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Tackling the solar photovoltaic modules waste

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Executive Summary

Solar energy is considered as a major component in the race against climate change. Supported by the policy makers, as well as the declining expenses in its installation and consumption, the solar energy sector is growing rapidly not only in the Indian sub-continent but also round the globe.

Despite challenges to growth due to the pandemic, the Indian solar energy market set another record with 68 GW of solar plants installed till date and missions installing 100 GW solar plants by the end of the year 2022. With India's ambitious solar target of 280 GW by 2030, it is time to formulate a sound solar waste management (1). India, as of now lacks a solar waste management policy, however, it possess an ambitious solar power installation target. Although policy makers lay emphasis on increasing the numbers and capacity, crucial aspects linked to manufacturing and the disposal after their use is being ignored.

Solar panels have a lifespan of 20-25 years. It's natural that India will be loaded with solar waste issues as soon as this decade ends. Solar wastes are likely to be the most prevalent type of e-waste accumulating in the landfills very soon. It becomes crucial that India prepares itself up today and not wait till the mounds of solar waste panels start accumulating.

1.Introduction

Solar energy has turned out to be a potential way to meet the increasing demand of the rapidly increasing population. Solar photovoltaic (PV) technology is an effective solution to produce electricity utilizing the energy from the sun thereby mitigating climate change. Solar PV technology is utilized for generating energy from solar power. The PV market is growing rapidly and further expansion is estimated worldwide. However, the disposal of these solar panels, post their lifespan, is a critical issue when PV technology is considered from life-cycle point of view and its end-of-life (EOL) management (3). Although the PV modules have a life-span of 20-25 years, PV technology starts degrading as soon as it enters the EOL stage. As more number of solar panels is being installed, the quantity that reaches the end of their useful life also increases proportionally. Suitable management at EOL of solar panels is a crucial issue for clean energy technologies.

Although there are no second thoughts on the positive impact that growth of solar PV has on the decarbonization system, but after the completion of their life-span or any damage to the panels during the transport or installation might turn it into a toxic waste if proper disposing methods are not adopted. According to a report published by National Solar Energy Foundation of India, by the year 2030, India could generate more than 34,600 tonnes of cumulative solar waste, and around 1.8 million tonnes solar waste by 2050.

Fig: 1 Solar panels after their EOL (Source: CEEW)

2.Classification of module waste and its environmental impact

PV module waste can be categorized based on its environmental impact, whether it's recyclable or not, and on commercial value. The basis of classification with reference to environmental impact is done based on the definition of hazardous waste issued by Hazardous and Other Waste Rules, 2019 of the Ministry of Environment, Forest and Climate Change. According to the rules, hazardous wastes are any such waste products which by virtue of its physical, chemical or biological nature, its reactivity, toxicity, flammability, corrosivity or its explosive nature cause danger or is potential to cause danger to health or nature/environment.

Although solar powered electricity generation does not include any noise or does not releases any toxic greenhouse gases, however, the solar industry uses a number of harmful and toxic chemicals. The manufacturing of PV modules is responsible for by-products such as H_2F, HCl and HNO_3. The volume of chemicals used completely depends upon what type of cell is being manufactured.

The environmental aspect of PV technology shows its ecological impacts. Crystalline silicon (C-Si) and thin film (mostly Cadmium telluride, CdTe) are the two most common technologies in India (5). Conventional silicon PV technology modules are comprised of a fewer toxic material when compared to their film PV technology.

Waste	Material	Recyclability	Environment Impact
Frame	Aluminum	Recyclable	Non-toxic
Modular Cover	Glass	Recyclable	Non-toxic
Solar cell	(i) Silicon (ii) Cadmium, tellurium, indium, gallium, selenium, compounds	Recyclable	Non-toxic Toxic
Solar cell coating	Silver,copper, lead,gallium/boron/ phosphorus, aluminum	Recyclable	Toxic
Cell and module interconnections	Lead, copper, tin	Recyclable	Toxic
Backsheet, encapsulants	Polymer	Non-recyclable	Toxic

Table 1 : Waste classification (Source: Bridge to India)

3.Composition of the PV module

Indian solar market has been dominated by Crystalline silicon (C-Si) module technology. By the end of financial year (FY) 2020, it accounted for around 95% market share. Thin solar modules, majorly Cadmium telluride (CdTe), account for the rest 5 % share.

The C-Si technology is composed of the following major components: a front cover, an electrical circuit that connects the solar cell internally, an envelope of two encapsulated layer which is required to protect the solar cells and a back cover (usually a backsheet or tempered glass). Moreover, metal sheets or frames are required for supporting the panel structure.

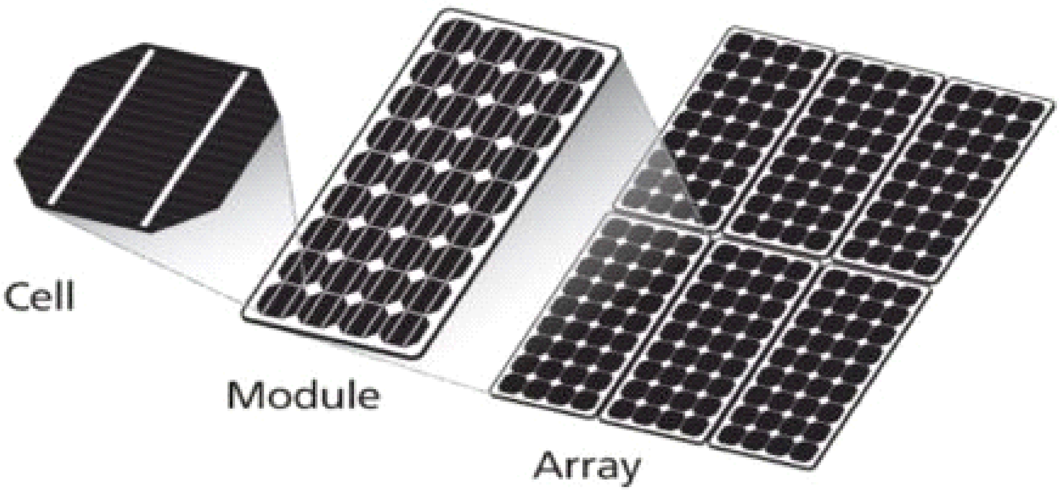

Fig: 1 Solar panels after their EOL (Source: CEEW)

Nonetheless, 80% of the overall weight of the C-Si technology is essentially composed of glass and aluminum. In addition, silicon and fractions of polymers are also taken into use. Different metals other than Aluminum used are traces of lead, copper, and tin. Copper is the major component used in the cables and in coating the PV cells.

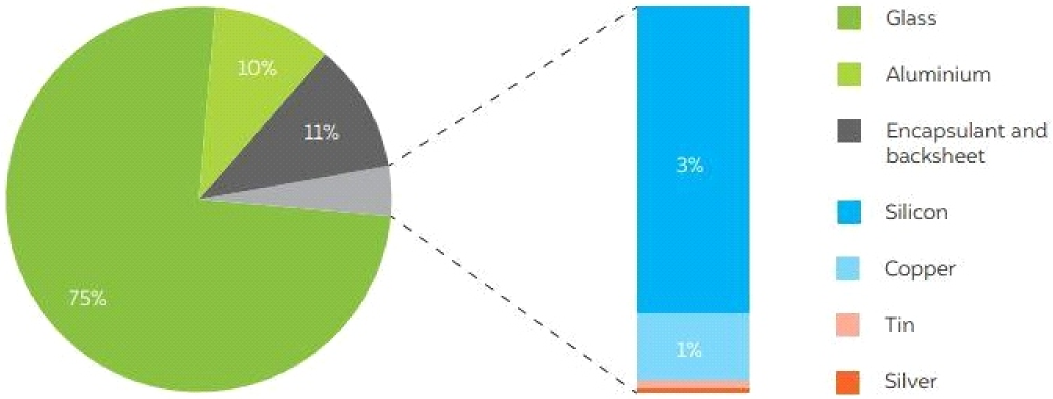

Fig: 3 Composition of crystalline silicon module (Source: European Commission DG ENV 2011 and CEEW)

On the contrary, amalgam of tin and cadmium [compounded semiconductor] are the major constituents of thin-film modules apart from glass and polymer sheets. In addition, some other bulk constituents of the thin-film also comprises of metals. For example, glass in a PV module consists of Antimony. This metal under light radiation improves the light's radiation. The module is enclosed under a frame that is composed of aluminum. Hence, metals are an integral part of the module.

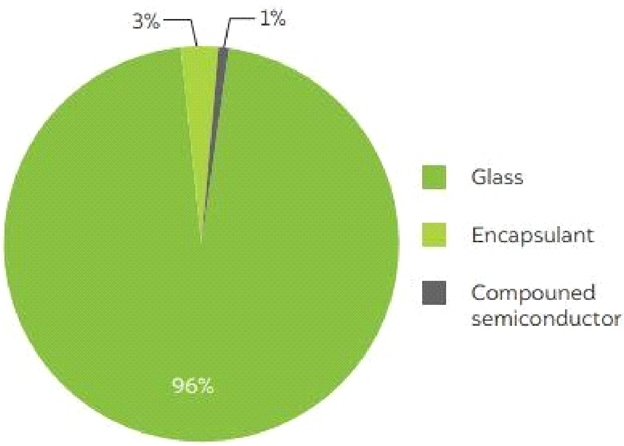

Fig: 4 Composition of the CdTe thin film module (Source: IRENA and IEA-PVPS 2016)

However, each of this metal holds a different environmental impact which necessitates their careful handling as well as their disposal procedures. On one hand where Aluminum and Silicon are comparatively less toxic, heavy metals like Lead and Cadmium are an environmental hazard as well as carcinogenic for humans. Reports show that the leaching of these metals occurs depending upon the pH of the surrounding. If the pH of the module and the pH of the surrounding are same, no leaching is reported. But, on exposure to low pH (acidic environment) for example around a landfill, leaching of Lead and Cadmium enhances, and is reported to be around 90 and 40 per cent respectively. This is equal to about 518 g/tonne of Lead from C-Si and around 153 g/tonne of Cadmium from Cd-Te PV module (6). The polymer sheet that is utilized as an encapsulant in the module is equally a toxic polluter like Lead and Cadmium. On damage, this sheet is incinerated which releases toxic gases like SO_2, H_2F, and H_2C apart from some other organic compounds (7). Thus, owing to the distinct materials utilized in these solar PV modules, it becomes mandatory to properly handle, and to adopt responsible disposal methods for the PV module waste to prevent any damage to the environment.

Organic as well as non organic solvents like HCl, HNO_3, H_2F, $(CH_3)_2CO$ AND C_2H_5OH are taken in use for cleaning the wafer as well as getting rid of the impurities caused during the fabrication process. Approximately, 37% of this waste is disposed to offsite treatment facilities, 35% of the waste is expelled as diluted acid solutions to treatment plants, and 0.8% of this waste has been reported to be dumped into the surface water (8).

Chemicals like Cadmium, Lead and polymer are disposed off in an uncontrolled manner which could result in severe environmental and health issues. Cd-Te can result in serious pulmonary inflammation and fibrosis (9)

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while leaching Lead, in plants, can cause reduced growth and less reproductive rate in plants. Biodiversity loss, improper kidney function and other health issues related to immune and nervous system in humans are some other impacts reported (8).

Fig: 5 Material Composition of C-Si solar modules (Source: IRENA and BRIDGE TO INDIA)

Fig: 6 Material Composition of thin-film solar modules (Source: IRENA and BRIDGE TO INDIA)

4.Resource Management Aspect

The resource management considers, and critically evaluates the importance of different metals present in the modules. Majority of the components used in the PV modules are extensively used in other sectors, and have limited reserves. Like in, Aluminum, the most extensively used metal present in C-Si modules, is globally the second most consumed metal. It is used in the power sector, infrastructure industry, machinery and equipment manufacturing industry. Around 2.5 kg of Aluminum is what India consumes per capita which is way lower than the global average which is 11 kg (10). However, the push from the policy makers for the Make In India campaign, for promoting clean energy and smart cities, the domestic demand and supply chain of Aluminum is going to enhance further.

Although Aluminum is an abundant metal, its recycling is thought to be more economical and environment friendly technique than its extraction (mining and refining) from bauxite ore (11).

In the similar manner, Cd, Te, In, Ga and Ge are some other metals which hold potential importance in the manufacturing of PV panels. These metals have limited reserves and are generally extracted from other metals as by-products (12). For an example, Tellurium is extracted from the production of Cu, Ga during the production of alumina from bauxite and Ge from coal ash. It would be unlikely to enhance the production of these base commodities (Al, Cu, and coal ash) just to meet the demand of these metals. Thus, their recovery from waste panels holds critical importance for sustainable production and deployment of thin-film PV technology.

5.Technique for PV module Recycling

while leaching Lead, in plants, can cause reduced growth and less reproductive rate in plants. Biodiversity loss, improper kidney function and other health issues related to immune and nervous system in humans are some other impacts reported (8).

5.1 Traditional Recycling Techniques

The most traditional process used by the glass and the metal recyclers is the mechanical process for disaggregating laminated structures of C-Si modules. In this procedure, either manual or machine based removal of Al and Cu is carried out from module frame and junction box respectively. This is followed by crushers, sieves, magnets, eddy currents devices and inductive and optical sorters to procure glass and polymer fraction.

The metal fraction thus obtained is further sent for smelting whereas glass fraction still remains contaminated with traces silicon, polymers and metals. The glass that is probably of low-quality is considered unfit to be utilized further in the manufacturing of new modules and finds use in glass fiber manufacturing. Further purification of glass requires a combination of thermal and chemical processes which is generally not taken as a part of traditional glass recycling procedure.

Traditional recycling techniques are reported to recover around 70-80% of the raw materials by weight of a C-Si module. Major portion of the recycled and procured products include glass, Al and Cu.

High cost materials for example, Ag and solar–grade Si and ecologically hazardous substances such as Pb and polymers are not recovered in the traditional recovering procedures.

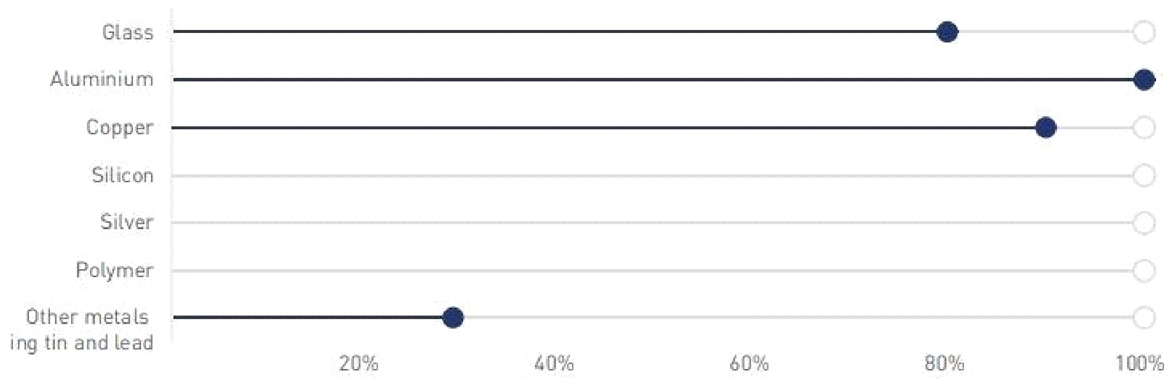

Fig: 7 Raw material recovered by conventional recycling (Source: BRIDGE TO INDIA)

5.2 Advanced/ Modern recycling Techniques

Specialized PV recycling utilizes a combination of mechanical, thermal and chemical techniques to obtain most substances which include glass, Al, Cu, Si, Ag, Pb and Sn. The fraction of polymer (8-10%) by weight is still not possible to recover and must be land filled or put to incineration. Since advanced solar waste recycling methods are still not very common, thus the data on proper recovery of materials is not sufficient. Although, research studies suggest that around 90-92% of the solar panel waste is recoverable.

Fig: 8 Advanced recycling of solar waste (Source: International Technology Roadmap for Photovoltaic (2018)

6. Regulatory Framework of different nations

Nations with huge solar panel installations are China, India, United States of America, Japan and Germany. Currently, nations of the EU are only the ones that hold sufficient regulations in place to manage PV module waste.

Nations	Regulations
Cyclonic Storms	• No national regulation • No specialized PV waste or disposal infrastructure • Delay in implementation of e-waste policies.
USA	• No federal law
EU	• WEEE directive 2012 includes PV wastes • Based on the principle of EPR [Extended Producer Responsibility] • All 28 EU member countries have transposed the directive into national regulations.
Japan	• No federal law • However, industries issue their voluntary recycling guidelines.
China	• No federal law

Table :2 international Regulation on solar wastes (Source: BRIDGE TO INDIA)

7. PV waste Recycling in India

In India, electronic waste (e-waste) is any electrical or electronic equipment discarded by an individual and not accepted by the manufacturing, refurbishment and repair processes. All such wastes are treated as per the E-Waste (Management) Rules, which considers the producers responsible for the activities under the EPR (13). Shockingly, solar panels whose basic and only purpose is to generate electricity, are not considered as e-waste. Hence, currently, not even single prevalent waste management policies and regulations include the waste solar panels.

The recycling of module waste is still a developing concept for the solar industry in India. A recent report published marked the awareness and point of view of the PV module producers and sellers in India (14). The report said that around 97% of the respondents showed the need for end-of-life management of solar panels. Out of these 87% were interested in recycling but only 24% of panel producer companies were engaged in second-life use and recycling of PV modules. The rest 76% had not yet involved them in the recycling process of any component of the damaged module and prefer passing on the waste to the informal sector (14). Some of the leading solar panel manufacturers are REC, First Solar and Vikram Solar. These organizations have set up their institutional initiatives to recycle their end-products at or beyond their EOL (15, 16).

A sustainability consulting and project management firm named Sofies, has initiated a Solar Waste Action Plan (SWAP). The major objective of this plan is to promote and build local capacity in India for Solar Waste management (17). Simultaneously, for addressing the scaling and financial hurdles E[co] work Association is in constant effort to develop sharing workspaces for micro-entrepreneurs working for e-waste (18). E[co] work is a catalyst for the empowerment of informal micro-entrepreneurs in the waste sector by creating and enabling solutions for safe and inclusive e-waste management (22). They provide rental recycling facilities for micro-entrepreneurs practicing e-waste management in India, by offering a safe- working space, efficient machinery and tools, as well as production equipments. In addition, they also provide training, transportation services and health care facilities to these entrepreneurs. Finances are delivered according to their plan pay-per-use schemes for working, storage and services. Their foremost pilot was developed in New Delhi, in the year 2021 (19).

To deal with the ecological consequences of waste solar modules, the MNRE has set up proposal for critical handling and safe disposal of the glass module to ensure that no Sb leaching occurs into the environment (20).

8. Recycling Capacity

Data issued by Central Pollution Control Board (CPCB) states that only 0.4 million tonnes of the e-waste has been recycled per year in India. This number is estimated to be even lesser since many facilities exist only on paper.

Low targets, poor enforcement and no-sufficient disposal facilities show that India is highly under-prepared to tackle with the increasing e-waste volumes. It is estimated that less than 4% of the estimated e-waste generated in India was sent to formal, registered recyclers during 2015 to 2019.

Fig: 9 Recycling of solar waste (Source: BRIDGE TO INDIA)

9. Conclusion

A number of recycling technologies are developed with distinct material efficiencies, energy consumption and having different environmental impacts, solar industries can customize their recycling methods by opting for a combination of these technologies as per their strengths and capabilities. They can also take guidance and examples from the worldwide prevalent financing models in order to arrange funds for their waste management activities.

The solar manufacturers are capable of reducing or keeping back their waste by putting their focus on the second-life use of their modules. For an example, they can go for non-monetary applications for refurbishing modules like solar lamps or solar pumps.

Solar waste is increasing with fast pace, and India needs to be ready to tackle this issue efficiently. The EU offers an effective international benchmark. It is expected that PV policies and regulations would be tightened worldwide with every passing year.

The recovery of high cost metals that are present in the module can further be utilized in the domestic manufacturing market. The informal sector if instutionalized and collaborated with PV module waste management industry, effective deployment for waste collection and recycling activities, informal workers can lead a better quality life.

Indian policy makers and solar market holders should also engage themselves in planning urgent actions for proper disposal of solar wastes. Existing e-waste rules provide a tentative initial step, suggesting rules for PV waste treatment. It is important that government at the centre as well at the state level, and private stakeholders act proactively for the long-term growth of the solar industry. The policies framed by the government should highlight the responsibility of various stakeholders around the supply chain, setting yearly targets for each stage of waste management. In addition, introducing innovative business plans, incentive mechanisms and issuing guidelines for proper handling, and safe disposal of different waste categories should also be a part of the forward action plans.

India being in the midst of a clean energy transition should not lose out on solar waste management

Abbreviations

PV: Photovoltaic

EOL: End-of-life

GW: Giga-watt

FY: Financial year

C-Si: Crystalline silicon

CdTe: Cadmium telluride

Al: Aluminum

Pb: Lead

Cu: Copper

Sb: Antimony

Si: Silicon

Cd: Cadmium

SO2 : Sulfur dioxide

H2F: Hydrogen fluride

H2C: Hydrogen carbide

HCl: Hydrochloric acid

HNO3: Nitric acid

(CH3)2CO: Acetone

C2H5OH: E

Te: Tellurium

Ga: Gallium

Abbreviations

Ge: Germanium

EU: European Union

Ag: Silver

EPR: Extended Producer Responsibility

MNRE: Ministry of New and Renewable Energy

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