



INTERNATIONAL LAW
JOURNAL

**WHITE BLACK
LEGAL LAW
JOURNAL
ISSN: 2581-
8503**

Peer - Reviewed & Refereed Journal

The Law Journal strives to provide a platform for discussion of International as well as National Developments in the Field of Law.

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ABOUT US

WHITE BLACK LEGAL is an open access, peer-reviewed and refereed journal provide dedicated to express views on topical legal issues, thereby generating a cross current of ideas on emerging matters. This platform shall also ignite the initiative and desire of young law students to contribute in the field of law. The erudite response of legal luminaries shall be solicited to enable readers to explore challenges that lie before law makers, lawyers and the society at large, in the event of the ever changing social, economic and technological scenario.

With this thought, we hereby present to you

**A GRANDILOQUENT QUEST TO RECTIFY THE
DEFICIENCIES IN INDIA'S SOLAR PHOTOVOLTAIC
DETRITUS MANAGEMENT: PROPITIOUS POSSIBILITIES
FOR PERDURABLE STORAGE, RECLAMATION, AND
POLICY EXECUTION**

AUTHORED BY - PROF. DR. C. USHA

ABSTRACT:-

India's rapid expansion of solar photovoltaic (PV) deployment has brought with it a pressing concern: the management of end-of-life (EoL) solar panels. As installations scale up, the country faces a growing volume of PV waste, with significant implications for environmental sustainability, resource recovery, and public health. In response, the Central Pollution Control Board (CPCB) has issued draft guidelines in 2025 under the E-Waste (Management) Rules, 2022, outlining measures for the safe storage, transportation, handling, and disposal of solar PV waste. Despite this regulatory progress, several critical gaps remain. This study seeks to interrogate the challenges of solar PV waste management in India by identifying deficiencies in data availability, recycling technology, economic viability, stakeholder preparedness, and enforcement capacity. Employing a mixed-methods approach—combining literature review, stakeholder interviews with manufacturers, recyclers, and regulators, case-study analysis, and techno-economic modelling—the research anticipates uncovering systemic barriers such as limited recycling infrastructure, high cost structures, dominance of informal recycling practices, low awareness among stakeholders, and field-level difficulties in implementing guidelines. The findings are intended to inform policymakers, industry, and the research community by highlighting opportunities to strengthen regulatory frameworks, enhance technological solutions, promote circularity, and ensure the long-term sustainability of India's solar energy transition.

1. Introduction

The proliferation of solar photovoltaic (PV) deployment in India over the past decade has marked a historic trajectory in the country's energy landscape. As of January 2025, India's installed solar capacity stands at more than 100.33 GW, a dramatic increase from just 2.82 GW

in 2014, evidencing a 36-fold leap within eleven years.¹ This rapid growth underscores India's commitment to diversifying its energy sources and reducing its carbon footprint in congruence with its Nationally Determined Contributions (NDCs) under the Paris Agreement.²

The scale of forthcoming PV waste mirrors this exponential deployment. According to data from the Central Pollution Control Board (CPCB), India is projected to generate 34,600 tonnes of cumulative solar PV waste by 2030, which could surge to 600,000 tonnes by 2040, and up to 1.8 million tonnes by 2050 under ambitious expansion scenarios.³ Other estimates indicate that, depending on installation rates and module lifespans, the cumulative PV waste by 2030 could vary from around 11,000 to 35,000 tonnes in low to high growth trajectories.⁴ Such quantities are significant given the variety of hazardous materials—such as lead, cadmium, arsenic, and selenium—typically present in PV panels. These substances, if subjected to improper disposal, unsafe storage, or unregulated handling, can leach into soil and water systems, generating acute and chronic toxicities for the environment and public health.⁵ The risk is compounded in informal recycling sectors, which lack adequate technological safeguards and regulatory oversight⁶.

In response to these emergent challenges, India's policy framework has seen crucial developments. The E-Waste (Management) Rules, 2022, represent the central regulatory regime and have recently been augmented by dedicated CPCB draft guidelines for safe management of end-of-life (EoL) solar modules, panels, and cells, released in mid-2025.⁷ These guidelines set out the responsibilities of manufacturers, bulk consumers, dismantlers, and recyclers for storage, handling, transportation, and disposal of solar PV waste. Importantly, they introduce and operationalize the Extended Producer Responsibility (EPR) principle for the solar sector, requiring producers involved in the manufacture, import, or sale of solar

¹ <https://visionias.in/current-affairs/monthly-magazine/2025-03-24/environment/solar-energy-in-india>

² Solar Energy in India | Current Affairs

<https://visionias.in/current-affairs/monthly-magazine/2025-03-24/environment/solar-energy-in-india>

³ India's Solar PV Waste Guidelines

<https://energy.economictimes.indiatimes.com/news/renewable/indias-solar-pv-waste-guidelines-managing-600000-tonnes-by-2040/121791901>

⁴ PV WASTE MANAGEMENT IN INDIA - CECP-EU.in

<https://www.cecp-eu.in/uploads/documents/events/pv-waste-management-report-25-01-2021.pdf>

⁵ [CECP-EU.in](https://www.cecp-eu.in)

⁶ A review of solar photovoltaic waste management in India <https://www.jetir.org/papers/JETIR2206245.pdf>

⁷ Enabling a Circular Economy in India's Solar Industry

<https://www.ceew.in/sites/default/files/how-can-india-enable-circular-economy-with-solar-waste-management.pdf>

PV modules to ensure proper end-of-life management, channeling waste strictly through registered dismantlers and recyclers.⁸

Despite these policy advances, several gaps persist. The lack of a distinct and comprehensive solar PV-specific waste regulation, inconsistent enforcement of EPR, insufficient formal recycling capacity, and limited stakeholder awareness hinder effective waste management.⁹ These challenges, if unaddressed, risk undermining the benefits of India's transition to renewable energy.

In conclusion, while India stands as a global leader in solar energy deployment, the management of solar PV waste is a nascent field fraught with environmental, health, and regulatory risks. Comprehensive and forward-looking policy implementation, robust institutional frameworks, and investments in recycling infrastructure are essential to bridging these gaps and ensuring a safe, sustainable solar energy future for India.¹⁰

2. Data Deficiency in India's Solar Waste Management

One of the most fundamental obstacles in addressing India's emerging solar photovoltaic (PV) waste challenge is the lack of reliable, granular, and systematically maintained data. Solar installations in India have expanded at a phenomenal pace in the past decade, with the country now ranking among the top nations in solar capacity. However, this growth has not been accompanied by a parallel effort to develop a comprehensive national database that records the location, type, commissioning year, technology specification, and expected end-of-life (EoL) timelines of solar modules. This omission severely handicaps both policymakers and waste management planners. Without accurate data, projections of future waste volumes remain speculative, often based on broad assumptions rather than actual ground realities.

For instance, while think tanks such as the Council on Energy, Environment and Water (CEEW) have attempted to estimate waste volumes using industry trends, such estimates are

⁸ Pollution Control Board releases draft guidelines for ...
<https://india.mongabay.com/short-article/pollution-control-board-releases-draft-guidelines-for-handling-solar-panel-waste/>

⁹ CPCB drafts India's first solar waste playbook on storage ...
<https://www.downtoearth.org.in/renewable-energy/cpcb-drafts-indias-first-solar-waste-playbook-on-storage-e-safety-sustainability>

¹⁰ India Prepares Solar Waste Policy as Installations Top 100 ...
<https://www.eqmagpro.com/india-prepares-solar-waste-policy-as-installations-top-100-gw-and-disposal-challenge-looms-eq/>

constrained by the absence of module-specific details. A rooftop installation in an urban apartment block has a very different lifecycle profile compared to a utility-scale solar park in Rajasthan's desert climate. Similarly, thin-film modules degrade differently compared to crystalline silicon modules. Unless these differences are captured in a structured dataset, India cannot develop reliable waste forecasts, nor can it plan infrastructure for recycling and safe storage in a geographically efficient manner.

This data deficiency also hampers financial planning. Investors and recyclers who might consider entering the solar waste management sector face significant uncertainty. Without visibility into where and when large volumes of waste will arise, it becomes risky to invest in recycling plants or collection networks. Moreover, state-level regulators and urban local bodies are left in the dark about the waste flows they will have to manage. The absence of predictive modelling, based on actual installation data, means that CPCB's guidelines, though well-intentioned, may fail in implementation simply because the "where" and "when" of solar waste remains poorly understood.

Globally, countries such as Japan and members of the European Union (EU) have already moved towards building integrated databases for renewable energy assets, including PV modules. In the EU, for example, the Waste Electrical and Electronic Equipment (WEEE) Directive mandates producer reporting on equipment placed in the market, which feeds into national and EU-wide databases. Such datasets not only enable accurate forecasting but also allow regulators to monitor compliance with Extended Producer Responsibility (EPR) obligations. India, by contrast, has yet to mandate any systematic data submission by manufacturers or solar developers. As a result, policymakers continue to operate in a partial information environment.

The lack of data also poses challenges for environmental and health risk assessments. Understanding the distribution of waste across climates and soil types is critical to modelling leaching behaviour of hazardous materials such as lead and cadmium. For example, waste modules discarded in humid coastal states may release toxins into groundwater more rapidly than those stored in arid regions. Without geospatially disaggregated data, such nuanced risk assessments remain impossible.

Finally, the absence of robust data undermines public awareness and participation. Consumers

and communities are less likely to engage in take-back or recycling initiatives if they do not know the scale of the issue in their own regions. Transparent, publicly accessible data could help build grassroots support for safe waste management and counter the tendency to neglect EoL responsibility.

Addressing this gap requires urgent action. India must establish a national solar module registry that mandates reporting by manufacturers, installers, and bulk consumers. Such a registry should include details on module type, quantity, commissioning date, and expected lifespan, and be periodically updated to reflect failures, replacements, and decommissioning. Leveraging geospatial technology to map installations will further enhance predictive modelling. Without such systematic data collection, India's solar waste policy will remain reactive rather than proactive—responding to crises instead of planning for them. In short, bridging the data deficiency is the foundational step upon which all other elements of solar waste management—technology, economics, regulation, and awareness—ultimately depend.

3. Importance

The issue of solar waste management is not merely a peripheral concern; it strikes at the heart of India's energy transition and environmental sustainability goals. Solar modules contain a combination of materials that can act both as environmental hazards and as valuable resources. On one hand, improper disposal of modules—such as open dumping, landfilling, or unsafe dismantling—poses serious environmental risks. Heavy metals like lead, cadmium, and selenium can leach into the soil and groundwater, contaminating ecosystems and creating long-term public health threats. Workers in the informal recycling sector, who often dismantle panels without protective equipment, face direct exposure to toxic dust, fumes, and sharp fragments. These practices not only endanger individual health but also risk creating localized pollution hotspots that could persist for decades.

On the other hand, when managed responsibly, end-of-life solar panels offer a remarkable opportunity. They contain recoverable quantities of aluminum, copper, silver, silicon, and high-quality glass—materials that are critical to the renewable energy industry itself. Efficient recycling could reduce India's dependence on costly imports of raw materials, strengthen the domestic renewable energy value chain, and open new avenues for job creation in the green economy. By establishing a circular system, the solar industry can reinforce its own sustainability while advancing the country's climate commitments.

Yet, the policy landscape currently weakens this potential. India's decision to defer Extended Producer Responsibility (EPR) targets for PV waste until 2034–35 effectively creates a regulatory vacuum. For nearly a decade, producers and operators are under no binding obligation to ensure proper recycling. This delay is particularly risky, as many of the utility-scale projects commissioned during the early years of India's solar mission will begin reaching retirement just within this window. Without mandatory systems in place, the country risks being overwhelmed by unregulated waste streams, undermining its clean energy achievements.

4. Technological Barriers

India's solar recycling ecosystem is still at a nascent stage, and this immaturity is most visible in the technological domain. The recycling technologies currently available are limited in scope and efficiency, especially when measured against international benchmarks. Most of the processes in use today are capable of recovering bulk materials such as aluminum frames and glass, which together account for the majority of the module's weight. However, they fall short when it comes to extracting high-value and scarce elements such as silver, indium, gallium, and silicon. These elements, though present in small quantities, contribute significantly to the economic and strategic value of recycling. Without effective recovery methods, India risks wasting an opportunity to build self-reliance in critical minerals needed for its clean energy future.

The challenge is compounded by the rising deployment of thin-film solar panels in utility-scale projects. Unlike crystalline silicon modules, thin-film panels often contain toxic metals such as cadmium and tellurium, which pose serious environmental hazards if not handled properly. The technology to recycle these panels requires specialized chemical and thermal treatments, which are neither widely available nor cost-competitive in India. At present, most informal recycling units, and even many formal ones, lack the expertise and infrastructure to deal with such hazardous content, increasing the risk of unsafe disposal.

Globally, research into advanced recycling methods—such as thermal delamination, electrochemical processes, and closed-loop silicon recovery—is underway, but these innovations have not yet been adapted or scaled in the Indian context. The absence of large-scale pilot plants, coupled with low private investment, means that India continues to rely on rudimentary methods. This technological stagnation creates a vicious cycle: because recovery

yields are low and processes costly, recyclers remain reluctant to enter the market, which in turn discourages innovation and commercialization of better methods.

5. Economic and Financial Constraints

Overlaying the technological barriers are equally daunting financial challenges. The CPCB's draft guidelines emphasize safe storage, fire protection, and transportation of solar PV waste, but they are largely silent on the question of costs. Establishing dedicated collection centers, maintaining specialized storage facilities with fire-resistant infrastructure, and transporting bulky modules over long distances all involve significant expenditure. Without clarity on who should shoulder these costs, the guidelines risk remaining aspirational rather than actionable.

Manufacturers argue that consumers and project developers should bear responsibility for EoL waste, while project developers often claim that recycling obligations should fall on producers under the principle of Extended Producer Responsibility (EPR). Recyclers, meanwhile, face a Catch-22: investing in infrastructure without guaranteed waste volumes is financially risky, yet without infrastructure, waste streams cannot be formalized. This lack of a clear financial model creates a policy vacuum where all stakeholders attempt to offload responsibility, increasing the likelihood of unsafe, low-cost disposal in informal channels.

Adding to the problem is the limited economic incentive for recycling under current conditions. With global commodity prices fluctuating, the revenue from recovered glass, aluminum, and copper often fails to cover operational costs. More advanced recycling technologies could improve margins by recovering high-value metals, but these require upfront investments in research and development. Without government subsidies, tax incentives, or buy-back schemes, private actors find little reason to enter the field.

The deferral of mandatory EPR targets until 2034–35 further weakens financial viability. For nearly a decade, recyclers cannot rely on a steady, regulated supply of waste, making long-term planning almost impossible. This gap may also encourage “wait-and-see” behavior, where stakeholders postpone action until legal obligations become unavoidable.

In short, unless technological innovation is paired with financial incentives and clear cost-sharing frameworks, India's solar waste challenge will remain unresolved. Advanced recycling methods must be made economically viable, not just environmentally necessary, if

the country is to build a sustainable and self-reliant solar economy.

6. Towards a Sustainable Solar Future

The Central Pollution Control Board's (CPCB) draft guidelines on solar waste management mark a significant milestone in India's journey towards a greener energy landscape. For the first time, a national authority has attempted to create a framework that recognizes solar modules not only as assets during their operating life but also as potential hazards once they reach their end of life. While this is an important beginning, the sheer scale and complexity of India's solar waste challenge demand a response that is far more holistic, coordinated, and forward-looking. If India's renewable energy transition is to be truly sustainable, the management of solar waste must become an integral part of policy, technology, and social practice.

A first step in this direction is the creation of a transparent and comprehensive national database. Currently, the absence of detailed information on installation dates, module types, and expected lifespans makes forecasting waste volumes highly speculative. A registry that captures this information, regularly updated by manufacturers and developers, would allow policymakers to anticipate waste flows and plan infrastructure accordingly. Such a database could also be integrated with geospatial mapping tools, enabling the strategic siting of collection and recycling facilities across different regions of the country.

Equally critical is investment in research and development (R&D) for cost-effective and efficient recycling technologies. India cannot afford to rely solely on rudimentary recycling processes that recover only low-value materials like glass and aluminum. Instead, the country must explore advanced techniques capable of extracting high-value metals such as silver, indium, and silicon. Partnerships between government laboratories, private industry, and academic institutions could accelerate innovation, while pilot projects would demonstrate the scalability of these technologies in Indian conditions.

No technological innovation will succeed, however, without robust financial mechanisms to make recycling economically attractive. At present, recyclers face slim profit margins due to high operational costs and uncertain waste flows. Policymakers must introduce incentives such as subsidies, tax rebates, green credits, or extended producer responsibility (EPR) schemes that

ensure a steady supply of waste and equitable distribution of costs. Innovative business models—such as buy-back guarantees from manufacturers or deposit-refund systems for consumers—could also enhance financial viability.

Another key requirement is capacity building for regulators and recyclers. State pollution control boards, urban local bodies, and private recycling operators often lack the technical know-how and infrastructure to implement CPCB's guidelines effectively. Training programs, knowledge-sharing workshops, and the development of standardized protocols could strengthen institutional capacity. At the same time, investment in fire-safe storage facilities, specialized transportation systems, and safety equipment for workers is essential to translate policy into practice.

Finally, public awareness campaigns must play a central role in building a circular solar economy. Consumers—whether rooftop solar owners or utility-scale developers—need to be made aware of their responsibilities in the waste value chain. Awareness initiatives could highlight both the environmental hazards of unsafe disposal and the economic opportunities of recycling. Schools, universities, and civil society groups could also be engaged to mainstream the idea that clean energy must be clean across its entire lifecycle.

In conclusion, while CPCB's guidelines represent a vital step forward, they must be seen as the foundation rather than the final word. India now has an opportunity to design a solar future that is not only renewable but also regenerative. By combining data-driven policy, technological innovation, financial incentives, regulatory capacity, and public participation, India can transform the solar waste challenge into a springboard for sustainable growth and resource security. The decisions taken in the coming years will determine whether solar energy remains a symbol of environmental hope or becomes another source of ecological burden.

7. Conclusion

India's solar energy journey has been one of remarkable growth, symbolizing both technological advancement and a commitment to cleaner sources of power. Yet, as this growth accelerates, it brings with it a pressing challenge—the management of end-of-life (EoL) solar photovoltaic (PV) waste. The draft guidelines issued by the Central Pollution Control Board (CPCB) in 2025 are a crucial step towards acknowledging and addressing this issue. However,

the road to effective solar waste management is still long, requiring a more comprehensive and integrated approach.

The analysis reveals multiple, interlinked gaps. The absence of reliable data on module distribution and lifespans makes waste forecasting uncertain. Technological barriers limit recovery of high-value materials, while financial uncertainties deter private investment. The informal sector, though deeply entrenched, lacks the safeguards necessary for safe recycling, and enforcement capacity across states remains uneven. Adding to these challenges is the low level of stakeholder awareness, which undermines the potential of take-back schemes and collective responsibility models.

At the same time, the risks and opportunities are too significant to ignore. Improper disposal could lead to widespread environmental contamination and health hazards, while efficient recycling offers the promise of resource recovery, reduced import dependence, and new green jobs. India must therefore embrace a circular approach to solar energy—one that ensures sustainability across the full lifecycle of solar modules.

Moving forward, a transparent database, investment in R&D, economic incentives, stronger regulatory frameworks, and awareness campaigns will be essential pillars of success. The deferral of Extended Producer Responsibility (EPR) until 2034–35 risks delaying action, but with timely intervention, India can still turn the tide. Ultimately, the measure of India's renewable energy revolution will not only be how much clean power it generates but also how responsibly it manages the waste it leaves behind.