STUDY

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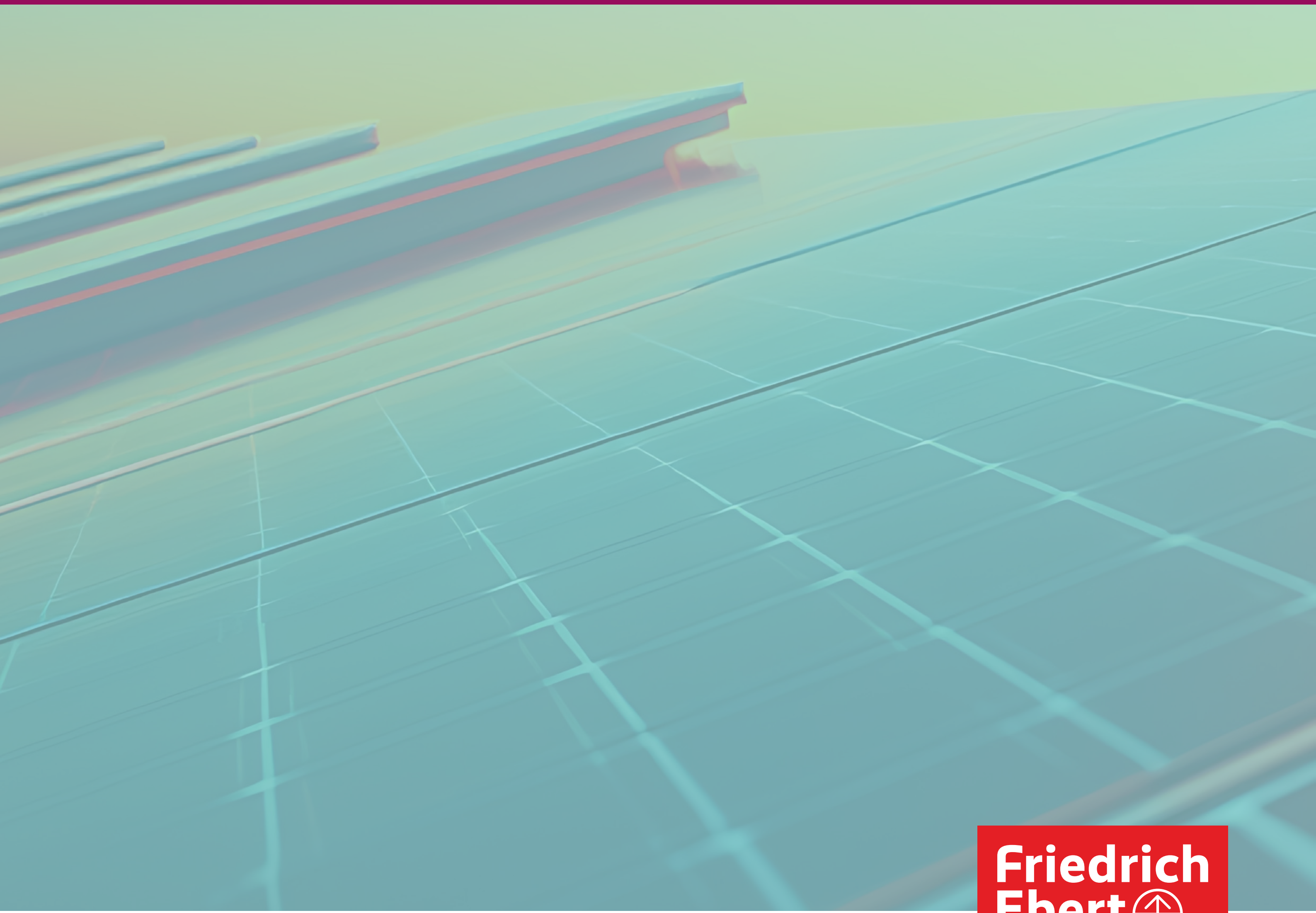
End-of-Life (EOL) Solar Panel Management from a Circular Economy Perspective: The Philippine Case



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Directory of Acronyms

c-Si: Crystalline Silicon

DAO: Department Administrative Order

DENR: Department of Environment and Natural Resources

DOE: Department of Energy

ECC: Environmental Compliance Certificate

EL: Electroluminescence

EOL: End-of-Life

EPR: Extended Producer Responsibility

ESWM: Ecological Solid Waste Management

EVA: Ethylene-vinyl Acetate

FPVS: Floating Photovoltaic

GW: Gigawatt

IEC: International Electrotechnical Commission

JAO: Joint Administrative Order

KIIs: Key Informant Interviews

LID: Light-Induced Degradation

METI: Ministry of Economy, Trade, and Industry (Japan)

MGS: Metallurgical-grade Silicon

MOE: Ministry of the Environment (Japan)

MW: Megawatt

NEA: National Environment Agency (Singapore)

PECC: Programmatic Environmental Compliance Certificate

PEISS: Philippine Environmental Impact Statement System

PID: Potential-Induced Degradation

PNS: Philippine National Standards

PR: Performance Ratio

PV: Photovoltaic

RA: Republic Act

RCRA: Resource Conservation and Recovery Act (US)

RE: Renewable Energy

SEIA: Solar Energy Industries Association (US)

SPM: Solar Panel Recycling and Management

TSD: Treatment, Storage, and Disposal

WEEE: Waste Electrical and Electronic Equipment

End-of-Life (EOL) Solar Panel Management from a Circular Economy Perspective: The Philippine Case

Introduction

The Philippines' turn to solar power and other renewable energy sources has intensified in the past two decades. One study estimates the country's total solar capacity as of July 2025 at 1,846.08 MW (ICSC, 2025) with another projecting that the country's solar energy market will grow at an annual rate of 4.74 percent from 2025 to 2029 (Statista, 2025). Factors that account for the increasing usage of solar power include the growing public awareness of the country's vulnerability to climate change, decreasing price of solar panel installation, and the generous fiscal incentives that the government provides under the Republic Act (RA) 9513 or the "Renewable Energy (RE) Act of 2008," which promotes the production and consumption of alternative green and clean power.

As other countries are finding out, however, the use of solar energy brings its own set of problems. Solar photovoltaic (PV) modules, which convert sunlight into electricity, reach their end of life (EOL) in 25 to 30 years. Without a clear EOL solar PV modules (heretofore, solar panel) management system, these panels end up in the waste stream as e-waste in landfills and are susceptible to leaching hazardous materials that pose serious health and environmental risks (Atasu, 2018).

In anticipation of such an eventuality, this paper presents findings from a four-month study that addressed the research question: What are the existing and emerging policies and technologies that may inform the development of the Philippines' EOL solar panel management system? Toward answering this question, a policy and technical review was conducted with the following objectives:

1. Undertake a review of policies on, technologies for, and best practices in EOL solar panel management globally;

2. Identify Philippine policies and programs that may serve as a basis for developing an EOL management system at the local and national levels;

3. Explore the feasibility of available technologies and processes in the Philippine setting;

4. Map the lifecycle of solar PV modules, highlighting critical stages for reuse, refurbishment, and recycling in which members of the community (both in the formal and informal sector) could participate; and,

5. Provide policy recommendations using the circular economy framework to promote sustainable, inclusive, and viable EOL solar panel management.

Research Methodology

The study employed a qualitative and policy-oriented approach aimed at mapping the EOL pathways of solar PV panels in the Philippines and identifying the policy environment for EOL solar PV module management through the following activities:

1. Comprehensive literature review of studies on policies and technologies on EOL solar panel recycling and management (SPM) in different countries and regions;

2. Review of existing Philippine policies, reports, and regulations, such as Republic Act 6969 and 9003, and guidelines from the Department of Energy (DOE) and the Department of Environment and Natural Resources (DENR);

3. Key informant interviews with stakeholders from the solar industry and national and local government agencies to capture institutional perspectives and implementation challenges; and,

4. Field visits to PV module installation sites to observe actual handling practices and infrastructure.

The collected data was analyzed to identify emerging trends as well as regulatory and operational gaps in EOL solar panel management, assess the feasibility of local recycling or second-life applications, and provide insights from international circularity models. The findings from the study informed the paper's policy recommendations to advance the circularity of solar power in the country.

Limitations

The research team faced time and resource constraints, which partly explain the exploratory nature of the research. The brief research period of four months, as well as a limited budget, also meant that the field visits were only conducted within Metro Manila and nearby provinces, when many of the oldest and largest facilities are understandably farther afield.

Since the Philippines has no experience in EOL solar panel management and lacks laws and recycling facilities specifically for this purpose, the interviews and policy review focused primarily on laws on and practices in the country's e-waste and municipal solid waste management.

The paper is organized as follows: a discussion of EOL management policies is followed by the technical review section. The paper concludes with a set of policy recommendations.

Policy Review

Currently, there is a growing awareness that solar power may present a double-edged sword. On the one hand, there is no question about the importance of solar power as a green, clean, and relatively affordable alternative to traditional fossil fuels. That it can be adopted at the household level, especially in remote areas, adds to the value of solar power as an energy source that could promote broad-based sustainable development, particularly in a tropical country such as the Philippines. On the other hand, the use of solar power also presents challenges, particularly because solar PV modules lose their full capacity after the same time when the manufacturer's warranty expires. After this period, the solar PV modules will begin to produce electricity at a declining rate. That solar panels have an expiration date underscores the need to prepare an effective management system to prevent their disposal in landfills and the risk of releasing hazardous substances into the environment. A comprehensive management system could ensure that, instead of being abandoned, EOL solar panels can be reused, recycled, repurposed, or become sources for valuable materials for new products.

In this connection, the solar energy market aligns with the circular economy framework. Using this framework, solar panels are considered an energy resource that can be managed to ensure their efficient use and reduce waste. Immediately, this would mean the use of mechanical, chemical, or thermal processes to reconfigure EOL modules for the second market or extract and valorize valuable materials such as silicon, aluminum, glass, and copper that could be used to make new products and thus also provide new business opportunities (Goh et al., 2024). Noteworthy, one study estimated that by 2050, EOL solar PV modules could yield approximately 78 tons of recovered materials, valued at USD 15 billion (Bueno et al., 2024).

Another study further discusses circularity actions in two stages for managing EOL solar panels (Shaw et al., 2024). First, the authors highlight the need to assess the feasibility of repairing or extending the modules' service life, which may be sold in the second-life market or reused especially in underserved communities. Here, the collection, transportation, and storage of decommissioned modules, as well as the issuance of a shelf-life warranty, are crucial considerations. Second, if extending the modules' service life is no longer an option, recycling and resource recovery become the alternatives. On PV circularity, for instance, the International Energy Agency (IEA) estimated that systematically recycling and recovering resources from EOL panels could meet 20 percent of the global solar industry's demand for aluminum, copper, glass, and silicon, and about 70 percent of the demand for silver (Garcia and Sarhada, 2024).

Circularity as Regulatory Framework

A prime example of circularity as a regulatory framework is Europe's Waste Electrical and Electronic Equipment (WEEE) Directive, passed in 2012, to improve "the collection, treatment and recycling of electrical and electronic equipment at the end of their life…[in order to]… increase resource efficiency and support the shift to a circular economy." Among the key policy instruments used to advance the circular economy is the producer responsibility framework, which places an obligation on manufacturers and distributors to minimize and recycle solar waste. This approach helps reduce waste across both the production cycle and the broader production-consumption nexus, thereby, supporting long-term resource sustainability (Bajagain, 2020). Key provisions include the following:

1. Setting of eco design requirements throughout the whole life cycle of solar panels, from product design to every stage after, to prolong their life, optimize their use and reuse, and facilitate resource extraction and

recovery (#11);

2. Financing of WEEE management is determined at the Union level, partly to harmonize producer financing (#s 22 and 23); and,

3. Private households may return WEEE free of charge (#23), while producers may show buyers "at the time of sale of new products the costs of collecting, treating, and disposing of WEEE" (#24).

In this arrangement, the manufacturers or producers are expected to fold into the price of the solar panels the cost of recycling and disposing of the WEEE, as an "ecotax" or "waste management contribution." In turn, they are required to take back the discarded panels from clients.

A survey of countries' approaches to EOL solar panels suggests an increasing appreciation that EOL solar module management is as integral to achieving a net-zero future as the promotion of solar energy itself. However, countries adopt different policies and approaches due to differing access to recycling technologies. Goh et al. (2024) also point out that countries adopt distinct policy tools and implementation strategies based on institutional settings such as the state's regulatory framework, government-industry relations, and available resources and infrastructure.

As observed, the two countries that are leaders in solar energy– the United States of America and China–adopt different EOL solar panel management systems. The USA does not have a federal mandate on solar panel recycling, leaving this decision up to the states and the private sector. While 35 states have some policies on solar panel decommissioning and disposal under the Federal Resource Conservation and Recovery Act (RCRA), only ten of these have regulations on EOL solar panel recycling (Talabong, 2025). Only Washington has a Photovoltaic Module Stewardship and Takeback Program, although the state legislature recently moved the implementation of the law from 2025 to 2031 (Dept of Ecology, Washington State, n.d.).

What fills the gap is the private sector. Notably, the Solar Energy Industries Association (SEIA) was established in 1974 and has, as of the start of 2026, more than 1,200 member companies (SEIA, 2023). Adopting a circular economy framework, this trade association helps set industry standards "for solar panel sustainability, training, consumer protection, and supply chain traceability". It also operates the National PV Recycling Program, which comprises a network of private EOL management service providers. That said, EOL management in the US remains limited, with fewer than 20 recycling facilities, many of which focus on reusing or refurbishing panels for a second life (Gracia and Sardana, 2024). Consequently, only 10 percent of solar panels in the US are recycled (Pinto, 2024).

In contrast to the US's more market-driven approach, China maintains a more state-led approach. In 2023, the central government issued guidelines to develop a comprehensive solar panel recycling system by 2030. This initiative, in which the government would draw up new industrial standards and regulations governing the decommissioning, dismantling, and recycling of wind and solar facilities, is led by the state planning agency, National Development and Reform Commission (NDRC). Other agencies involved include the National Energy Administration, the Ministry of Industry and Information Technology, the Ministry of Ecology and Environment, the Ministry of Commerce, the State-owned Asset Supervision and Administration Commission, and the Administration Commission of the State Council (Allbright, 2023).

Another leader in solar energy is Japan, which also presents a different institutional arrangement in EOL management. The country first adopted solar PV cells in the 1950s as a renewable energy source and has since seen the solar power industry mature in open-market settings. Nevertheless, studies estimating that, within a decade, the annual volume of decommissioned EOL solar panels in the country will reach 500,000 tons (Japan Times, 2025), has led the national government to recently intensify efforts in EOL management). In response to the projected surge in EOL solar panels, the Ministry of Economy, Trade, and Industry (METI) and the Ministry of the Environment (MOE) are actively drafting legislation, making recycling mandatory, similar to the EPR requirement for its automotive and household electronics industries. Key provisions include:

1. Solar panel producers and importers will be required to cover the recycling cost of panels, while solar power facility owners will pay the "demolition cost" (i.e., the physical dismantling of the facility).

2. Solar panel homeowners will pay a "demolition fee" to a government-accredited third-party service provider.

Southeast Asia has only recently promoted the circularity of solar power in EOL management. In fact, in 2021, the region reportedly did not have a single solar panel recycling plant, primarily due to the infancy of the solar panel industry. Additionally, there was an insufficient number of decommissioned panels and were no regulations and financial incentives to make the establishment of solar panel recycling facilities viable (Giap, 2021). Since then, however, the region has become the world's second-largest manufacturer of solar PV panels, after China (Ho et al., 2025), prompting governments, notably Singapore and Vietnam, to be more proactive in promoting circularity in solar energy production and consumption.

Singapore has EPR regulations for electronic waste, including EOL solar PV modules. Under the National Environment Agency's (NEA) Resource Sustainability Act, companies that import solar panels and use or sell these in the country are required to take back for free EOL solar panels from their customers and then engage NEA-licensed waste collectors or e-waste recyclers to dispose of or recycle these solar panels (Tan, 2022). For its part, Singapore Polytechnic, a public university, leads and collaborates with the private sector to develop recycling methods that extract valuable materials for other uses (Singapore Polytechnic, n.d.).

Vietnam has also passed Decree 08/2022/ND-CP, imposing mandatory recycling for producers and importers of solar panels to be sold and used domestically, and set up a Vietnam Environmental Protection Fund to which manufacturers and importers are required to contribute financially to have their products recycled (Rodl, n.d.; IEA, 2025).

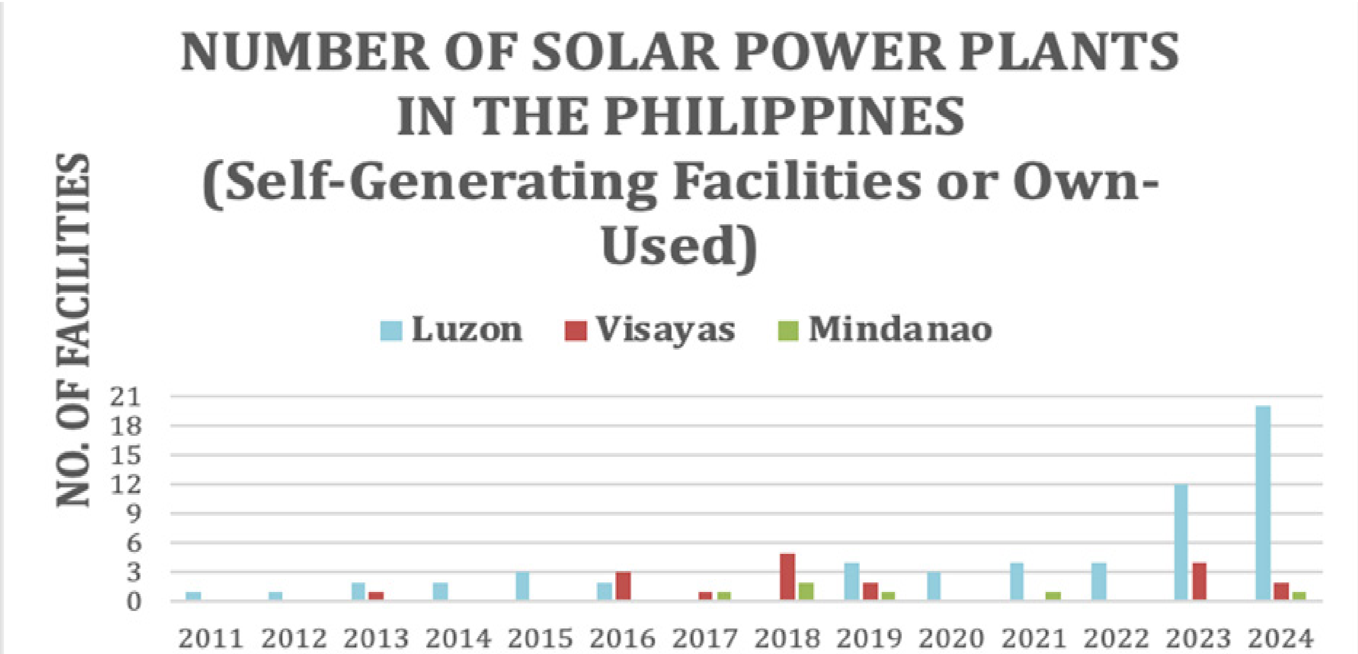
Except perhaps for the US, the cases above demonstrate how, even in market economies, the emerging trend is for governments to resort to extended producer responsibility as a policy tool for EOL management and thus make solar power live up to its promise of providing clean, green, and and relatively low-cost energy.

Noteworthy, there is also wide agreement that the EOL solar panel management theory and praxes are in an early phase and thus the need for extensive research and development (Xu, 2024). In all the countries cited above, regardless of what sector takes the lead in EOL management, government research arms are deep in work on the area of resource recovery, apparently, the cutting-edge in EOL solar panel technology today.

Case Study: The Philippines

The Philippine solar sector has undergone rapid expansion since the passage of the Renewable Energy Act of 2008. While early DOE reports recorded only 39 utility-scale solar facilities established between 2008 and 2018, the sector has since quadrupled in size. As of the latest records in April 2025, the Philippines had a total of 156 solar power plants, comprising 82 self-generating or own-use facilities and seventy-four (74) grid-connected installations (DOE, 2025). The deployment of self-generating solar facilities has notably increased starting in 2024, while grid-connected solar plants reached their peak installation year in 2016. Charts 1 and 2 present the registered solar facilities listed by the DOE, along with the corresponding years in which they commenced operation.

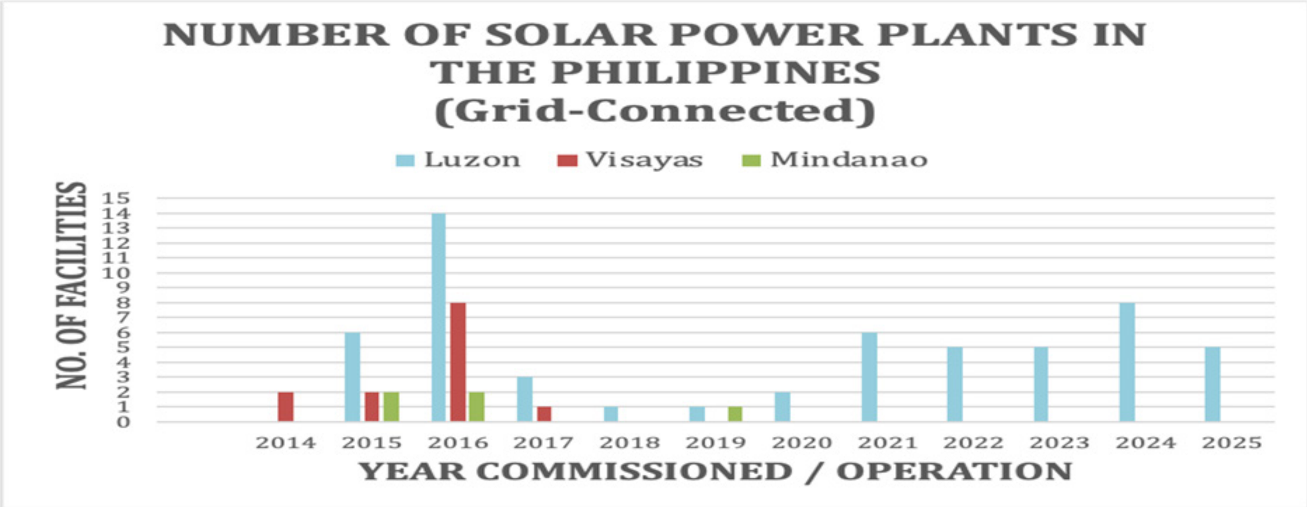
Chart 1. Number of Self-Generating Solar Power Plants in the Philippines



Reference: Tabulated by the authors from DOE List of Existing Solar Generating Plants (Self-Generating Facilities or Own-Use) as of 30 November 2025.

That said, the country's solar energy sector remains behind its neighbors. Despite the progress in the past decades, solar power represents only one percent of the country's total energy consumption (Koons, 2024). As such, government has been actively attracting investment in solar energy production and distribution, with the goal of raising the country's solar energy capacity to 15.3 GW by 2030 (Gupta, 2021). Toward this end, government

Chart 2. Number of Grid-Connected Solar Power Plants in the Philippines



References: Tabulated by the authors from DOE List of Existing Power Plants per Grid as of February 2025.

regulations and incentives have focused on bringing in foreign solar power companies, whether in partnership with Filipino businesses or on their own.

Nevertheless, a surge in installation would directly correlate to future waste volume. With the country's total solar energy capacity estimated at 1,846.08 MW as of July 2025 (ICSC, 2025), a baseline for future waste generation can be established. Applying the International Renewable Energy Agency (IRENA) global benchmark of approximately 75 metrics tons of PV waste per megawatt (MW) of installed capacity, the Philippines is projected to generate approximately 138,450 metric tons of retired PV modules from currently installed capacity alone. Given the typical lifespan of solar PV panels ranging from 25 to 30 years, the first significant wave of this mass decommissioning is anticipated to occur around 2041.

Projections show that by 2040, the country will have generated approximately 12,310 tons of decommissioned PV module waste, sufficient to justify the operation of a dedicated recycling facility (Bergado, 2022). By 2050, utility-scale solar installations alone could generate up to 962,000 tons of PV module waste. Material testing further revealed the presence of most RCRA 8 heavy metals in PV modules, with lead (Pb) concentrations exceeding the US EPA allowable limit of 5.0 ppm, raising concerns about potential environmental and public health risks.

Philippines Policy Environment

In the past decade, there has been some realization that the promotion of solar power needs to be informed as well by the requirements of EOL management to avoid second-generation problems. In the main, this awareness seems to come from academic researchers, indicated by the few published studies focusing on EOL management. So far, the most comprehensive study on the state of the Philippine solar industry in relation to solar panel recycling strategies is that of Miriam Bergado (2022), entitled "Assessment of Philippines' Preparedness in Handling the Decommissioned PV Module Waste," which drew attention to the critical need for developing comprehensive strategies for EOL management – including recycling, repurposing, and second-life applications – well before the bulk of this waste stream materializes. Bergado's findings indicate that the Philippines faces a significant and growing PV waste challenge and thus call attention to the country's need to develop an effective, sustainable, and inclusive EOL management program.

Since the country does not have a single solar panel recycling facility, there are only a few academic studies on the Philippine case that stress the importance of undertaking EOL solar panel management where they are located. At least five studies explore the possibility of setting up recycling facilities in the country. Two other works focus on identifying factors that should be considered in choosing location for recycling facilities at the local level (Vanguardia, n.d.; Diccion and Duran, 2024). The case study of Laguna province, which has 17 commercial PV systems, triangulated geographic spatial analysis with other analytical methods to determine the optimum location for treatment, storage, and disposal facilities in relation to PV waste generators (Diccion and Duran, 2024). Such studies suggest that in EOL solar panel management, geographic location–where there would likely be a critical mass of EOL solar panels due to the presence of a number of solar plants and solar farms, for instance–and the distance of generators to storage, recycling and other related facilities matter.

Overall, however, there is not enough public awareness of the challenge that awaits the country in a decade or so when the problem of what to do with EOL solar panels intensifies as the interviews with government and industry players suggest. Strikingly, there are no laws or policies directly dealing with EOL solar panel management. The key legislation that guides the development of solar energy in the country is RA 9513, which promotes the use of solar and other renewable energy resources by providing fiscal and non-fiscal incentives for renewable energy developers, manufacturers or importers, and operators. These incentives include income tax holidays and duty-free importation of machinery and equipment. There is no provision in the law that links the adoption of solar energy and management of EOL solar panels.

Nevertheless, there are other pieces of legislation and administrative orders, especially those that address the management of solid waste (which includes electronic and hazardous waste) that may be used as a springboard for the discussion on EOL solar PV module management. Below are some of the relevant policies and their key provisions.

1. **Republic Act 6969 or Act to Control Toxic Substances and Hazardous and Nuclear Wastes of 1990**

RA 6969 seeks to regulate and monitor the importation, manufacture, use, and disposal of toxic substances as well as hazardous and nuclear wastes to protect public health and the environment. It gives the DENR the principal role in waste management of hazardous materials and requires "manufacturers, processors or importers to shoulder the cost of testing...substances that will be manufactured, processed or imported" (sec 9).

The law is elaborated in the Implementing Rules and Regulations as well as DENR manual on the procedures for generation, treatment, storage, and disposal facilities of hazardous wastes (i.e., DAO 2013-22, or the Revised Procedures and Standards for the Management of Hazardous Wastes).

2. **Republic Act 9003 or the Ecological Solid Waste Management (ESWM) Act of 2000**

The law aims to reduce the volume of solid waste with the process of segregation, collection, transport, storage, treatment, and disposal of solid wastes, including those that can be recycled and reused to produce new products. Relevant to the setting up of the country's EOL management systems are provisions that do the following:

- Give local governments the primary responsibility for solid waste management, notably, at the household and community levels;
- Provide for the setting up of materials recovery facilities for segregating and processing biodegradable and recyclable materials, as well as buyback centers to purchase recyclable materials;
- Establish National Ecology Center that, among other functions, would promote a national recycling market and pilot test solid waste management facilities; and,
- Call for the establishment of a Solid Waste Management Fund (that, in succeeding policy papers of the DENR, may tap the national government's annual budget, official development assistance, and public-private projects for financial support).

3. **DENR Administrative Order 2023-08 or Guidelines in Securing Environmental Compliance Certificate (ECC) under the Philippine Environmental Impact Statement (PEISS) for Floating Photovoltaic (FPVS) Plants within Laguna Lake**

The DAO-2023-08 regulates the pre-installation, construction, operation and maintenance, and decommissioning of utility-scale floating photovoltaic projects in Laguna Lake to address their environment, social, and economic impact. In fact, the department order is the only policy that anticipates the decommissioning stage of solar power plants and required the plant owners-operators to submit an "abandonment plan," involving the dismantling of the project and components such as the panels, restoring and rehabilitating the site to its original state, and "collecting, transporting, and properly treating or disposing of any waste or debris, including the recycling, reusing, or recovery of materials" (sec. 5.4).

For the other stages in setting up the solar power plant, the DAO does the following:

- Requires the project proponent during the pre-construction phase to make an Environmental Impact Assessment report, detailing the design, materials, equipment with specification, timeline, and mitigation measures that will go into the Programmatic Environmental Compliance Certificate (PECC) to be submitted by the Laguna Lake Development Authority to the DENR-EMB Central Office, and
- Provides the guidelines for the construction phase (involving the delivery and installation of PV panels and inverters) as well as operation and maintenance (ensuring the prevention of and repairs to damage of panels and the plant) for the long-term viability and sustainability of the project.

From the policies cited above, there are provisions that would prove useful in developing the country's EOL management framework. Immediately, as envisioned in RA 9003, local governments and communities play a critical role in any EOL management system. As one case study on the application of RA 9003 in Cebu City, the role of the local government in partnership with the private sector (notably, mall owners) and civil society (especially in education) proved critical in achieving one key result area: the dramatic lowering of the amount of e-waste generated in the city (Santos, 2025).

In fact, studies suggest that the site selection for waste or recycling management facilities need to include economic and social settings. The studies also show the need to extend and strengthen the role of local governments, as envisioned in RA 9003, beyond the management of household e-waste (Santisteban, et al. 2024; Arabeyyat et al., 2024).

This discussion on the Philippine policy environment, nevertheless, raises questions when taken in the context of the global trend that, more and more, puts the circularity framework at the core of the EOL solar panel management. While many countries have begun to seriously invest in achieving an efficient and sustainable EOL solar panel management, the Philippines has yet to begin the national discussion on EOL solar panels. A more strategic approach to EOL solar PV modules would entail a paradigmatic shift from waste management to their "second life" and resource extraction.

As such, for the country to move forward in step with other countries that are preparing to be ahead of what has been coined as the "global solar panel tsunami" in 2030 and 2050 (Kritz, 2025), there is a need to keep in mind the key questions from the global comparisons, such as:

1. Who is primarily responsible for recycling and EOL management? In the Philippine case, what is the role of the national government beyond the provision of guidelines and as regulator? How do we get the buy-in from those who manufacture, import, sell, or install and use solar panels?

2. What kinds of incentives and controls are in place in the country? Most of the regulations today are at the front end, such as licensing and environmental compliance certificates that a producer or operator must submit in order to get permission to import or use solar panels, but these are not binding at later stages of the product cycle, especially at these panels' EOL phase.

3. What leverage can be brought to bear and at what point in the process of managing solar power use so that solar panel recycling and resource recovery can be mandated? At what point in a project's life could leverage be used to ensure compliance to national and international standards? What is the nature of that leverage?

4. What kinds of end-of-life trajectories do we envision? How do we shift the goals of EOL solar panel management from waste disposal and pollution control to repurposing and, in the long term, resource extraction? As of now, in the Philippines, the goal seems to be safe disposal, but is there a need to do a deeper dive into safe repurposing and distribution of still useful assets especially to communities in underserved areas?

5. Given the broader socio-economic context, what policy provisions can be imagined to include small players, such as community power generators, working class households, and the informal sector in EOL solar panel management? On the one hand, this is partly a technical matter given that the process today is highly capital intensive. On the other hand, can there be government or private sector assistance of some kind—possibly funded by producers' mandatory contributions—that would support households and villages install end of life panels that still produce significant electricity?

As many countries, including those with market economies, have come to realize, EOL solar PV module management will depend first and foremost on a strong and cohesive national policy leadership. In the Philippines, this would mean immediately for the DOE and DENR to jointly set clear, complementary, and enforceable guidelines that institutionalize circularity across the entire solar value chain. On the one hand, the DOE is mainly responsible for promoting and regulating the country's use of solar energy: it sets policies and standards on solar power use as well as registers solar power plants and regulates their operation as well as market participation. On the other hand, the DENR oversees monitoring and regulating the environmental impact of solar power plant operations and closure. In this connection, what to do with EOL solar panels comes under its purview.

That two distinct agencies manage the installation and closure of solar power plants require tight coordination between them. Central to this effort is the establishment of a national and comprehensive database that documents solar power plants and the PV modules they deploy, enabling systematic tracking, monitoring, and forward planning for decommissioning and recovery. Integrating reverse logistics principles into these guidelines will further ensure traceability from deployment through reuse, recycling, or disposal, laying the foundation for a functional circular solar economy.

At the same time, the success of any national framework will hinge on the capacity of local governments to operationalize EOL solar PV management on the ground. While RA 9003 assigns LGUs a central role in waste management, clear policy direction, technical guidance, public information campaigns, and sustained capacity-building support from the national government are necessary to address the specific challenges posed by solar PV waste. Strengthening local systems will allow communities that host solar power plants to anticipate and respond to increasing volumes of decommissioned panels as installations intensifies. This will also enable LGUs to engage more effectively with solar developers, recyclers, and community stakeholders in implementing localized EOL solutions.

Given the cross-cutting nature of solar PV life-cycle management, a whole-of-government and whole-life-cycle approach is essential. Coordinated action among the DOE and DENR as well as the Department of Trade and Industry (DTI), Department of interior and Local Government (DILG), and Department of Science and Technology (DOST) can prevent policy fragmentation and ensure coherence across planning, regulation, investment, and innovation. Aligning agency mandates and resources will improve monitoring, enforcement, and data-sharing, while enabling a more strategic allocation of incentives and research funding. Such coordination is particularly important in balancing environmental protection objectives with industrial development and energy transition goals.

As a final note to this policy review, finding the answers to these questions requires the country to continue studying and learning from the policies, technologies, and experiences of other countries. As noted, the solar industry in the Philippines is still at an early stage. If the country thinks strategically and commits to a medium-term horizon, such as a five-year plan, as many countries are doing, there remains a significant opportunity to learn by doing. This window allows policymakers to refine approaches, test solutions, and build institutional capacity before the full wave of end-of-life solar PV modules hits the country.

Technical Review

This section provides a technical foundation for understanding EOL challenges and opportunities associated with solar PV panels in the Philippines. It examines the full lifecycle of PV modules, highlighting the material, engineering, and environmental considerations that shape EOL outcomes.

By synthesizing international literature, regional practices, and the Philippine regulatory and market context, the review identifies critical stages where technical interventions can support circular economy objectives. This technical review section underpins the policy discussion by clarifying what is technically feasible, economically viable, and institutionally actionable within the country's evolving solar energy sector.

Managing EOL solar PV panels involves a range of technologies and processes aimed at extending the life of solar panels and recovering valuable materials while minimizing environmental and health risks. Existing approaches vary in terms of technical complexity, recovery efficiency, energy requirements, and safety considerations

Examining these technologies also provides insight into current best practices and their limitations, especially in contexts where recycling infrastructure remains limited, if non-existent, even as the number of retired solar panels are expected to increase.

A. Global Practices

The recycling of PV panels generally follows a two-phase process: (a) disassembly and delamination, and (b) recovery of PV cell components (Wang et al., 2024).

During the disassembly stage, PV panels are carefully dismantled to separate their components, including glass, aluminum frames, junction boxes, wires, and polymer layers. High-value materials, including glass, aluminum, wiring, and polymers, are recovered using a combination of thermal, mechanical, and chemical recycling technologies. These techniques are designed to minimize impurities and enhance the resale value of the recovered materials in secondary markets (Kamano et al., 2022). Globally, three primary delamination techniques are employed to separate and recover valuable components from solar PV modules, as summarized below:

Table 4. Summary of technology employed.

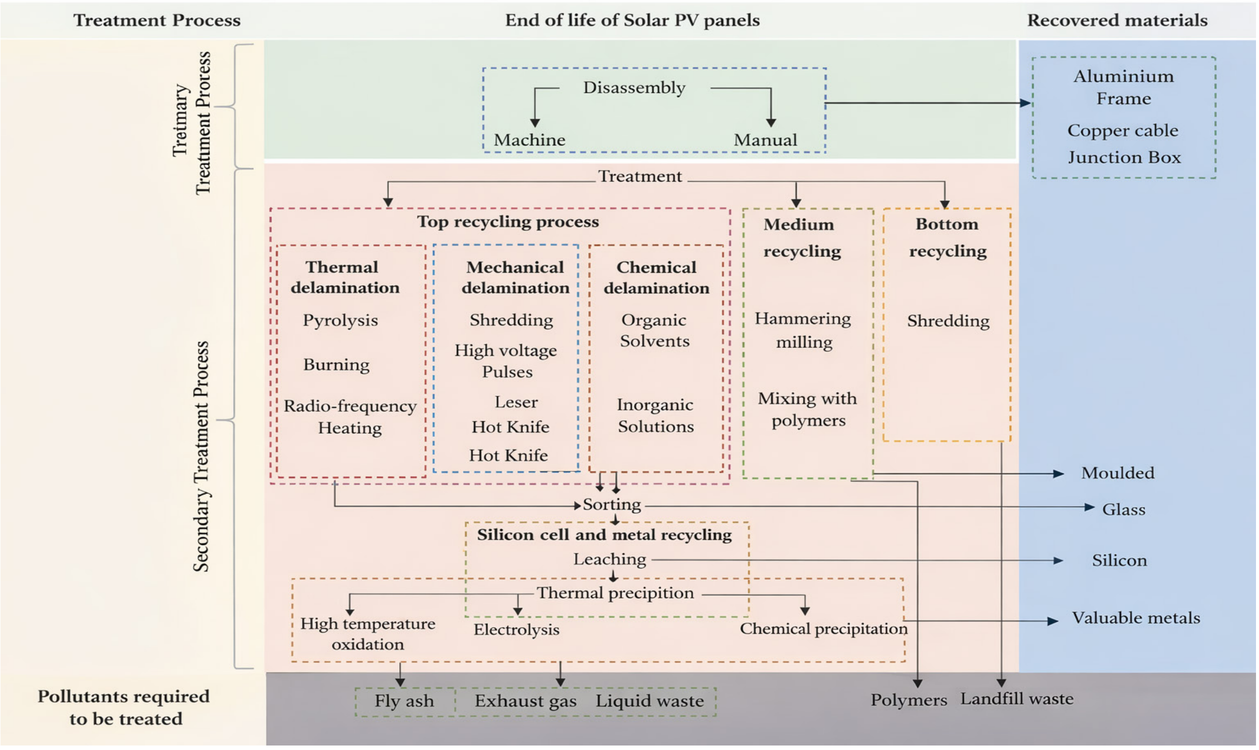
Technology	Description	Concerns
Thermal Delamination	Utilizes elevated temperatures to separate layers within PV panels (Kaladeo & Favour, 2024).	High energy consumption, raising concerns regarding economic and environmental sustainability (Wang et al., 2024).
Mechanical Delamination	Involves physical disintegration through shredding, cutting, peeling, fragmentation, or contactless methods (Cheema et al., 2024).	The resulting material mixture is often complex, requiring extensive post-sorting (Wang et al., 2024).
Chemical Delamination	Employs organic or inorganic solvents to dissolve encapsulating materials (Cheema et al., 2024).	The use and disposal of toxic solvents present potential environmental and health risks (Wang et al., 2024).

References: Cheema et al., 2024; Kaladeio & Favour, 2024.

Following these pre-treatment processes, the PV module typically adopts the structure EVA (ethylene-vinyl acetate)–Solar Cells–Back sheet. Subsequent recycling treatments—categorized as top, medium, and bottom recycling—is applied based on the material grade and recovery objectives. Although these recycling processes significantly reduce landfill waste and overall energy consumption, they often also result in recovered materials of lower quality, which limits their reusability in the secondary market and poses challenges to achieving economic viability and efficient metal recovery (Preet and Smith, 2024).

The top recycling treatment is primarily used to recover high-purity silicon wafers, glass, and valuable metals such as silver, aluminum, and copper. This treatment involves two critical stages: (a) module delamination and (b) recovery of silicon and metallic components, as shown in Figure one (ibid).

Figure 1. Overview of the Treatment Process of Solar PV Panels



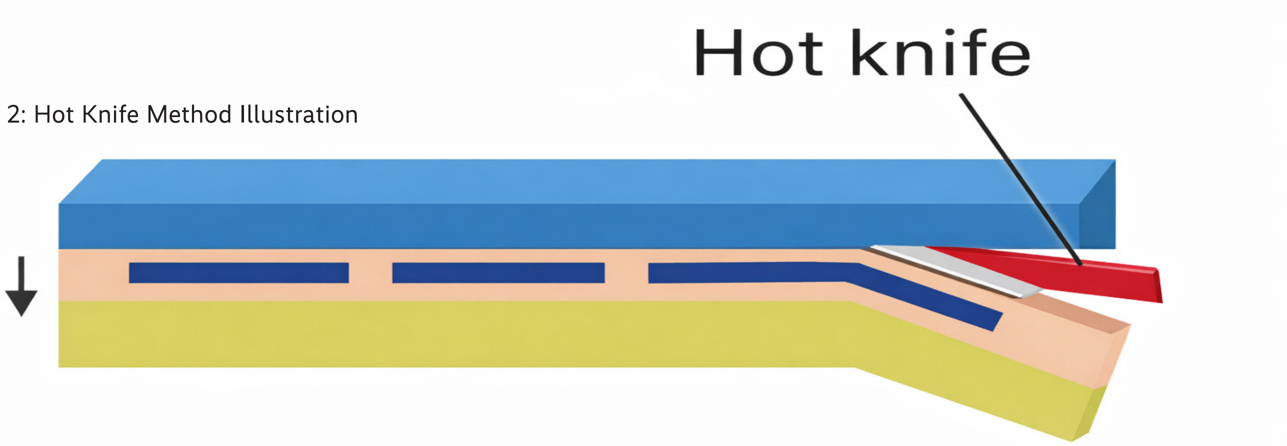
Reference: Preet and Smith, 2024

B. Country-Specific PV Module Recycling Initiatives in Asia

Below is the state of the art of EOL solar panel management in three developed and one emerging economy in Asia. The discussion focuses on industry actors' use of distinct technologies in EOL solar panel management.

Starting with Japan: the NPC Incorporated has developed an intermediate PV module recycling process utilizing its proprietary Hot Knife Separation Method (NPC Incorporated, 2025). This method utilizes a heated blade to separate the backsheet from damaged silicon solar cells without crushing the glass layer, as illustrated in Figure two. Experiments conducted by M. Wahman et al., demonstrated a 99.42 percent recovery rate of backsheets from various PV brands. The recovered backsheets were of high quality, suitable for reuse in new module production. Moreover, the method effectively mitigates the emission of harmful gases typically associated with conventional thermal delamination (Ibid).

Figure 2: Hot Knife Method Illustration



In Malaysia, Zenviro Solar Panel Recycling, located in Kuala Lumpur, is a pioneering facility dedicated to the recycling of PV modules. Its current operations primarily focus on recovering aluminum frames while safely disposing of other components. The recycling workflow includes:

- Junction box and aluminum frame removal, performed by mechanical force to separate the plastic junction box;
- Glass extraction, using advanced skimming technology to ensure clean glass cullet recovery without loss of precious metals;
- Shredding and grinding to reduce remaining materials to fine particles for downstream processing; and,
- Electrostatic separation isolates the remaining precious metal mixtures into copper, silicon, and EVA-plastic fractions. (Zenviro Solar Panel Recycling Sendirian Berhad, n.d.).

For its part, India's Beyond Renewables and Recycling Private Limited has developed a high-efficiency solar panel recycling technology capable, of recovering over 95 percent of materials from damaged or end-of-life PV modules. The recovered materials, including silicon, copper, silver, and EVA film, attain purities exceeding 90 percent, significantly enhancing their market value and potential for reuse in manufacturing new modules (Beyond Renewables, 2025).

Finally, in South Korea, Dynamic Industry Corporation operates an environmentally sustainable PV module recycling plant that does not rely on chemical treatment. Their process involves the dismantling of aluminum frames and tempered glass, followed by cell separation and mineral extraction, ensuring an eco-friendly recovery route for end-of-life modules (Dynamic Industry Corporation, n.d.).

Technical Feasibility of Second-Life PV Panels

To ensure recovered modules meet safety and performance benchmarks, the industry utilizes technical standards such as CENELEC CLC/TS 50640 (Evaluation of potential for re-use of PV modules). This standard prescribes a rigorous sorting protocol, including visual inspection, insulation resistance testing, and peak power determination, to certify that a module is safe for re-deployment.

The specific second-life applications of PV modules depend on the intended use and settings. While the European market focuses on residential installations and stand-alone off-grid systems certified under rigorous standards, local approaches in the Philippines have had to adapt to the lack of such testing infrastructure.

Lifecycle of Solar Panels

A. Raw Material Extraction and Manufacturing

The Philippine solar market is dominated by crystalline silicon (c-Si) technologies, with monocrystalline modules increasingly preferred for utility-scale projects. Domestic production is limited to module assembly, such as at Solar Philippines in Batangas (PV Tech, 2017) while critical upstream processes remain imported.

Silicon Pathway. Metallurgical-grade silicon (MGS) is refined to solar-grade polysilicon (9N purity) via the Siemens process. Polysilicon is melted, cast into ingots, and sewn into wafers. These wafers undergo phosphorus/boron doping to establish p-n junctions, deposition of anti-reflective coatings (e.g., silicon nitride, Si_3N_4), and screen-printing of metallic contacts, using silver and aluminum pastes.

Module Assembly. Cells are soldered into strings with copper ribbons coated in Pb-Sn solder. Lamination produces the standard module architecture:

- Front Cover: low-iron tempered glass (~3.2 mm)
- Encapsulant: cross-linked ethylene-vinyl acetate (EVA)
- Backsheet: polymer laminates (TPT or KPK)
- Frame: anodized aluminum alloy
- Junction Box: housing bypass diodes and cables.

This imported component reliance constrains the Philippines' participation in upstream PV manufacturing value chains.

B. Deployment and Use Phase

PV modules in the Philippines operate under conditions of high humidity, strong UV radiation, and elevated temperatures, which exacerbate degradation mechanisms.

- Light-Induced Degradation (LID): Early-stage efficiency loss (one to three percent) in p-type c-Si modules.
- Potential-Induced Degradation (PID): Prominent in humid climates where leakage currents cause ion migration, leading to severe power losses (Maysun Solar, 2024).
- Hydrolysis and UV Damage: EVA browning and backsheet cracking reduce optical performance and compromise insulation (Voronko et al., 2021).
- Corrosion: Coastal saline aerosols accelerate frame and interconnect corrosion.

System reliability is evaluated through the Performance Ratio (PR), comparing measured output (Emeas) against theoretical yield from irradiance (Hi) and module's nominal power (Pnom). A downward trend in PR over time signals degradation, with service lifetimes generally rated at 25 to 30 years, after which time output falls below 80% of initial capacity.

C. EOL Pathways

EOL management represents the most significant technical and policy gap in the Philippines. PV modules are composite structures containing both high-value and hazardous fractions.

- Material Composition. A standard c-Si module comprises ~76 percent glass, 10 percent polymers, 8 percent aluminum, 5 percent silicon, and <1 percent metals (Cu, Ag, Pb) (Wahman et al., 2024). Despite their low mass contribution, silver and silicon are critical for economic recycling viability, while the large fractions of glass and aluminum drive recycling rates.
- Hazardous Components. Pb in solder and Cd/Te in thin-film modules, fall under Republic Act 6969; however, broader solid waste handling is governed by Republic Act 9003.

D. Technical Recycling Pathways

At EOL, solar PV module recycling typically begins with dismantling, which involves the manual removal of aluminum frames and junction boxes to recover readily accessible materials such as aluminum and copper. This is followed by delamination processes that separate the laminated components of the module, including the glass, encapsulant, and solar cells. Thermal delamination, commonly achieved through pyrolysis at temperatures of approximately 500°C, enables high-purity material recovery but entails substantial energy consumption (Rathore & Panwar, 2022). Mechanical delamination, in contrast, relies on shredding and crushing, producing mixed material fractions of lower purity that often require additional downstream sorting. Chemical delamination selectively dissolves the EVA encapsulant, allowing for intact solar cell recovery, but introduces environmental and occupational risks associated with solvent use. Following delamination, metallurgical refining processes are applied to recover valuable materials such as silicon, silver, and copper for reuse in manufacturing and secondary markets.

In the absence of local recycling facilities, decommissioned solar PV modules in the Philippines are at risk of being stockpiled, landfilled, or subjected to informal dismantling practices (Petroli et al., 2025). Landfilling poses long-term environmental risks due to the potential leaching of hazardous substances, while informal recovery typically focuses only on easily extractable components, discarding most of the module mass and exposing workers to unsafe conditions. The projected increase in PV waste, particularly in provinces such as Laguna with high concentration of solar installations, underscores the urgent need for accredited Treatment, Storage, and Disposal (TSD) facilities capable of managing EOL PV modules in an environmentally sound and regulated manner.

Critical Stages for Intervention

The Philippines' rapid adoption of solar energy, while a crucial step toward renewable energy, necessitates a technically sound strategy for managing EOL solar panels. The present discussion on the five critical intervention stages seeks to balance international best practices with the technical, economic, and logistical realities of the Philippine context.

1. Design and Materials Selection

Upstream interventions emphasize eco-design, where modules are manufactured for easier EOL management. Innovations include lead-free solder alloys and thermoplastic encapsulants that can be re-melted, simplifying material separation (IEC, 2020). As a net importer of PV modules, the Philippines has little influence over manufacturing, but policy can serve as an enabling tool. The Bureau of Philippine Standards can adopt international eco-design and hazardous substance regulations, while government procurement through the Department of Energy can prioritize modules with higher recyclability (UNEP, 2018). These measures enable the country to steer imports toward more sustainable designs without requiring domestic R&D capacity.

2. Module Removal and Collection Logistics

Safe removal and transport are crucial to avoid microcracks that compromise performance and reuse potential. Best practice involves skilled handling and optimized reverse logistics to collect modules across dispersed sites. In the Philippines, archipelagic geography complicates centralized systems, raising costs and risks (Magalang et al., 2020). A more feasible approach is a regional hub-and-spoke collection model, supported by training programs for both formal and informal waste workers. Extended Producer Responsibility (EPR) policies could provide a financing mechanism by charging fees on imports to fund collection and transport networks (IRENA & IEA-PVPS, 2016).

3. Testing and Sorting

Testing determines whether modules can be reused, refurbished, or recycled. A standard cascade of tests, insulation resistance, I-V curve tracing, and electroluminescence imaging, provides comprehensive performance and safety diagnostics (Dias et al., 2017). In the Philippines, technical expertise exists in universities and the private sector, and the required equipment is commercially available. The primary challenge is ensuring uniform grading protocols across the country. Developing a national standard with quantitative thresholds would build trust in second-life markets by guaranteeing consistent module quality.

4. Refurbishment Facilities

Refurbishment focuses on correcting non-cell failures such as junction box replacement or backsheet patching, while full relamination remains infeasible outside factory settings. In the Philippines, refurbishment is highly viable given the strong domestic demand for low-cost power solutions in off-grid communities (World Bank, 2023). The country's electronics repair sector provides a skilled labor base that can be tap for PV refurbishment, creating new opportunities for green jobs. Refurbished modules can be resold at a lower cost, directly contributing to rural electrification and social equity.

5. Recycling Facilities

Recycling involves recovering materials through processes such as thermal delamination and hydrometallurgical leaching, targeting high recovery rates for metals like silver and copper (Dias et al., 2017). While the Philippines has the engineering capacity to operate such systems, the economics is prohibitive in the short term. A recycling facility requires large volumes of feedstock to be viable, which the Philippines is unlikely to generate until after 2035. A phased strategy is more practical: initially establishing pre-processing plants for dismantling frames and shredding laminates for export, then transitioning to a

Table 2. Comparative assessments of circular economy interventions for PV modules.

Stage	International Best Practice	Philippine Feasibility	Opportunity	Main Limitation
Design & Materials Selection	Eco-design: lead-free solders, recyclable encapsulants (e.g., TPO), IEC TS 63092 compliance.	No upstream R&D or manufacturing. Influence possible via Philippine National Standards (PNS) adoption and DOE procurement policies.	Use import regulations and procurement policies to favor recyclable, low-toxicity modules.	No domestic R&D or manufacturing influence.
Module Removal & Collection Logistics	Controlled dismantling to avoid microcracks; GIS-based reverse logistics with predictive failure models.	High labor intensity raises risk of damage. Requires skills training, electroluminescence QC, and a national PV installation database.	Integration of informal waste sector with proper training; Extended Producer Responsibility (EPR) to finance logistics (IRENA & IEA-PVPS, 2016).	High transport cost; risk of handling-induced damage.
Testing & Sorting	Standardized cascade testing (Hipot, I-V tracing, EL imaging) with uniform grading protocols (e.g., IEC 61215).	Equipment available and skills present in universities and private labs. Barrier: capital investment and standardization across hubs.	Establish national grading standards to ensure quality in second-life markets.	Requires upfront capital and nationwide standardization.
Refurbishment Facilities	Tier-1 repairs (junction box, cable replacement); limited polymeric repair; re-lamination feasible in factories only.	Electrical repairs are highly feasible using local electronics expertise. Polymeric repairs more challenging in humid, tropical conditions	Low-cost refurbished panels for off-grid electrification; creation of green jobs.	Quality of backsheet repairs under high humidity and UV exposure.
Recycling Facilities	Thermal/chemical recycling achieving >95 percent Ag and >85 percent Si recovery; large-scale throughput (>several thousand tons/year).	Technical know-how exists but volumes are too low for viability until ~2035. Near-term strategy: pre-processing (frame removal, shredding) and export of concentrates.	Early investment in dismantling and export; long-term pathway to domestic recycling.	High CAPEX and insufficient EOL feedstock in near term.

References: Dias et al., 2017; IEC, 2020; IRENA & IEA-PVPS, 2016; Magalang et al., 2020; UNEP, 2018; World Bank, 2023)

domestic facility once volumes justify the investment.
The Philippine solar market is overwhelmingly dominated by crystalline silicon (c-Si) modules, particularly high-efficiency monocrystalline PERC (Passivated Emitter and Rear Cell) panels imported from major manufacturers such as Jinko Solar, Trina Solar, LONGi, and Canadian Solar (Fraunhofer ISE, 2025). These modules exhibit a standardized composition across brands, enabling a representative material inventory (Table 2).

Component	Material(s)	Approx Weight (%)
Front Cover	Low-iron tempered glass	74.2
Frame	Anodized aluminum alloy	10.3
Encapsulant	Ethylene-vinyl acetate (EVA)	6.8
Solar Cells	Monocrystalline silicon	5.2
Backsheet	Polymer laminate (PVF, PET, PE)	2.5
Junction Box & Cables	Copper, plastics	1.0
Interconnects & Solder	Copper, tin, lead	<0.1

References: First Solar 2023; First Solar n.d.; Fraunhofer ISE 2025; IEA-PVPS 2020.

Although constituting less than one percent of module mass, silver and lead are critical for end-of-life (EOL) management. Modern PERC cells contain ~10–15 mg Ag/Wp, equivalent to 5.5–8.3 g per 550 W panel (Fraunhofer ISE, 2025). Lead solder contributes one to two grams per module (IEA-PVPS, 2020), representing a diffuse environmental liability when scaled across millions of units. This breakdown underscores that, while high-value materials such as silver and silicon account for only a small fraction of total mass, their recovery is central to the economic viability of advanced recycling. Conversely, the dominance of glass and aluminum in module weight makes their recovery indispensable for achieving high overall recycling rates.
Cadmium telluride (CdTe) thin-film modules are present only in select utility-scale projects, almost exclusively supplied by First Solar. These consist primarily of glass (>97 percent) with CdTe and CdS comprising <0.1 percent of weight (Table 2) (First Solar 2023). Their EOL management is expected to be centralized, with recycling conducted through First Solar's global take-back program, which recovers >90 percent of semiconductor content (First Solar, n.d.).

Crystalline silicon modules constitute more than 95 percent of installed capacity in the Philippines (Fraunhofer ISE, 2025), and thus must anchor any national end-of-life (EOL) management framework. Their material composition presents two distinct imperatives. On one hand, high-value but low-mass fractions such as silver and silicon are critical to the economic viability of advanced recycling, as their recovery generates revenue streams that can offset processing costs. On the other hand, the bulk fractions of glass and aluminum, while less valuable per unit mass, are indispensable for achieving high overall recycling rates and reducing landfill burdens.

Component	Material(s)	Approx Weight (%)
Glass	Soda-lime, heat-strengthened	97.6
Laminates/Sealant	Polyolefin, EVA, edge sealant	2.2
Semiconductor & Contacts	CdTe, CdS, metals	<0.1
Junction Box & Cables	Copper, plastics	<0.2

References: First Solar, 2023; First Solar n.d.; Fraunhofer ISE, 2025; IEA-PVPS, 2020.

This dual challenge implies that Philippine EOL policy should not only focus on hazardous elements such as lead solder but also create conditions for investment in technologies capable of simultaneously recovering precious metals, bulk materials, and semiconductors. A systematic collection and aggregation network is essential, enabling economies of scale that make both resource recovery and environmental protection achievable within the Philippine context.

In the Philippines, Cagayan Electric Power and Light Company (CEPALCO) has initiated a reuse and refurbishment program for damaged and decommissioned PV modules. Unlike the standard "second life" pathway which requires electrical validation, CEPALCO donates panels to employees and partner academic institutions for non-electrical applications. Among employees, the panels are repurposed as construction materials, specifically for roofing and fencing, taking advantage of the mechanical durability of the frames while bypassing the need for complex electrical safety testing. For educational institutions, the panels serve as hands-on research materials (L. Castillo, Interview October 17, 2025).

While this initiative demonstrates immediate circularity, it remains limited in scale. To transition from this informal "structural repurposing" to true "energy-generating second-life" applications, structured frameworks, including safety testing, certification standards, and regulatory oversight, will be required.

Economic Benefits and Challenges

The management of EOL solar PV modules presents significant economic opportunities and challenges. From an economic standpoint, treating EOL solar panels as a resource rather than waste presents a lucrative opportunity. Recovering valuable materials, developing secondary markets, and investing in recycling and refurbishment can support local industries, generate green jobs, and strengthen the circular economy of the solar sector. Specifically, resource recovery impacts the industry's return on investments.

In the Philippines, Faraon et al. (2022) reported that establishing a PV module recycling facility could yield a 54% return on investment (ROI) with an estimated one-year payback period. This finding highlights the financial viability of domestic PV recycling enterprises, particularly when coupled with the potential recovery of high-value materials such as aluminum, silver, and silicon from the estimated 138,000-plus tons of future feedstock.

That said, there is also wide agreement of the steep cost of EOL solar management technology that has prevented more private sector participation even in advanced countries. Globally, solar panel recycling remains in an early or emerging stage, with comprehensive recycling infrastructure and industrial-scale processes still lacking in many countries. Research and development are widely recognized as crucial for advancing viable recycling methods, improving efficient and precise material recovery technologies, and identifying new applications for recovered photovoltaic components and materials to support circular economy opportunities (Wei et al., 2025). The complex construction and harmful material content of solar PV modules also require highly specialized and thus expensive equipment and processes (Ali et al., 2024). Due to the high costs of recycling EOL solar panels, the dominant mode of disposing of decommissioned solar panels globally is still by putting them in landfills. In 2023, for instance, the cost of using landfills was estimated at one to five dollars per solar PV module; in contrast, recycling a module went as high as US$15 to 45 (Shaw et al., 2024).

Thus, to better ensure the promotion of solar industry circularity, the national and local governments have to step up and set and pursue the strategic direction for research and development, provide an enabling policy environment and targeted incentives to lessen the financial burden on the private sector, develop the secondhand market, and solve coordination problems among agencies and other stakeholders pursuing distinct energy, environment, and economic agendas.

Policy and Technology Recommendations

All told, the expansion of the solar energy sector in the Philippines creates both opportunities for sustainable development and challenges related to EOL management of solar PV modules. To ensure responsible sector growth, a coordinated national strategy anchored on circular economy principles is essential. The following recommendations outline policy, institutional, and technical actions that can guide national and local stakeholders toward a more resilient and sustainable solar industry.

1. Enhance the Policy and Incentive Environment for Recycling Investments

Amendments to the RA 9513 and related policies are needed to encourage private investment in EOL panel recycling. Offering fiscal and non-fiscal incentives and other forms of subsidies would help defray the steep costs of recycling. This will reduce the current practice of companies exporting discarded solar panels (as revealed in an interview with government).

2. Enact and enforce legislation on extended producer responsibility (EPR)

Importers, manufacturers, and distributors should be legally mandated to take responsibility for the collection, recycling, and proper handling of EOL PV modules. An EPR system ensures accountability throughout the life cycle of solar products. It also encourages producers to design more durable and repairable modules. Clear compliance mechanisms and reporting requirements will strengthen this approach. Toward ensuring the smooth implementation of mandatory recycling of decommissioned panels, there is also a need to learn the lessons from the implementation of the Philippine Extended Producers' Act of 2022 that requires large enterprises to recover and recycle their plastic packaging

3. **Invest in Research, Development, and Technology Deployment**

With EOL management in its infancy stage, there is a need for the national government to invest in advancing EOL management, especially innovation in recycling and materials recovery technology. Apart from the DOST, other agencies involved in the energy sector need to step up in helping fund innovation. For instance, a significant portion of the newly created Renewable Energy Trust Fund should be directed toward research that advances eco-design, repair technologies, and local recycling methods for PV modules.

Supporting innovation will strengthen the domestic solar industry's ability to manage future waste. Research and development investment can also generate local expertise and support the creation of sustainable green jobs, immediately perhaps in the second-life market. For instance, one study identified three actors here: the decommissioners, recyclers, and end-users. Over time, this will build a strong foundation for a circular solar economy.

4. **Develop Pilot-Scale PV Recycling and Circularity Models**

Pilot recycling initiatives should be established to test feasible approaches to EOL PV management in real-life settings. Taking off from the findings of studies on factors to consider in site location of recycling facilities, pilot locations should be selected based on the concentration of solar installations and projected EOL panel volumes, allowing policymakers and local stakeholders to anticipate future operational conditions. These pilots can be implemented through partnerships among government agencies, solar power developers and operators, and community organizations. Demonstrating successful local models will help guide the design of larger national programs. Such pilots also enable early identification of regulatory, technical, and financial gaps.

5. **Develop a Second-Life Market especially for Underserved Communities**

Repurposing functioning EOL PV modules can expand access to energy among rural, remote, and underserved communities. Establishing a formal redistribution system ensures that refurbished modules are safely and equitably deployed. This approach promotes sustainability while addressing existing energy gaps. It also maximizes the use of materials that still have functional value.

6. **Adopt a Whole-of-Government, Whole-Life-Cycle Approach**

Managing EOL PV modules requires coordinated action across national agencies, including the DOE, DENR, DOST, DTI and DILG. Each agency should align its mandates and resources to support a streamlined life-cycle management system. For instance, the DTI handles certification and standards of local industries, and thus is important in the creation of the second life market for EOL solar panels. The DILG's policy guidance and technical and logistical assistance to local governments are critical in the effective and sustained implementation of RA 9003. This integrated approach prevents policy fragmentation and strengthens implementation on the ground. A unified strategy will enable more efficient planning, monitoring, and regulation.

7. **Integrate Gender-Responsive and Inclusive Approaches in EOL Solar PV Management**

Women and individuals situated in the informal economy play significant but often underrecognized roles in community energy initiatives, waste management, and informal recycling sectors. Policies and programs on EOL solar PV management should therefore integrate gender-responsive approaches, including gender-sensitive training, equitable access to green jobs, and targeted support for women-led and micro enterprises in recycling, repair, and second-life markets.

Government agencies should ensure that capacity-building programs, pilot projects, and financing mechanisms intentionally include women, marginalized genders, and urban poor sectors. Embedding Gender Equality and Social Inclusion (GESI) into planning and implementation will help ensure that the transition toward a circular solar economy is not only environmentally sustainable but also socially inclusive and equitable.

8. **Conduct an information campaign to raise public awareness on the importance of recycling**

A comprehensive public information campaign is essential to ensure that communities understand the environmental and economic value of properly managing end-of-life solar PV modules. Public participation is a critical pillar of any recycling program, and awareness efforts must clarify how individuals, households, and institutions can contribute to responsible disposal and circularity initiatives. This campaign should include clear guidance on collection points, safety considerations, and the long-term benefits of supporting a circular solar industry. Integrating public education into school curricula, local community orientations, and media platforms will help build a culture of environmental responsibility and strengthen the long-term sustainability of recycling programs and facilities. The sustainability of recycling programs and facilities will depend on the participation of the public and the local communities.

9. **Develop a Medium-Term National Program for EOL PV Management**

A comprehensive medium-term program and enabling legislation should be created to guide the country's long-term approach to EOL PV management. Such a program must support domestic recycling infrastructure, technology transfer, and access to financing for companies investing in circular solutions. Establishing clear national targets will foster consistency across programs and investments. This will help transition the Philippines toward a self-sustaining and circular solar industry.

The future of the Philippines' solar sector depends on the country's ability to manage its environmental impacts while maximizing its social and economic benefits. By adopting a coherent set of policies, strengthening institutions, and fostering innovation, the government can steer the industry toward sustainability. These recommendations offer a roadmap for building a circular, resilient, and equitable solar energy system. With timely coordination and decisive action, the Philippines can lead the region in responsible renewable energy development.

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End-of-Life (EOL) Solar Panel Management from a Circular Economy Perspective: The Philippine Case

As the Philippines accelerates its turn to renewable energy and, in particular, solar power, there is a growing need to establish an efficient, sustainable and inclusive approach to the end-of-life (EOL) solar panel management. This study examines the country's potential shift from a predominantly disposal-oriented waste management paradigm toward a circular economy framework that prioritizes repair, reuse, and recycling and high-value material recovery. Drawing on international experiences, the study stresses the need for the Philippines to begin addressing the policy, technological, infrastructure, and social requirements to build domestic capacity to manage the hundreds of thousands of solar photovoltaic (PV) modules that are being installed in the country for when they reach their end of life (in 25 to 30 years), lest these end up in landfills – a default setting that poses health and environmental threats. The promotion of solar industry circularity would extend the life or second life of EOL solar panels, minimize waste generation as well as ensure resource use efficiency and sustainability. Toward this end, the study draws attention to the need for government leadership, targeted investment in domestic recycling technologies, and the development of second-life markets.

Further information on this topic can be found here: www.microrenewables.org

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