SOLAR PANELS WASTE IN INDIA: THE URGENT NEED FOR AN ENVIRONMENTAL LAW FRAMEWORK

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1. Introduction

India's ambitious renewable energy goals aiming for an installed capacity of 500 GW by 2030, including 280 GW from solar resource[1] pose a huge opportunity but also a huge environmental issue.[2] While solar energy enables the generation of clean electricity, end-of-life (EoL) processing of photovoltaic (PV) panels is fast becoming an environmental issue to waste management. Existing estimates place India at around 34,600 tonnes of solar PV waste by 2030, projected to increase to 1.8 million tonnes by 2050 (MNRE, 2021).[3]

India's existing response to management of solar photovoltaic (PV) waste has a number of outstanding deficiencies, making a compelling argument for policy reform.[4] This research identifies four key concerns: first, the absence of distinct e-waste legislation for PV waste in India's existing e-waste management legislation leaves this new waste category largely unregulated;[5] second, the failure of extended producer responsibility (EPR) regimes third, the absence of appropriate recycling capacity strongly limits acceptable disposal channels; and fourth, the risk of environmental pollution through hazardous contents such as lead, cadmium, and silicon tetrachloride poses significant ecological and public health risks.[6]

[1] Ministry of New and Renewable Energy, Annual Report 2022-23 (Government of India 2023) 45

[2] P Jayapradha and D Barik, 'A Review of Solar Photovoltaic Power Utilizations in India and Impacts of Segregation and Safe Disposal of Toxic Components from Retired Solar Panels' (2023) 11 International Journal of Energy Research 1, 3

[3] Suresh Jain, Tanya Sharma and Anil Kumar Gupta, 'End-of-life Management of Solar PV Waste in India: Situation Analysis and Proposed Policy Framework' (2022) 14 Environmental Law Review 215, 218

[4] Ministry of Environment, Forest and Climate Change, Solid Waste Management Rules (Notification No. S.O. 1357(E), 2016

[5] Central Pollution Control Board, Guidelines for Environmentally Sound Management of E-Waste (CPCB 2020) para 4.2

[6] National Green Tribunal, Research on Hazardous Waste from Renewable Energy Equipment (NGT Report No. 15/2021) 34-37

2. Current Status of Solar PV Waste in India

2.1 Growth of Solar Energy and Waste Projections

India's solar industry has grown exponentially from 161 MW in 2010 to more than 70 GW in 2023.[7] With the average 25-30 year life of solar panels, the original installations of 2010-2015 will begin reaching end-of-life (EoL) from the year 2035.[8] Although annual volumes of waste are currently not very high, they will grow at an exponential rate in the decades to come.[9] India will become the world's second-largest generator of solar PV waste following China in 2050, and efficient waste management is the hour of need.[10]

2.2 Hazardous Components and Environmental Risks

Solar panels must be handled carefully as they hold a number of hazardous substances. Cadmium telluride (CdTe) thin-film panels employ carcinogenic cadmium compounds.[11] contrast panels of crystalline silicon (c-Si) employ lead solder and emit silicon tetrachloride as a by-product in production. The plastics employed to encapsulate the panels- EVA and Tedlar if not incinerated after use release toxic gases. Also, if not disposed of properly, the materials leach into soil further contaminating groundwater,[12] further causing serious threats to human health including kidney damage and problems in nerves, while also potentially harm ecosystems and lead to greenhouse gas emissions through unsafe disposal practices.[13]

3. Regulatory Gaps in Current Framework

Existing Indian laws fall short in regards to management of solar photovoltaic (PV) waste, resulting in very serious challenges in recycling and disposal. The largest lacuna is that express exclusion of solar PV panels from the E-Waste (Management) Rules, 2022, that regulate disposal of other electronic equipment. Regulatory oversight is the polar opposite of forward-looking models such as the European Union's WEEE Directive that expressly covers PV

[7] Ministry of New and Renewable Energy, Annual Report 2022-23 (Government of India 2023) 12
[8] International Renewable Energy Agency, End-of-Life Management: Solar Photovoltaic Panels (IRENA 2016) 24
[9] Jayapradha and Barik (n 2) 4
[10] Jain, Sharma and Gupta (n 3) 218
[11] International Agency for Research on Cancer, Cadmium and Cadmium Compounds (IARC Monographs vol 100C, 2012) 121-145.
[12] Central Pollution Control Board, Guidelines for Hazardous Waste Management (CPCB 2019) para 4.3.
[13] Intergovernmental Panel on Climate Change, Guidelines for National Greenhouse Gas Inventories (IPCC 2006) vol 5, ch 3

panels,[14] or state policy in the US such as Washington's broad PV stewardship program.[15] India has not yet added solar panels to the e-waste rules thus lacking the legal framework to ensure that the panels are collected, recycled, or disposed of in a proper manner- something that's going to continue to happen as the solar installations rise.[16]

The second major gap is the absence of any Extended Producer Responsibility (EPR) policy for solar producers in India.[17] Research shows that the current policies are deficient in three basic essential EPR components: end-of-life take-back as a mandate, clear recycling targets, and provisions for financial assurance of responsibility for waste management This policy loophole in the given policy eliminates incentives for companies to create recyclable products or invest in recycling facilities, essentially environmental solar PV waste cost externalizing. In the absence of robust mandates under EPR, India will be repeating the same errors in other product segments where uncontrolled waste disposal leads to environment degradation.[18]

India's infrastructure shortfall aggravates such regulation shortcomings, and a study indicates drastic constraints on India's ability to manage solar PV waste. There are merely two or three pilot-scale recycling plants across the nation, none of which are commercially operational or in a position to address the broad range of PV technologies available. The lack of standard recycling processes exacerbates the issue, as does limited technical capability for safe management of hazardous materials such as lead and cadmium employed in PV modules. This infrastructure gap is key in the present scenario with the impending spike in volumes of solid waste, with India ill-equipped to manage the wave of end-of-life panels that will inundate the waste stream over the next decade. These regulatory and infrastructural shortcomings combined form a great mix that can undermine environmental protection objectives as well as India's sustainability of the renewable energy transition.[19]

[14] European Parliament and Council Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) [2012] OJ L197/38, art 2(1)(h) (including photovoltaic panels
[15] Washington State Legislature, Photovoltaic Module Stewardship and Takeback Program (RCW 70A.500.010-70A.500.900, 2017)
[16] Jayapradha and Barik (n 2) 4
[17] Ministry of Environment, Forest and Climate Change, "E-Waste (Management) Rules, 2022" (Notification No. G.S.R. 645(E)) sch I (excluding photovoltaic panels from EPR scope)
[18] Central Pollution Control Board, "Post-Mortem Analysis of India's E-Waste Policy Failures: 2000-2011" (CPCB 2020) 12-15
[19] National Institution for Transforming India, Sustainable Energy Transition Roadmap (NITI Aayog Policy Paper 2023) 33-35.

4. Global Best Practices for Solar PV Waste Management

Comparatively, Various international approaches reveal various successful systems that India could adapt to its context. The European Union has pioneered a comprehensive circular economy approach through its Waste Electrical and Electronic Equipment (WEEE) Directive, which mandates ambitious 85% collection and 80% recycling rates for PV panels.[20] Complementing this regime is PV Cycle, industry-led take-back and recycling that has been extremely successful. The EU also promotes environmentally friendly design in the form of eco-design regulations that motivate producers to design panels with respect to scope of recyclability, thus minimizing the complexity of material recovery at end-of-life phases.[21]

The United States has also acted more in a decentralized manner through actions at the state level. California SB 489 is a leadership bill mandating PV panel recycling, and Washington's PV stewardship law mandates a recycling program paid for by the manufacturers. Federal action consists of the National PV Recycling R&D program providing much-needed funding for technology development to support cost-effective recycling technology. These programs demonstrate how policy actions can compel and push solar waste management through compliance and innovation.[22]

Developing countries provide especially good models for India's new context. China created special pilot recycling zones with government-subsidized facilities that integrate centralized processing with local network collection. Brazil's innovative reverse logistics program makes use of established retail infrastructure through the transformation of electronics shops into collection points for end-of-life PV panels. These models show that developing countries can have good waste management systems without having to spend enormous capital at the start.[23]

5. Proposed Policy Framework for India

Based on these international examples and home country research statistics, a three-pillar policy approach would be capable of sufficiently tackling India's solar PV waste issue. The

[20] Directive 2012/19/EU on waste electrical and electronic equipment [2012] OJ L197/38, art 11(2)
[21] Eurostat, Circular Material Use Rate Indicators (2024) https://ec.europa.eu accessed 15 April 2025.
[22] 1 California Senate Bill 489 (2015); Washington HB 2645 (2017); National PV Recycling R&D Program, US Department of Energy, Solar Energy Technologies Office (2023) https://www.energy.gov/eere/solar/solar-energy-technologies-office accessed 18 April 2025.
[23] For China's pilot zones, see Mei Zhang, 'Solar Waste Management in China: Policies and Pilot Programs' (2021) 12 Renewable Energy Law & Policy Review 45, 48–50

first pillar encompasses crucial regulatory reform, starting from amending the E-Waste Rules to explicitly cover PV panels by name. These reforms should set transparent collection targets (e.g., 70% by 2030) and material recovery obligations depending on various PV technologies. An equally important requirement is enforcing Extended Producer Responsibility (EPR) mandating manufacturers to set up collection networks, finance recycling initiatives, and publish annual waste management performance reports. These actions would implement the appropriate accountability in the product life cycle.[24]

Infrastructure development is the second key pillar of this approach. India needs to establish standalone PV recycling units through innovative financing mechanisms such as Production-Linked Incentive (PLI) schemes for recyclers and public-private partnership (PPP) models for local plants. Concurrently with this, the development of indigenous recycling technology through CSIR labs focused on PV-centric innovations and startup grants for innovative procedures would enhance local capability and minimize dependence on foreign technology. This concurrent strategy would address near-term infrastructure shortages as well as long-term technological independence.[25]

The third pillar is mass stakeholder participation to make policies effective. Formal-informal sector integration can be in the form of training informal recyclers in proper handling practices and establishing formal buy-back facilities for collected waste. Consumer education campaigns must give clear disposal instructions to end-users and can be supplemented with deposit-refund schemes to make proper returns easy. This multi-stakeholder strategy acknowledges that proper waste management involves working with the entire value chain, from producers to end-users to waste handlers. All three pillars together would form a strong ecosystem for sustainable solar PV waste management in India.[26]

[24] International Renewable Energy Agency (IRENA), End-of-Life Management: Solar Photovoltaic Panels (2016) 12-15; Ministry of Environment, Forest and Climate Change (India), Annual Report on E-Waste Management in India (2022) 45-48.

[25] Ministry of New and Renewable Energy (India), National Solar Mission Phase-III (2021) 23–25; Council of Scientific & Industrial Research (CSIR), Annual Report on Renewable Energy Technologies (2023) 17–19; International Energy Agency (IEA), Solar PV Global Supply Chains (2022) 42–45

[26] Ministry of Environment, Forest and Climate Change (India), Draft Guidelines for Environmentally Sound Management of Solar PV Waste (2023) para 4.2–4.5; International Solar Alliance (ISA), Best Practices for Solar Waste Recycling in Emerging Economies (2022) 31–34; International Renewable Energy Agency (IRENA), Consumer Awareness and PV Waste Collection Schemes (2021) 18–20

6. Implementation Challenges

The transition to an effective solar PV waste management system in India is met with several key implementation challenges that must be addressed. Technically, the lack of cost-effective recycling technologies that are specifically suited to solar panel types that predominate the Indian market is a major challenge.[27] Recycling technologies in existence, which were developed primarily for Western economies, may not be optimally suited to India's mix of panel technologies as well as the extreme environmental conditions to which they are subject. The economic challenges are also formidable, with the capital-intensive nature of the cost of establishing recycling facilities as a primary financial challenge, particularly in consideration of the need for specialized facilities to safely dispose of hazardous materials. This economic problem is also compounded by institutional problems arising from the presence of several government agencies - the Ministry of New and Renewable Energy (MNRE), the Ministry of Environment, Forest and Climate Change (MoEFCC), and the Central Pollution Control Board (CPCB) - that have the potential to create overlapping jurisdictions and administrative inefficiencies in policy enforcement. Perhaps most of all, behavioral problems arising from low awareness among solar installers and end-consumers[28] of the correct method of disposal risk undermining even optimally-designed regulatory systems. This awareness gap is especially insidious in the case of India's large informal recycling sector[29], where unsafe dismantling practices could spread without targeted education and training efforts. Overall, these technical, economic, institutional, and behavioral problems constitute a polymorphic implementation environment that will need concerted, multi-faceted solutions to overcome.[30]

7. Conclusion and Recommendations

The findings of this research conclusively determine the imperative necessity of India putting in place a comprehensive solar PV waste management framework. A number of key recommendations follow from this analysis. Regulatory intervention is most urgently needed to formally categorize PV waste as either hazardous waste or e-waste law, thus bridging the existing policy vacuum. A phased implementation of Extended Producer Responsibility (EPR) should be given priority, starting with large-scale producers with greater capacity to organize

[27] International Renewable Energy Agency (IRENA) and International Energy Agency Photovoltaic Power Systems Programme (IEA-PVPS), End-of-Life Management: Solar Photovoltaic Panels (IRENA 2016) 38–42
[28] International Solar Alliance (ISA), Global Solar Waste Management Report (2023) 27–30
[29] Ibid 29
[30] IRENA (n 1) 42

take-back and recycling facilities. In parallel, targeted investment must go into the development of recycling infrastructure and R&D for India-tailored recycling technologies. No less important is the establishment of multi-stakeholder partnerships among government departments, industry players, and research institutions to establish a holistic solar waste management ecosystem. As rightly advised, "Proactive policy measures today can prevent an environmental crisis tomorrow" - a warning that assumes particular urgency in the light of India's exponential growth of solar capacity[31]. With the onset of the first major wave of panel retirements imminent, the establishment of this framework cannot wait without incurring very serious environmental costs that would vitiate the very gains of India's renewable energy transition. The time for firm action is now, before tons of accumulated waste render the challenge exponentially more difficult to meet.

[31] Jain, Sharma and Gupta (n 3) 218

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