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SUSTAINABLE MATERIAL FLOWS IN THE PV SECTOR: WHAT WORK REMAINS TO BE DONE TO ACHIEVE SDG 12?

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ABSTRACT: The large-scale deployment of photovoltaics (PV) is a central pillar in decarbonizing energy systems and reaching climate goals. Although PV is inherently associated to environmental awareness, it is not immune to reputational risks nor exempt of a responsibility for transparency and sustainability leadership. Over the last years, advances in the PV industry have mainly been shaped by cost-reduction targets. We identified in previous works 16 topics where the PV sector comes short in addressing the United Nations Sustainable Development Goal 12 (SDG 12) "Ensure sustainable consumption and production patterns". In this paper, approaches to address these sustainability gaps are proposed. The best-practices identified for the PV sector cover all aspects of sustainability as defined by SDG 12 – from resource use through corporate reporting and risk assessment to due diligence and waste management. Insights on methodological needs to improve sustainability accounting in PV are also provided. The compiled list of actions needed, although not intended to be exhaustive, constitutes a starting point for stakeholders to achieve more sustainability in PV value chains.
Keywords: Sustainable, Environmental Effect, Manufacturing and Processing, Recycling

1 INTRODUCTION

For the past 15 years, sustainable practices associated with the production and disposal of photovoltaic (PV) modules have been a growing subject of concern. The use of critical materials [1], incidents linking PV manufacturing to chemical pollution [2] and limited waste regulation outside the EU [3] have been cited as some hotspots in the sector. More recently, the allegations of forced labor in the Xinjiang Province of China, upon which the global solar industry is dependent for polysilicon, brought to public light the lack of traceability in supply chains [4]. The terawatt-scale deployment of solar energy, necessary to achieve long-term climate goals [5,6], have the potential to aggravate the current gaps existing in the sector. Reputational risks are also not to be overlooked. Initiatives from policymakers, industrials and researchers have multiplied to advance sustainability in PV. A snapshot of this sustainability landscape is provided in Fig. 1.

Despite a wave of activities, the PV value-chain appears relatively fragmented. Sustainable practices linked to the use phase and raw material supply are limited. Trends such as the switch from slurry-based wafering to diamond wire sawing, the continuous reduction of silver paste use per cell and the production of thinner wafers [7] have admittedly shaped a more efficient use of resources. They are however primarily driven by cost reduction: Their potential to sufficiently contribute to a sustainable manufacturing from an environmental and social point of view remains uncertain. While Life Cycle Assessment (LCA) is a well-established method for stakeholders to quantify their environmental impacts, there is no consensus on how to measure circularity [8] and criticality [9] and integrate them into product development. Scientific debate on how to perform social LCA is also still ongoing. Sustainable practices as reported by PV manufacturers can be characterized by a lack of transparency and common assessment frameworks [10].

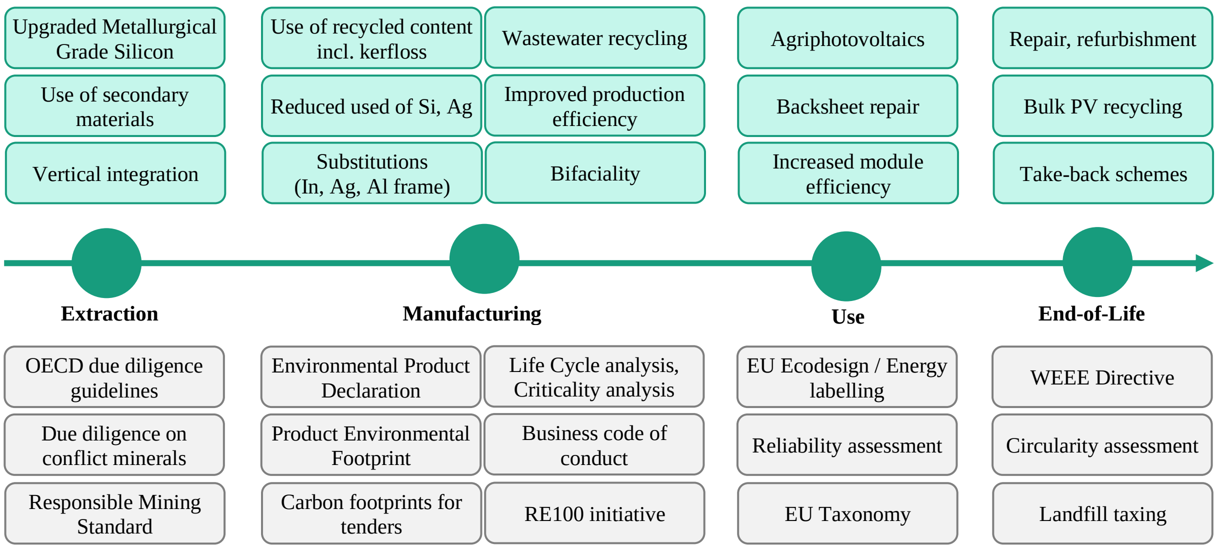

Figure 1: Exemplary snapshot of the sustainability landscape over the PV value chain. Practices implemented or in development for industrial applications are in green; policies, research instruments and standards are in grey.

In this paper, we review the state-of-the art sustainability challenges faced by the PV sector and provide insights on how to improve existing shortcomings as well as sustainability assessment. The concept of sustainability as proposed by the United Nations Sustainable Development Goal 12 (SDG 12) "responsible consumption and production" is hereby used. Its framework is well adapted for translating global needs into business practices over the entire value-chain, from raw material extraction to End-of-Life (EoL), and unites different sustainability topics, from environmental aspects to social responsibility. This paper aims at paving the way for a structured course of action in the PV sector towards sustainability in its broad sense.

2 APPROACH

SDG 12 calls for the implementation of sustainable consumption and production patterns. According to the UN, it is about "doing more and better with less. It is also about decoupling economic growth from environmental degradation, increasing resource efficiency and promoting sustainable lifestyles" [11]. SDG 12 is a holistic approach, broken down into 8 targets, requiring collaboration among stakeholders to achieve transformative changes.

Based on the scope of SDG 12 originally created for nations, sustainability targets for the PV sector were defined by Gervais et al. [10]. A gap analysis highlighted a need for progress in 16 areas or "sustainability strategies" displayed in Table I. The challenges associated with the operation of a PV power plant are not listed but could also be integrated in the SDG 12 framework (e.g. by considering land as a natural resource).

This paper builds upon these previous results and specifies what work remains to be done to implement each sustainability strategy.

3 RESULTS

The reader is referred to the peer-reviewed version of this paper for the comprehensive results. As an example, approaches to advance the sustainability strategies "reduce material intensity" and "ensure the social and environmental performances of suppliers" are briefly discussed.

3.1 Reduce material intensity

A lifecycle inventory is necessary to determine the total material demand from raw material extraction to module use, repair and recovery and must include components of the PV system, as well as production losses, auxiliary materials and utilities. The unused extraction, i.e. the materials that have to be moved to gain access to the coveted materials and tailings should further be taken into account [12].

Instead of targeting overall resource efficiency through increased module performance, individual raw materials should be prioritized for the development of reduction measures. This selection needs to be based on environmental, social and economic considerations combined. For instance, around 10% of primary silver production is estimated to be linked to artisanal and small-scale mining which relies on a mostly unskilled workforce and is associated to poor health and safety practices. Silver mining shows further high environmental hazard potential as it might be linked to acid mine drainage, heavy metal concentrations in deposits and toxic chemicals use for extraction and processing [13]. Silver also accounts for 10% of PV module costs [14].

Cell design adaptations such as increasing the number of busbars and thinner wafers are already paving the way towards a reduced use of selected materials [7]. More ambitious approaches such as kerfless wafering or frameless modules are further required. Short-term targets for material intensity reduction beyond considerations on material cost savings need to be defined and their avoided environmental and social impacts assessed.

Table I: Sustainability targets and strategies for the PV sector under the lens of SDG 12 [10]

# SDG	Topic	Target for the PV sector	Sustainability strategy for the PV sector
12.1	Instruments	Collectively support coherent sustainable practices in the PV sector	Define common sustainability goals with all stakeholders
			Implement methodology to assess progress towards sustainability
12.2	Natural resources	Achieve the sustainable management of natural resources	Reduce material intensity
			Reduce water use
			Reduce (fossil-fuel based) energy consumption
12.4	Hazardous waste & Chemicals	Achieve the environmentally sound management of chemicals and wastes	Optimize the treatment of production line outputs
			Avoid the release of harmful substances during extraction, use and EoL
12.5	Waste generation	Substantially reduce PV material waste generation	Increase the collection rate of EoL modules
			Extend the use phase of products
			Increase the efficiency of EoL recycling
			Increase the use of recycled materials in production
12.6	CSR & reporting	Ensure stakeholder well-being and demonstrate sustainability commitment	Standardize sustainability reporting
			Standardize corporate social responsibility (CSR) practices
12.7	Sustainable procurement	Adopt sustainable procurement practices	Improve the supply security of products
			Ensure the social and environmental performances of suppliers
12.8	Public awareness	Inform consumers on the sustainability of product/company	Democratize sustainability labelling for PV modules

Recommended actions:

- Prioritize raw materials for efficiency measures based on multidimensional sustainability assessment (environmental, social, economic)
- Report at corporate level total primary material intensity in kg/MWp
- Accelerate the switch to far-less material intensive production techniques

3.2 Ensure the social and environmental performances of suppliers

Corporates are expected to take full responsibility for the supply chains associated with their goods and services. This is however mostly done on a voluntary basis, as due diligence regulations only concern a few countries or conflict minerals such as tin. The adoption of mandatory due diligence legislation for instance at EU scale could foster progress in human rights and environmental standards and create a level playing field. As already done by some top tier PV manufacturers, suppliers and their environmental and social performances can also be fully disclosed in sustainability reports [15].

In particular, raw material procurement for the PV industry needs to gain in transparency and traceability via third-party verification. The Certification of Raw Materials (CERA) [16] is an example of a standardized certification framework ensuring environmental, social and economic sustainability in extraction, processing and trading. Schemes similar to the Battery Passport introduced by the EU could be used in PV supply chains. Distributed ledgers such as blockchain associated to an evolution towards smart factories are a promising tool to support supply chain due diligence and should be tested for PV. Challenges regarding data-quality and implementation costs need to be addressed in the process.

Recommended actions:

- Adopt sustainability certification schemes for mineral value chains
- Disclose sustainability performances of suppliers in corporate reporting
- Advance applied research on product tracking related challenges as closing data gaps, ensuring data quality and data exchange processes

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