



**A Comprehensive Recycling Framework
and Policy Solutions for
Managing Solar Photovoltaic
Waste in India**

Designed and Edited by CSTEP

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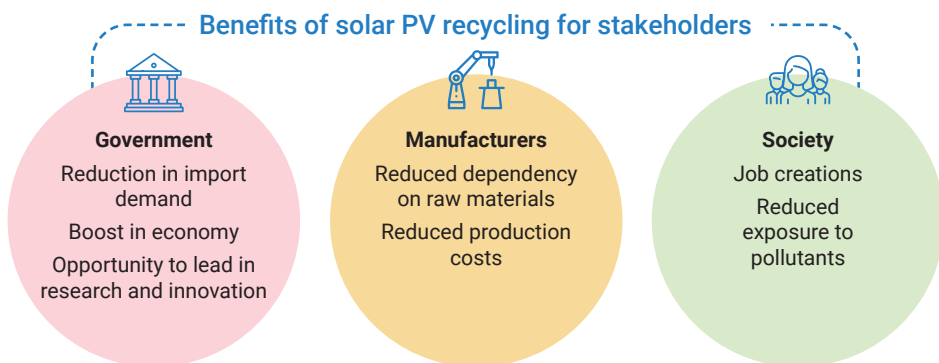
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INTRODUCTION

India is among the top five leading countries in solar power installed capacity. Of India's ambitious target of 500-GW RE capacity by 2030, over 292 GW is likely to be generated using solar power. This increase in installed capacity, while promising, also opens doors to massive waste streams and increased emissions. According to the Center for Study of Science, Technology and Policy's (CSTEP's) analysis, India is projected to generate approximately 4.5 million tonnes of solar photovoltaic (PV) waste by 2050. However, only 20% of solar PV waste is recovered typically, while the rest is disposed of informally.

Thus, closing this recovery gap is essential to effectively manage the increasing quantity of solar PV waste. Further, it will benefit a wide range of stakeholders, as mentioned in the figure below.



DRIVERS

- Environmental concerns (Air pollution, soil contamination, and health hazards)
- Resource scarcity (Natural resource depletion)
- Regulatory pressure (Encouraging circular economy practices)
- Rise in energy demands (Due to industrialisation and modernisation)



BARRIERS

- Lack of awareness of circular economy practices in the solar industry (Need for awareness on waste disposal practices and benefits of circular economy)
- Informal sector involvement (Need for tracking and disposing of the PV waste properly, incentives to recyclers, and creation of a stable market)
- Lack of recycling infrastructure (Need for cutting-edge technologies and infrastructure)

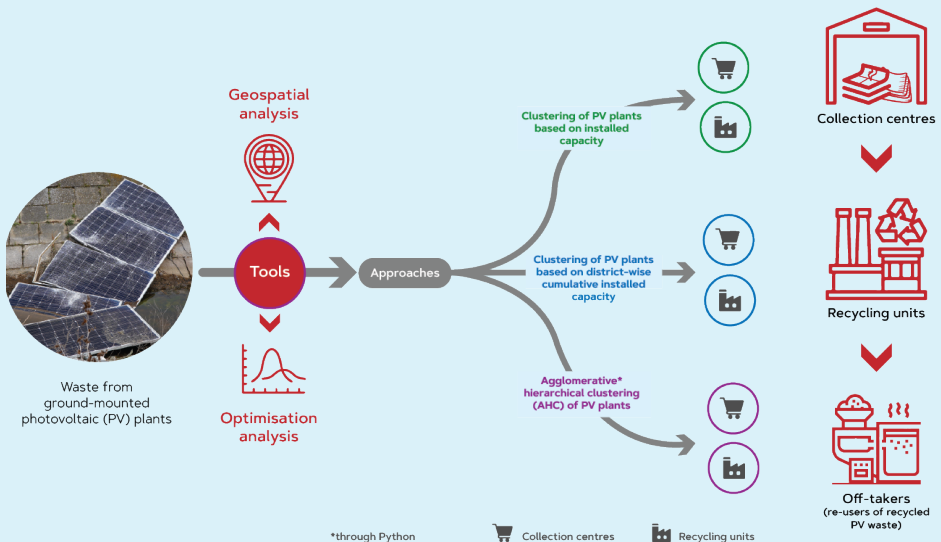


ENABLERS

- Innovation (Technology and business models to enable circular economy practices)
- Collaboration (Between government, industry, and other stakeholders)
- Consumer demand (Demand for eco-friendly product and services)
- Business investments (To commercialise PV recycling)

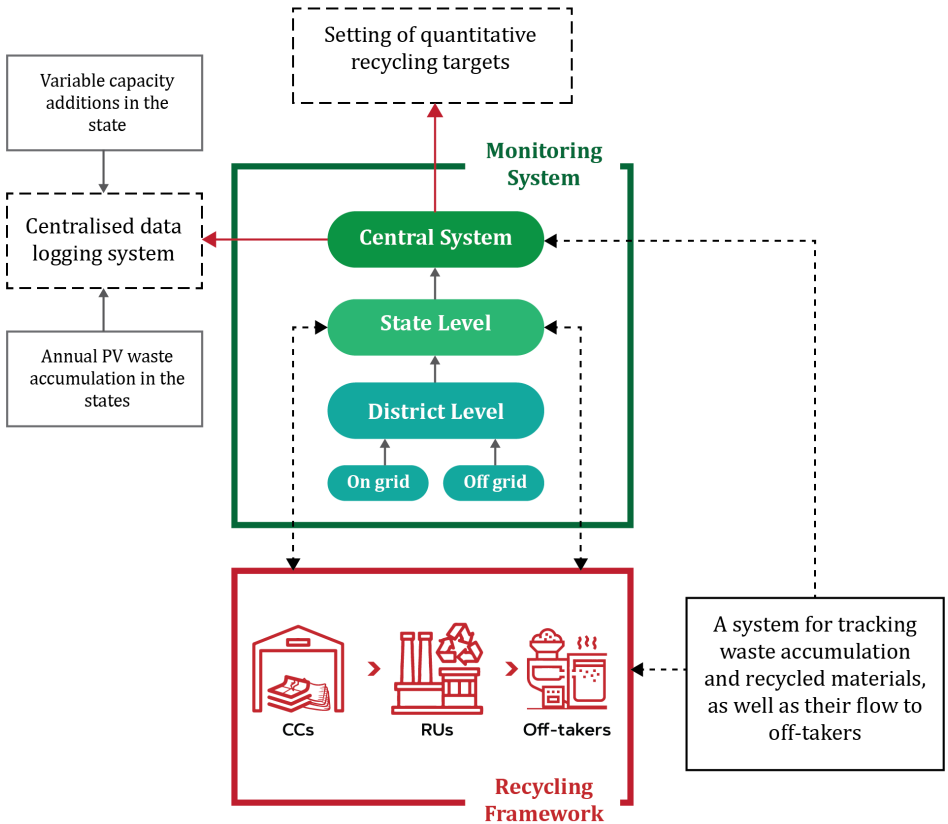
INSIGHTS

To address the challenges in PV waste management, CSTEP has proposed an optimisation-modelling-driven recycling framework, which identifies clusters, collection centres, and optimal locations for setting up recycling units. The recycling framework consists of three approaches. The first approach considers the 'shortest distance' to identify the optimal locations for recycling units. The second approach considers the 'minimum transport cost' (of transporting waste) to identify collection centres and the 'shortest distance' to identify the optimal locations for recycling units. The third approach considers agglomerative hierarchical clustering (AHC@) to determine the number of clusters and 'minimum transport cost' to identify collection centres and the optimal locations for recycling units.



While implementing a recycling framework, a robust monitoring and reporting (M&R) system could help track PV installations, as well as report and regulate the amount of PV waste generated, recycled, and reused in the economy. This system would assist in setting recycling targets, supervising the accomplishment of such targets, and regulating the informal handling of PV waste in India.

@ AHC is a clustering algorithm that clusters data on the basis of the similarity between data points. This modelling technique is used to determine the number of clusters of PV plants.



Thus, the proposed recycling framework and a robust M&R system will address India’s challenges in solar PV waste management pertaining to the fields of ‘technology and business’, ‘policy ecosystem’, and ‘infrastructure facilitation’.

CHALLENGES



Technology and Business

- Limited recycling technologies.
- Lack of profitable business models to enable circular economy in PV waste management.



Policy Ecosystem

- Ambiguity in PV waste guidelines and regulations.
- Absence of penalty or a landfill tax.
- Absence of a national M&R system or mechanism to examine, evaluate, report, and regulate the quantum of PV waste produced, recycled, or reused.
- Lack of proper channels for information dissemination on recycling rates, Extended Producer Responsibility (EPR) guidelines, technology developments, regulations, and employment opportunities.
- Absence of a regulatory body to cover the financial losses.



Infrastructure Facilitation

- Absence of adequate infrastructure for collecting, recycling, and repurposing PV waste.
- Limited job opportunities and investments in PV waste recycling.
- Resource scarcity, limited domestic manufacturing of PV panels, and increased dependency on imports.

INTERVENTIONS

2027

----- Immediate to Short Term

Policy Ecosystem



Clearly define who is responsible for collecting and recycling PV waste at each stage



Consider a special provision for PV waste handling under e-waste management



License collectors and recyclers to limit the informal handling of PV waste and establish a stable market for recycled panels



Regulate the informal recycling market, and implement an automated tax on those non-adhering to guidelines



Establish PV waste collection centres near PV installations



Levy a high penalty or landfill tax to disincentivise PV waste landfills

Interlinkages and Engagements

- Create a national committee or a core group, involving stakeholders from the government, industry (including off-takers), and civil society, to formulate appropriate waste disposal practices, ensure circularity in goods and services, and encourage discussions and discourses for developing effective policy instruments and setting up recycling benchmarks (e.g. the government-formed committees for promoting artificial intelligence initiatives and developing a policy framework).
- Promote transparent and correct information flow through awareness campaigns, sensitisation initiatives, and skill-enhancement programmes.

Policy Ecosystem



Regulate market mechanisms for off-takers to recycle glass and aluminium. Establish protocols for the circularity of materials, which in turn will regulate the market price of PV panels



Develop recycling action plans in states by considering the current and projected solar installations and estimated waste generation, as well as by capitalising on the states' untapped potential for solar PV installations



Regulate waste collection fees to cover the producer's or end user's financial losses



Establish recycling units by considering the states' requirements and waste generation

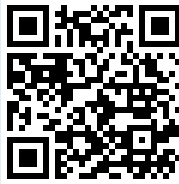
Interlinkages and Engagements

- Create attractive pricing mechanisms for start-ups, manufacturers, and producers to enable proper PV waste disposition.
- Fund R&D programmes to develop high-end and efficient recycling technologies.
- Incentivise the development of innovative PV technologies and domestic manufacturing of PV panels through investor-friendly schemes, infrastructure facilities, guidance from global peers, and adequate funding support.

M&R System

- Maintain a centralised database and establish a data repository of current and future PV capacities and waste produced at state and national levels.
- Track, report, and regulate the amount of PV waste generated, recycled, and reused in the economy, thereby ensuring circularity of goods and services.

For more details, refer to the [white paper](#) on this topic



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