Ecodesign, Ecolabeling and Green Procurement Policies – enabling more Sustainable Photovoltaics?

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***Abstract* — The exponential deployment of photovoltaic (PV) systems over the past decade has led to increasing stakeholder interest in their sustainability performance. Public tenders, corporate customers, and private consumers alike have begun considering environmental performance criteria and discussions on ecodesign requirements, ecolabels and environmental footprinting have gained significant momentum across many regions in recent years. This paper presents the current status of voluntary and regulatory activities focused on improving the sustainability performance of PV modules and systems. We estimate the potential sustainability benefits of introducing product environmental footprint-based performance metrics as steering instruments for private and public sector PV investments.**

***Index Terms* — ecodesign, ecolabeling, green public procurement, product environmental footprint, sustainability leadership standard.**

I. Introduction

In 2016, solar PV net additions grew by more than 50% compared to 2015, reaching 77.3 GW, bringing global cumulative installations to over 320 GW [1]. This marks the first time that the net capacity expansion of any renewable energy technology was larger than any other fuel since the industrial revolution [2]. Achieving multiple terawatts of deployment by mid-century is needed to meet the objectives of the Paris Agreement to limit global warming to below 2 degrees Celsius through a consequent decarbonization of the energy system. These growth trajectories go beyond the forecasted technology scenarios and will involve new materials, manufacturing and deployment approaches. Building the manufacturing facilities needed to produce billions of photovoltaic devices, manufacturing the modules and deploying them in systems, operating and maintaining these systems throughout a 30+ year lifetime, and decommissioning the installations for recycling at end-of-life, will have environmental impacts to multiple environmental media. Minimizing those impacts and developing strategies to manage the global transformation into a solar society will require political and societal stakeholders to develop and implement frameworks for sustainable growth along the value chain of the PV industry.

This study portrays a number of these initiatives – covering the spectrum of voluntary corporate sustainability reporting and benchmarking, industry standardization aimed at establishing sustainability leadership and ecolabeling, as well as European Union regulatory instruments such as Ecodesign and Green Public Procurement.

II. Methods

An overview of the initiatives and instruments analyzed is presented in Table I, which also categorizes drivers and dimensions of impact. Whereas some of the tools analyzed focus only on the product (i.e., the module), or on a specific life cycle stage (i.e., end-of-life), all aim to improve the environmental performance of photovoltaic electricity generation.

TABLE I. Influence-Interest Matrix of Initiatives & Instruments for more Sustainable Photovoltaics [X- Direct Relation/ (X) – Indirect Relation]

Initiative / Instrument	Drivers					Dimensions of Impact			
	Regulator	Investor	Customer (B2B, B2C)	Industry Peers	Society	Market access	Bankability	Compliance	Value Proposition
SVTC Solar Scorecard		X	X	X	X		(X)	(X)	X
NSF 457 Sustainability Leadership Standard		X	X	X	X		X	X	X
EPEAT Listing	(X)	X	X	X	X	(X)	X	(X)	X
EU Ecodesign	X					X		X	
EU Ecolabeling	(X)	(X)	X	X	X				X
EU Green Public Procurement	X	X	(X)		X	X			(X)
EU WEEE	X		X			X		X	
PV Recycling Standards	X		X	X				X	X
Cradle-to-Cradle Certification			X		X				X

This performance is quantified using the concept of life cycle assessment, which helps to allocate all environmental impacts associated with the life cycle of a specific product to a common functional unit. In the case of solar PV, the Product Environmental Footprint Pilot project established a common methodology to help companies conduct a life cycle assessment and identify so-called hotspots in the life cycle of the product through the application of Product Environmental Footprint Category Rules (PEFCRs) [3]. As shown in Fig. 1, the life cycle environmental footprint is quantified using the 15 environmental indicators required by the European Union [4] and 3 additional indicators (cumulative energy demand – renewable and non-renewable, and nuclear waste) as specified in the draft PEFCRs [3]. In order to determine the relevance of the different environmental impacts and to identify the life cycle stages and processes with the biggest impacts ('hotspots'), normalization factors from Benini *et.al.* [5] were applied. The environmental performance of 1 kWh of DC electricity produced with the average PV panel mix in Europe is used as a benchmark. The environmental performance of the average PV product is mainly influenced by the production of the panels with the exception of human toxicity cancer effects, freshwater eutrophication, and ecotoxicity, which are attributed primarily to the installation and mounting, while renewable energy demand is associated with module operation (Fig. 1).

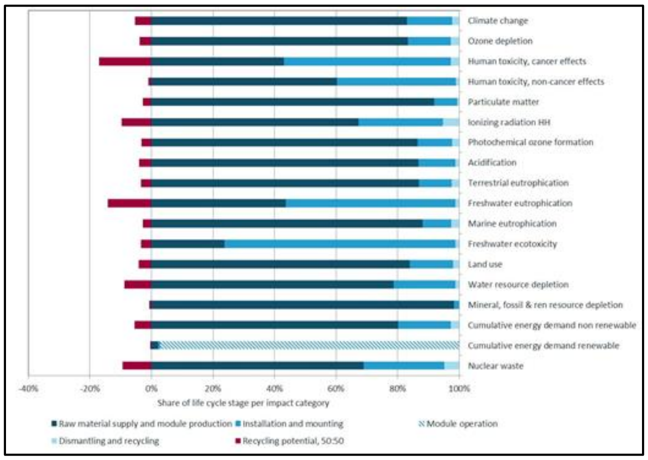

Fig. 1. Environmental impact results (characterized, indexed to 100 %) of 1 kWh of DC electricity produced with a residential scale (3 kWp) PV system with average PV panels mounted on a slanted roof. The potential benefits due to recycling are illustrated relative to the overall environmental impacts from production to end-of-life. [6]

The average PV panel is a virtual representative product composed of the European Union market share weighted averages of different PV technologies in 2012 and based on global supply chain data from 2011 and module efficiencies shown in Table II.

TABLE II. ASSUMPTIONS RELATED TO THE REPRESENTATIVE PRODUCT [7]

	Average PV 1)		Average PV (2015)	
	Market share	Module efficiency	Market share 2)	Module efficiency 2)
CdTe	6.3%	14.0%	4.0%	15.6%
CIS	3.5%	10.8%	1.7%	13.8%
micromorph-Si	4.5%	10.0%	0.9%	-
multi-c-Si	45.2%	14.7%	69.5%	~16%
mono-c-Si	40.5%	15.1%	23.9%	~17%

1) according to PEF Screening Report [6] / 2) according to PVthin and treeze position paper on the indium anomaly [8]

From 2011 to 2015, the global supply chain of module production by region has remained reasonably consistent, with production in China and Taiwan increasing from about 65% in 2011 to about 70% in 2015 [7]. Accounting for the technology market shares and increased module efficiencies in 2015, the environmental impacts of the average PV module as portrayed in [6] may be reduced by about 10% [7].

When analyzing the distribution of environmental impacts across the life cycle and the different categories, it becomes clear that the production stage and the construction stage (mounting and installation) are responsible for the majority of the environmental impact of a representative, residential scale, roof-mount PV installation. Although the environmental impact shares of the life cycle stages will vary across the different PV technologies, the production and construction stages remain the most important in terms of their contribution to life cycle environmental impacts. The leading categories contributing to cumulative weighted environmental impacts ('hotspots') are mineral, fossil and renewable resource depletion, human toxicity (cancer and non-cancer effects), freshwater ecotoxicity, particulate matter potential and acidification potential [6] (see Table III).

TABLE III. HOTSPOTS ROOT CAUSES

Impact category	Root cause for process hotspot
Mineral, fossil and renewable resource depletion	Supply chain of semiconductor materials (cadmium, tellurium, indium), silver (mainly used in metallization paste for multi- and mono-crystalline Si PV modules), copper (mainly used in the electric installation) and zinc (used in various processes such as secondary aluminum production).
Human toxicity (cancer and non-cancer effects)	Cancer effects: disposal of redmud from bauxite digestion (supply chain of primary aluminum) and disposal of slag generated in the production of unalloyed electric steel – substance hotspots are chromium VI emitted to water and chromium emissions to air, both being primarily associated with the supply chain of steel production Non-cancer effects: production of primary copper and zinc and related emissions from leaching residues and hard coal ash as well as zinc and mercury emitted to air in the process of unalloyed electric steel production and emissions of arsenic to water during the beneficiation of iron ore.
Freshwater ecotoxicity	Waste incineration of plastic components from the module and electric installation and the disposal of redmud from bauxite digestion (supply chain of primary aluminum).
Particulate matter potential	Supply chain of electricity, dominated by electricity production from Chinese hard coal power plants.
Acidification potential	Emissions of sulfur dioxide and nitrogen oxides to air due to operation of transoceanic freight ships, flat glass production and hard coal based electricity production.

Effective improvement of the overall environmental performance of photovoltaic systems through regulatory and non-regulatory sustainability initiatives and instruments should focus on the root cause of the identified hotspots. The instruments listed in Table I should aim to minimize those, either directly or indirectly.

A direct minimization strategy would involve setting quantitative and qualitative performance targets. An indirect minimization strategy would entail empowering customers and investors to benchmark products and consciously select the products with the social and environmental attributes, thereby building an internal market pressure by rewarding sustainability leaders over lower performers.

The next paragraphs describe the instruments and initiatives listed in Table I, followed by a qualitative assessment of how they address the root causes of identified environmental impact hotspots.

III. RESULTS AND DISCUSSION

A. SVTC Solar Scorecard

The Solar Scorecard [9] is an annual ranking of photovoltaic manufacturers based on sustainability and corporate social responsibility criteria. The scorecard's objective is to serve as a resource for consumers, institutional purchasers, investors, installers, and anyone seeking to purchase PV modules from responsible product stewards. The Silicon Valley Toxics Coalition (SVTC) is an environmental and public health environmental justice organization formed in the late 1970s in response to chemical contamination and environmental health and safety issues in semiconductor and electronics manufacturing in Santa Clara County, California..

In 2009, SVTC prepared a white paper identifying some of the environmental, health, and safety challenges in photovoltaic manufacturing. Several socially responsible investment firms—Boston Common, PAX, and Henderson Global Investors—reached out to SVTC with interest in identifying industry leaders in sustainability, which led to the Solar Scorecard. Several PV companies reached out as well, and it became clear to SVTC that some companies wanted to produce truly clean and green energy systems and were already taking steps to implement more sustainable practices, some companies—Avancis, First Solar, SolarWorld Industries, Solon, and Solopower—even invited SVTC to tour facilities.

The aim of the Solar Scorecard since its first publication in 2010 is to measure how companies perform on SVTC's sustainability and social justice benchmarks to ensure that the PV manufacturers protect workers, communities, and the environment. These categories selected in the scorecard were based on peer reviewed scientific research papers and reports, consultation with environmental, health, and safety researchers, environmental and labor groups and stakeholders, photovoltaic producers, and visits to manufacturing facilities. The scoring criteria are continuously amended based on conversations with industry, new science or information, or input from other stakeholder groups. The broader framework and general commitment to environmental improvement, worker health and safety, and community benefits from the solar industry led the Solar Scorecard to be the starting point for discussion of the NSF 457 Sustainability Leadership Standard for PV Module Manufacturing initiated by the Green Electronics Council in 2015.

The Solar Scorecard provided a multi-dimensional classification of manufacturers who responded to the annual survey. In case no active responses were received, the SVTC started to gather publicly available information to score manufacturers as of 2013. The evolution of the classification categories is presented in Table IV. The change in categories and sub-categories makes year-on-year comparisons and the identification of trends impossible.

TABLE IV. DEVELOPMENT OF SOLAR SCORECARD

2010	Extended Producer Responsibility (EPR) and Takeback / Supply Chain Monitoring and Green Jobs / Chemical Use and Life Cycle Analysis / Disclosure
2011	Recycling / Green jobs / Toxics / Disclosure
2012	EPR I: Company publicly supports public policies for extended producer responsibility (EPR) / EPR II: Waste or scrap PV modules are recycled at a facility with a documented environmental management system and worker safeguards consistent with ISO 14001 / EPR III: Company performed a hazardous waste determination for PV modules? / Workers' rights, health and safety I: Company currently does not use prison labor (e.g. UNICOR) during any aspect of the product life cycle Workers' rights, health and safety II: Company manufacturing operations are certified with a code of conduct in alignment with Social Accountability International (SA8000) / Workers' rights, health and safety III: Company discloses the percentage of employees that manufacture their brand name products and that are paid more than minimum wage for that region/country / Chemical use and disclosure I: Company posts chemical emissions to the environment on their website and/or annual report Chemical use and disclosure II: Company posts annual volume of wastewater discharged on their website and/or annual report Supply Chain transparency I: Company has a code of conduct with their suppliers in alignment with the principles of SA8000 Supply Chain transparency II: Company is willing to publicly disclose contract manufacturing network on an annual basis LCA I: Company conducts a life cycle analysis on their modules LCA II: Company has a "zero waste" and/or annual waste diversion targets for PV manufacturing facilities
2013	EPR / Emissions Transparency / Chemical Reduction Plan / Worker Rights, Health, Safety / Supply Chains / Conflict Minerals / Module Toxicity / C2C Recycling / Prison Labor / Biodiversity / Water / Energy & GHGs
2014	EPR / Emissions Transparency / Chemical Reduction Plan / Worker Rights, Health and Safety / Supply Chains / Conflict Minerals / Module Toxicity / High Value Recycling / Prison Labor / Biodiversity / Water / Energy & GHGs
2015	EPR / High Value Recycling (C2C) / Emissions Transparency / Chemical Reduction Plan / Worker Rights, Health and Safety / Supply Chains / Module Toxicity / Biodiversity / Energy / GHGs / Conflict Minerals / Water / Prison Labor
2016/ 2017	EPR / Emissions Reporting / Worker Rights, Health and Safety / Supply Chains / Module Toxicity and Materials / Energy & GHGs / Conflict Minerals / Water
2018	Extended Producer Responsibility / Recycling / Green Design Chemical Use Reporting / Waste Reduction & Management of Substances / Workers Rights, Health and Safety / Socially Responsible Supply Chains / Energy Use & Greenhouse Gas Emissions / Water / Packaging / Life Cycle Assessment

Over the years, manufacturers have been generally grouped into four main categories [10], ranging from a "sunny" rating exemplifying industry leadership to a "rainy" rating for non-disclosure. Applying the meta-classification, Fig. 2 depicts the following distribution of Solar Scorecard respondents since 2010.

The main challenge with this voluntary survey remains the validation of the information self-reported by the manufacturers or posted on company website or sustainability reports. It is further complicated by the evolving categories of classification, clustering and weighting of results collected year on year. Therefore, it is not possible to determine whether the introduction of the Solar Scorecard helped drive any improvements in the environmental performance of photovoltaic modules manufactured in this timeframe. The qualitative interpretation of scorecard results does suggest that companies are reporting on and disclosing more sustainability metrics and information than in 2010.

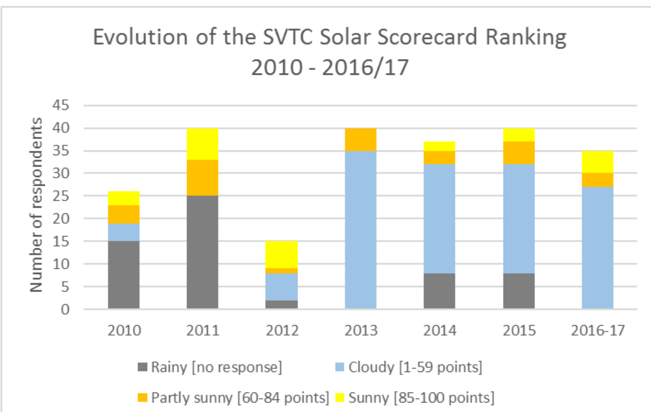

Fig. 2. Classification of SVTC Solar Scorecard Respondents.

The NSF 457 Sustainability Leadership Standard for PV Module Manufacturing was developed based on the learnings of the Solar Scorecard.

B. NSF 457 Sustainability Leadership Standard for PV Module Manufacturing

The standard provides a framework and standardized set of performance objectives for manufacturers and the supply chain of PV module components (Fig. 3). For purchasers, this standard provides a consensus-based definition of key sustainability attributes and performance metrics, alleviating individual purchasers from the arduous and complex task of defining sustainability performance for PV modules. This standard can be used within an established system for the identification of sustainability/environmentally preferable products by purchasers and to provide market recognition for conforming products and brand manufacturers.

In addition to product metrics, NSF 457 requires participating companies to report on corporate sustainability performance metrics in accordance with standardized sustainability reporting frameworks such as the Global Reporting Initiative (GRI) standards, Carbon Disclosure Project (CDP), and the Sustainability Accounting Standards Board (SASB) Solar Energy Standard to ensure data is reported in a consistent and comprehensive manner. Standardized reporting frameworks such as GRI, SASB, and CDP promote transparency by requiring companies to report on both absolute and normalized metrics which enables a more meaningful comparison across different companies.

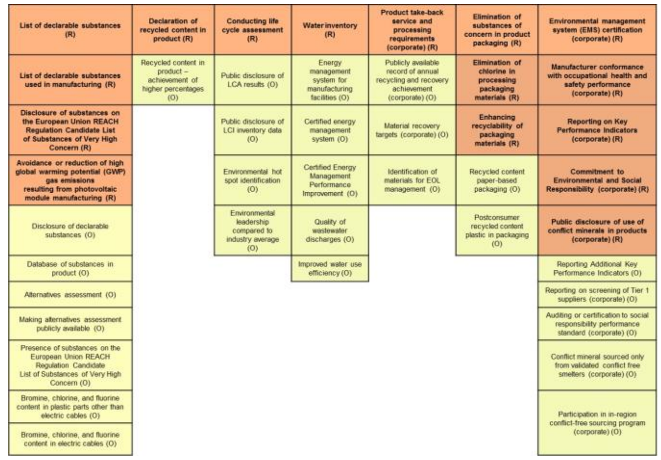

Fig. 3. Overview of the required (R) and optional (O) criteria as presented in the NSF 457 Sustainability Leadership Standard for PV Module Manufacturing.

This standard was developed based on the principle that only sustainability leadership products, those in the top third of the market, are expected to qualify to the standard at the Bronze level at the date of the standard's publication. Only a few products are expected to meet the highest performance level (Gold) at the date of the standard's publication.

C. EPEAT Listing of PV Modules

The Electronic Product Environmental Assessment Tool (EPEAT) is the leading global ecolabel for electronics and information technology (IT) products. The Green Electronics Council, which oversees the EPEAT ecolabel, partnered with NSF International to develop NSF 457 Sustainability Leadership Standard for Photovoltaic Modules (see section B). This PV module standard could potentially be adopted by EPEAT, with products that conform to the standard included in the EPEAT Registry. This Registry lists all products which have met the EPEAT criteria according to the relevant product category leadership standard (Fig. 4). Both public and private sector large-scale purchasers consult the Registry, as part of their procurement process, to identify sustainable electronic and IT products. Given the global value chain of photovoltaics and the prospects for further global deployment, having an internationally recognized ecolabel for front-runner products in place provides significant value for public, private and commercial customers and would make it easier to include environmental performance criteria in future photovoltaic modules tenders.

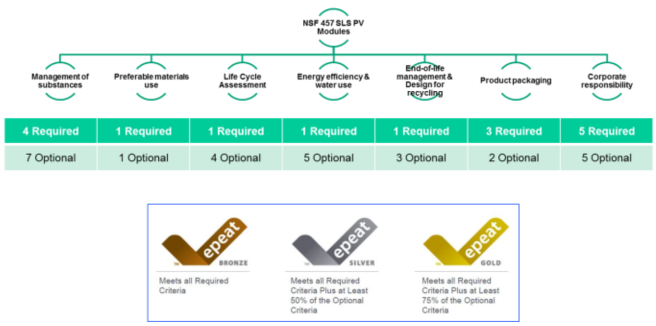

Fig. 4. EPEAT ranking of sustainability leadership in PV manufacturing.

A listing of PV modules in the EPEAT registry would also offer the opportunity to streamline sustainability leadership criteria in different regions and could potentially offer a template for an EU Ecolabel or similar national measures which aim at improving the sustainability performance of PV module manufacturing globally.

D. EU Ecodesign, Ecolabeling and Green Public Procurement of PV panels, inverters and systems

The European Commission included PV panels, inverters and systems in the Ecodesign workplan to establish potential criteria for these product groups going forward [11]. In an attempt to streamline the different product policy instruments, the preparatory study for ecodesign was expanded to also cover the feasibility assessment of other policy instruments, depicted in Fig. 5.

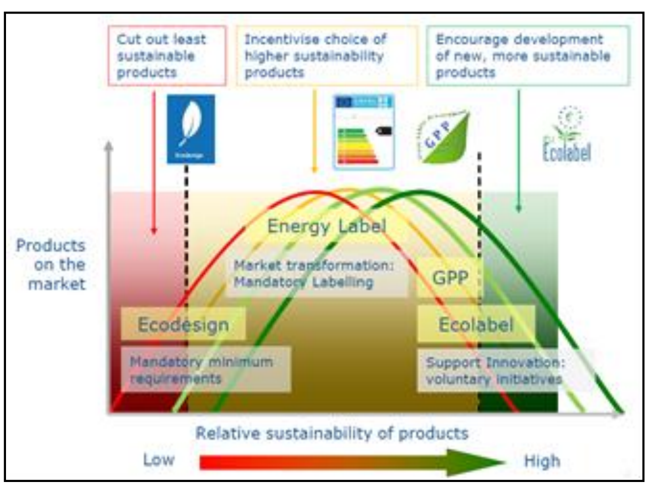

Fig. 5. Overlay of different environmental policy instruments in the European Union [12]

Whereas the results of the preparatory study are expected to be published in 2019, a pre-feasibility assessment conducted on behalf of the European Commission for the Ecodesign of PV panels and inverters, already established a benchmark scenario and estimates additional electricity generation due to higher average system efficiencies of 0.48 TWh/a (2020), 3.41 TWh/a (2025) and 6.36 TWh/a (2030) from PV systems in the EU if Ecodesign requirements are adopted [13].

To what extent the proposed policy measures will address the identified environmental hotspots remains to be seen. However, increasing the overall energy yield and annual electricity production of the installed systems would influence the denominator of each individual impact category and hence could be evaluated as an overarching benefit across all impact categories.

E. EU WEEE and PV Recycling Standards

Since 2012, photovoltaic modules are included in the scope of the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive [14]. Through the various national transpositions of the Directive, end-of-life photovoltaic panels are now being collected and recycled in the European Union and EU Member States are obliged to fulfill annual collection and recycling targets. Since 2017, the WEEE Directive requirements are complemented by a series of European standards, which aim at assisting treatment operators in fulfilling the requirements of the Directive, providing additional guidance on the treatment of waste from all products within the extended scope [15]. European Standard EN50625-2-4 [16] and Technical Specification TS50625-3-5 [17] clarify treatment and de-pollution requirements for photovoltaic panels.

In the U.S., the Basel Action network and SVTC led stakeholder discussions in 2013 to develop best practices and procedures for end-of-life photovoltaics to be incorporated into the e-Stewards Standard, an e-waste handler certification.

IV. CONCLUSION

As outlined above, this paper aims to evaluate the impact and effectiveness of the various regulatory and voluntary initiatives on the sustainability profile of photovoltaic electricity generation, using the concept of life cycle assessment and applying the Product Environmental Footprint Category Rules for PV electricity generation. Application of the draft PEFCRs on the average, representative product revealed the root causes for the predominant environmental hotspots (Table III). A quantitative benchmark of the different measures and initiatives portrayed is not feasible at this stage, as most of the initiatives have not been fully implemented or are still evolving. Qualitatively though, one can highlight the areas within those measures which potentially yield the biggest impact in addressing the root causes of environmental hotspots in the life cycle of PV module manufacturing, deployment, installation, operation, maintenance, dismantling and recycling (Fig. 6).

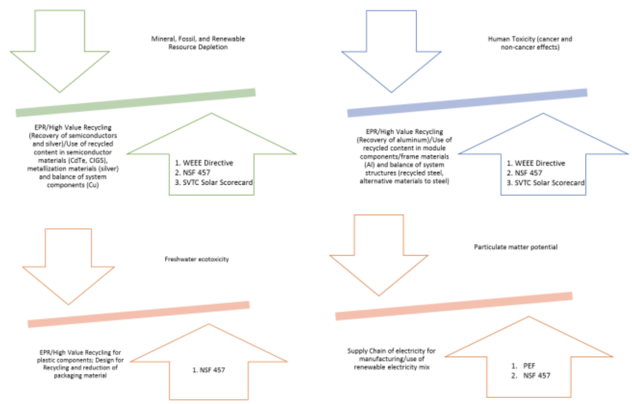

Fig. 6. Qualitative ranking of measures to address the hotspots in the PV module life cycle.

Measures that enable and encourage a circular economy and the decarbonization of the electricity mix would help to effectively relieve some major hotspots by addressing resource depletion of critical materials in module manufacturing, facilitating recycled content for primary materials in the BOS e.g. copper, steel, and aluminum, thereby reducing cumulative energy demand, as well. In addition, all measures which enhance the energy yield, i.e. improvements in conversion efficiencies, optimal installation, grid integration and management would also positively influence the overall environmental performance, if those can be achieved without increasing the impacts specified above.

As demonstrated in this paper, the selection of parameters for the definition of frameworks should be done with an eye towards the environmental impacts which occur during the different life cycle stages of PV. Based on the analysis of existing and emerging measures and initiatives, one can ascertain that the implementation of extended producer responsibility schemes which enable and encourage circular life cycle management models by closing material flows – through design for recycling, collection, recycling and reuse of post-industrial and post-consumer recycled materials – ultimately offer opportunities to further reduce the environmental impact of photovoltaic systems. Mandatory collection and recycling requirements, as stipulated by the WEEE Directive in Europe, coupled with minimum treatment standards and high value recycling requirements for specific materials and components can be one measure to achieve this objective. The award of ecolabels to front runners which adhere to these practices – i.e. through conformance with the NSF 457 Sustainability leadership standard, could stimulate a positive market response – or in turn be achieved through a market pull by implementing green procurement criteria which address those impacts.

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