Applications of Recycled Solar Photovoltaic Modules and their Environmental Impact Analysis

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Abstract:

With the increasing population density energy requirements have heightened drastically and it was fulfilled by the renewable energy technology. In this solar photovoltaic technology proved as the main contributing factor. Solar photovoltaic installations in India have started from the late 1993. It further hiked exponentially from early 2010 to 2018. Till December 2019 total solar installations was reported to 33.730 GW. This article is pertaining to the state wise installations of solar photovoltaic system in the country. At the end life cycle solar photovoltaic modules will bring damaging effects on the ecosystem; however these effects can be curtailed by persuading towards recycling methods. A feasibility analysis is carried out on the recycled products so as to bring out their utilization in various aspects. The recovery product can be further utilized for applications like making window frames of Aluminium parts, using copper wires for new connections, making decorative items of silicon panels, also utilizing the solar panels for making the buildings, tables, cupboards and toys working under low voltage requirements. The damaged solar panels can be used in making monuments and dustbins for public use. The panels can be used for making vehicle's body, travel bags and also can be utilized for making road after the removal of harmful elements from the used and damaged solar panels. Recovery product of recycling is analysed quantitatively so as to know the payback of recycling procedures. Existing recycling methods of solar photovoltaic technology are assessed and their environmental impacts are studied. Landfilling option is also taken under consideration but due to lower economic value it cannot be taken forward on commercial scale. The paper lays emphasis upon the environmental impact of the solar photovoltaic technology along with their recycling economic analysis. Recycling came out to be less burdensome than landfilling procedure. Value can be made from the damaged and decommissioned solar panels. Further recycling brought out the environmental benefits in terms of human toxicity potential, global warming potential, abiotic resource depletion potential, acidification potential etc. Solar waste disposal, its handling and coordination of economy makes recycling a realistic phenomenon.

Keywords: Solar Photovoltaic, Solar PV Module Recycling, Environmental impact

Introduction:

Accelerated growth of solar photovoltaic installations in India is attributed to Jawaharlal Nehru National Solar Mission launched in 2010 by the Indian government (Manju & Sagar, 2017; Sahoo, 2016; Sharma, 2011). The main objective of this mission was to establish India as a leader in the field of solar energy. Solar installations in India started from early 1993. Overconsumption of the fossil fuels lead to their exploitation and paved way for the alternative renewable sources of energy. Among this solar energy is considered to be a clean and prominent source of energy as it's freely available from the Sun. Being free from harmful gaseous emission during the operational phase solar photovoltaic technology is considered as an important clean source of energy among the other renewable technologies.

The solar power installations have gone upto 3MW from 2010 to 26,869 MW in 2018 in India and are expected to proliferate to 479 GW by 2047 (Arora et al., 2018). Along with this the waste accumulation in the country will reach 200,000 tonnes in 2030 and 1.8 million tonnes by 2050 (Suresh et al., 2019). Due to their restricted lifespan of twenty five to thirty years the amount of waste accumulation has been left unnoticed. The amount of solar photovoltaic waste accumulated is directly proportional to their installation (Blanco et al., 2019; Chowdhury et al., 2020; Deng et al., 2019). Due to further negligence solar photovoltaic waste will become a disaster in approaching times. Solar photovoltaic waste is included in the Waste Electrical and Electronic Equipment directive by the European Union. Further it was given responsibility to the manufacturers to look after the waste so generated from the solar photovoltaic panels (McDonald & Pearce, 2010).

State wise installations of solar photovoltaic technology is shown in Figure 1. From the figure data it is analysed that Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, Gujarat are leading states in solar power installations. While Meghalaya, Sikkim, Mizoram, Lakshadweep, Nagaland have lesser installations in comparison to other states. With the surplus installations in the country land requirement is also a major issue which needs emphasis as amount of waste generated at the end life cycle of solar photovoltaic panels is to be dumped on land before sending it to any recycling firm (Held & Ilg, 2011; Pagnanelli et al., 2017; Sica et al., 2018).

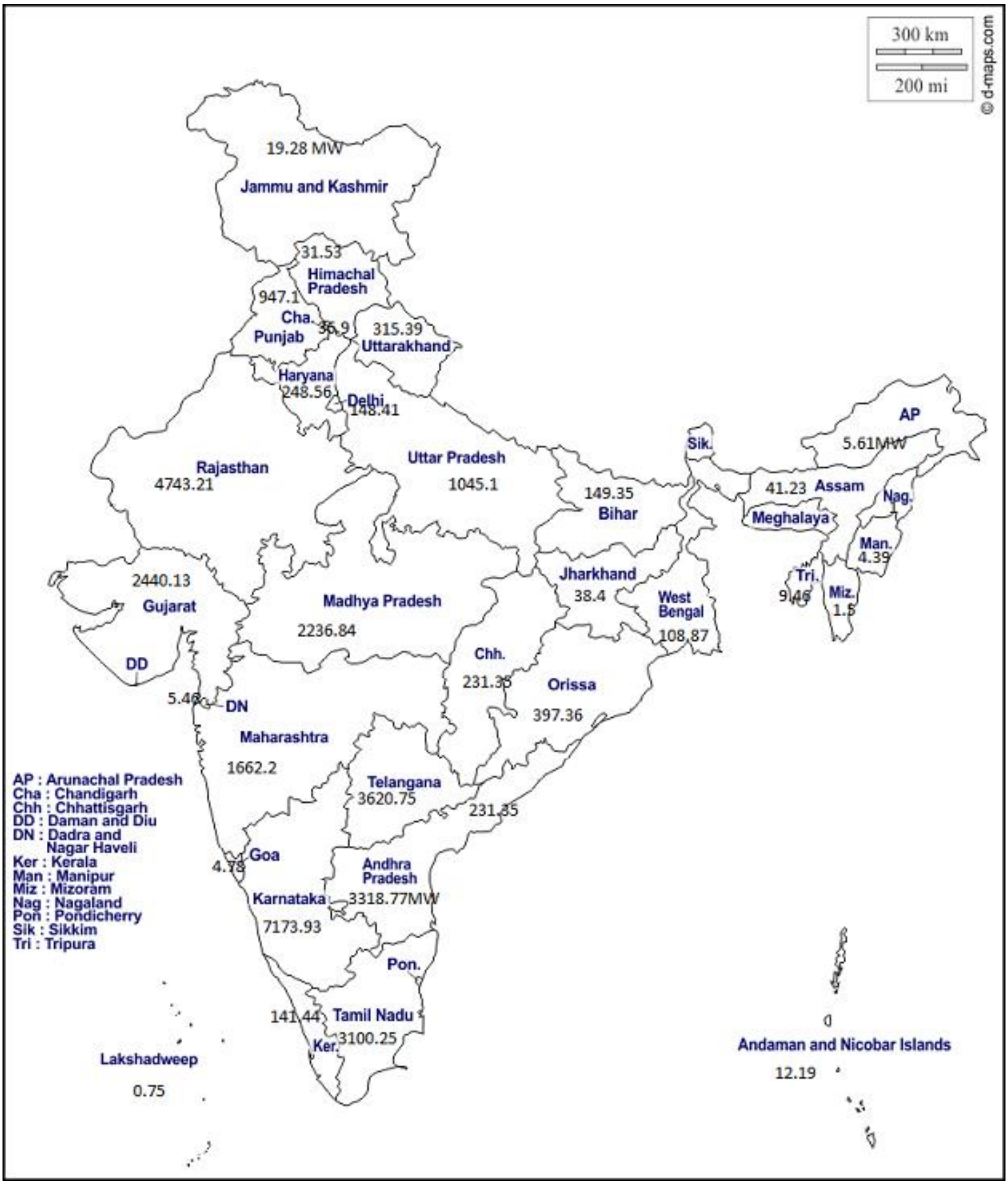

Figure 1: State wise installations of solar photovoltaic technology (MNRE)

Environmental impact of solar photovoltaic technology:

Elements like selenium, cadmium, lead, tellurium present in first and second generation solar photovoltaic modules are categorized as hazardous as these affect the aquatic and terrestrial inhabitants as it affects the kidney, bones and lungs due to its higher absorption capacity

(Faircloth et al., 2019; Fthenakis et al., 2008; Goe & Gaustad, 2016; Prakash & Rayabagi, 2015). Cadmium and lead pose danger due to further leaching into soil from decommissioned and damaged solar photovoltaic panels. During manufacturing phase emissions from the firm also affects the health of working people(Contreras-Lisperguer et al., 2017; Prakash & Rayabagi, 2015). Safe disposal of solar photovoltaic waste is an impeding factor for environment. Analysis of environmental impact provides viable impulse to the manufacturer for completely ensuring the safe disposal of hazardous components of solar panels.

Recycling of solar photovoltaic panels:

Analysis of recycling methods requires determination of economic feasibility of crystalline silicon, amorphous silicon, copper indium gallium diselenide, cadmium telluride, and polycrystalline silicon photovoltaic panels. Recycling process of thin film photovoltaic panels involves the smeltering, acid bath for the recovery of elements like Ga, Se, In. Glass can also be removed by decomposition through high temperature, acid dissolution can also be used for the removal of EVA polymer layer (Granata et al., 2014; Klugmann-Radziemska, 2012; Mahmoudi et al., 2019). Stripping with the help of chemicals is processed in case of cadmium telluride panels for the removal of metals. Further separation of these metals can be done by precipitation, electrodeposition and evaporation (Marwede et al., 2013; Paiano, 2015). Due to maximum installations of crystalline silicon photovoltaic modules in India emphasis is laid on its economic recycling analysis and also on the solar panels containing elements of economic benefit like Gallium, Indium, Silicon, Cadmium, Tellurium, Aluminium etc. (Kim et al., 2014). Frame made of glass and aluminium separated by the physical process isn't taken into consideration for economic recycling analysis. For the determination of economic feasibility of recycling on various generation of the solar cells like a-Si, c-Si, CIGS, CdTe, GaAs an analysis is carried out.

The analysis is carried out on 1m^2 area of solar panel (Deng et al., 2019). The recovered product mass is depicted as $m_r = A t_s \rho_s Z_s$ [g/module] (1)

m_r = recovered product mass

A= area in cm^2

t_s= thickness in cm

ρ_s= semiconductor material density in g/cm^3

Z_s = material recovered in %

The profit made from selling of the recovered semiconductor is estimated by

$P_s = m_r v_s$ [$/module] (2)

v_s = money earned by reselling

Other than semiconductor materials, profit can also be earned by recovering the glass

$m_{g.r} = At_g\rho_g Z_g$ [g/module] (3)

$m_{g.r}$ = recovered product mass

A= area

t_g= thickness of glass in cm

ρ_g= glass density in g/cm^3

Z_g = glass recovered, it is taken as 100 %

$P_g = m_g v_g$ [\$/module] (4)

P_g = profit from recycling glass

v_g = money earned by selling recovered glass

Along with recycling the disposal cost for landfill can be calculated depending on the waste generated by a module. $W = AEw / N_p$ [kg/module] (5)

E = power of each module in per unit area in W/ m^2

w = weight of module in Kg

Np = nominal power in Watt

The overall disposal cost (D) is calculated as D= WT [\$/module] (6)

W = solar module waste mass

T= tipping fees paid for disposal site. The cumulative profit (P_c) earned by the recycling

$P_c = (P_s + P_g) + D- C$ [\$/module] (7)

C = recycling cost of the material prevailing in the market

The recovered mass from different PV modules like c-Si (279.6 g), a-Si (1.17g), CIGS (5.23 g of Ga and 8.62 g of In), CdTe (8.98 g of Cd and 9.15 g of Te) (Fthenakis 2003). The recovered product mass from each of the above solar panels is 16.64 kg from c-Si, 17.680 kg from CIGS and 16.64 kg from CdTe panels. P_s of c-Si panels is 7.54, in CIGS panels 25.85 from Ga and 15.70 from In, in CdTe panels 0.23 from Cd and 2.02 from Te. P_g from c-Si, CIGS, CdTe are 0.06, 0.07 and 0.06 respectively (McDonald & Pearce, 2010). Weight (kg) of different panels were 12.32 (c-Si), 11.64 (mc-Si), 13.43 (a-Si), 17.5 (CIGS), 16.72 (CdTe) (Xsunx, 2009). P_c of c-Si, mc-Si, a-Si, CIGS, CdTe were -23.96, -23.99, 0.73-C, 22.25 and -0.24 respectively (McDonald & Pearce, 2010). The overall disposal cost of c-Si, mc-Si, a-Si, CIGS and CdTe panels came out to be 0.61, 0.58, 0.67, 0.87, 6.45 for each in $ and 43.31, 41.18, 47.57, 61.77, 457.95 in rupees respectively.

From the above it is concluded that CIGS panels are economically feasible for the recycling however disposal cost for the CdTe panels are highest and it also possess environmental hazards due to the presence of Cd. Recycling of a-Si panels isn’t practiced on commercial level due to less recyclable semiconductor material. 16 -17 kg/m^2 of glass can be recovered. Environmental friendly recycling needs to be practiced along with aiming economic value. The recycled products so obtained and their reuse is depicted by the figure 2 as shown below.

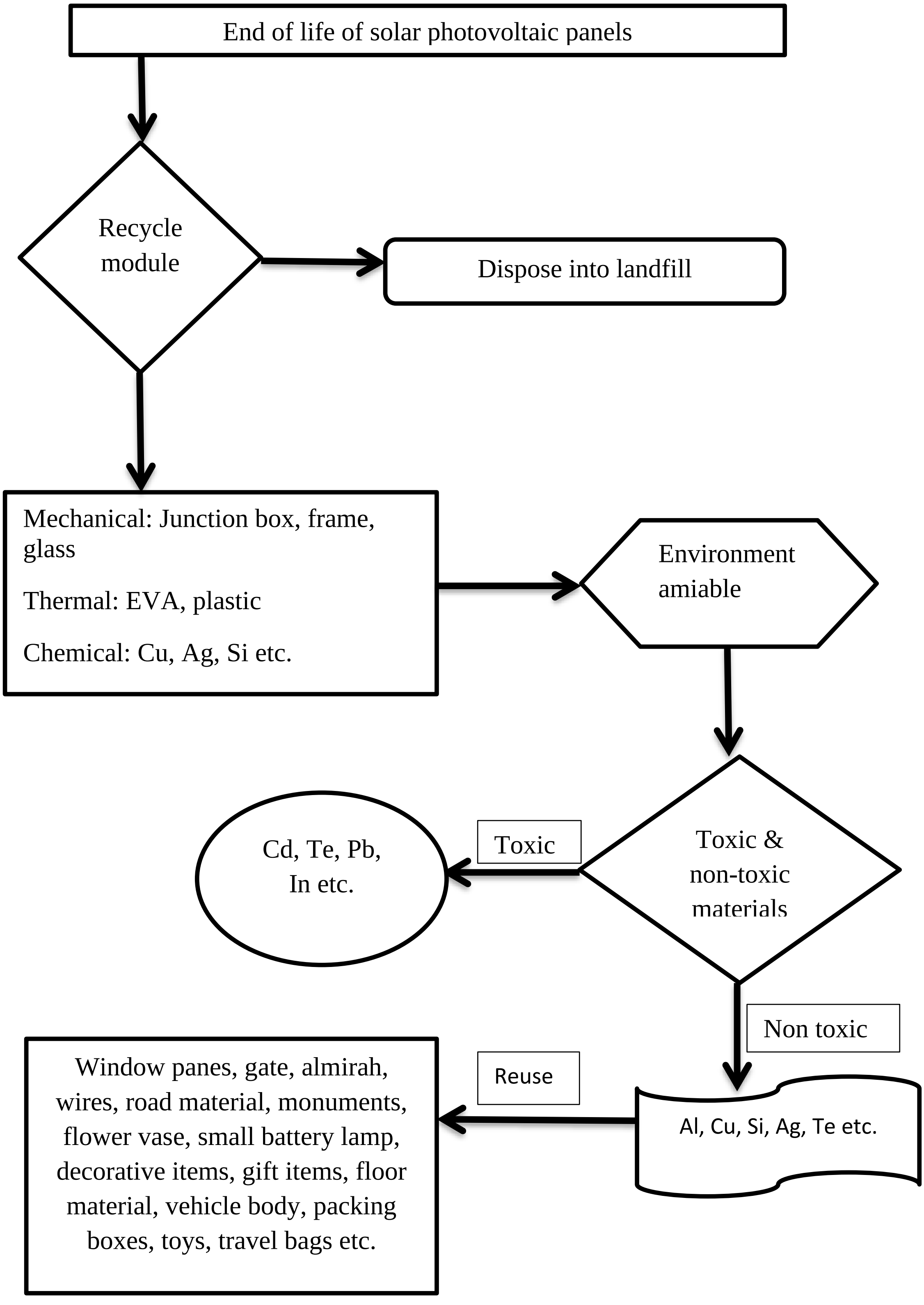

Figure 2: Solar PV recycled materials and their application

Conclusion:

With the increasing installations of the solar photovoltaic plants in the country amount of waste gathered will reach to 200,000 million ton in 2030 and 1.8 million ton by 2050. Negligence towards solar photovoltaic waste will be the main culprit for adverse effects on environment. Value can be generated from the solar photovoltaic waste by their recycling at end life. Recycling techniques needs to be practiced at commercial scale so as to recover the valuable materials as it will boon the employment sector by establishing recycling industry and further new industry will be set up to utilize the recycled materials. Construction industry can utilize the recovered aluminium in making doors, window panes and floor tiles. Automotive industry can utilise Al, Cu, glass etc. Packaging industry can also utilize the recycled solar panel parts. Interior designing can be furnished by the recycled products. Recycling of the CIGS solar panels is most economical due to the presence of CdS buffer layer, however CdTe panel recycling is not economically beneficial but it's must for the reduction of toxicity occurring due to disposal of CdTe panels in the environment. Crystalline silicon panels though contain fewer amounts of valuable materials other than silver are non-toxic to environment. Recycling should be taken ahead with focusing on both environmental and economic benefit to attain sustainability in terms of development.

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