overall Performance Ratio and taking into account the module degradation over a fixed lifetime. It is to be decided for the package approach whether a declaration is needed for 3 climate zones in order to capture variations in the module yield performance, for example due to temperature dependency. The Energy Efficiency Index (EEI) for the system approach is proposed as being based on the estimated system yield with a range of derate factors applied that are to be tailored to the design and location.
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 predicted 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 for individual products the performance further derating losses may be reduced 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. • Historical evidence for improvement in system performance ratio due to better design and reduced losses.
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. Using a Performance Ratio avoids the need to normalise the package energy yield to m^2 or Wp values. 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 have specified PR targets in their subsidy regimes.
Possible drawback: Labelling is a new concept for PV system packages or system designs. 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[13].

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

This initial Energy Labelling option would introduce energy classes for packages formed by combinations of modules and inverters. The results of Tasks 5 and 6 have shown that for modules increased electricity generation and for inverters a higher euro efficiency 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 simplified package approach: This would combine the module efficiency tested under Standard Test Conditions with the Euro Efficiency of the inverter.
2. A more complex system approach: This would entail modelling of a design's yield and performance ratio, and taking into account more parameters that are specific to the installation, for example, shading, inclination, orientation.

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

The option is simpler to calculate as for both components it is proposed to be based on the reported efficiency. The module efficiency combined with the euro efficiency would be a proxy as the Energy Efficiency Index (EEI) for improved yield.

Table 7-13. Energy label policy option 3.1: Efficiency-based EEI

Performance aspect	**Detailed proposed requirements**	**Modelling assumptions**
3.1 Simple efficiency based approach	The package provider shall combine the module efficiency measured according to IEC 61853-1 under Standard Test Conditions with the Euro Efficiency measured according to EN 50530.	The label is modelled to 2030 and that a label class E is removed in 2022 and D in 2024.

In this scenario, a new label class differentiation is created with seven energy classes ranging from A to G. Bands of efficiency are then assigned to label classes based on a combination of module and inverter product performance. Because of the relatively wide possible tolerances for the performance of the individual products (up

[13] 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

to +/-5%) the number of label classes has to be cut down from A>G to A>E. According to ENF database the majority of the models had a tolerance of approximately +/- 5%.[14]

Table 7-14 shows the indicative energy label class distribution, together with an indication, per each class, of the typical values of inverter and module efficiency (though the energy class of the package would be determined by the product of the efficiencies of the actual module and inverter, therefore combinations other than those of the table are also possible)..

Table 7-14. 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%	-
B	>19.6 – 21.6%	>19 – 21.5%	4%	>98%	11.6%	SHJ, bifacial + MOSFET
C	15.3 – 19.6%	>16.5 – 19%	40.6%	>96 – 98%	55.5%	Optimised BSF, PERC/PERT +String Central
D	12.2 - 15.3%	>14 – 16.5%	43.7%	>94 – 96%	16.4%	BSF, CIGS, CdTe +Micro-inverters
E	8.5% - 12.2%	9-14%	10.9%	<94%	16.3%	BSF
F						
G						

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

This option is more complex to calculate but will accommodate a wider range of product performance characteristics under conditions in the field and would allow for system designers to tailor the modelling to the specific parameters of the installation and reflect the quality of the electrical design and use of low-loss wiring. There would be the potential to later certify the final design energy rating. Within the frame of the transitional methods under development a simplified tool for modelling and reporting on a system yield is 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 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 required to take into account a number of design and derate factors such as:

- The solar radiation for the location,
- The orientation and inclination of the module array,
- the temperature dependency of the modules,
- the spectral response of the modules,
- the degradation rate of the modules,

[14] 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.

- System losses from mismatch, AC/DC cabling and soiling

It is anticipated that this option would have the effect of encouraging both the selection of modules and inverters to achieve higher yields, but also for system designers and installers to offer to clients higher yield system design options and services.

Table 7-15. Energy label policy option 3.2: System yield and PR based EEI

Performance aspect	**Detailed proposed requirements**
3.2 Yield based approach	The package 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 representation of a notional 25 year service life. – The derate factors to be considered, together with default values, are to be provided in the Implementing Regulation. – The potential to report the PR for a reference location and up to 2-3 other EU climate zones shall be considered.
3.2.1 Module DC Performance Ratio input variable to the system EEI	The system provider shall calculate the module according to IEC 61853-3. In addition: – The module yield shall be adjusted to take into account an average degradation rate over 25 years. – The degradation rate shall be the default for the module technology or a declared rate that complies with the evidence requirements in the Transitional Method.
3.2.2 Inverter AC input variable to the system EEI	The package provider shall calculate the inverter Euro Efficiency according to EN 50530.

Various possible locations and configurations for a PV system should be reflected in the label. This has been done including a yield calculation for the following three climate zones: subtropical arid, temperate coastal, and temperate continental (as defined in IEC 61853-4). A defined PV system would have for the considered default derating factors a system yield during its lifetime in kWh/kWm^2 as indicated in the example in Table 7-16. For more details on the calculation, please see the separate calculator tool.

Table 7-16. Lifetime PV system AC Energy yield ($kWh/kW.m^2$)

	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**

Indicative scale (see also the draft report 'Transitional methods for PV modules, inverters and systems in an Ecodesign Framework', prepared by JRC.C2) and the sensitivity by climate zone is shown in Table 7-17.

Table 7-17. Energy label classes classified by the lifetime energy yield of a PV system in three different climate zones

	Lifetime AC Energy yield (MWh/kW.m^2)		
Energy Label	Subtropical arid	Temperate coastal	Temperate continental
A	> 3.61	> 1.58	> 2.04
B	[3.61 - 2.93)	[1.58 - 1.28)	[2.04 - 1.65)
C	[2.93 - 2.24)	[1.28 - 0.98)	[1.65 - 1.27)
D	[2.24 - 1.55)	[0.98 - 0.68)	[1.27 - 0.88)
E	< 1.55	< 0.68	<0.88

To the label as for other product categories that are under Energy label requirements it could be added a QR code, which refers to the energy product database, where main energy parameters are gathered. In this case the performance of the selected modules and inverters could be interrogated.

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[15]. Guidelines have been prepared in order to clarify the responsibilities of manufacturers, dealers and installers[16]. Comments from stakeholders on this kind of labels, 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[17]), highlighted some areas for potential improvement, as summarised as follows:

- potential user groups are not familiar with the label or do not recognize 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.

[15] See Commission Delegated Regulation (EU) No 811/2013, Commission Delegated Regulation (EU) No 812/2013 and Commission Delegated Regulation (EU) No 2015/1187
[16] https://ec.europa.eu/energy/sites/ener/files/documents/guidelinesspacewaterheaters_final.pdf
[17] 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 package placed on the EU market or a service offered to consumers.
Rationale: To foster innovation in module and inverter design and improve the quality of photovoltaic installations. An approach focussed on the two key components is considered to be justified because they are business to business components of all PV systems and so the criteria could support the choice of superior products at the point of being placed on the market to distributors, retailers and installer. Modules and inverters could be labelled allowing installers and designers to choose Ecolabel components to offer as part of an Ecolabel service.
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 it in order to have a better energy payback time. 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 staff training in the following aspects when providing a service: surveying and simulating the installation conditions, in electrical engineering in solar energy systems and having protocols for the handling and transport of module.
Expected benefits: o Benchmarks would be established in the market for products with reduced environmental performance and for the quality of services provided to clients. o A focus on the whole life cycle, quality and circular aspects that have been demanded by industry. o 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: o If the criteria were not compatible with the existing NSF standard there could be duplicated efforts to stablish labels with different criteria o Whilst there appears to be interest from the sector, there is a risk with a multi criteria set that no products can comply with all criteria. o It is not clear that there is a consumer demand for higher environmental performance of modules, inverters or services.

Proposed EU Ecolabel criteria set under Policy Option 4

The background evaluation for the EU Ecolabel was published in a separate document in support of the Preparatory Study[18]. Section 7 of this report presented the findings of an LCA hot spot analysis which, together with other requirements established by the Ecolabel Regulation and a review of existing standards and ecolabels, was used to identify a set of possible criteria areas.

An approach is proposed that is 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 Member State, two options could be considered for a multi-criteria set:

1. Package approach: There would be criteria for modules and inverters. The criteria would differ from policy options 2 and 3 by focussing more on life cycle hot spots, hazardous substances and circular design
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:
    - the system design factors taken into account,
    - protocols for the transport/handling of modules;
    - the installation of monitoring and
    - provision of maintenance/aftercare services

Because of the uncertainty related to possible take-up of the EU Ecolabel only one option has been modelled. The second has been selected as it is considered to represent a more consumer-facing approach that could create added value for installers using the label.

The Task 6 results for PV modules have shown that on the lead indicator, i.e. primary energy that the margin for reduction between the best product and the base case, is 31% and that corresponds to kerfless cells. For CIGS, the margin for reduction is 24%. It is notable that for CIGS that even with a lower module efficiency and a higher degradation rate the 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.

The LCA hot spot analysis Task 5 also highlighted the important influence of the 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.

The results of the hot spot analysis have also shown that the ratio between the production impacts and the electricity generated in the use phase can vary between locations. For multi-silicon this energy payback time (EPBT) can be 8 or 4,31 years if the modules are installed in Helsinki or Madrid respectively. There is therefore significant margin to reduce this EPBT in climates with less solar resource. For the inverter, the results of Task 6 showed that the inverters designed for repair and a longer lifetime were closely matched for the BAT and LLCC

[18] 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

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 hazardous substances such as lead and cadmium, as well as bulk materials such as copper and aluminium. While requirements under the RoHS Directive don't apply to modules the EU Ecolabel could include criteria controlling their presence in ecolabelled products.

The potential benefits of the advanced yield monitoring and fault diagnosis of 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 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 both key environmental hot spots for both modules and inverters, 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.

It is proposed that the residential package with services is targeted primarily at the residential market segment. Because the EU Ecolabel is a voluntary instrument it is difficult to estimate the possible impact of the 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 7-18. Ecolabel criteria set for modules, inverters and services

Performance aspect	**Detailed requirements**
4.1 Energy payback time criterion	The EU Ecolabel applicant shall calculate the energy payback time for the module and inverter package. The energy payback time should be below 2 years. The production and use stage primary energy use shall be estimated according to ISO 14064 and adjusted for the inverter replacement rate. This primary energy use shall be related to the energy yield over 30 years, which shall be adjusted for the declared degradation rate of the module performance. *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	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.
4.4. Circular economy criterion	*Criteria shall apply to the module (5.4.1-2) and inverter (5.4.3-4) – see below.*

4.4.1 Module degradation rate	Declaration of the rate shall be validated by minimum field observations and demonstrate an average performance degradation rate over a 30 year time period of 0.6%
4.4.2 Module repair potential	The module design shall allow for ease of access and replacement of bypass diodes in junction boxes or the replacement of the junction box.
4.4.3 Inverter preventative repair cycle	In order to use a different inverter lifetime than the default for the EPBT calculation manufacturers shall provide a recommended preventative maintenance and replacement cycle. This shall include a list of parts recommended to be replaced and the timing of the replacement as a preventative measure to achieve an intended design technical lifetime.
4.5 System service criteria	*Criterion shall apply to the system provider – see below.*
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: – Possible shading, – Local climatic conditions, – 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. An additional option would be for a public authority to play a role in boosting local solar PV installations in the residential sector by acting as an intermediary.

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 a direct influence on the competencies of contractors, the design of systems, the specification of components and
is direct in most cases. In the case of reverse auctions or the procurement of electricity this influence can be extended to third party, citizen installations.

Evidence:

- 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 it in order to have a better energy payback time.
- 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.
- 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 electrical engineering in solar energy systems and having protocols for the handling and transport of module.

Expected benefits:

- 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 performance ratio.
- 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 and maximise electricity revenue.
- 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:

- Public authorities may prefer to procure solar electricity rather than engage in the installation of systems and the associated cost and risk.
- Public authorities may not use the criteria because of pressure to focus only on minimising initial capital cost rather than life cycle cost.
- As a voluntary criteria set only some easier criteria may be used so that only some of the benefits would be realised.

The background evaluation for possible Green Public Procurement (GPP) criteria was published in a separate document in support of the Preparatory Study[19]. Section 7 presented the findings of an LCA hot spot analysis which, together with a focus on Life Cycle Cost which is 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.

GPP criteria option 5.1: Improved PV system life cycle performance

[19] 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

The GPP policy option is based on the same environmental analysis presented in support of the EU Ecolabel criteria under policy option 5. In addition a focus is introduced on the project management of a PV system installation. This could extend from contractor selection through to decommissioning.

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 it was identified how to manage solar PV system procurement processes in order to:

- optimise the potential to generate solar power,
- minimise risks to loss of income from and,
- 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 their Cost Priority Number (CPN) and potential impact on LCOE. These 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 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 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.

Table 7-19. 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	*Technical requirement for specific design qualification tests according to IEC61215*: – Core: Cell inspection, UV preconditioning, damp heat cycling and water ingress (Core level) *or* – Comprehensive: Extended requirements for these tests (see Ecodesign options 2.2.1 – 3 and 2.4.1)
5.1.2 Module degradation rate	*Award criteria based on declared module degradation rate* Points shall be awarded based on the declared average performance degradation rate period expressed as the average annual % loss over a 25 year time. Accelerated laboratory testing or monitoring results in the field shall be used as the basis for declaration.
5.1.3 Inverter quality and failure rate	Mean Time Between Failure (MTBF) shall be included in the Energy Pay Back Time calculation based on data according to MIL-HDBK-217, it shall be at mínimum above 20 years.
Design and yield estimation	

5.1.3 Energy payback time criterion	*Award criteria based on energy payback time (dependent on climate/location).* The bidder shall calculate the energy payback time for the system. The production and use stage primary energy use shall be estimated according to ISO 14064 and adjusted for the inverter replacement rate. This primary energy use shall be related to the energy yield over 30 years, which shall be adjusted for the declared degradation rate of the module performance. *Note: there is an option to provide default values in tabular form as has been done by the French Government for the National capacity auction process.*
5.1.4 Performance Ratio	*Award criteria based on an estimate of the Performance Ratio (with reference to IEC 61724)* The design Performance Ratio shall be calculated and declared taking into account, as a minimum, the derate factors identified in the transitional method: – Mismatch – Shading – Soiling – *See transitional method*
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.
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 different inverter lifetime than the default for the EPBT calculation manufacturers shall provide a recommended preventative maintenance and replacement cycle. This shall include a list of parts recommended to be replaced and the timing of the replacement as a preventative measure to achieve an intended design technical lifetime.
5.1.8 Monitoring and maintenance	*Technical Specification/Award Criteria for the granularity of monitoring system (e.g. IEC 61724-1) and provision of aftercare services* The service shall include, for a minimum of x years, the monitoring of the system performance and 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 quality criteria are envisaged as mirroring some of those of the GPP proposal outlined in policy option 6.1, 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 [20]. 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[21]. 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.

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

[21] 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 7-20

Table 7-20. Evaluation of policy combinations

Policy combination	**Advantages**	**Disadvantages**
GPP (voluntary) + Energy Label (mandatory)	• 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 • The label rating can provide a benchmark for a criterion within the GPP	• May result in conflicting information if a high performing system has components that cannot meet the GPP module/inverter criteria
EU Ecolabel (voluntary) + Ecodesign (mandatory)	• The EU Ecolabel criteria could be used to address some aspects of system performance • Complementarity – ecodesign would cut off the worst performing products whilst the other would reward the best performers. • The Ecodesign requirements can provide a performance metrics and test methods for criteria within the EU Ecolabel	-
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 meeting ambitious environmental criteria • Both have a degree of uncertainty as to the take-up

Additional 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 BNAT technologies that offer improved life cycle performance.

Policy option 8.1: 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 PERC 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 8.2 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 of Task 6, consumer expenditure and employment depending on the market evolution of PV modules, inverters and systems. The different policy options have been identified and possible technical performance criteria 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 done 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 we assume a fixed lifetime for the equipment of 30 years. During this lifetime, repairs can be done, for example 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(BSF), PERC silicon, PERC silicon bifacial, thin film modules (CIGS/CdTe), epitaxial modules, Hetero-junction(HJT/BJT).
- **The Task 6 Best Available Technology and system (BAT) scenario**: It is a proxy scenario that achieve all the best that could be obtained out of Task 6, including the proposed policy at product level and system level. This scenario is set up to provide the benchmark and is of use as a basis for the EU Ecolabel scenario. 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 2021 and will be assumed effect in the scenario calculations from 2022 onwards
- Tier 2 policy in place in 2024 and will be assumed effect in the scenario calculations from 2022 onwards

The four variants of the Ecodesign scenario have been modelled separately and in combination for the products, with each having effect on various performance aspects for the two sub-products:

- **The Ecodesign performance requirements on modules on efficiency and 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 and durability (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 and durability 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.
- **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 and 5.2):** 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 modelled for 5.2
- **The combined effect of mandatory and voluntary options (COM 6.1)**: 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 between 2022 and 2023, taking full effect from 2024.

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 B. Label scenarios LAB 3.1 and LAB 5.1 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 2.3 within 2021 Tier 1 of Ecodesign resulting in the removal of label class E and in 2024 Tier 2 resulting in removal of label class D. Also it assumes a substitution of other less efficient module products by more efficient products (BSF by PERC, PERC by SHJ), 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 optimised BSF module technology being substituted by PERC or SHJ module technology, as the driver is choice based on efficiency.
- 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 5.1 is a similar scenario to LAB 4.1 to model GPP policy option 5.1, it assumes that 12% of commercial stock or BC2 is affected and BAT would be applied to 20% by 2022, 40% by 2024 and 60% by 2026.
- 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++). The same assumptions can be applied to LAB 3.2 which is therefore assumed to have identical impact.
- The combined effect from COM 6.1 will be assumed identical to achieving BAT. On one hand this might be seen as an overestimate however on such a time scale BNAT (see Tasks 4/6) is expected to enter the market which isn’t modelled and therefore an underestimate.

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

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 7-1 and Figure 7-2. 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 annual build-up of stock has a very uneven profile. This is because the projections are 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.

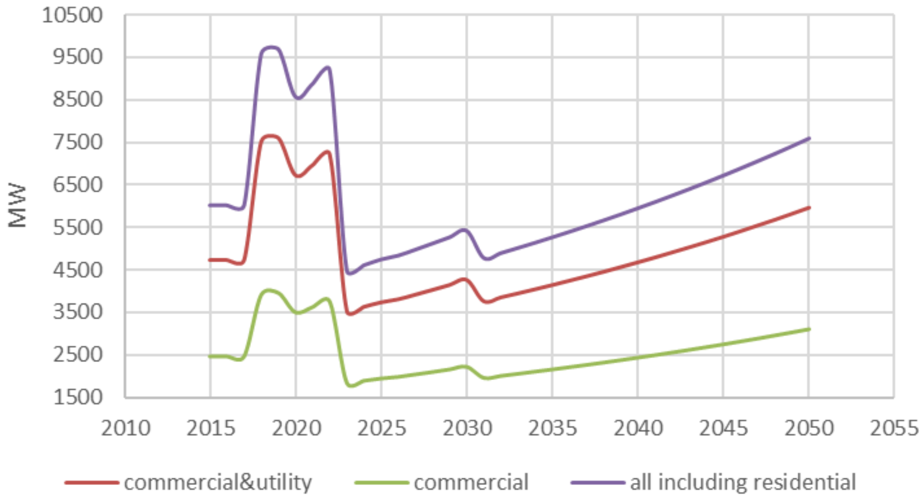

Figure 7-1: Annual sales MWp per application market

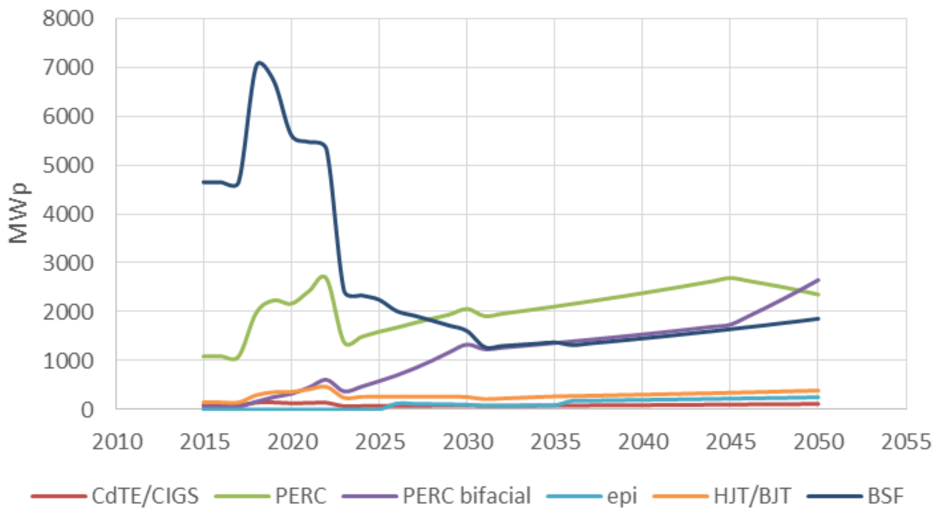

Figure 7-2: BAU annual market in MWp per technology

For the purpose of this study a tailored scenario calculation spreadsheet was developed taking into account the impact from all life cycle stages that came out of the Ecoreport tools 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 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 is assumed at a fixed life time of 30 year 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 with reference year 2016 which means the Net Present Value (NPV) in 2016. The model always assumes that a full photovoltaic system is presented, meaning when a module improvement is added the impact of this improvement option is always analysed in the context of its 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 environmental impact both the Annual Yield (TWh) and the Gross Energy Requirement (GJ) were calculated for all scenarios. When looking to the scenarios it is important to look at both impacts on Yield and GER, because the forecasted impact is a combination of effects. Improvements in efficiency are mostly reflected in greater yield so that the GER per functional unit is reduced 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, e.g. module performance degradation.

Figure 7-3 includes the annual yield (TWh) for **the BAU and a reference BAT scenario** 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 we cannot have impact on this with future policy.

Figure 7-4 includes the GER (TWh) (Gross Energy Requirements) for **the BAU and a reference BAT scenario,** herein 1 TWh GER equals 3600 TJ. These apply to all three market segments. The BAT scenario combines the best solutions for modules, inverters and systems that were identified in Task 6 and therefore provides a benchmark for how much improvement in the GER for the stock could hypothetically be achieved. As a comparison in 2016 the gross electricity production in EU reached 3255 TWh. Also worth noting is the primary energy or GER for manufacturing in 2015 (Figure 7-4) is 1500000 TJ or 41,7 TWh which is 6.4 times the generated power in 2015 (6,48 TWh) from this installed PV systems, this follows the energy pay-back time[22] which is also reflected in Figure 7-4.

The slight decrease in annual yield compared to BAU is due to the higher anticipated degradation rate of thin film modules (CIGS/CdTe) used in the BAT scenario. Due to the switch to thin film modules (BAT) the impact on GER is, however, significant.

[22] To calculate the energy pay-back time'EPBT) most often a Primary Energy Factor(PEF) is applied (2,1 -3) to have a better comparison with electricity from coal plants, this reduces the from 6.4 to 3,0 years (with factor 2,1) or 2,14 years (with factor 3).

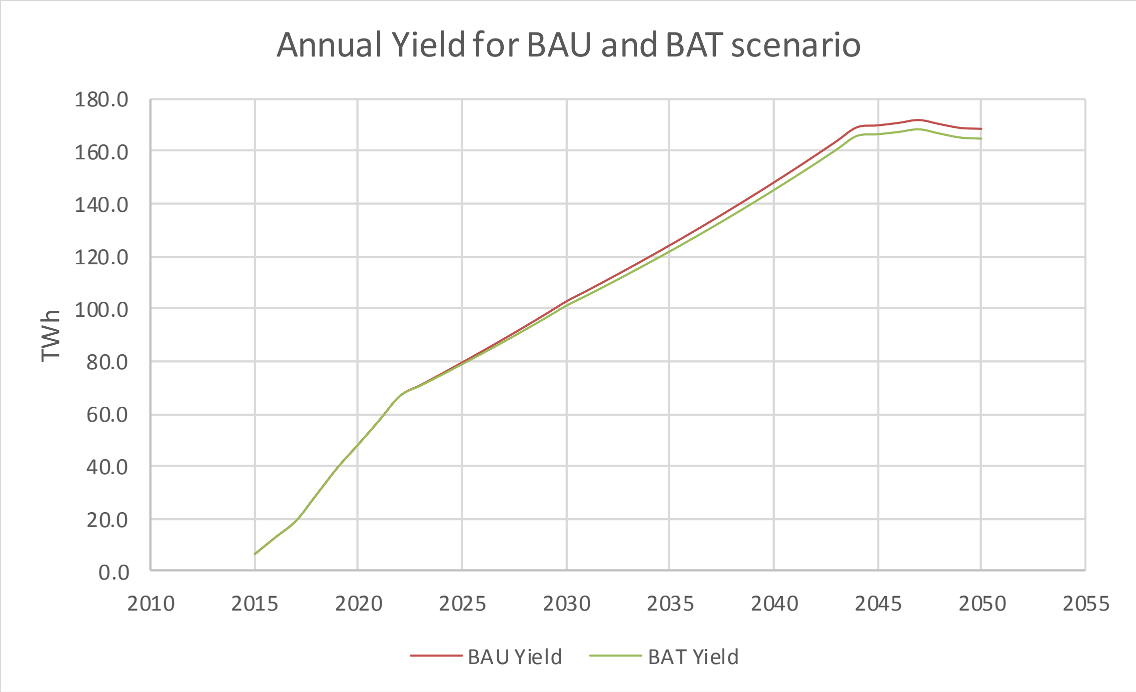

Figure 7-3: Annual yield for BAU and BAT Scenarios for PV systems

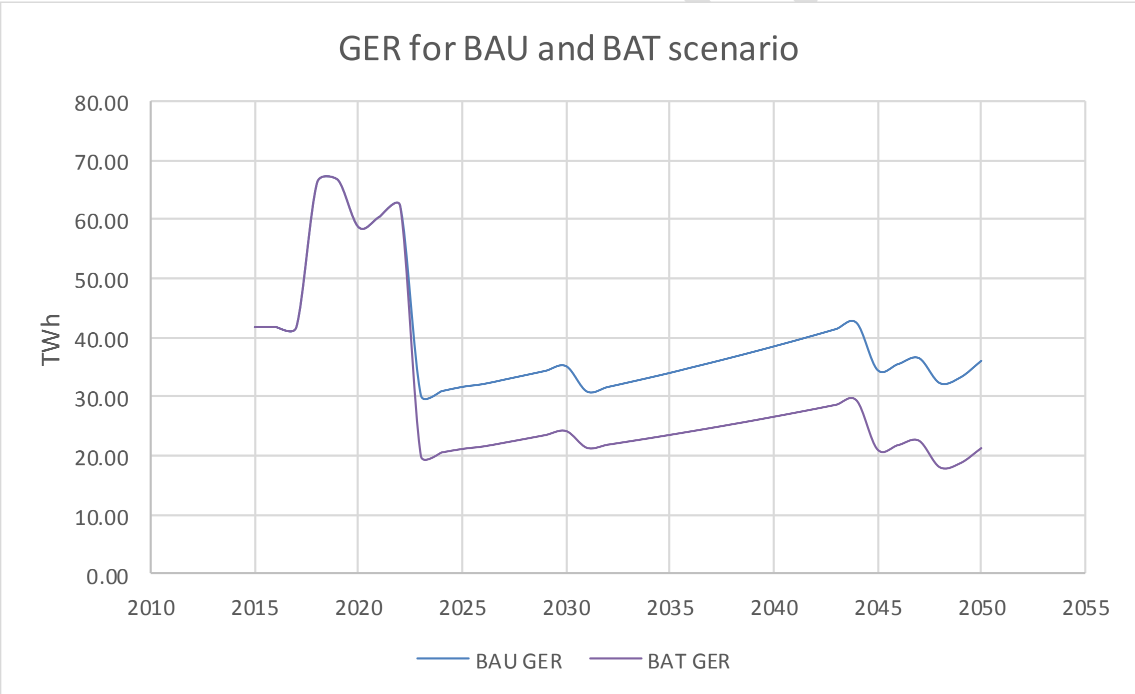

Figure 7-4: Gross energy requirements for BAU and BAT Scenarios for modules inverters and systems

All subsequent scenarios are calculated relative to the Business-as-Usual (BAU) scenario and the Best Available technology (BAT) - data is included in Annex C and assumptions in Annex B.

Policy option 2

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 impact because they remove a small underperforming proportion of the market (see Annex B). 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 an average efficiency (16%) that represents a poor performing module 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 are m^2 basis, resulting in more installed capacity. Values for this scenario are in Annex C.

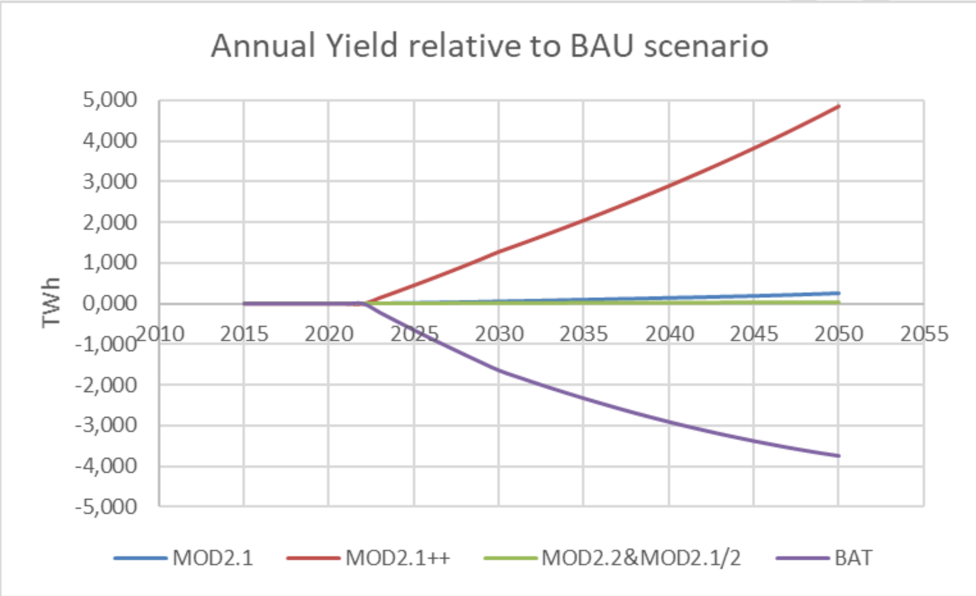

Figure 7-5 Annual Yield relative to the BAU for various modules policy options and the BAT scenario

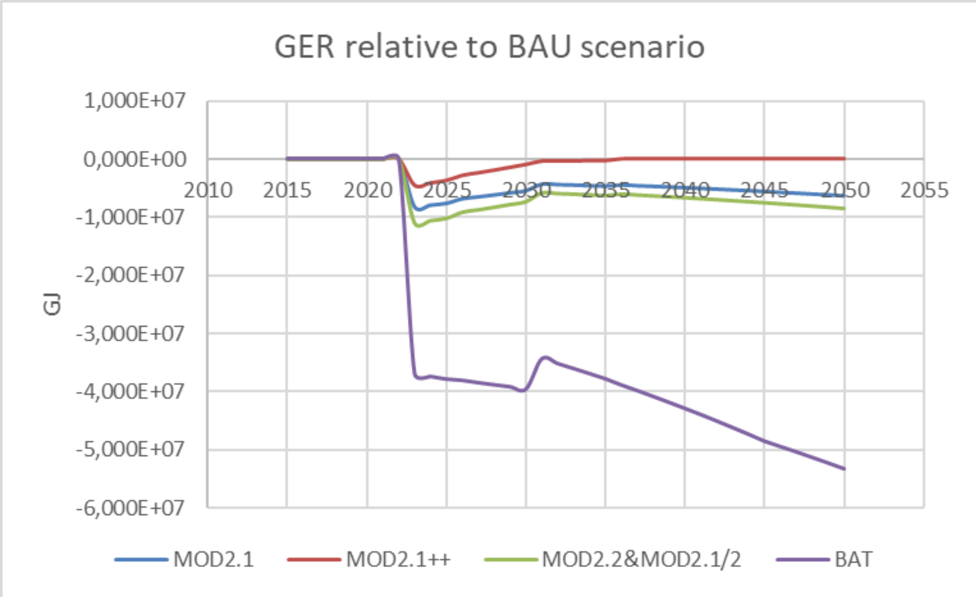

Figure 7-6 Gross Energy Requirement (GER) relative to the BAU for various modules policy options and the BAT scenario

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).

The scenario with Ecodesign requirements on **inverter efficiency and yield 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 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 an average efficiency (96%) that represents a poor performing inverter has been substituted in the stock model, whereas models with a performance as low as 93% are on sale.

The Ecodesign requirements on the **quality and durability 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 as the design options are already commonplace in the other segments. It can also be easily compared to the labelling scenarios which are also targeted at this segment (LAB 3.1 and 5.1). 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.

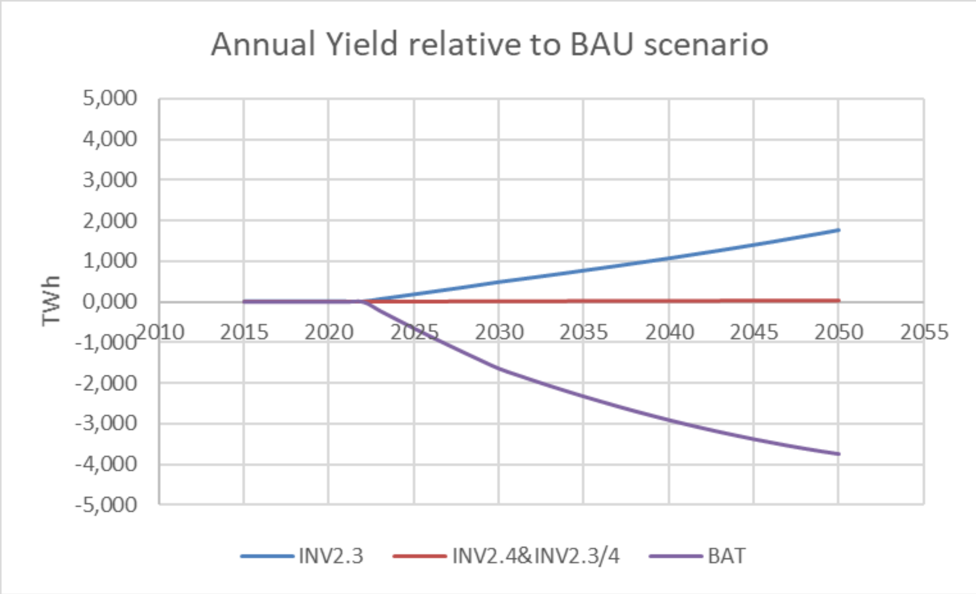

Figure 7-7 Annual Yield relative to the BAU for various inverter policy options and the BAT scenario

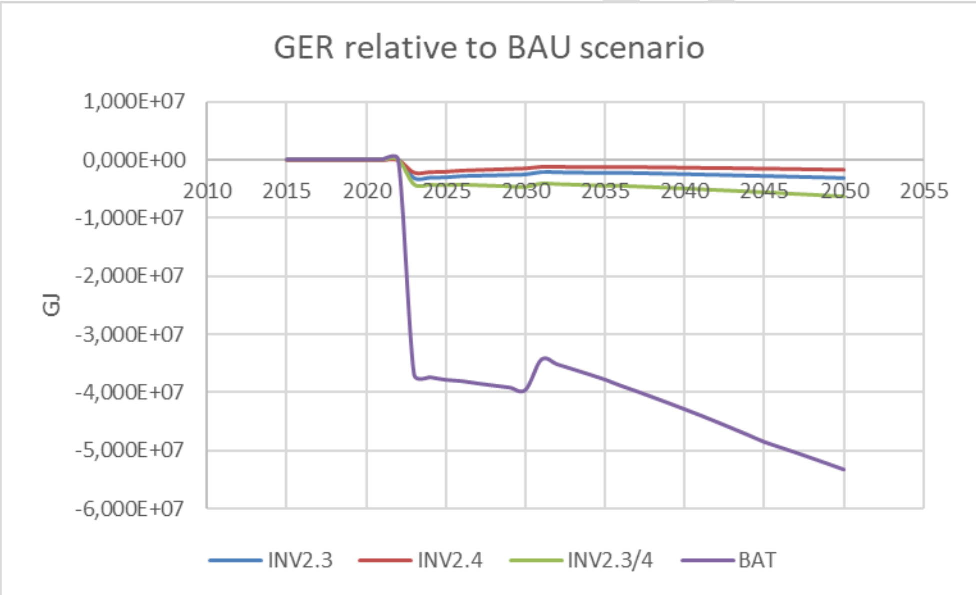

Figure 7-8 Gross Energy Requirement (GER) relative to the BAU for various inverter policy options and the BAT scenario

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 7 and Figure 7 8.

Policy option 3

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 D 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 (m²) 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 and not in 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 (BSF optimised>PERC, PERC>SHJ).

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 (m^2) basis, resulting in more installed MWp capacity (e.g. 3 kWp system with BSF modules substituted by PERC modules increases to 3.5 kWp with an 18% yield increase).The BAT is included as a reference point and it can be seen that the BAU yield cannot be maintained because the Bat modules have a lower efficiency and therefore yield. The difference between the two increases over time as high yield modules enter into the BAU stock model. This may not however be realistic because the BAT modules are also expected to improve in yield.

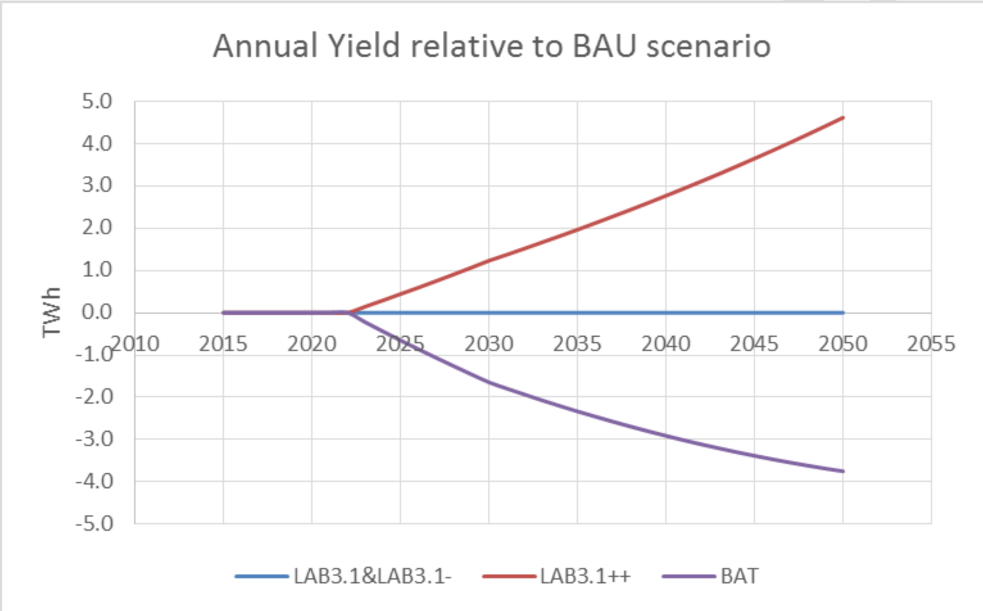

Figure 7-9 Annual Yield relative to the BAU for energy label policy options

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).

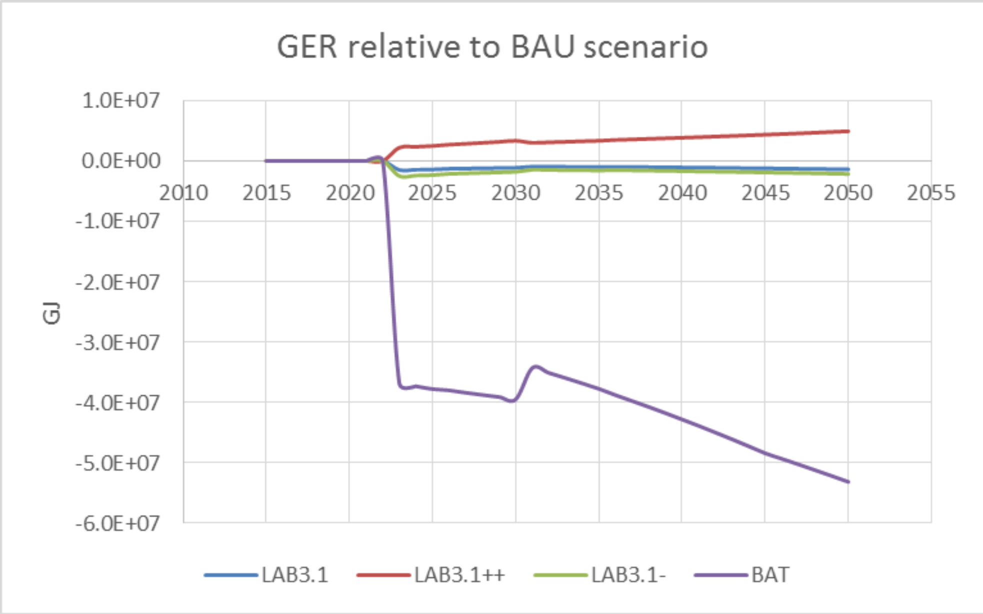

Figure 7-10 Gross Energy Requirement (GER) relative to the BAU for energy label policy

Policy option 4

The residential **EU Ecolabel criteria for packages and services LAB 4.1** is presented in and. 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 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.

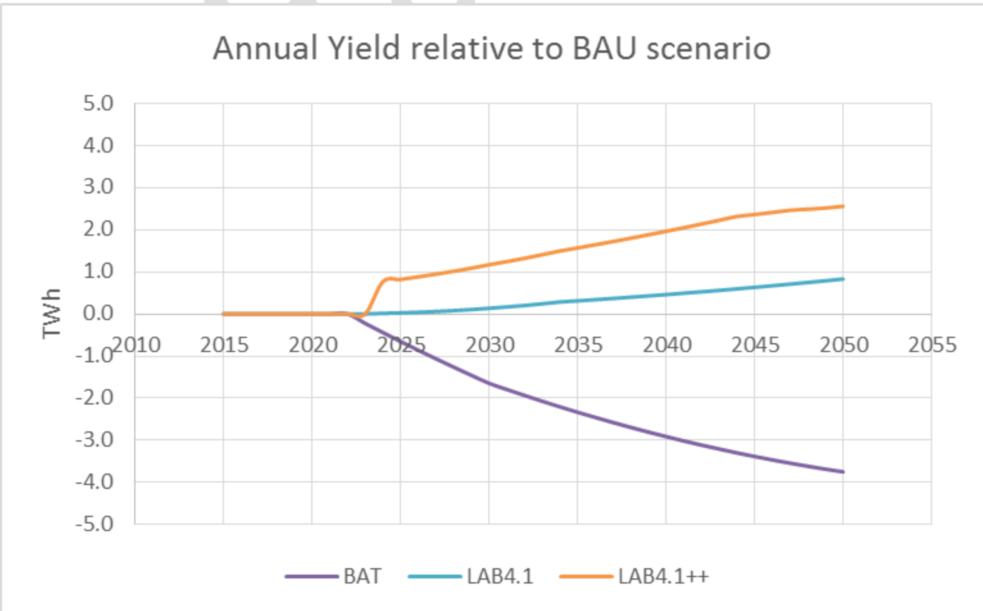

Figure 7-11 Gross Energy Requirement (GER) relative to the BAU for EU Ecolabel policy

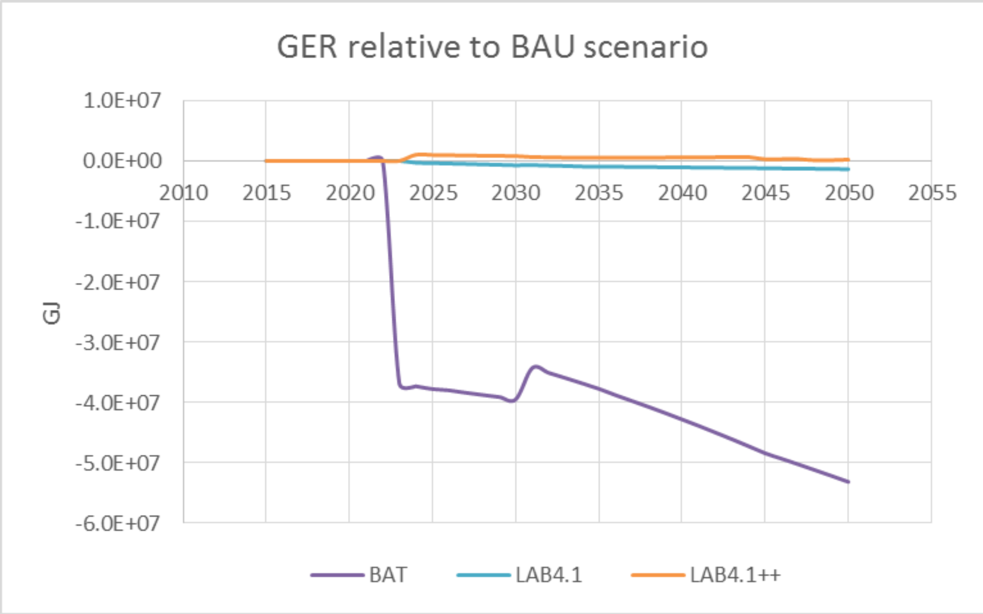

Figure 7-12 Gross Energy Requirement (GER) relative to the BAU for EU Ecolabel policy

Policy option 5

The **GPP5.1** policy option projected results are in Figure 7-13 and Figure 7-14 It builds on BC2 and the uptake of BAT in the public sector (12 % of BC 2).

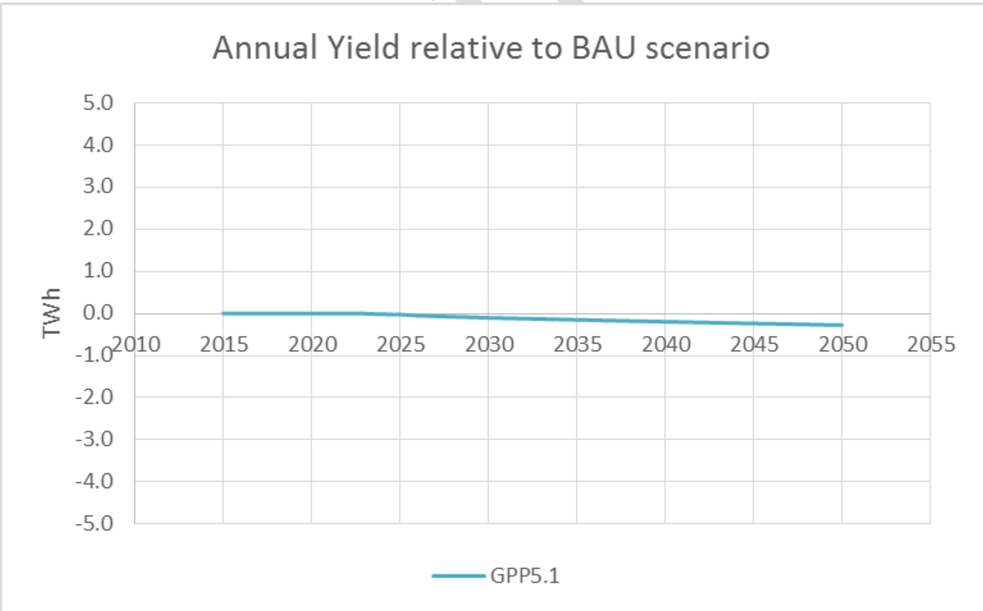

Figure 7-13 Annual Yield relative to the BAU for the GPP 5.1 policy option

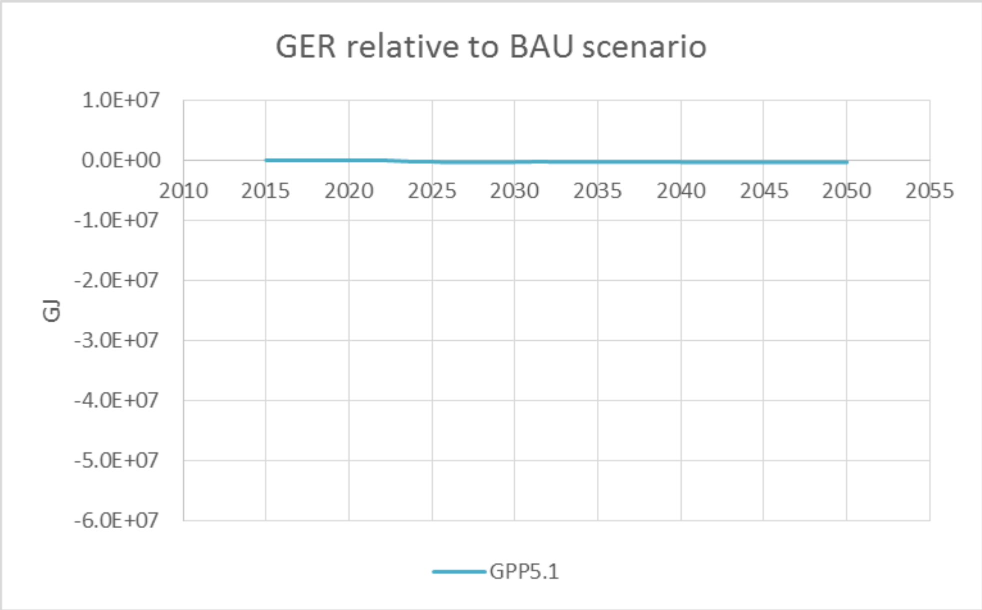

Figure 7-14 Annual Gross Energy Requirement (GER) relative to the BAU for the GPP5.1 policy option

For the policy option **GPP5.2**, only a scenario for the possible increase in stock is shown in order to illustrate the potential impact on the market (Figure 7-15). Even with the modelling being based on relatively conservative assumptions the potential impact could be significant.

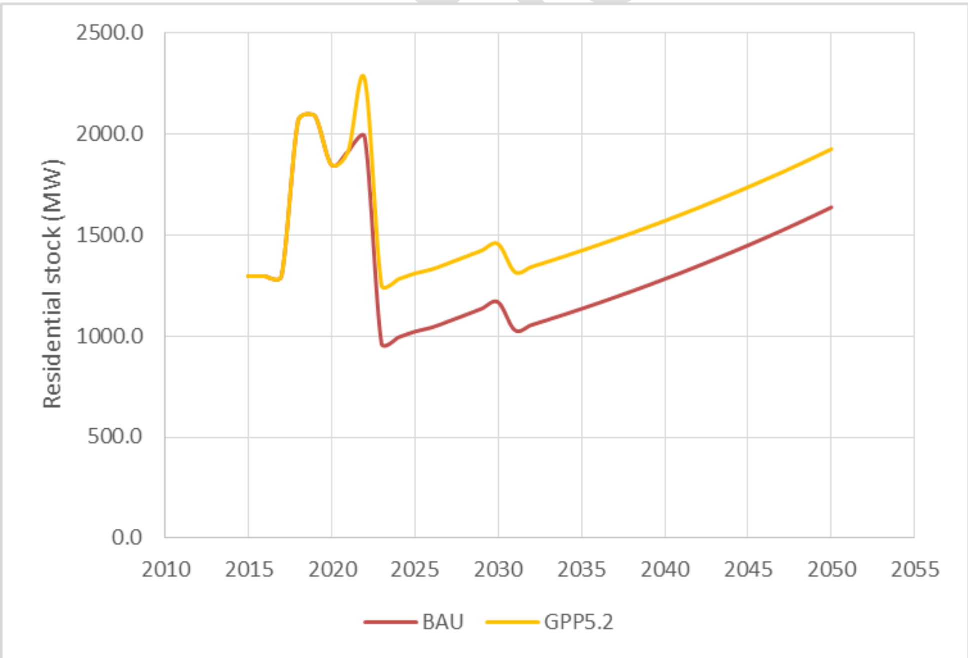

Figure 7-15 Annual stock for the GPP 5.2 policy option in comparison with the BAU stock

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 – particularly the substitution on a drop-in basis of standard polycrystalline wafers with so-called kerfless wafers grown using epitaxial techniques. The benefits of the next generation of wide bandwidth inverters – for example, the potential for higher euro efficiencies and lower temperature induced failure - is also as yet unclear. Hence the impact is likely underestimated and potentially an ambitious label can support driving the market to those BNAT. This was not modelled because the benefit of their uptake in the market would mainly be reflected in the GER. It could therefore not be fully addressed by the mandatory policy instruments in the scope of section 7.1.3 but rather by the effect of voluntary instruments such as the EU Ecolabel, which allow for requirements on production stage impacts. 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 7-16). 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 in net present value in 2016.

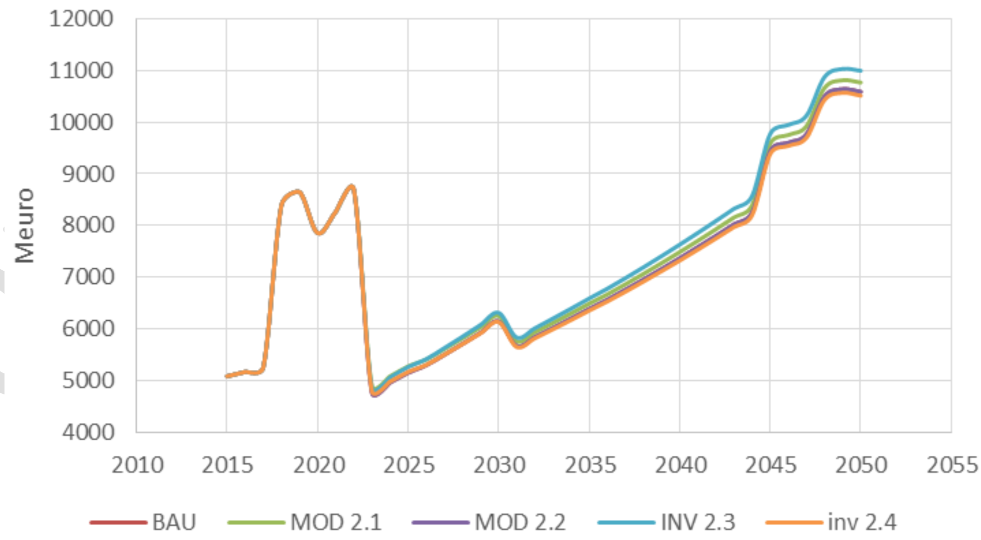

Figure 7-16 Calculated total annual expenditure for different scenarios (NPV with reference year 2016)

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 7-21).

Table 7-21 PRIMES projected electricity prices to 2050 (source: PRIMES[23])

	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 7-16 with the economic benefits in Figure 7-17, 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.

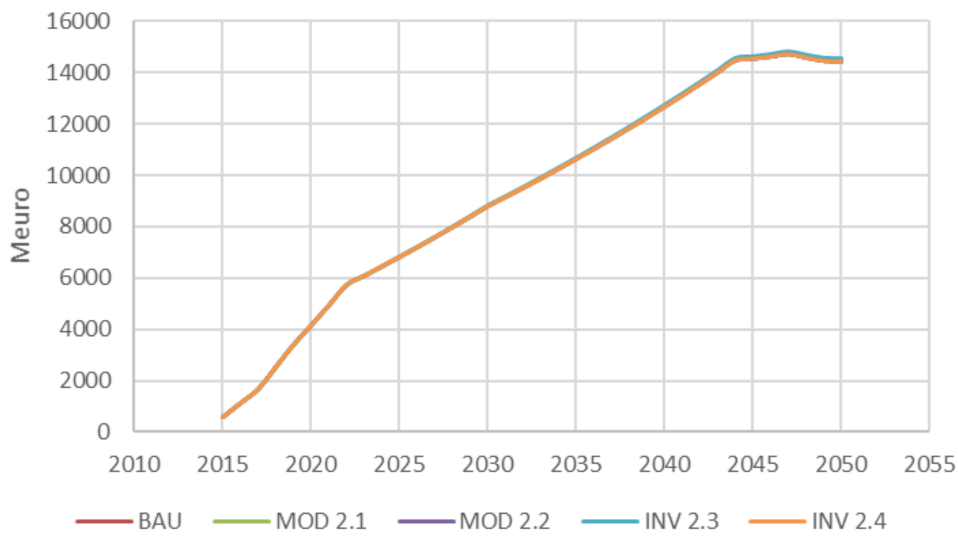

Figure 7-17 Value of generated electricity per year

23

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 cell and module manufacturing takes place outside Europe (see Task 2).

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 [24] [25]. 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.

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

[25] 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.

- 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[26]. 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 into the constituent activities that add value to the delivery of a PV system to a client.

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

Table 7-22 applies 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%) [27].

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.

[27] 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 7-22 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 7-23. 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 anticipated only 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 by existing installers upon system designs.

Table 7-23 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 have a disproportionate impact on EU employment.

It can be seen in Figure 7-18: 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.

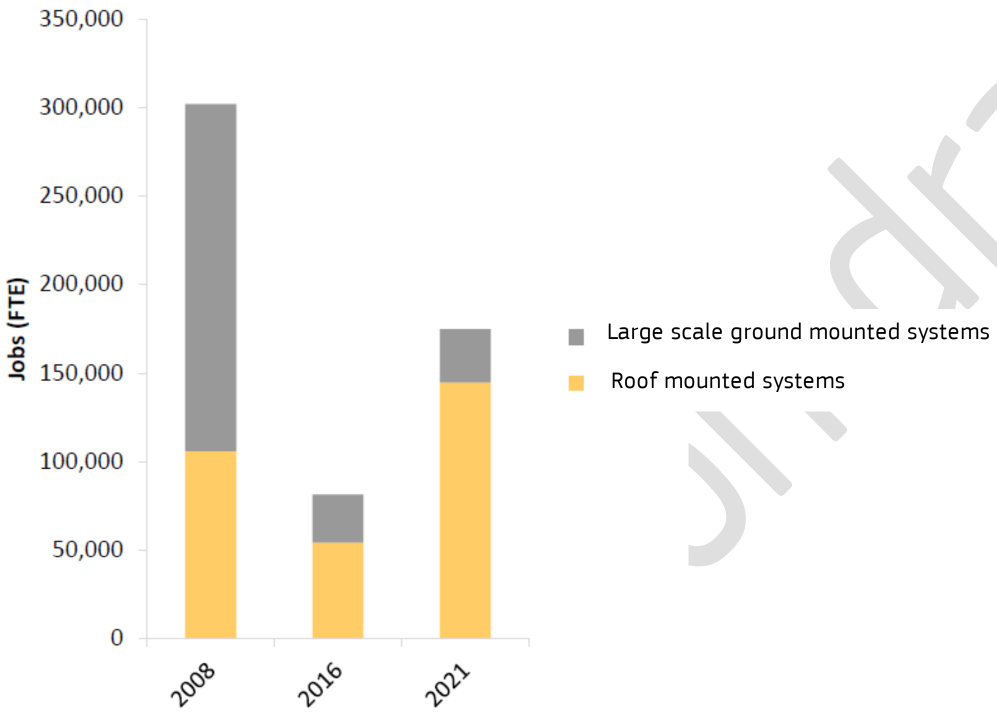

Figure 7-18: Upstream and downstream employment supported by EU PV system installations

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 7-24). 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 7-24 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.

7.3.2.4. Module manufacturing cost structure

Despite a >97% decrease in costs since 1980 and an average learning rate of 21% [28] [29], 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 [30]. 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 are already within this price

[28] 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.
[29] Kavlak et al, *Evaluating the causes of cost reduction in photovoltaic modules*, Energy Policy 123 (2018) 700–710
[30] 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

window [31]. Figure 7-19 and Figure 7-20 illustrate an indicative cost structure for a module manufacturing plant and associated capital expenditure in 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 PERC 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.

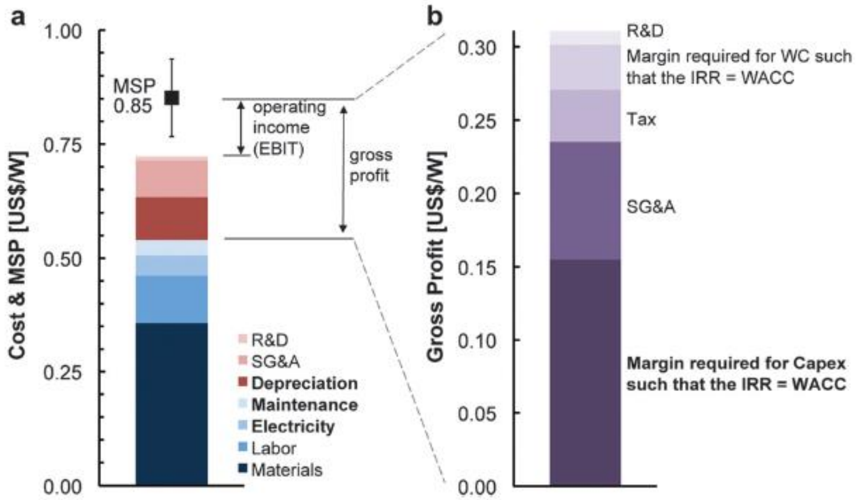

Figure 7-19: Indicative cost structure for a crystalline module manufacturing plant

Source: NREL (2015)

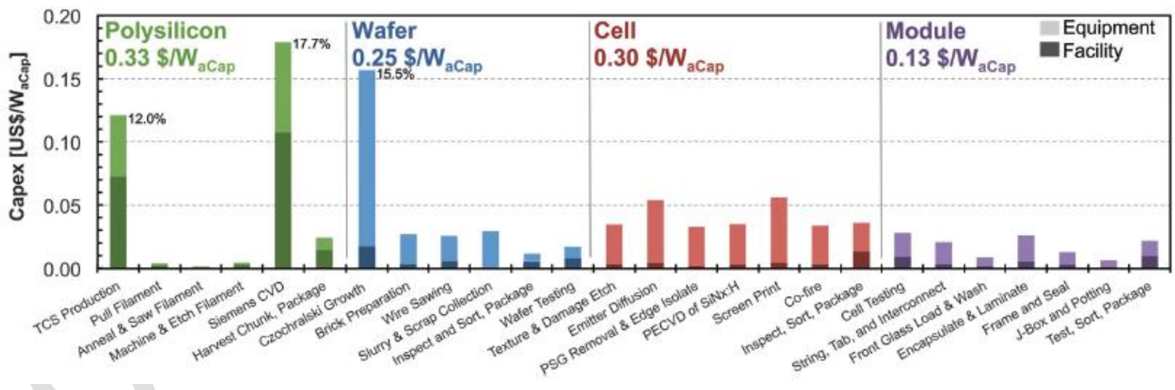

Figure 7-20: Indicative annual capital expenditure for upstream processes of crystaline module manufacturing

Source: NREL (2015)

[31] See footnote 28

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.

A previous reference study that analysed the sensitivity of solar PV system LCOE highlighted the relative importance of the location, the Weighted Cost of Capital, Operational expenditure and Capital expenditure as having greater significance than technical parameters such as lifetime and degradation (see Figure 7-21).

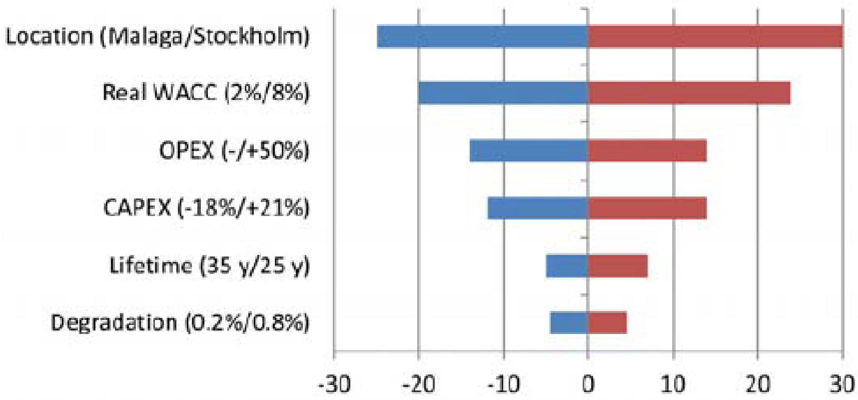

Figure 7-21: Sensitivity analysis of LCOE (%)

Source: PVTP (2015)

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 (see Table 7-25):

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.

Table 7-25 Proposed parameters for the sensitivity analysis (TBD = To Be Defined)

parameter	**Min.**	**default**	**Max.**
Economic life time(y)	**25**	**30**	**35**
Reference Yield (h)	**1170 (Zone 1)**	**1331 (Zone 2)**	**1900 (Zone 3)**
HJT/BJT euro/Wp	TBD?	TBD?	TBD?
CdTe euro/Wp	TBD?	TBD?	TBD?
CIGS euro/Wp	TBD?	TBD?	TBD?
Epi euro/Wp	TBD?	TBD?	TBD?
Discount rate (%)	**2 %**	**4 %**	**12 %**

Outcomes:

It is not expected that this will change the Task 6 results in a way that it will influence the proposed policy. This calculation will be made in the final review.

ANNEXES

A. Forecast for the stock model evolution

Year	Additions low Scenario	Additions high scenario	Stock Forecast High	Stock forecast Low
2016			101856	101856
2017	6022	6022	107878	107878
2018	9595	10212	117473	118090
2019	9705	11179	127178	129269
2020	8580	12237	135758	141506
2021	8885	13853	144643	155359
2022	9205	15209	153848	170568
2023	4482	16698	158330	187266
2024	4613	18333	162943	205599
2025	4747	20127	167690	225727
2026	4839	26404	172529	252131
2027	4979	29493	177508	281623
2028	5123	32942	182631	314565
2029	5271	36796	187901	351361
2030	5423	41100	193324	392461
2031	4780	9146	198104	401607
2032	4898	9359	203002	410965
2033	5019	9577	208021	420542
2034	5143	9800	213164	430342
2035	5270	10028	218435	440370
2036	5401	10262	223835	450632
2037	5534	10501	229370	461133
2038	5671	10746	235041	471879
2039	5811	10996	240852	482875
2040	5955	11252	246807	494128

2041	6102	11515	252909	505642
2042	6253	11783	259162	517425
2043	6408	12058	265570	529483
2044	6566	12339	272136	541822
2045	6728	12626	278865	554448
2046	6895	12920	285759	567368
2047	7065	13221	292825	580589
2048	7240	13530	300065	594119
2049	7419	13845	307484	607964
2050	7602	14167	315086	622131

B. Annex proxies used in the scenario modelling tool

Market	CIGS/ CdTe	PERC normal	PERC bifacial	epi	HJT BJT	BSF
MOD 2.1 on module efficiency and life time yield scenario(Tier 2)						
Base Case 1						
	2.09E+07	2.56E+07	2.61E+07	2.95E+07	2.53E+07	2.56E+07
	3.96E+03	7.65E+03	7.83E+03	8.38E+03	7.55E+03	7.65E+03
	-3.04E+06	-5.36E+06	-5.51E+06	-6.09E+06	-5.30E+06	-5.36E+06
proxy Task 6	BC1 - CIGS	BC1 - PERC	BC1 - PERC bifacial	BNAT kerfless new	BC1 - SHJ	BC1 - PERC
Base Case 2						
	8.88E+06	2.32E+07	2.08E+07	2.70E+07	2.29E+07	2.32E+07
	1.70E+03	6.96E+03	6.30E+03	7.69E+03	6.86E+03	6.96E+03
	-1.13E+06	-4.93E+06	-4.47E+06	-5.66E+06	-4.87E+06	-4.93E+06
proxy Task 6	BC2 -CdTe	BC2 - PERC	BC2 - PERCbf	BC2 - kerfless old	BC2 - SHJ	BC2 - PERC
Base Case 3						
	7.32E+06	2.16E+07	1.92E+07	2.55E+07	2.13E+07	2.16E+07
	1.27E+03	6.51E+03	5.83E+03	7.30E+03	6.41E+03	6.51E+03
	-1.07E+06	-4.85E+06	-4.35E+06	-5.67E+06	-4.78E+06	-4.85E+06
proxy Task 6	BC3 -CdTe	BC3 - PERC	BC3 - PERCbf	BC3 - kerfless old	BC3 - SHJ	BC3 - PERC

MOD 2.2 on module module performance on quality and durability						
Base Case 1						
	2.09E+07	2.56E+07	2.61E+07	2.95E+07	2.53E+07	2.37E+07
	3.96E+03	7.65E+03	7.83E+03	8.38E+03	7.55E+03	6.90E+03
	-3.04E+06	-5.36E+06	-5.51E+06	-6.09E+06	-5.30E+06	-4.91E+06
proxy Task 6	BC1 - CIGS	BC1 - PERC	BC1 - PERC bifacial	BNAT kerfless new	BC1 - SHJ	BC1 - MSiO
Base Case 2						
	8.88E+06	2.32E+07	2.08E+07	2.70E+07	2.29E+07	2.13E+07
	1.70E+03	6.96E+03	6.30E+03	7.69E+03	6.86E+03	6.21E+03
	-1.13E+06	-4.93E+06	-4.47E+06	-5.66E+06	-4.87E+06	-4.48E+06
proxy Task 6	BC2 -CdTe	BC2 - PERC	BC2 - PERCbf	BC2 - kerfless old	BC2 - SHJ	BC2 - MSio
Base Case 3						
	7.32E+06	2.16E+07	1.92E+07	2.55E+07	2.13E+07	1.97E+07

	1.27E+03	6.51E+03	5.83E+03	7.30E+03	6.41E+03	5.79E+03
	-1.07E+06	-4.85E+06	-4.35E+06	-5.67E+06	-4.78E+06	-4.43E+06
proxy Task 6	**BC3 -CdTe**	**BC3 - PERC**	**BC3 - PERCbf**	**BC3 - kerfless old**	**BC3 - SHJ**	**BC3 - MSio**

MOD 2.1+2 on module module performance on quality and durability						
Base Case 1						
	2.09E+07	2.56E+07	2.61E+07	2.95E+07	2.56E+07	2.37E+07
	3.96E+03	7.65E+03	7.83E+03	8.38E+03	7.65E+03	6.90E+03
	-3.04E+06	-5.36E+06	-5.51E+06	-6.09E+06	-5.36E+06	-4.91E+06
proxy Task 6	**BC1 - CIGS**	**BC1 - PERC**	**BC1 - PERC bifacial**	**BNAT kerfless new**	**BC1 - PERC**	**BC1 - MSiO**
Base Case 2						
	8.88E+06	2.32E+07	2.08E+07	2.70E+07	2.32E+07	2.13E+07
	1.70E+03	6.96E+03	6.30E+03	7.69E+03	6.96E+03	6.21E+03
	-1.13E+06	-4.93E+06	-4.47E+06	-5.66E+06	-4.93E+06	-4.48E+06
proxy Task 6	**BC2 -CdTe**	**BC2 - PERC**	**BC2 - PERCbf**	**BC2 - kerfless old**	**BC2 - PERC**	**BC2 - MSio**
Base Case 3						
	7.32E+06	2.16E+07	1.92E+07	2.55E+07	2.16E+07	1.97E+07
	1.27E+03	6.51E+03	5.83E+03	7.30E+03	6.51E+03	5.79E+03
	-1.07E+06	-4.85E+06	-4.35E+06	-5.67E+06	-4.85E+06	-4.43E+06
proxy Task 6	**BC3 -CdTe**	**BC3 - PERC**	**BC3 - PERCbf**	**BC3 - kerfless old**	**BC3 - PERC**	**BC3 - MSio**

INV 2.3 on inverters efficiency and life time electricity yield						
Base Case 1						
	2.09E+07	2.56E+07	2.61E+07	2.95E+07	2.53E+07	2.71E+07
	3.96E+03	7.65E+03	7.83E+03	8.38E+03	7.55E+03	7.93E+03
	-3.04E+06	-5.36E+06	-5.51E+06	-6.09E+06	-5.30E+06	-5.65E+06
proxy Task 6	**BC1 - CIGS**	**PERC + EE**	**BC1 - PERC bifacial**	**BNAT kerfless new**	**BC1 - SHJ**	**BC1- Efficient**
Base Case 2						
	8.88E+06	2.32E+07	2.08E+07	2.70E+07	2.29E+07	2.47E+07
	1.70E+03	6.96E+03	6.30E+03	7.69E+03	6.86E+03	7.25E+03
	-1.13E+06	-4.93E+06	-4.47E+06	-5.66E+06	-4.87E+06	-5.22E+06
proxy Task 6	**BC2 -CdTe**	**PERC + EE**	**PERC bifacial + EE**	**BC2 - kerfless old**	**BC2 - SHJ**	**BC2-EE**

Base Case 3						
	7.32E+06	2.10E+07	1.87E+07	2.55E+07	2.13E+07	2.32E+07
	1.27E+03	6.33E+03	5.67E+03	7.30E+03	6.41E+03	6.84E+03
	-1.07E+06	-4.74E+06	-4.26E+06	-5.67E+06	-4.78E+06	-5.21E+06
proxy Task 6	**BC3 -CdTe**	**PERC + EE**	**PERC bifacial + EE**	**BC3 - kerfless old**	**BC3 - SHJ**	**BC3-EE +BOS**

INV 2.4 on inverters on quality and durability						
Base Case 1						
	2.09E+07	2.56E+07	2.61E+07	2.95E+07	2.53E+07	2.42E+07
	3.96E+03	7.65E+03	7.83E+03	8.38E+03	7.55E+03	7.08E+03
	-3.04E+06	-5.36E+06	-5.51E+06	-6.09E+06	-5.30E+06	-5.11E+06
proxy Task 6	**BC1 - CIGS**	**BC1 - PERC**	**BC1 - PERC bifacial**	**BNAT kerfless new**	**BC1 - SHJ**	**BC1- Longer life**
Base Case 2						
	8.88E+06	2.32E+07	2.08E+07	2.70E+07	2.29E+07	2.35E+07
	1.70E+03	6.96E+03	6.30E+03	7.69E+03	6.86E+03	6.87E+03
	-1.13E+06	-4.93E+06	-4.47E+06	-5.66E+06	-4.87E+06	-4.98E+06
proxy Task 6	**BC2 -CdTe**	**BC2 - PERC**	**BC2 - PERCbf**	**BC2 - kerfless old**	**BC2 - SHJ**	**BC2-R**
Base Case 3						
	7.32E+06	2.16E+07	1.92E+07	2.55E+07	2.13E+07	2.43E+07
	1.27E+03	6.51E+03	5.83E+03	7.30E+03	6.41E+03	7.19E+03
	-1.07E+06	-4.85E+06	-4.35E+06	-5.67E+06	-4.78E+06	-5.47E+06
proxy Task 6	**BC3 -CdTe**	**BC3 - PERC**	**BC3 - PERCbf**	**BC3 - kerfless old**	**BC3 - SHJ**	**BC3 - MSi**

INV 2.3+4 on inverters on quality and durability						
Base Case 1						
	2.09E+07	2.27E+07	2.61E+07	2.95E+07	2.53E+07	2.71E+07
	3.96E+03	6.79E+03	7.83E+03	8.38E+03	7.55E+03	7.93E+03
	-3.04E+06	-4.83E+06	-5.51E+06	-6.09E+06	-5.30E+06	-5.65E+06
proxy Task 6	**BC1 - CIGS**	**PERC + EE+LL**	**BC1 - PERC bifacial**	**BNAT kerfless new**	**BC1 - SHJ**	**BC1- Efficient**
Base Case 2						
	8.88E+06	2.20E+07	1.96E+07	2.70E+07	2.29E+07	2.47E+07
	1.70E+03	6.58E+03	5.92E+03	7.69E+03	6.86E+03	7.25E+03
	-1.13E+06	-4.70E+06	-4.24E+06	-5.66E+06	-4.87E+06	-5.22E+06

proxy Task 6	BC2 -CdTe	PERC + EE+R	PERC bifacial + EE+R	BC2 - kerfless old	BC2 - SHJ	BC2-EE
Base Case 3						
	7.32E+06	2.10E+07	1.87E+07	2.55E+07	2.13E+07	2.32E+07
	1.27E+03	6.33E+03	5.67E+03	7.30E+03	6.41E+03	6.84E+03
	-1.07E+06	-4.74E+06	-4.26E+06	-5.67E+06	-4.78E+06	-5.21E+06
proxy Task 6	BC3 -CdTe	PERC + EE	PERC bifacial + EE	BC3 - kerfless old	BC3 - SHJ	BC3-EE +BOS

LAB 3.1 simple residential Energy label (Tier 2)						
Base Case 1						
	2.09E+07	2.53E+07	2.61E+07	2.95E+07	2.53E+07	2.56E+07
	3.96E+03	7.55E+03	7.83E+03	8.38E+03	7.55E+03	7.65E+03
	-3.04E+06	-5.30E+06	-5.51E+06	-6.09E+06	-5.30E+06	-5.36E+06
proxy Task 6	BC1 - CIGS	BC1 - SHJ	BC1 - PERC bifacial	BNAT kerfless new	BC1 - SHJ	BC1 - PERC

LAB 3.1- simple residential Energy label (Tier 2)						
Base Case 1						
	2.09E+07	2.53E+07	2.61E+07	2.95E+07	2.53E+07	2.37E+07
	3.96E+03	7.55E+03	7.83E+03	8.38E+03	7.55E+03	6.90E+03
	-3.04E+06	-5.30E+06	-5.51E+06	-6.09E+06	-5.30E+06	-4.91E+06
proxy Task 6	BC1 - CIGS	BC1 - SHJ	BC1 - PERC bifacial	BNAT kerfless new	BC1 - SHJ	BC1 - MSiO

C. Annual Yield and GER for modelled scenarios

	Annual yield (TWh)														
	BAU BC1-3	BAT	MOD2.1	MOD2.1++	MOD2.2	MOD2.1/2	INV2.3	INV2.4	INV2.3/4	BAU BC1	LAB3.1	LAB3.1-	LAB3.1+	LAB4.1	LAB4.1++
2015	6.482	6.482	6.482	6.482	6.482	6.482	6.482	6.482	6.482	1.294	1.294	1.294	1.294	1.294	1.294
2016	12.899	12.899	12.899	12.899	12.899	12.899	12.899	12.899	12.899	2.576	2.576	2.576	2.576	2.576	2.576
2017	19.252	19.252	19.252	19.252	19.252	19.252	19.252	19.252	19.252	3.844	3.844	3.844	3.844	3.844	3.844
2018	29.387	29.387	29.387	29.387	29.387	29.387	29.387	29.387	29.387	5.868	5.868	5.868	5.868	5.868	5.868
2019	39.540	39.540	39.540	39.540	39.540	39.540	39.540	39.540	39.540	7.896	7.896	7.896	7.896	7.896	7.896
2020	48.380	48.380	48.380	48.380	48.380	48.380	48.380	48.380	48.380	9.661	9.661	9.661	9.661	9.661	9.661
2021	57.461	57.461	57.461	57.461	57.461	57.461	57.461	57.461	57.461	11.474	11.474	11.474	11.474	11.474	11.474
2022	66.796	66.796	66.796	66.796	66.796	66.796	66.796	66.796	66.796	13.338	13.338	13.338	13.338	13.338	13.338
2023	70.953	70.731	70.957	71.102	70.955	70.955	71.011	70.954	71.011	14.168	14.168	14.168	14.312	14.168	14.168
2024	75.210	74.770	75.219	75.510	75.214	75.214	75.326	75.212	75.326	15.018	15.018	15.018	15.309	15.031	15.783
2025	79.568	78.915	79.582	80.024	79.574	79.574	79.744	79.571	79.744	15.888	15.888	15.888	16.330	15.913	16.709
2026	83.982	83.123	84.002	84.596	83.990	83.990	84.217	83.986	84.217	16.769	16.769	16.769	17.362	16.809	17.649
2027	88.503	87.441	88.530	89.278	88.513	88.513	88.798	88.508	88.798	17.671	17.671	17.671	18.420	17.730	18.616
2028	93.134	91.874	93.168	94.074	93.145	93.145	93.490	93.140	93.490	18.596	18.596	18.596	19.502	18.676	19.610
2029	97.878	96.424	97.920	98.987	97.890	97.890	98.297	97.885	98.297	19.543	19.543	19.543	20.610	19.649	20.631
2030	102.739	101.094	102.789	104.020	102.752	102.752	103.221	102.746	103.221	20.513	20.513	20.513	21.744	20.649	21.681
2031	106.858	105.068	106.917	108.289	106.873	106.873	107.396	106.866	107.396	21.335	21.335	21.335	22.708	21.503	22.578
2032	111.064	109.132	111.130	112.647	111.079	111.079	111.658	111.072	111.658	22.175	22.175	22.175	23.692	22.377	23.496
2033	115.358	113.288	115.432	117.096	115.374	115.374	116.009	115.366	116.009	23.032	23.032	23.032	24.695	23.274	24.437
2034	119.742	117.540	119.825	121.637	119.759	119.759	120.451	119.751	120.451	23.907	23.907	23.907	25.720	24.192	25.402
2035	124.219	121.889	124.310	126.275	124.238	124.238	124.987	124.229	124.987	24.801	24.801	24.801	26.765	25.113	26.369
2036	128.793	126.338	128.893	131.011	128.812	128.812	129.619	128.803	129.619	25.713	25.713	25.713	27.832	26.054	27.356

2037	133.464	130.889	133.572	135.848	133.484	133.484	134.350	133.475	134.350	26.646	26.646	26.646	28.922	27.015	28.366
2038	138.236	135.546	138.353	140.789	138.257	138.257	139.182	138.247	139.182	27.598	27.598	27.598	30.035	27.997	29.397
2039	143.111	140.309	143.237	145.836	143.133	143.133	144.119	143.123	144.119	28.571	28.571	28.571	31.171	29.001	30.451
2040	148.092	145.183	148.227	150.992	148.115	148.115	149.163	148.104	149.163	29.566	29.566	29.566	32.331	30.026	31.528
2041	153.182	150.170	153.326	156.260	153.206	153.206	154.317	153.195	154.317	30.582	30.582	30.582	33.516	31.075	32.628
2042	158.383	155.273	158.537	161.643	158.409	158.409	159.584	158.397	159.584	31.620	31.620	31.620	34.726	32.146	33.754
2043	163.700	160.495	163.863	167.145	163.726	163.726	164.967	163.714	164.967	32.681	32.681	32.681	35.963	33.242	34.904
2044	169.133	165.839	169.306	172.767	169.161	169.161	170.468	169.148	170.468	33.765	33.765	33.765	37.226	34.362	36.080
2045	169.892	166.512	170.075	173.718	169.921	169.921	171.296	169.907	171.296	33.916	33.916	33.916	37.560	34.549	36.276
2046	170.823	167.361	171.017	174.846	170.853	170.853	172.298	170.839	172.298	34.102	34.102	34.102	37.931	34.772	36.510
2047	171.928	168.389	172.133	176.152	171.959	171.959	173.474	171.944	173.474	34.322	34.322	34.322	38.341	35.030	36.782
2048	170.365	166.753	170.583	174.795	170.397	170.397	171.985	170.382	171.985	34.009	34.009	34.009	38.221	34.757	36.495
2049	168.923	165.242	169.155	173.564	168.956	168.956	170.617	168.940	170.617	33.721	33.721	33.721	38.130	34.510	36.235
2050	168.588	164.842	168.835	173.445	168.622	168.622	170.359	168.606	170.359	33.653	33.653	33.653	38.263	34.484	36.208

	GER (GJ)														
	BAU BC 1-3	**BAT**	**MOD2.1**	**MOD2.1++**	**MOD2.2**	**MOD2.1/2**	**INV2.3**	**INV2.4**	**INV2.3/4**	**BAU BC3**	**LAB3.1**	**LAB3.1-**	**LAB3.1+**	**LAB4.1**	**LAB4.1++**
2015	1.503E+08	1.503E+08	1.503E+08	1.503E+08	1.503E+08	1.503E+08	1.503E+08	3.583E+07	1.503E+08	3.583E+07	3.583E+07	3.583E+07	3.583E+07	3.583E+07	3.583E+07
2016	1.503E+08	1.503E+08	1.503E+08	1.503E+08	1.503E+08	1.503E+08	1.503E+08	3.584E+07	1.503E+08	3.584E+07	3.584E+07	3.584E+07	3.584E+07	3.584E+07	3.584E+07
2017	1.504E+08	1.504E+08	1.504E+08	1.504E+08	1.504E+08	1.504E+08	1.504E+08	3.586E+07	1.504E+08	3.586E+07	3.586E+07	3.586E+07	3.586E+07	3.586E+07	3.586E+07
2018	2.383E+08	2.383E+08	2.383E+08	2.383E+08	2.383E+08	2.383E+08	2.383E+08	5.690E+07	2.383E+08	5.690E+07	5.690E+07	5.690E+07	5.690E+07	5.690E+07	5.690E+07
2019	2.399E+08	2.399E+08	2.399E+08	2.399E+08	2.399E+08	2.399E+08	2.399E+08	5.735E+07	2.399E+08	5.735E+07	5.735E+07	5.735E+07	5.735E+07	5.735E+07	5.735E+07
2020	2.110E+08	2.110E+08	2.110E+08	2.110E+08	2.110E+08	2.110E+08	2.110E+08	5.053E+07	2.110E+08	5.053E+07	5.053E+07	5.053E+07	5.053E+07	5.053E+07	5.053E+07
2021	2.174E+08	2.174E+08	2.174E+08	2.174E+08	2.174E+08	2.174E+08	2.174E+08	5.215E+07	2.174E+08	5.215E+07	5.215E+07	5.215E+07	5.215E+07	5.215E+07	5.215E+07
2022	2.240E+08	2.240E+08	2.240E+08	2.240E+08	2.240E+08	2.240E+08	2.240E+08	5.384E+07	2.240E+08	5.384E+07	5.384E+07	5.384E+07	5.384E+07	5.384E+07	5.384E+07
2023	1.087E+08	7.184E+07	1.006E+08	1.043E+08	9.764E+07	9.766E+07	1.056E+08	2.405E+07	1.045E+08	2.619E+07	2.469E+07	2.369E+07	2.838E+07	2.619E+07	2.619E+07
2024	1.113E+08	7.394E+07	1.034E+08	1.072E+08	1.006E+08	1.006E+08	1.082E+08	2.481E+07	1.070E+08	2.686E+07	2.540E+07	2.444E+07	2.920E+07	2.656E+07	2.788E+07
2025	1.139E+08	7.610E+07	1.063E+08	1.102E+08	1.036E+08	1.036E+08	1.109E+08	2.558E+07	1.095E+08	2.756E+07	2.614E+07	2.521E+07	3.004E+07	2.719E+07	2.855E+07
2026	1.156E+08	7.758E+07	1.088E+08	1.128E+08	1.064E+08	1.064E+08	1.128E+08	2.627E+07	1.113E+08	2.804E+07	2.674E+07	2.591E+07	3.073E+07	2.760E+07	2.898E+07
2027	1.182E+08	7.983E+07	1.118E+08	1.159E+08	1.095E+08	1.095E+08	1.155E+08	2.707E+07	1.139E+08	2.876E+07	2.750E+07	2.671E+07	3.160E+07	2.826E+07	2.967E+07
2028	1.209E+08	8.215E+07	1.148E+08	1.190E+08	1.126E+08	1.126E+08	1.183E+08	2.790E+07	1.165E+08	2.950E+07	2.828E+07	2.753E+07	3.250E+07	2.893E+07	3.037E+07
2029	1.236E+08	8.453E+07	1.178E+08	1.222E+08	1.158E+08	1.158E+08	1.210E+08	2.875E+07	1.191E+08	3.026E+07	2.908E+07	2.837E+07	3.343E+07	2.962E+07	3.110E+07
2030	1.265E+08	8.697E+07	1.211E+08	1.256E+08	1.191E+08	1.191E+08	1.240E+08	2.963E+07	1.218E+08	3.104E+07	2.991E+07	2.924E+07	3.437E+07	3.032E+07	3.184E+07
2031	1.110E+08	7.675E+07	1.067E+08	1.107E+08	1.052E+08	1.052E+08	1.090E+08	2.618E+07	1.070E+08	2.731E+07	2.637E+07	2.585E+07	3.031E+07	2.662E+07	2.795E+07
2032	1.138E+08	7.865E+07	1.094E+08	1.135E+08	1.078E+08	1.078E+08	1.116E+08	2.683E+07	1.096E+08	2.798E+07	2.703E+07	2.649E+07	3.106E+07	2.722E+07	2.858E+07
2033	1.166E+08	8.060E+07	1.121E+08	1.163E+08	1.105E+08	1.105E+08	1.144E+08	2.750E+07	1.123E+08	2.867E+07	2.770E+07	2.715E+07	3.183E+07	2.783E+07	2.922E+07
2034	1.194E+08	8.260E+07	1.149E+08	1.192E+08	1.133E+08	1.133E+08	1.172E+08	2.818E+07	1.151E+08	2.938E+07	2.838E+07	2.783E+07	3.262E+07	2.846E+07	2.988E+07
2035	1.224E+08	8.464E+07	1.178E+08	1.221E+08	1.161E+08	1.161E+08	1.201E+08	2.888E+07	1.179E+08	3.010E+07	2.909E+07	2.852E+07	3.343E+07	2.916E+07	3.061E+07
2036	1.255E+08	8.675E+07	1.211E+08	1.256E+08	1.195E+08	1.195E+08	1.233E+08	2.971E+07	1.211E+08	3.088E+07	2.989E+07	2.934E+07	3.435E+07	2.990E+07	3.140E+07
2037	1.287E+08	8.889E+07	1.241E+08	1.287E+08	1.225E+08	1.225E+08	1.264E+08	3.044E+07	1.241E+08	3.164E+07	3.063E+07	3.007E+07	3.520E+07	3.064E+07	3.218E+07
2038	1.319E+08	9.110E+07	1.272E+08	1.319E+08	1.255E+08	1.255E+08	1.295E+08	3.120E+07	1.272E+08	3.243E+07	3.139E+07	3.082E+07	3.608E+07	3.141E+07	3.298E+07
2039	1.351E+08	9.335E+07	1.303E+08	1.352E+08	1.286E+08	1.286E+08	1.327E+08	3.197E+07	1.303E+08	3.323E+07	3.217E+07	3.158E+07	3.698E+07	3.219E+07	3.379E+07

2040	1.385E+08	9.567E+07	1.336E+08	1.385E+08	1.318E+08	1.318E+08	1.360E+08	3.277E+07	1.336E+08	3.406E+07	3.297E+07	3.237E+07	3.790E+07	3.299E+07	3.464E+07
2041	1.419E+08	9.804E+07	1.369E+08	1.420E+08	1.351E+08	1.351E+08	1.394E+08	3.358E+07	1.369E+08	3.490E+07	3.378E+07	3.317E+07	3.884E+07	3.380E+07	3.549E+07
2042	1.454E+08	1.005E+08	1.403E+08	1.455E+08	1.384E+08	1.385E+08	1.429E+08	3.442E+07	1.403E+08	3.577E+07	3.462E+07	3.399E+07	3.980E+07	3.464E+07	3.638E+07
2043	1.491E+08	1.030E+08	1.438E+08	1.491E+08	1.419E+08	1.419E+08	1.464E+08	3.527E+07	1.438E+08	3.666E+07	3.549E+07	3.484E+07	4.079E+07	3.551E+07	3.728E+07
2044	1.528E+08	1.055E+08	1.473E+08	1.528E+08	1.454E+08	1.454E+08	1.501E+08	3.614E+07	1.473E+08	3.757E+07	3.636E+07	3.570E+07	4.180E+07	3.638E+07	3.820E+07
2045	1.242E+08	7.578E+07	1.187E+08	1.243E+08	1.167E+08	1.167E+08	1.214E+08	2.959E+07	1.186E+08	3.105E+07	2.982E+07	2.914E+07	3.539E+07	2.984E+07	3.133E+07
2046	1.278E+08	7.843E+07	1.221E+08	1.278E+08	1.200E+08	1.201E+08	1.249E+08	3.050E+07	1.221E+08	3.200E+07	3.073E+07	3.004E+07	3.645E+07	3.075E+07	3.229E+07
2047	1.314E+08	8.112E+07	1.256E+08	1.315E+08	1.235E+08	1.235E+08	1.285E+08	3.143E+07	1.255E+08	3.296E+07	3.167E+07	3.096E+07	3.752E+07	3.169E+07	3.327E+07
2048	1.162E+08	6.496E+07	1.102E+08	1.163E+08	1.081E+08	1.081E+08	1.132E+08	2.801E+07	1.102E+08	2.958E+07	2.826E+07	2.753E+07	3.426E+07	2.828E+07	2.969E+07
2049	1.196E+08	6.745E+07	1.135E+08	1.197E+08	1.113E+08	1.113E+08	1.166E+08	2.889E+07	1.135E+08	3.050E+07	2.914E+07	2.839E+07	3.529E+07	2.917E+07	3.062E+07
2050	1.297E+08	7.654E+07	1.234E+08	1.298E+08	1.212E+08	1.212E+08	1.266E+08	3.131E+07	1.234E+08	3.296E+07	3.156E+07	3.080E+07	3.786E+07	3.159E+07	3.317E+07