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India's Solar Mission: Current Scenario & Challenges ahead- A Overview

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Abstract : The energy demand including electricity demand have been exponentially increased in last few decades due to various factors. And to meet this increased demand various renewable and non-renewable energy resources were explored, and are being in use, globally as well as in India. The Solar Photo Voltaic (PV) panels are the predominant option amongst all. And also has significant role to play to achieve IPCC climate target of reducing the 90% energy related carbon emission by 2050. Further, India has set an ambitious goal to cut its emissions to net zero by 2070, and to reduce its projected carbon emission by producing countries 50% energy requirement through renewable resources with major focus on PV Solar Panels. This will further promote and increase the installation of PV solar panels in the country. This article reviews the present scenario and associated challenges with respect to the essential raw material demand-supply, management of end-of-Life PV solar panel waste, available regulatory policy framework, etc. And based on the study, needed interventions are highlighted.

Keywords: *Photovoltaic, Panels, Climate Change, Renewable, Energy*

INTRODUCTION :

Total Energy demand, including electricity demand, have increased many folds in India during last few decades. This has resulted, due to rapid industrialization & urbanization, automation in various sectors including agriculture, increase in living standards and comfort level of the individual. As per EIA, 2021 Report, the global electricity consumption has increased from 7,323 to 23,321 billion kilowatt hours (billion kWh) during 1980 to 2018, where as in India, it has increased from 98 to 1,265 billion kWh during the same period. Based on the various factors including economic trends, GDP growth rate, industrial activities and policy settings, etc., the global estimated and projected electricity generation to meet the demand will be 45 trillion kWh by 2050 [1], where as in India it will be 8,000 billion kWh by 2052 [2]. In order to meet this existing & futuristic energy demand, various renewable (Hydropower, Geothermal, Wind, Solar, Tidal, etc.), and non-renewable energy resources (Coal, Gas, Oil & Nuclear energy) are being used. Further, the non-renewable resources, mainly fossil fuels, are fast depleting and also have negative impact on the environment due to release of carbon dioxide and other Global Warming Gases (GWG). This has compelled various countries across the world to find out and propagate the alternative strategy towards the evolution and usage of renewable energy alternatives such as Hydropower, Wind, Solar, Tidal, etc. since 1990's. The abundance of solar energy and decrease in manufacturing cost makes the power generation from Solar Photo Voltaic (PV) panels as the predominant and major energy generation option globally and in India as well.

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The global PV energy installation and generation has increased tremendously in past few years and accounts to about 760.4 GW in 2020, where as in India it was 47.4 GW, with share total electricity consumption of 3.7% & 6.5%, respectively [3]. The global projected growth rate of solar PV power installations could reach 2,840 GW by 2030, and to 8 519 GW by 2050 [4].

Realizing the effect of climate change and analysing the adverse impact of electricity generation on environment, the Intergovernmental Panel on Climate Change (IPCC) has set the Paris climate target of reducing the 90% energy related carbon emission by 2050 from different sectors. IPCC propose to achieve this target, through deployment of various renewable resources combined with massive electrification and increasing energy efficiency. The promotion and deployment of Solar Photovoltaic (PV) have significant role to play in next 3 decades to achieve this Paris Climate target which may reduce 4.9 gigatones of carbon dioxide (Gt CO) emissions in 2050, which would have emission mitigation potential of about 21% in the energy sector [4].

PHOTOVOLTAIC (PV) SOLAR PANELS: TYPES, COMPOSITION AND ITS MARKET

The PV Solar panels are the devices which converts the solar energy in to electricity without using any moving parts like motor, rotors, gear box, heat engines, rotating shaft, blades-fans, etc. for power generation. The generally installed, standard 250W PV Solar panel has the average weight of 40 pounds (approx. 19 Kg) and contains 60 or 72 solar cell (0.152 m x 0.152 m each) either made with mono-crystalline or poly-crystalline silicon, and has the dimension of 0.99 m x 1.676 m (3.25 x 5.5 feet's). In the last two decades, the 2 major types of PV Solar Panels were introduced. First generation PV modules included crystalline Silicon (c-Si) including mono-crystalline, poly-crystalline or ribbon sheets; whereas Second generation PV modules included thin film amorphous silicon (a-Si), cadmium telluride (CdTe), multi-junction cells (a-Si-µc-Si), copper indium gallium diselenide (CIGS), and copper indium diselenide (CIS). The second generation of PV modules are cost effective and has better efficiency [5,6]. The recent (Third generation) PV modules in addition to first two types includes Concentrating Solar PV (CPV), Organic PV/dye-sensitised cells (OPV), Crystalline silicon (advanced c-Si), CIGS alternatives, heavy metals (e.g., Perovskite), advanced III-V, etc. [7]. Although the c-Si panel dominates the market at present, the other types are now emerging as the futuristic technologies.

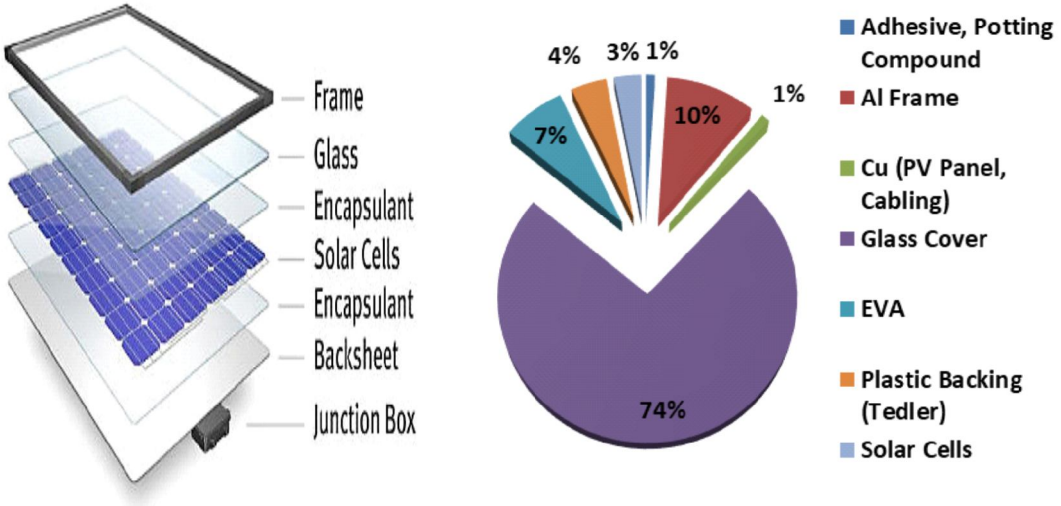


Figure 1. Structure and Average Composition of PV Solar Panel (Source: Compiled from [8,9])

Solar Panel PV module are composed of front Glass (74%), with frame support of Al (10%), Back sheet (TPT, TPE etc.) 4%, Si Solar Cell (4% including valuable & hazardous materials- Si, Ag, Al, Cu, Pb, Cd, etc.) encapsulated in 2 layer of EVA (Copolymer) (7%), and Junction Box (Cu, Plastic, etc.) (1%) (Figure 1). Thus, the Solar panel contains both valuable as well as hazardous material, and the safe handling and environmental-friendly disposal will be needed at its End-Of-Life (EOL).

Figure 2 gives the material requirement for the manufacturing and installation of 1 MW of PV solar panels in tonnes, whereas the table 1 provides the total materials that could be needed in the projected two scenarios in 2030 and 2050 in million tonnes, if the targeted electricity generation to be envisaged from the PV Solar panels.

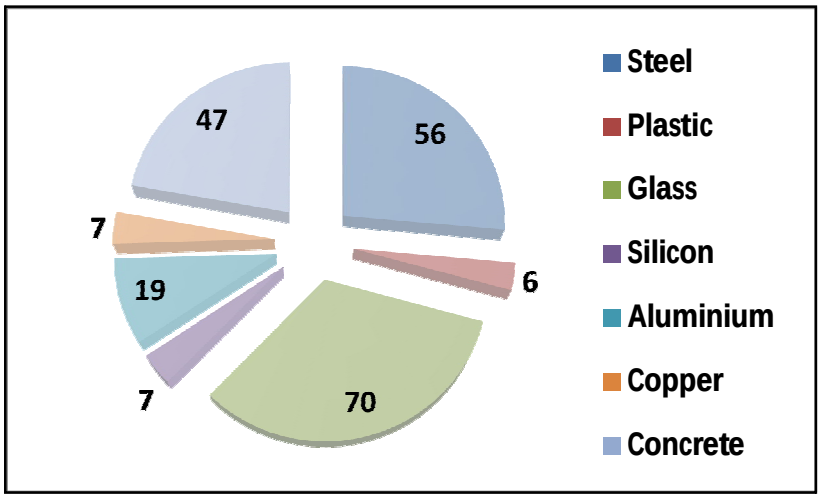


Figure 2. Materials required for 1MW Solar PV Plant (in Tonnes)
Source: Compiled from [10]

Table 1. Futuristic Material demand for the Global Projected Scenarios in 2030 & 2050 (in Million Tonnes)

Materials	Materials needed for a 1 MW solar PV Plant (in Tonnes)	Present Annual Global Production (in Million Tons)	Estimated Materials needed for Projected Solar PV Plants (in Million Tonnes)	
	1 MW		2840 GW @2030	8519 GW @2050
Steel	56	186[#1]	159	477
Plastic	6	-	17	51
Glass	70	-	199	596
Silicon	7	8.5[#2]	20	60
Aluminium	19	67.24[#3]	54	162
Copper	7	21[#4]	20	60
Concrete	47	-	133	400

Source: Compiled from [11 - 14]

Thus, to meet the futuristic electricity production through Solar PV panels, the essential raw material demand & production needs will be comparatively many times more than the present demand and production capacity. Subsequently the systemized and deliberate collaborative efforts with reference to policy and research are needed to meet this demand.

MARKET SCENARIO

The life cycle emissions of CO_2 equivalent per GWh (gigawatt hours) generation from PV solar source is only 39 ton, in comparison to predominant energy source Coal, which is 1041 ton [15]. Further Paris Climate Convention targeted towards the reduction in GHG emission from various sectors including energy sector has further emphasized its usage. And to meet this targeted goal, Governments of various countries, has promoted the PV Solar panel installation by undertaking various initiative for its popularization and easy availability through many subsidies-schemes. The continuous research and development efforts towards the increase in efficiency and use of alternative raw materials for cost reductions have promoted the PV Solar Panel manufacturers to undertake mass production at much cheaper rate. As per the report, there is significant drop in the cost of about 80%, of the PV solar panel since 2010, [16] which was the major reason for its acceptance and adaptation amongst the public. Moreover, the cost of the PV Solar panel has decrease from 0.285 US$/kWh to 0.126 US$/kWh [17, 18], whereas the efficiency has increased from about 8 - 9 in 1980's to around 20% at present. Reduction in the installation cost driven by the need for decarbonising the energy generation and supply results in the increased in the PV Solar panel demand.

Table 2. Types of PV Solar Panels & its Market Share

Technology		2014	2020	2030
Silicon-based (c-Si)	Monocrystalline	92%	73%	44.80%
	Poly- or multi-crystalline			
	Ribbon			
	a-Si (amorph/micromorph)			
Thin-film based	Copper indium gallium (di)selenide (CIGS)	2%	5.20%	6.40%
	Cadmium telluride (CdTe)	5%	5.20%	4.70%
Other	Concentrating solar PV (CPV)	1%	1.20%	0.60%
	Organic PV/dye-sensitised cells (OPV)		5.80%	8.70%
	Crystalline silicon (advanced c-Si)		8.70%	25.60%
	CIGS alternatives, heavy metals (e.g., perovskite), advanced III-V		0.60%	9.30%

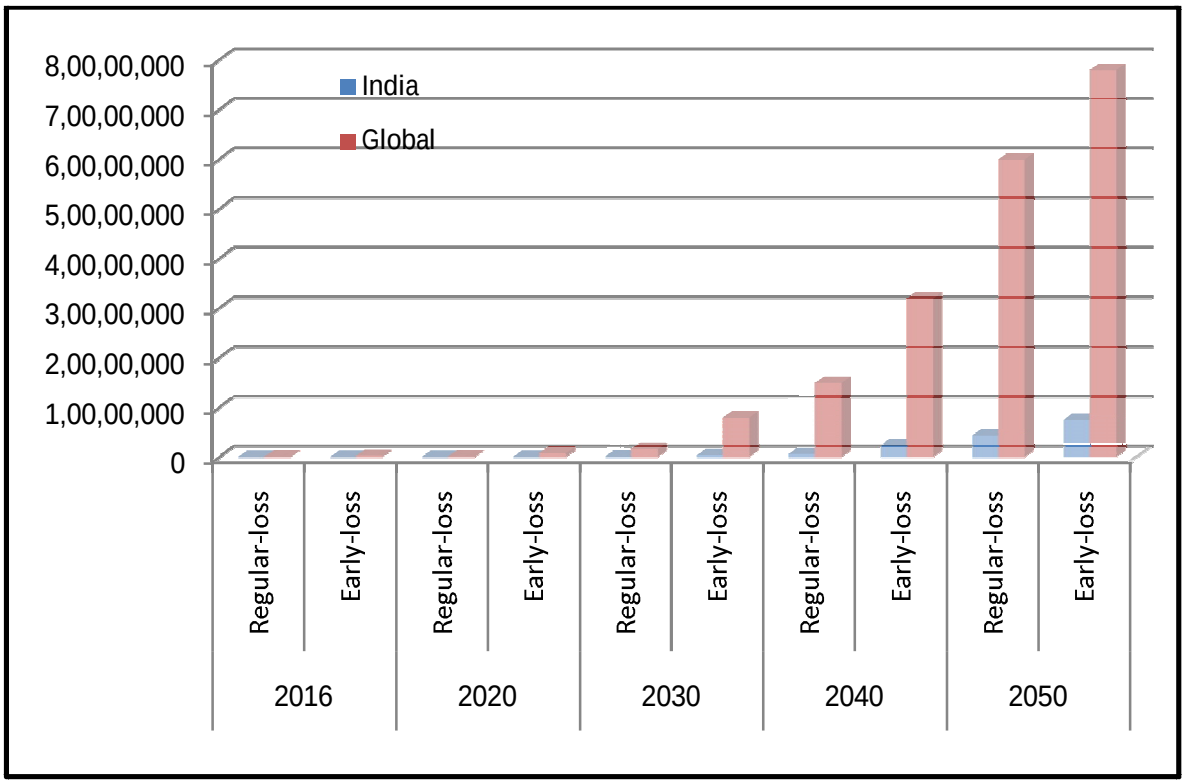
Source: IRENA 16, based on Fraunhofer Institute for Solar Energy Systems [18, 19]

Table 2 provides the present and future market share of various types of PV panels globally. The Crystalline Si (c-Si) solar cells have dominated the solar Panel market and currently occupies more than 90% market share globally, whereas the other types have comparatively much lesser market share. This condition is going to change in the next few decades and the other types of technologies will be substantially going to increase its market share. The China and Taiwan are being the dominating players in terms of PV cells module manufacturer [20]. Further as per the IRENA 2019 report, in terms of total PV solar installed capacity by 2050, China will continue to play dominant role with a projected share of 50%, succeeded by North America (20%) and Europe (10%).

ASSOCIATED PROBLEMS, CHALLENGES & OPPORTUNITIES WITH PV SOLAR PANEL WASTE

Quantum of Waste Generation

The increase in usage and installation has brought the associated problem of generation of huge quantum of PV Solar panel waste and more importantly its safe disposal. As per the experts in the field, the average life span of the PV solar panel may range from 20 to 25 years [21]. Hence, the quantum of associated waste generated will be enormous, in future- from the discarded PV solar panel, whereas at present- from the process waste generated during the production of new PV Solar panel. Figure 3 provides the estimated results of the PV solar waste which could be generated from the end-of-life PV solar panels globally and in India as well based on the historic cumulative installed PV capacity.



Source: Compiled from [16]

Figure 3. Projected Volumes of End-of-life PV panels Global vs India (tonnes)

Hazardous Waste Material

With the increasing quantum of waste generation from discarded PV solar panel, the major associated problem is the presence of various hazardous materials in the PV panels. There are several pollutants found in solar cells and other parts, which include arsenic, chromium, lead and cadmium in batteries, Mercury, Brominated Fire Retardant's (BFR), etc. In the recent past, public has whole heartedly accepted the solar energy system globally, although, public worry over the disposal of hazardous material including Cd, Se, Pb, and other metals in PV cells are increasing, that has provoked the industry and concern authorities around the world to find out safer options for its recycling and disposal. The hazardous materials found in the discarded PV solar panels have various severe environmental and health implications if not been handle and process systematically & scientifically.

Waste Disposal Options

The major environmental challenge at present is - how to disposed-off the waste PV solar panel after its end-of-life (EOL) due to the presence of various hazardous pollutants found in PV cells and panel parts such as arsenic, cadmium, selenium, copper, tellurium and hexavalent chromium, etc. The generated waste from (EOL) PV solar panel may further add up to the already stressed existing waste management systems including municipal solid waste (MSW) and hazardous industrial waste. Disposal to landfill is also not feasible due to its bulky and hard nature. It also consists of rare metals such as gallium and indium, due to which disposal to landfill is not an option.

Most of the countries are yet to find out any suitable policy and strategy for safe disposal of EOL PV Panels. However, in the EU, member countries, the suppliers of the PV Solar panels have to follow the directions and procedures, pertaining to its collection and recycling, as per the EU directives which will be enforced by its member nations [22]. Although RoHS directives has presently excluded PV solar panels, but is expected to review its inclusion during the schedule reviewing of RoHS directives. Although, EU has come up with the directive for the handling and processing of discarded PV solar panels still majority of the countries have not taken policy decision in this regard.

Further, the recycling and recovery of valuable materials options should also address the environmental concerns and implications associated with the hazardous materials such as Plastics- BFR, heavy metals, etc contented in it. The processing of EOL PV panels mostly includes mechanical, thermal and chemical treatment in highly corrosive reagents- HCl, HNO_3, H_2SO_4, NaOH, KOH, etc. However, such processing has following drawbacks/limitations:

- Environmental Concerns: Toxic emissions, High process waste –Sludge & Wastewater generation
- Process Economy: Are expensive & less efficient in terms of Yield Recovery & Purity

Shortage of Essential Raw Material & Opportunities

The essential raw material needed for the manufacturing of PV Solar panel includes Silicon, base metals along with rare-earth metals, which has limited availability and supply globally, and has monopoly of few countries dominated by Republic of China [13, 23]. This demand supply gap has attracted many industrial players in the

PV solar panel manufacturing business to search for the alternative options including adopting recycling and recovery process strategy for the material recovery.

Considering the average life span of PV Solar panel, the first generation - PV crystalline solar panel which has dominated the PV solar panel market, will find its way in to the waste stream in the coming years. The materials which could be prominently available in waste PV panels for recovery in the 2030-50 majorly include Si, Ag, Cu, and Al; part of crystalline (c-Si) solar cells [6]. Table 3 provides the average content of various material fractions that can be found in the different parts of discarded PV solar panel. Thus, the waste PV solar panels could be a rich source of valuable materials such as Al, Cu, plastic, Silicon, Silver and other rare earth materials such as indium, gallium, germanium, etc. for recovery.

Table 3. PV Waste material Composition

Panel Part	Material Composition	%	Kg/Tonne (PV Waste)
Frame	Aluminium Steel	14.7 8.65	147.0 86.5
Junction box & cable	Copper Plastic	1.90 2.85	19.0 28.5
Encapsulant	Ethylene-Vinyl acetate (EVA)	4.25	42.5
Back sheet	Polyethylene terephthalate (PET)	1.91	19.1
Front Glass	Glass	59.51	595.1
Solar Cell	Silicon Aluminium Copper Silver	1.82 2.01 1.99 0.12	18.2 20.1 19.9 1.24

Source: [24]

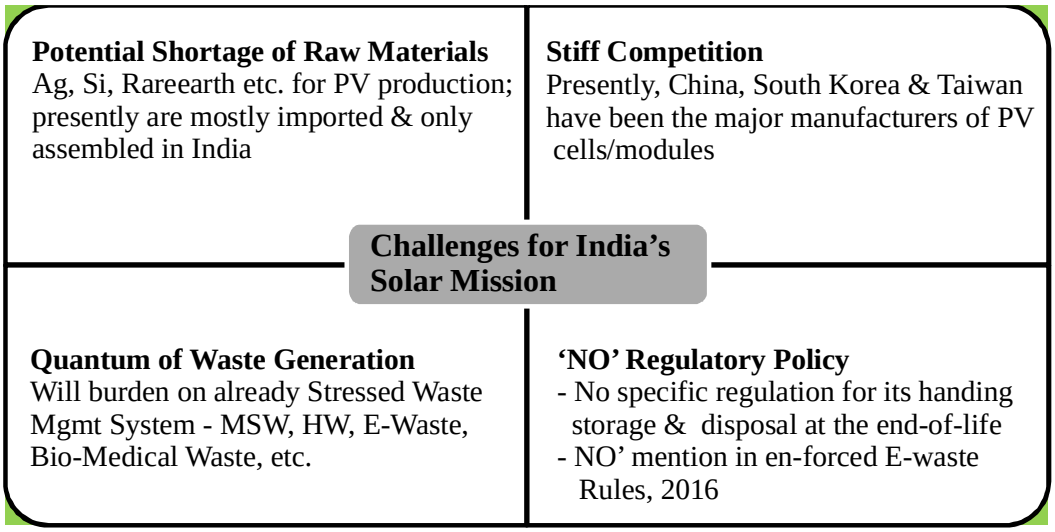
Considering the quantum of waste PV solar panel that would be generated in future, its scientific management options need thorough study in terms of its significant socio-economic and ecological implications [25] along with exploring the opportunity of recycling and recovery of valuable material within it.

INDIAN SCENARIO AND CHALLENGES

In India the major boost for PV installation started after 2010 and is now targeted to install and produce 100 gigawatts (GW) from PV solar panels by 2022 (https://mnre.gov.in/solar/current-status/), as an alternative renewable green energy. With the continual decrease in prices and availability of various government schemes to promote installation of solar panels there will be further addition in its uses & installation. Further, in the Conference of the Parties (COP 26) to the UNFCCC, 2021 summit - missing a key goal for countries to commit to reach that target by 2050, held at Paris, India has set a target to cut its emissions to net zero by 2070 and by 2030 reduce its projected carbon emission by one billion tons by producing countries' 50% energy

requirement through renewable resources, which will further promote and increase the installation of PV solar panels in country.

Perspective of unmet needs in India in this domain: Challenges & Opportunities



Waste Generation

At present waste generation from PV solar panels is comparatively less. However, it will definitely increase significantly in near future, in view of the increase in PV solar panel usage for private and commercial purpose. It is estimated that after 2030, approximately 50,000 to 320,000 MT of EOL PV solar Panels will be generated which may further increase to 4.4 to 7.5 million MT by 2050 as shown in Figure 3. This would put tremendous pressure on the concerned regulatory agencies with respect to environmentally sound management of such a huge quantum of waste PV panels. This waste will be in addition to the projected 55 million MT of municipal solid waste generation (MSW) [26] and 14 million MT of E-waste by 2030 [27]. And necessary infrastructure and plan strategies will be needed to handle these waste streams at local as well as national level.

Essential Raw Material Demand Vs. Supply

Indian manufacturers do not make solar cells in the country, they just assemble them, as India does not have the resources for essential metals. Based on the Hindustan Zinc Limited estimation India's targeted 100 GW of Solar electricity in India will require 4000 MT of Ag per, whereas India produces about 441 Tonnes in 2019-20 and import about 7474 Tonnes in the preceding year [28].Thus there is wide gap in the demand and production, and major part of demand is fulfilled through imports. And the estimated Silicon requirement will be about 704225 MT based on IRENA 2017 estimation. Presently, China, South Korea and Taiwan together have about 49% share in production of PV cells and modules [20]. Potential shortage of raw materials such as Si, Ag, etc. for PV production; thus, presently are imported and only assembled in India.

In view of the shortage of requisite raw materials which would be needed for the development & production of PV Solar Panel within India, the recovery of Si, Ag, Rare Earth, etc. can be good option specifically considering the demand and supply gap and also in terms of overall process economy.

PRESENT REGULATORY FRAMEWORK

The MoEF & CC which has enacted and enforced the SWM Rule, and the Hazardous and other rules in 2016, along with its subsequent amendments. These regulations prescribe the necessary procedures and guidelines to be followed for the safe management, disposal and transboundary movement of solid waste including hazardous waste in the country. However, these rules don't mention anything about the waste PV solar panel and are not applicable to it.

Similarly, the E-waste Rules, 2016, which provided the general requirement for the safe collection, handing and disposal of the discarded E-waste, also does not mention anything about waste PV solar panels.

In absence of any regulatory framework specifically focussing on the safe handling, collection and recycling/recovery of the EOL PV solar panel, the safe and environmentally sound management of this waste will be difficult.

Hence, the concerned regulatory authorities should take cognizance of this and should be well-prepared for managing the PV solar panel waste in environmental- friendly manner. Management model/methodology which includes policy as well as scientific processing interventions should be delineated on an urgent basis. This will be useful not only for the EOL waste PV solar panels but also for the PV solar panels which are presently getting damaged due to natural calamity or not fit for use-category.

INTERVENTIONS NEEDED

In view of the prevailing situation with respect to management of waste PV solar panels, following interventions are suggested:

- Establishment of robust PV waste management laws
- Policy decision for the environmental sound management of the waste solar panels becomes priority as no effective collection and disposal options are available.
    - Encouragement and support for Recycling Industry to take active participation in recycling of EOL solar PV panels by proposing new business models, incentives and issuing of green certificates
    - Self-sustainable EPR model for recyclers and producers and capacity building programme
- Encouraging Research and Development to come up with solutions-innovations in design and technology advancement of PV panels to reduce the type of waste generated after PV panels and also to develop clean recycle and reuse technologies such as :
    - Development of processes & facility for safe disposal & valuable material recovery in terms of process economy and environmental issues.
    - Recovery/recycling options for scared raw materials such as Si, Ag, etc. to minimize dependence on China & other countries.

CONCLUSIONS

At present waste generation from PV solar panels is less. However, in view of the increase in PV solar panel usage at private and commercial level in general, and also due to various promotional scheme and programme facilitated by Government of India to promote solar energy usage since last decade, the waste generation from end-of-life PV solar panels will be huge by 2025-30. The concern authority should take cognizance and should be well-prepared for managing the waste in environmental- friendly manner. Management model/methodology which includes policy as well as scientific processing interventions should be delineated on an urgent basis. This will be useful for waste PV solar panels not only for those which will reach its end-of-life in future, but also to take care of the PV solar panels which were damage due to natural calamity/ not fit for use-category, etc. at present. Goal is already identified as by Government of India as the priority of national mission for green and renewable energy. Promoting the R&D for the end-of-life PV solar panel treatment process options and technologies could be helpful in meeting its present need & goal related to Solar Mission, along with the development of sustainable management strategy for the environmentally sound management of the discarded PV solar panels and recovery of valuable materials from it.

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