Translating LCA Evidence into Performance-Based Policy Criteria for the Photovoltaic Product Group

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Abstract Life cycle assessment has the potential to generate valuable information and knowledge for policy makers, as insights can be gained by applying LCA to the development of policy criteria. This potential has been used in the development of a number of EU policy instruments aimed at photovoltaic products, i.e. Ecodesign, Energy Labelling, the EU Ecolabel and Green Public Procurement. They are the regulatory and voluntary policy instruments for sustainable production and consumption at the European Commission. Each instrument has different market objectives; e.g. Ecodesign sets mandatory minimum requirements for products entering the EU market, while the EU Ecolabel is a voluntary instrument to differentiate the most sustainable choices. An eight-step approach based on the Ecodesign methodology including a systematic LCA review has been used with a focus on the information needs of the policy instruments and an interpretation of the results per component/substance. Through the identification of hotspots at the component level and at life cycle stages, it has been possible to translate them into criteria.

1 Introduction

The EU has a number of legislative instruments which translate EU energy and climate policy goals into various strands of action. Ecodesign and Energy Labelling legislations support the Commission's overarching priority to strengthen Europe's competitiveness and boost job creation and economic growth [1, 2]. They are mandatory instruments that ensure a level playing field in the internal market, drive investment and innovation in a sustainable manner and save money for consumers while reducing CO₂ emissions. These instruments contribute to the Energy Union 2020 and 2030 energy efficiency targets, and to a deeper and fairer internal market.

Two further voluntary policy instruments contribute to fulfil the mentioned objectives: the EU Ecolabel and the Green Public Procurement. The EU Ecolabel (set up under the provisions of Regulation EC 66/2010) aims at reducing the

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negative impact of products and services on the environment, health, climate and natural resources [3]. The EU Ecolabel criteria take into account the environmental improvement potential along the life cycle of products. Green Public Procurement (GPP) is defined in COM(2008)400 as a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact through their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured [4]. GPP takes recently into consideration circular economy aspects in new criteria.

The Ecodesign Working plan that periodically lays out which product groups offer an energy saving potential included in its 2016–2019 edition [5] the photovoltaic group product as one that justified an analysis of the feasibility of potential implementing measures under ED and EL. In parallel, the EU Commission proposed to develop EU Ecolabel criteria for photovoltaic modules.

Given this, there was interest in examining the potential synergies between the different instruments. As a result, a preparatory study was launched by the EU Commission in November 2017 on solar modules, inverters and systems, to assess ED and/or EL requirements. Unlike the standard case, in which ED/EL products are assessed independently from Ecolabel or Green Public Procurement policies, for solar photovoltaic products, the preparatory work intended to occur at the same time for the four mentioned policies. This way, the European Commission would build the evidence base in one single research process, providing supporting information to ED/EL, GPP and EU Ecolabel decision-making processes, avoiding duplicities and overburdening. The study investigated also in great detail the potential for environmental improvement, including aspects relevant to the circular economy such as reuse, repair and recycling.

To assess the environmental impacts of electricity systems and evaluate the potential benefits brought by the switch to renewables, one obvious approach is the use of life cycle assessment (LCA) [7]. It is a useful decision-support tool to quantify the environmental impacts of a product, technology or system from a life cycle perspective, i.e. from the extraction of the raw materials through to their manufacture and use up to their end of life [8]. However, to be of relevant use, a LCA study should report the values, or give an interpretation of the results per component/substance, in order to support hotspot identification. This is specifically useful to develop requirements, e.g. for EU Ecolabel.

A systematic LCA review was conducted as part of the preparatory study with a focus on the information needs of the policy tools. The LCA review analysis has complemented the identification of hotspots at component and life cycle stages, and the determination of the type of information needed to translate hotspots into verifiable criteria on aspects of performance for which there is improvement potential. LCA evidence has therefore been translated into technical performance-based criteria for the PV product group. This has been detailed in Sect. 2. For ED, it has been preliminarily identified that for modules a minimum level of energy yield and reporting on performance degradation should be achieved under fixed climatic conditions. For inverters, a minimum efficiency shall be defined, together with repairable key components. For the EU Ecolabel, it has been found that the reparability

of key components along the design lifetime, as well as energy return on investment, could be feasible. Project stage-related criteria that minimize both life cycle environmental impacts and costs, together with GWP-based impact category results – as required in some national PV capacity auctions – could be integrated into a GPP criteria set. The proposals for the four policy instruments are detailed in Sect. 3.

2 Methodology

The standard preparatory studies on Ecodesign/Energy Labelling are conducted by a specific methodology for energy-related products (MEErP) [9]. Given that a combined approach between the analysis on ED/EL, GPP and the EU Ecolabel was envisaged for this specific study, additional methodological considerations were needed to complement MEErP. Moreover, the draft Product Environmental Footprint Category Rules (PEFCR) for ‘Production of photovoltaic modules used in photovoltaic power systems’ have been a complementary source for the identification of environmental hotspots for photovoltaic modules [10].

For its practical operation, the current version of the MEErP makes use of the so-called *Ecoreport* tool, which is a streamlined (i.e. simplified and standardized) life cycle analysis (LCA), that leads to the identification of the environmental ‘hotspots’ of a product or system of products, and to a quantification of the purchase cost, and production cost over the whole life cycle of the product. Once this information is available, the second part of the process (the techno-economic-environmental assessment) takes place, which takes the form of a ranking of various design options according to their life cycle costs. The analysis of the life cycle costs leads to the identification of the design option that delivers to a consumer the least life cycle cost (LLCC). The LLCC is unique per product category and provides the optimum level from a regulatory perspective because it minimizes the total cost of ownership for the consumer, and it pushes all manufacturers, at the same time, to make the necessary improvements on their products with existing technologies to produce designs linked to the LLCC.

The EU Ecolabel criteria shall among other requirements under the regulation be based on the environmental performance of products, take into account the latest strategic objectives of the community in the field of the environment and be determined on a scientific basis considering the whole life cycle of products. Compared to ED/EL, it investigates more thoroughly chemistry and toxicity aspects and tries to define the best in class based on an overall environmental assessment.

The EU GPP criteria shall mainly take into consideration the net environmental balance between the environmental benefits and burdens, including health and safety aspects. They also shall be based on the most significant environmental impacts of the product, be expressed as far as reasonably possible via technical key environmental performance indicators of the product and be easily verifiable. They also usually include a life cycle cost perspective, to encourage consideration of the total cost of ownership and not just the lowest bid price.

Figure 1 shows the overlay of EU product policy instruments under development when looking at the relative sustainability of products they target. In particular, for example, EU Ecolabel offers a higher sustainability, and GPP support for innovation through voluntary initiatives.

As prescribed by the MEErP, base cases for modules for inverters and for systems were defined.¹ The selected base case for modules is a module consisting of multicrystalline silicon cell back surface field (BSF) design, later updated to a multicrystalline silicon cell PERC (passivated emitter rear cell) design to reflect advancements in market share. For inverters, three base cases have been selected, a 2500 W string one-phase inverter, a 20 kW string three-phase inverter and a central inverter. The selected base cases for systems are a combination of the proposed base cases for modules and inverters, deployed in three types of segments: residential, commercial and utility scale with the rated capacities of 3 kW, 24.4 kW and 1.875 MW. An environmental and economic assessment of the base cases identified along the preparatory study was undertaken following the MEErP.

Then a screening of existing LCA literature has been made to identify ‘hotspots’ for environmental impacts along the life cycle. These may relate to specific material flows/inputs, components or emissions related to a life cycle stage. A preliminary analysis has then been made of the potential for EU Ecolabel and/or GPP criteria to

Fig. 1 Overlay of EU product policy instruments under development

¹ See Task 4 of the preparatory study for a detailed description of the base cases.

address these hotspots. Table 1 shows a summary of the analysis made to translate the findings from the LCA review for module inverters and systems into possible criteria.

3 Results

The focus of the preparatory study has been on the feasibility of employing four individual policy instruments, either individually or in combination. Each instrument has distinct characteristics and requirements that must be taken into consideration when deciding whether an intervention in the market is required. The proposals for each are each briefly summarized in Table 2 and presented in the sections below.

3.1 *Policy Requirements Proposal: Mandatory Instruments*

Policy recommendations based on the results of the analysis in the preparatory study and hotspots identification are presented below. In this context, the added value brought by each instrument and the potential synergies are considered as well as the relevance and feasibility of potentially having the product(s) covered by one or several schemes.

3.1.1 **Recommendation 1: Ecodesign Minimum Mandatory Requirements for Modules and Inverters**

- (1) Requirements are proposed for modules on lifetime electricity yield, quality, durability, and circularity. On the yield, the preferred option is for an Ecodesign information requirement. The reason for selecting this option is that it is more representative of performance under real life conditions. The yield also takes into account PV module performance characteristics such as the spectral response under low light conditions. However, thresholds/information on the market spread for PV modules is currently missing.
- (2) Another Ecodesign option could be to introduce a stringent set of quality and durability tests for module products. Testing is costly and timely; however, it is understood to already be considered as a market entry requirement by major manufacturers, and it may be difficult to separate the test sequences and/or to introduce recommended new aspects (such as encapsulant browning or inspections for cell cracking). Requirements for inverters on efficiency quality, durability and circularity are also important. The first option is based on the calculation the 'Euro Efficiency' of an inverter. This is an important derating factor for the performance of a solar PV system, so the removal of the worst performing, sub 94% efficient inverters, would contribute as a minimum

Table 1 Summary of hotspots to be translated into criteria for EU Ecolabel at R (residential), C (commercial) and U (Utility) segments

Product	PV tech/ system size	Hotspots LCA	Improvement measures identified (suitability)	Scoping of the improvement potential	Possible technical requirement	Verification options	Precedents
	Si tech	Ingot/wafer production	(1) Low-energy manufacturing processes (2) Si ingot slicing, e.g. change of laser cutting, lift-off, kerfless, etc.	Reduction of: (1) Primary energy consumed (2) Losses from slicing and minimizing the Si needed for the same energy output	(1) Reduction in primary energy from ingot/wafer manufacturing (2) Reduction in GWP from silicon slicing	(1 and 2) Primary energy and GHG emissions reporting standard production specific, e.g. ISO 14064, 50001 Ener. Manag. Syst.	NSF 457 (7.1.1 required criteria)
	Si tech	Grid electricity mix	Change of site to a location with a lower grid emissions factor	Reduction of GWP up to approx. 100%	Reduction in GWP from production stage electricity use	GHG emissions reporting standard production specific, e.g. 14064	French national PV auction, GHG emissions method

Modules	All techs	Silver metallization paste	(1) Use of less silver metallization paste (2) Substitute silver by copper plating	A reduction down to 50 mg per cell is expected to be possible by 2028	Report the amount of silver per m ² or per Wp of module	No standard procedure. Could be an info requirement, similar to ROHS	–
	Thin film	Metal deposition in thin films	Use of less energy-intensive step/process	Reduction of primary energy consumed by the deposition process (reduction of, e.g. toxicity impacts)	Reduction in primary energy from metal deposition processes	Primary energy reporting according to ISO14001 Energy Management System, EPBT or EROl calculation	NSF 457 (8.1 required criteria), Blue Angel proposal
		Extraction of Cd and Te	Reduce the consumption of Cd and Te	Two CIGS manufacturers – Solar Frontier and Steon – claim ‘RoHS compliant’ modules (Cd below 0.01%)	(1) Reduction of cadmium or tellurium content (2) Circular loop recovery process for semiconductor materials	(1) No standard procedure. ROHS requirement (2) Producer responsibility scheme ensuring min. recovery level, or min. recycling	NSF 457 EoL management and design for recycling and record of annual recycling and recovery rate
	Thin film	Flat glass production	Use of thinner glass, change the type, facilitate recycling or reuse	First solar series 6 has a reduced glass thickness front: 2.8 mm. Back: 2.2 mm. Environmental impact of transport reduced	(1) Glass thickness for specific grade (2) Ease of separation of lamination from glass	(1) Verification of glass specification (2) Dismantling tests to show the separation	UBA WEEE criteria: on unloading storage and handling, on preferable recycling of glass
	All techs	Lifetime and degradation	Extended lifetime and lower failure rates	Reduction of degradation rate	(1) Establish a technical lifetime according to the yield (>80% at 30y) (2) Degradation target, e.g. < 0.5%/yr	(1) Declaration made based on field data or experimental laboratory test results	–

(continued)

Table 1 (continued)

Product	PV tech/ system size	Hotspots LCA	Improvement measures identified (suitability)	Scoping of the improvement potential	Possible technical requirement	Verification options	Precedents
	All techs	Energy payback time	(1) Use of less energy intensive manufacturing processes (2) Change in geographical location	(1) Rise on the energy payback time (2) Mc Si modules installed in a reference system can have 8 years or 4.31 years if they are installed in Helsinki or Sevilla, respectively	(1) To maintain an EPBT below a certain threshold for a given climate conditions (2) To include it in an energy label	No standard exists to calculate the manufacturing primary energy. Third -party verification used against EN 15804 (EPD) standard or ISO 14064 (scope 3 CO ₂ emissions) for construction prod	NSF 457 (7.1.1) French national PV auction, GHG emissions calculation method
Inverters	R&C	Print board assembly	(1) Avoiding toxic elements such as Cd, Hg, Be, As, Pb and Cr (2) Pb-free soldering techniques	Hazardous substances content limitation/ improve their supply by recovery (WEEE directive)	(1) Avoiding toxic elements such as Cd, Hg, Be, As, Pb and Cr (2) Pb-free soldering techniques (3) Ease of disassembly for EoL treatments	No standards on hazardous substances in PCBs. Declaration of: (1) Substances content (targeted list (2) Lead-free content (3) Protocols for the disassembly and recycling	Ecodesign regulations for washing machines/DWs/ fridges/TVs/ servers WEEE directive – PCBs>10 cm ²

Systems	R,C,U all techs	Electricity demand in the supply chain of aluminium and copper production (construction stage)	Use of less or no framing and mounting structure, use of less cabling	Dual junction box design to reduce cabling and structure (e.g. 87% cable saving by Q cells), alternative frame materials or lighter structure or roof integrated PV	Amount of cabling from module/module connections Module's GWP to capture framing Integrated modules – how to credit the integration?	Feasibility uncertain: (1) Declaration of cabling material (2) GHG emissions reporting standard production specific, e.g. 14064	–
	U	BOS in thin-film technologies	Use of lighter structures or more sustainable materials	Share of the BOS in the total impact could be lower	Dual junction box design to reduce the amount of cabling and structure, or use of lighter structure, or roof integrated PV	Feasibility uncertain: (1) Declaration of cabling material (2) GHG emissions standard production specific, e.g. 14064	–
		Consumption of Cu from the electrical installation and Al from the mounting structure	Recycled content or recovery processes	Reduce consumption of Cu from the electrical installation and Al from the mounting structure	(1) Ease of dismantling and recovery (2) Recycled content	(1) Declaration of protocols of dismantling (2) Producer responsibility scheme ensuring min. recovery level, or min. recycling	–

Table 2 Proposal for product policy instruments, scope, life cycle stage and verification

Policy instrument	Stringency	Scope	Life cycle stage	Verification
Ecodesign	Mandatory	Products, packages of products	Requirements refer normally to measurable characteristics of the product (tested use stage product performance) Material efficiency requirements relating to other LC stages (e.g. reparability, durability) can be proposed, but need to be verified on the product itself 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. The EEI cannot be applied to other LC stages	Market surveillance is carried out at Member State level
EU Ecolabel	Voluntary	Can be products or services	Criteria can be set on any LC stage and include manufacturing sites/tested product performance	MS Competent Bodies verify compliance and award the label
Green Public Procurement (GPP)	Voluntary	Can be products or services	Criteria can be set on any LC stage and can include manufacturing sites, or tested product performance (link to the subject matter)	Through evidence from tenderers provided during the procurement

requirement. Introducing a standard for the minimum durability of inverters placed on the market, together with a focus on information about the reparability of the inverter, would be an important first step in extending the potential service life of inverters, particularly for those intended to be placed in outdoor environments – as failure rates can be high during the first ten years.

An additional overarching Ecodesign option would establish a standard for the collection, analysis and presentation of module and inverter life cycle data and Life Cycle Assessment (LCA) results in the EU. It could be initially on two impact categories – primary energy (GER) and Global Warming Potential (GWP).

3.1.2 Recommendation 2: Energy Label for Residential Systems

An Energy Label for solar PV systems is proposed to target the residential market segment in order to enable consumers to make an informed choice based on the performance of system designs offered by retailers and installers. It would need to be placed on the as-built rather than the monitored performance of a system.

3.2 Policy Requirements Proposal: Voluntary Instruments

3.2.1 Recommendation 3: EU Ecolabel for Residential Systems

It is proposed that a new EU Ecolabel product group is established targeted at residential systems of <10 kWp. The multi-criteria set is recommended to comprise two aspects: the package of modules and inverters and the design and installation service provided to the retail consumer. In the first approach, the criteria for modules and inverters could make use of input data from Policy Recommendations 1 (Ecodesign) and 2 (Energy Label) in order to set criteria that have an extended and stricter focus with pass/fail criteria on life cycle performance, hazardous substances and circular design. For the service approach, there would be criteria covering aspects of the service provided by system installers, e.g. the system design, or monitoring and maintenance.

3.2.2 Recommendation 4: EU Green Public Procurement Criteria for PV Systems

It is lastly proposed that a new GPP product group is established targeted at the procurement of well-designed, high-performance, long-term PV systems, and with a broader focus also on the public authority acting as a catalyst to increase local residential installations by aggregating household demand for systems and to create demand for green (solar) electricity via arrangements such as Power Purchase Agreements.

3.2.3 Combined Policy Option Recommendations

- Combined policy option 1: Mandatory instruments plus Green Public Procurement (GPP). Introduction of the two mandatory instruments would ensure a consistent focus in the market on long-term performance and circularity, acting at both component and system level. The introduction of the GPP criteria would then be to use public sector influence, in particular at regional and local level, to exploit a range of synergies with the mandatory instruments and provide guidance and criteria in three key areas:
 - The direct procurement of new solar PV systems, with reference to component performance and life cycle requirements proposed to be established under Ecodesign
 - The establishment of procurement frameworks for residential ‘reverse auctions’ that would facilitate an increase in residential installations, with reference to component requirements established under Ecodesign and the Energy Label

- The auction of usage rights for public assets (land and roofs) as the basis for green (solar) electricity generation, with bilateral Power Purchase Agreements as a related option
- Combined policy option 2: Voluntary instruments plus Ecodesign. While the establishment of mandatory Ecodesign requirements would establish the units of measurement and methods required for energy yield, derating factors or performance degradation, the two voluntary instruments would provide a broader means of stimulating green innovation in a coherent framework of criteria that address life cycle hotspots, focusing attention on module and inverter designs (EU Ecolabel) and on the system service ‘offer’ of installers (both voluntary policies).

4 Conclusions

Recommendations for policy criteria have been derived from the main MEERP study, LCA evidence and policy-specific methodologies, forming part of a preparatory study on the feasibility to apply Ecodesign, Energy Label, EU Ecolabel and GPP to photovoltaic products. The study has been made with stakeholder input. Several challenges relating to competing policy objectives and trade-offs have had to be solved by, for example, acting partially on life cycle stages. The different performance-based policy criteria have been carefully selected by prioritizing where to act, e.g. use of proxies to ensure no burden shifting. To further support the use of LCA in policy making for energy-generating products, solutions are needed to prioritize which impact categories to focus on and to reconcile the benefits and burdens of the electricity generated and other ‘embodied’ impacts. One solution could be to use weighting and normalization factors as recommended under the PEF method. However, to date, no methodology exists to consistently assess the environmental burden or benefits caused by electricity generation within the context of the entire global, regional or national footprint caused by humans. If this was to become available, this information can be expected to be provided a significant support to policy making.

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