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Review Article

A Review of Solar Photovoltaic Power Utilizations in India and Impacts of Segregation and Safe Disposal of Toxic Components from Retired Solar Panels

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Environmental impacts of electricity production through nonrenewable sources are greatly reduced by solar energy production through PV cells. The use of solar energy as an alternative to conventional methods is about to increase tenfold by the year 2050. This considerably increases the number of solar cell wastes for which the recycling processes are confronted with various issues due to the presence of hazardous materials like Al, lead, chromium, glass, silver, and ethylene vinyl. Different approaches for the disposal and segregation of these materials through mechanical, thermal, and chemical means are investigated in this review work. Since many countries have begun to implement mechanisms to deal with the destruction of solar PV (photovoltaic) panels, this evaluation will concentrate on the existing mechanisms and procedures. Existing mechanisms like landfilling, open dumping, and regulations and policies of the retired solar panel were discussed.

1. Introduction

Solar panels are widely used in many applications like residential, commercial, industrial, and community development or requirement. E-waste is under worldwide consideration because of its likely natural contamination and human well-being hazard other than its substance of important assets. The ISA, International Solar Alliance, is suggested by India and is also headquartered in India. India has the additionally progressive idea of "One Sun One World One Grid" and "WSB (World Solar Bank)" to set about plentiful sunlight-based force on international scale. The 20 GW initial destination capacity goal established by the Indian government for 2022 was achieved four years early. Worldwide-introduced PV limit is stretched throughout 400 GW by 2017 and is relied upon to enlarge further to 4500 GW by 2050. Recognizing a normal board lifespan of 25 years, the overall sun-oriented PV squander is foreseen to reach within 4%-14% of all out-age limit by 2030 and ascend to over 80% (around 78 million tons) by 2050. Along these lines, the removal of PV boards will turn into an appropriate ecological issue in the following decades. In the end, there will be extraordinary degrees to deliberately examine the removal and reusing of PV board end of life (EoL) [1]. From this review, it exhibits the need to enlarge the authorities of the producers not only in the photovoltaic manufacturing area but also all over the entire energy industry [2].

Actually, solar power force has included all the new limits both atomic and petroleum product energy-initiation limit as appeared in this article. The introduced limit of wind power and solar power innovation has nearly multiplied, with an extra of 99 GWh of sun-powered PV vitality that became a matrix associated in 2017 [3, 4]. Managing sunlight-based PV boards toward the finish of their helpful life will be, in any case, an exorbitant undertaking; thus, early activity could bring about better options for the specialists. The natural hazard coming about because of ill-advised administration would simply be too high to even think about leaving it unattended [5]. The vitality consumption in a reusing procedure is not exactly that spent in the production of another board. The chemical process' primary goals are to recover the module metal fraction and to employ reagents and other solvents. Chemical procedures are designed to recover the module metal fraction while also utilizing solvents and other chemicals [6]. There are three different methods that are involved in segregating the PV panel. In the chemical method, H_2SO_4 was able to segregate the partial conductor material. Mechanical processing followed by sieving had the option to isolate silver from copper, and thermogravimetric analyses were performed [7]. Electrohydraulic fragmentation (EHF) utilization on photovoltaic-based board squander offers a direct elective answer for the consolidated quick disassembling fractionation of important metal and metalloid parts from EoL boards [8].

The proficiency of metallurgical procedures for isolating the majority of the polluting influence components was illustrated, and to advance the reusing productivity, an exhaustive administration and reusing framework considering the accepted manuscript metallurgical standards of EoL silicon wafer refining is basic [9]. It is emphatically encouraged to utilize EOL on the executive techniques in dealing with the PV waste and add to lessen the ecological effects [10]. Because of the high energy use of the destroying machine, the pretreatment step has the highest commitment (about 40%) for all effect classes. Separation of silicon and glass may be present nearly about 25% with the minimal contribution of polymeric and copper fraction separation around 10% [11]. Minimizing dangerous gaseous emissions, the principal innovative particular of the suggested treatment lies in the total ejection of the emissions of HF and fluorinated organic compound degradation [12]. On the off chance that CdTe PV boards are discarded in landfills rather than reused, our evaluation recommends that a well-being hazard related with arranging utilized boards in landfills is distant at current CdTe board use rates [13]. Various specialized issues influencing sustainable power source research are likewise featured, alongside valuable connections between guideline strategy systems and their future possibilities [14]. In this article, it is observed that analysis of different biomass catalyzed with scrapped PV cells during combustion process, the degradation rate of biomass was increased [15]. The article talks about different answers for reusing photovoltaic modules as a major aspect of a technique advancing the practical administration of waste from lapsed PV frameworks [16].

On the off chance that the sun-based boards are not reused or reused, extra time, there will be a notable loss of valuable assets, for example, aluminium and glass. Because PV panels also employ rare metals like gallium and indium, failing to recycle them at the end of their useful lives could result in their constant consumption [17]. This investigation, along with a series of wind tunnel experiments for various effects, found that there are grid-generated flow, two boundary-layer flows, and low-turbulence flow [18]. This paper prefers the propagation of the photovoltaic industry by seeking the concept of an extension of industrial symbiosis (IS) and life cycle symbiosis (LCS) [19]. Waste solar cells were converted to 3,6,8,8-tetramethyl 2,3,4,7,8, 8a-hexahydro-1H-3a, 7-methanoazulene from (EVA) ethylene-vinyl acetate, copolymer, and polyethylene terephthalate (PET) (cedrene). It is the forerunner of priceless wound-healing medication [20]. This analysis provides the environment performances of various places like Los Angeles, China, Miami, Europe, US, and Seattle [21]. Nearly 2000 tonnes of discarded crystalline silicon photovoltaic modules is evaluated in this study [22]. This is about the end of life of solar panel management and International Renewable Energy Agency (IRENA) [23]. This technology was used to recycle solar panels that had been thrown away. A single-motion-type electrostatic separator was used to isolate blended particles of polyethylene terephthalate and silver, silicon and polyethylene terephthalate, and silicon and silver [24].

In this recycling process to retrieve silicon, silver, aluminum dissolve in to potassium hydroxide and nitric after that removal of anti-reflection coating by using phosphoric acid (H_3PO_4) [25]. This research reveals that certain components were found in the two panels, with no trial that exceeds the Toxicity Characteristic Leaching Procedure test which manages a second era PV squander modules, known as slight film, by means of applying substance treatment methods [26]. This article is depicted in regard to the turn of events and advancement of a procedure including both hydrometallurgical and physical pretreatment for the recuperation of target metal [27]. The impacts are focused on the panel's exemplification layers being burned; then, there are treatments to recover silver, silicon metal, copper, and aluminium according to the investigation. This could result in a 20% increase in global warming [28, 29]. The authors in their investigation focused on the removal of hazards like 93% of Pb, 80% of Si, 79% of Cu, and 90% of Ag. The metals are diffused by immersing a solar panel in a 5 M HNO_3 solution and agitating it at 200 rpm [30]. In this research, the elimination of polymeric ethylene-vinyl acetate (PEVA) by using 30 minutes of pyrolysis at 500°C from waste solar panel can remove <99% of polymers present in the PV cells [31, 32]. Actually, that PV solar power can be viewed as a developing innovation and can well contend with other sustainable and nonsustainable alternatives for power generation [33].

PV reusing focuses can be developed in the ideally chosen areas to limit the absolute opposite coordination cost for shipping the PV squanders from different assortment offices to the reusing focus [34]. In this article, it is reported that the electronics industries are not focusing about the end of life of PV solar panels. The solar energy industry can maintain a strategic distance from a comparative error by not just representing the materials utilized during assembling [35]. This paper inspected the possible requirement for sun-oriented photovoltaic reusing arrangements by breaking down the existing reusing compact for the 5 significant kinds of popularized PV materials [36]. The results revealed that as both the contact duration with the corrosive and the corrosive fixation in the arrangement expanded by nitric corrosive extraction, the measures of broken up metals increased, and 16 different metals were discovered. The increments in metal fixations in the dirt were along these lines identified with the measures of thin film solar panels included and the soil properties [37]. Requiring either merchants/wholesalers to source makers to create PV boards and BESS that are intended for condition is of significance to guarantee the high recyclability and restoration of the introduced items [38].

Metal filtering energy from this examination shows that the moderate filtering conduct is more applicable in PVs since the greatest metal delivery has seen 68.2 mg/L (29.8%) for Ni (mono-Si) trailed by 683.1 mg/L (26.9%) for Ag (a-Si), 31.3 mg/L (24.43%) for Pb (multi-Si), and 417.3 mg/L (21.3%) for Al (multi-Si) under the most distressing conditions [39]. For more energy security, it would be better to use an electric truck rather than the ordinary transportation framework, adopt pyrolysis rather than open air burning, and utilize a sustainable power source for electricity utilization to upgrade the waste solar panel treatment system [40]. They suggest that administration approaches, and sun-powered cell makers ought to consider the most pessimistic scenario situations for leachable exacerbates that could antagonistically affect human and natural well-being so as to get ready for crises or buyer requests [41]. They compared the end-of-life PV panel and CdTe structure, and they discover that general CdTe has a superior exhibition in most effect classifications assessed, bringing about lower ecological effects and vitality utilization [42, 43]. The utilization of reused silicon material represents about 42%. The absolute natural effect of PV creation can be diminished by as much as 58%, principally because of decreased vitality utilization during the creation of high virtue glasslike silicon [44].

The aggregation of data identified with beginning metal substance and metal draining from various PV advancements was accomplished to give information/contributions towards chance evaluation and assessing contamination capability of dumped squander alongside PV solar waste [45]. Off-grid solar products' effects are examined in the settings of repair, breakdown, and disposal in this article [46]. High voltage fragmentation (HVF) method could be involved in this various parameter used. The effective condition for high voltage fragmentation was at 160 kV after 300 pulses with 193 J/g consumed [47]. The purpose of this essay is to investigate how, in contrast to only considering solar power, the shipping of sun-based boards may vary if ecological compensation prioritizing was taken into account [48]. Different disposal methods are identified in India such as land filling and open dumping. One of the most serious problems with open dumping is the enormous surface water and groundwater contamination caused by leachate percolation. India is one of the most widely recognized to use such methods, especially in urban areas where waste sites are already overburdened. Some of the countries have these types of disposal method, which is not eco-friendly or environmentally friendly. It is observed that many countries do not follow any regulations and policies of disposal of solar panel [49].

This present work describes the segregation of waste/end of life of solar panel and discussed various disposal methods that are followed by various countries. The policy for the safe disposal of the retired solar panels implemented by various regulatory and policymakers is projected for implementation in India. Apart from this, the demand for solar energy and aspects of future energy sources and various techniques can be adopted for the safe disposal of solar panels that are discussed broadly in this manuscript. The proposed study gives a broad idea on the solutions to dispose the accumulated solid waste in the form of dead solar panels. Apart from this, the issues such as soil contamination, underground water contamination, and release of toxic components to the soil and air can be drastically reduced by following the proposed disposal methods.

1.1. Solar Potential in India (Top 20 States). The Indian government established a goal of 20 GW capacity by 2022, which was achieved four years early. By 2022, the objective was upped to 100 GW of solar capacity, with 40 GW as a result of rooftop solar and a $100 billion investment. To give developers of solar power plants access to land, India has constructed close to 43 solar parks. India increased its installed solar power capacity by 233 times, from 161 MW to 37,627 MW, in ten years leading up to March 31, 2020. Solar power utilization of the top 20 states is mentioned in Table 1. Total solar potential is about 37,627 MW at March 2020 worldwide. The Indian government is advancing solar energy and has allotted budget around 380 crore for the national solar mission for last year. Cumulative year-wise power utilization in MW is shown in Figure 1.

Currently, solar power generation is now rapidly growing worldwide, and details of installations by application are mentioned in Table 2. There are three categories for installation: solar power ground mounted is around 27,930.32 MW, solar power rooftop is around 2,141.03 MW, and off-grid solar power is around 919.15 MW. The details of generation of solar power are shown in Figure 2.

1.1.1. Indian Developers of Large-Scale Solar Power Face Obstacles. Increasing solar electricity output and expanding the solar industry is hampered by a number of limitations, overlaps, and gaps. The shift to solar power production in India is hampered by five major challenges: infrastructure barriers, funding barriers, transparency and accountability barriers, and technological barriers.

1.1.2. Technological Barriers. India is attempting to increase the number of manufacturing and R&D facilities in the last ten years; however, owing to lack of policies and ignorance, poor quality and a lack of funding have harmed this initiative. Government funding for solar manufacturing facilities is given in Table 3.

According to official data, the normal size of an Indian-manufactured solar modules and cell facility is just under 86 MW and 69 MW annually, respectively.

1.1.3. Policy and Regulatory Barriers. As and when necessary, policies have been released to support the expansion of solar power. The creators expressly identified several significant problems. All solar developers faced the same primary problem, which is that neither the Renewable Purchase Obligation (RPO) nor its state counterparts are legally enforceable. Approximately 55% of the developers believed

Table 1: India's solar potential [50, 51].

State	Year 2015	2016	2017	2019	2020	2021	2022
Gujarat	1,000.05	1,119.17	1,249.37	2,440.13	4431	4,430.82	7,806.8
Rajasthan	942.10	1,269.93	1,812.93	3,226.79	5733	5,732.58	14,454.7
Madhya Pradesh	558.58	776.37	857.04	1,840.16	2463	2,463.22	2,746.27
Tamil Nadu	142.6	1,061.3	1,691.9	2,575	4475	4,475.21	5,690.79
Punjab	185.27	405.06	793.95	905.62	560	959.50	1,117.99
Telangana	167.05	527.84	1,286.98	3,592.09	3953	3,953.12	4,621.07
Maharashtra	360.75	385.76	452.8	1,633.54	2290	2,289.97	2,753.30
Andhra Pradesh	135.9	573	1,867	3,085.7	4203	4,203.00	4,390.48
Karnataka	77.22	145.46	1,027.84	6,095.56	7355	7,355.17	7,597.92
Uttar Pradesh	71.26	143.50	336.73	960.10	1713	1,712.50	2,244.56
Odisha	31.76	66.92	79.42	394.73	401	401.72	452.13
Haryana	12.80	15.39	81.40	224.52	408	407.83	943.61
Jharkhand	16.00	16.19	23.27	34.95	52	52.06	88.79
Chhattisgarh	7.60	93.58	128.86	231.35	253	252.48	529.32
West Bengal	7.21	7.77	26.14	75.95	150	149.84	176.00
Andaman Nicobar	5.10	5.10	6.56	11.73	29	29.22	29.91
Bihar	23	96	109	142	160	159.51	190.69
Delhi	5.47	14.28	40.27	126.89	193	192.97	211.12
Tripura	5.0	5.0	5.09	5.09	9	9.41	15.87
Kerala	0.03	13.05	74.20	138.59	257	257.00	539.60

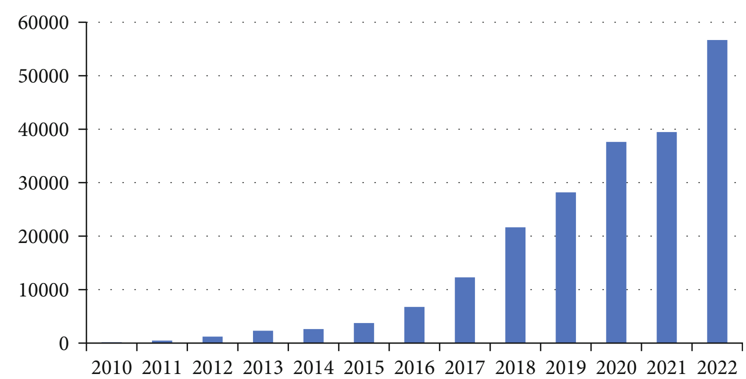

Figure 1: Cumulative year-wise power utilization in MW [50].

Table 2: Installed capacity of solar panel in worldwide in MW [50, 51].

Country	Year (2020) New	Total
Canada	15	3325
UK	177	13563
Australia	1699	17627
India	4122	39211
Germany	4583	53783
Spain	5378	14089
USA	41890	75572
China	49655	254355

that the Central Electricity Regulatory Commission must take such site-specific tariff into account (CERC). Policy and regulatory barriers are given in Table 4.

1.1.4. Financial Obstacles. The lack of nonrecourse finance, often known as a loan where the lender is only entitled to repayment from the project's profit and not from other assets of the borrower, is a second hurdle to the development of solar power.

Even while infrastructure projects in India are technically eligible for it, it is currently practically nonexistent. The majority of developers in the nation use either full or limited recourse financing, which greatly increases the developer's financial risk.

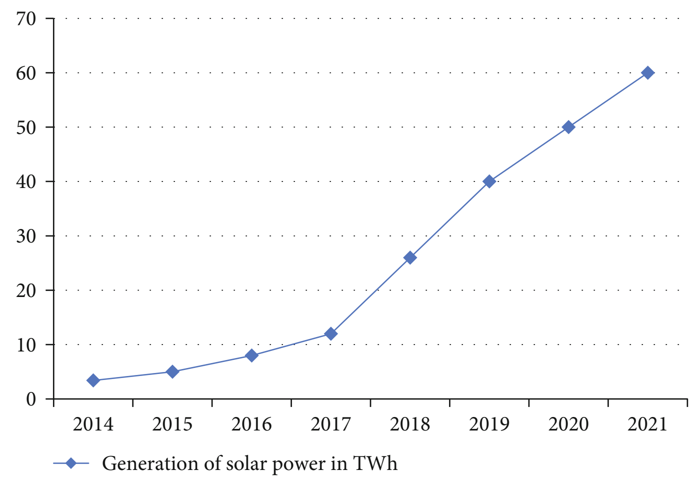

Figure 2: Details of generation of solar power.

Table 3: Comparing government funding for solar manufacturing facilities [51].

Country	R&D support	Low interest loans	Subsidized utilities	Capital subsidies	Assistance with getting land
India	—	—	—	Y	—
USA	Y	Y		Y	Y
China	Y	Y	Y	Y	Y
Malaysia	—	Y	Y	—	Y
Taiwan	Y	Y	Y	Y	Y

*Y: yes.

1.1.5. Accountability and Transparency. 70% of developers of solar energy believe that doing business in India is more challenging than in many other nations, and as a result, they will put less emphasis to investing in India. According to them, getting approvals, grants, inspections, and site acquisition takes around 60% of the overall time for the solar project. India placed 130 out of 185 nations in the World Bank report's ease of doing business ranking. To be able to provide a favorable environment for developers of large-scale solar power, there is therefore a very considerable potential for development.

1.1.6. Infrastructure Obstacles. The cost of compensating the displaced communities falls on the developer, who is also responsible for the increased financial burden. According to the developers, building a solar power plant in India requires obtaining several licenses even after receiving a plot of land. Here are a few of these approvals:

(i) Authority on land use approval

(ii) The state pollution control board's approval

(iii) Approval from regional authorities, such as panchayats and the district magistrate

(iv) Energy department certificate of approval

1.1.7. Solar Cities. Through a mix of increasing the availability of energy efficiency and renewable energy in the city initiatives, the Solar City seeks to reduce expected demand for conventional energy by at least 10% at the end of five years.

The program's goals are listed as follows:

(i) To provide local government more authority to deal with the city's energy problems

(ii) To analyze the current energy situation in order to create a master plan for anticipated future demand

(iii) To educate and train people on solar energy in order to increase public awareness

(iv) Including interested parties in the planning process

2. Recycling of PV Panels

Today's market primarily consists of five different cell kinds, which may be further divided into two groups: (1) 1st generation and (2) 2nd generation, such as, p-Si and c-Si types are under the first generation and CIGS, and a-Si and CdTe types are under the second generation category. X-Si-based PV is widely used in the global PV production industry. It has been discovered that mono- and multicrystalline silicon compositions make for nearly 88% of solar cell output.

Pyrolysis is the suggested recycling method, and it recovers crystalline silicon wafers from the modules. Additionally, at a temperature of around 500 degrees Celsius, the inert environment pyrolysis vaporises the ethylene-vinyl acetate present in the lamination layer. Using an acid bath or a smelting process to extract metals like indium, selenium, and gallium from materials is another suggested method of recycling thin film solar cell. To remove any remaining layers, the glass is treated using heat decomposition, solvent, or acid dissolution.

2.1. Environmental Concerns during the Production of Photovoltaic Cells. The manufacturing of a-Si cells with stabilised efficiency has recently advanced, and since a-Si has a high

Table 4: Policy and regulatory barriers [25, 51].

Policy	Good practices
Regulations for renewable energy	(i) Comprehensive and consistent policy (ii) Considering renewable energy certificate (iii) Taking location, project size, and land use into account
Tendering or auction process	(i) Reducing an expense of the policy (ii) Taking into account the technical expertise and developer experience
Encourage private investment	(i) Demonstrating initiatives (ii) Lowering risk (iii) Educating financial institutions
Interconnection requirements	(i) Proper execution on the ground (ii) Creating a suitable billing strategy
Net metering and feed-in tariffs	(i) Proper execution on the ground (ii) Creating a suitable billing strategy

absorption coefficient, just a thin layer is needed. Now that there is less a-Si material, it is much more commercially viable.

2.2. Impacts and Disposal Plans for Solar Panel Materials. The ecosystem and all living things are seriously threatened by a number of hazardous and carcinogenic compounds found in solar panels. Consuming these drugs can seriously affect how important organs like the kidney and liver operate as well as cause catastrophic bone damage. Some of these compounds have even been linked to lung cancer through inhalation. Solar panels use a variety of rare metals, including indium and gallium. There may be an irreversible depletion of these rare metals if they are not recovered at the end of the life of solar panels. All the materials used in solar panels have had their effects and disposal methods attempted to list.

2.3. Disposal Methods for Following Materials. As stated above, dangerous substances like brominated fire retardants, lead, and hexavalent chromium are present in c-Si PV circuits and inverters. The modules themselves have toxic levels below those set by the EPA. Options for recycling include melting used silicon (Si) wafers into ingots and then cutting them into fresh wafers. The active materials present in dead solar panel and its ill causes on the environment are shown in Table 5.

3. Disposal Methods

3.1. Physical/Mechanical Processes. Manual removal of the aluminium frame by crushing of laminate layers is shown in Figure 3.

In solar panel, the outer layer or frame is removed by a mechanical method, and the removal of the glass layer from the semiconductor layer of the solar panel is done by using a hammer, which is also under the mechanical method. This mechanical method ignores the energy-intensive process needed to manufacture the silicon ingot, wafer, cell, and module, respectively, even though it is suitable for high throughput and manageable with current PV waste flows.

3.2. Thermal Process. They experimented with two different processes: one involved crushing with two-blade rotors followed by hammering, and the other featured crushing with two-blade rotors followed by heat treatment in an undefined environment. They discovered that the best technique for the most mass recovery involved two-blade rotor crushing followed by hammer crushing. At 600°C, the plastic parts are burned. After that, the solar cells, glass, and metals are manually separated [52, 53].

(i) *Thermal Deconstruction*. The thermal dismantling procedure requires heating the ethylene-vinyl acetate compounds to their melting point, approximately 1,472°F

(ii) *Landfill Method*. Landfilling is the chosen method of disposal. If the incinerator can remove hydrogen fluoride and other acidic components, it can also be burned

(iii) *Attrition from Wet Mechanical Treatment*. The standard method for separating soil from harmful compounds is to employ mixing apparatuses with revolving agitators. Chemicals are typically not used because adding water is the only thing that matters

(iv) *A Vacuum Blast*. A technique called vacuum blasting substitutes vacuum for air pressure

  (1) The advantages of vacuum blast are as follows:

    (a) It helps to remove layers of the semiconductor without any chemicals

    (b) Clean glasses are recovered from this method

  (2) The disadvantages of vacuum blast are as follows:

    (a) It required further mechanical/chemical treatments

    (b) This process is relatively slow

Table 5: Active materials present in dead solar panel and its ill causes on the environment [17].

Materials	Causes
CuO	Due to its strong solar absorption and moderate thermal emittance, it creates an effective absorbing layer. The endocrine and central neurological systems may be harmed. Skin or eye irritation might result from contact.
CdSe, CdS	These increase the efficiency of solar cells. The effects of exposure to this include cancer, nausea, and respiratory and gastrointestinal pain.
FeS_2	Using an acid bath or a smelting process to extract metals like indium, selenium, and gallium from materials. Acidic rock drainage and possibly acid rain result from the combination of sulfuric acid and water produced when sulphate from decaying pyrite is discharged.
SnS	In n-type solar cells, the SnS absorption layer has a large band gap. It is not very hazardous to both people and the environment.
Mg_2Si	Due to its problems in crystal formation, magnesium silicide is generally utilized in thin film applications.
$CuInSe_2$	In the absorber layer, $CuInSe_2$ is employed.
ZnSe	This buffer layer has demonstrated total area efficiencies of up to 9.6%, an open circuit, a fill factor of up to 64%, voltage of 482 mV, and a short circuit current of 31.0 mA/cm^2 under AM 1.5 illumination.
MnS	MnS is a window/buffer layer found in PV cells that is a weak magnetic semiconductor. Manganese produces disruption in the plant's mechanism when it enters the soil. The distribution of hydrogen and oxygen in the planet's atmosphere is disturbed.
Crystalline silicon (c-Si)	Silane gas, which is used to create crystalline silicon, produces poisonous waste in the form of silicon tetrachloride. It has the potential to be harmful but can be recycled into additional silane gas.
GaAs	If left in landfills, crystals will leak arsine or arsenic. Arsenic is extremely poisonous and cancer-causing. GaAs may have significant impacts on the blood, liver, immunological, and respiratory systems, according to the scant toxicological information available. There is no way to recycle.
Sulphur hexafluoride	The reactor used to produce silicon is cleaned using sulphur hexafluoride. If it leaked, it would be a potent greenhouse gas. Additionally, it can combine with silicon to form a variety of different compounds. SF_6 is a chemical that is 22,800 times more environmentally harmful than CO_2 according to the Intergovernmental Panel on Climate Change.

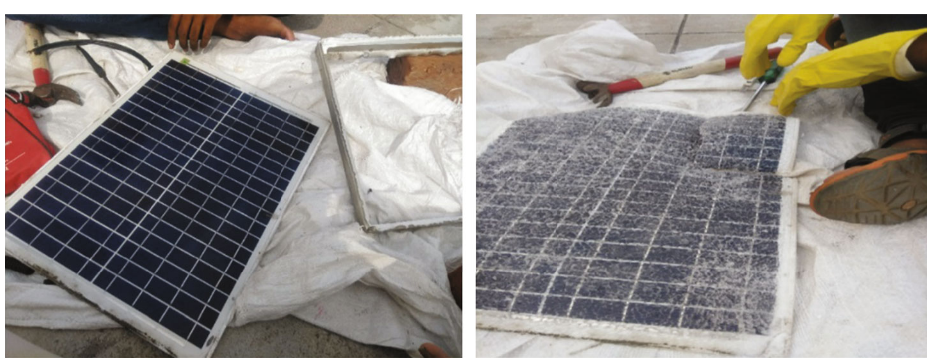

Figure 3: Removal of aluminium frame and glass layer.

(v) *Tedlar Film*. It is constructed of polyvinyl fluoride. Although Tedlar film is safe by itself, heating it causes it to produce hydrogen fluoride. Choking, coughing, and severe eye, nose, and throat discomfort may result from inhaling this. Overexposure to this can potentially harm the kidney and liver. It also contains dimethyl acetamide, which can lead to a number of skin issues. Landfilling is the chosen method of disposal. If the incinerator can remove hydrogen fluoride and other acidic components, it can also be burned. The layout for the segregation and disposal of dead solar panel is shown in Figure 4

3.2.1. Examining the Waste PV Cell Production Produces. Solar PV equipment that is damaged, faulty, or no longer in use may end up in the trash stream in the absence of efficient and secure recycling systems. It will be disposed of in landfills. A responsible option to disposal that keeps toxics out of landfills and municipal incinerators is to recycle solar

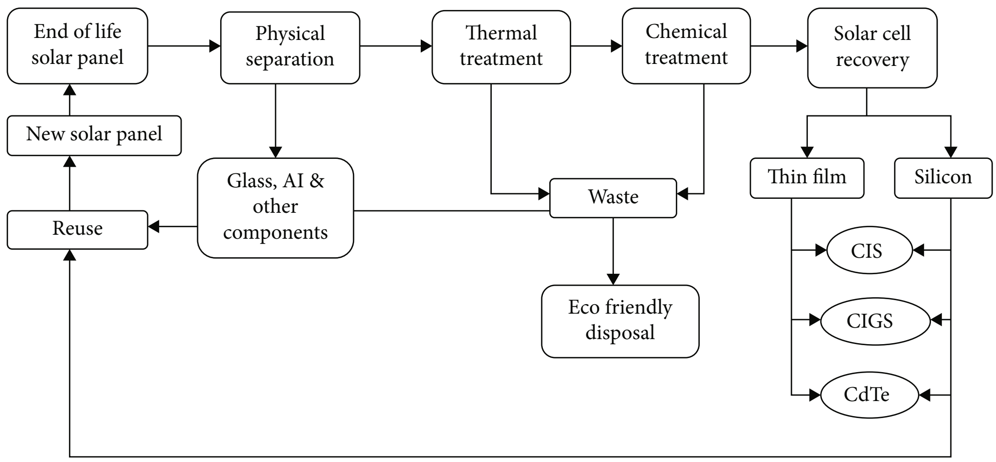

Figure 4: Layout for segregation and disposal of dead solar panels.

PV panels at facilities that also recover lead- and cadmium-containing batteries or at e-waste recycling businesses.

However, in order to reduce their environmental impact, these hazardous waste recovery facilities frequently employ subpar technology and require significant research and development. In the long run, there will be a considerable waste of valuable resources like glass and aluminium if the solar panels are not recycled or reused. Gallium and indium, two rare metals also used in solar PV panels, could permanently run out if they are not collected at the end of their useful lives. An investigation of the quantity of solar waste produced annually in India is conducted to get a better understanding of the true issue. It is well known that solar panels have a 20% maximum efficiency.

3.2.2. Environmental Concern Related to PV Panels. According to a study done for the European Full Recovery End-of-Life Photovoltaic (FRELP) project, the incineration of plastic and some mechanical and chemical processes (such as sieving, acid leaching, electrolysis, and neutralization) used to recover metals have an adverse effect on the environment.

Additionally, additional chemical processing is required for silver, aluminium, and recycled silicon from solar cells before it can be utilized once more. The chemical treatments could have an adverse effect on the ecosystem. In addition, it is crucial to remember that no process has yet been able to recycle 100% of the materials recovered from solar modules.

When c-Si recycling and landfill EoL scenarios were compared, it was discovered that the environmental effects of the recycling process were less severe than those of the landfill, presuming that the recycled resources were used again in the production of PV cells and modules. These findings took into account the recycling process, which included disassembly, remelting, thermal treatment, and chemical processing [54].

3.3. Challenges Faced in the Material Segregation and Disposal of Solar Panels. Presently, many of these dead panels are dumped in landfills, even though they contain valuable elements such as silicon, silver, and copper. The difficulty with recycling solar panels is not that the materials they are made from are hard to recycle, rather, it is that they are constructed from many parts all used together in one product. Separating those materials and recycling them each in a unique way is a complex and expensive process. E-waste refers to all kinds of electronic waste. Hazardous waste refers to all items, products, and byproducts that contain corrosive, toxic, ignitable, or reactive ingredients. Inert waste refers to waste items that are neither chemically or biologically reactive nor decompose easily. The combined wastes of all the types are very difficult, and so far, no proper technology is developed [55, 56].

3.4. Protocols for the Disposal of Dead Solar Panels

(i) The UK also has a "take-back and recycling scheme" that is controlled by the industry, under which all PV makers are required to register and submit information about their goods used in both the home solar market (B2C) and nonresidential market

(ii) Regulations for extended producer responsibility (EPR) have been developed in Washington and California. Manufacturers of PV modules must now pay for the removal, reuse, or recycling of PV modules sold in or into the state without charging the consumer

(iii) Additionally, legislation was approved in 2019 in New Jersey and North Carolina to research and examine PV module management methods that may aid in the development of future legislation

(iv) An industry-led product stewardship programme for PV systems has been developed and will be implemented with a $2 million grant from the Australian federal government's National Product Stewardship Investment Fund

(v) A number of nations, including Japan and South Korea, have already expressed their intention to draught specific legislation to handle the PV waste issue

3.5. Indian Scenario

(i) It is time to create a sensible solar waste management policy in light of India's ambitious solar target of 280 GW by 2030. India does not have a programme for managing solar waste, although it does have aggressive goals for installing solar electricity. India should concentrate its efforts on creating detailed regulations to handle solar waste

(ii) The 2016 electronic waste management regulations did not address the problem. According to a report created by the National Solar Energy Federation of India, SolarPower Europe, and PV Cycle, supported by the European Union in India and the Union Ministry of New and Renewable Energy, there is a possibility of production of over 34,600 tons of total solar waste in India by 2030. By the end of this decade, India is likely to experience issues with solar waste, which will eventually become the most common type of garbage in landfills [55, 56]

4. Conclusions

There is now no optimal technology available, and the first generation of solar panels is nearing the end of its useful life. Incineration cannot be carried out properly in India because the solid waste has high organic constitution and moisture content. Many solar enterprises should consider how to recycle panels wherever possible. In order for the solar recycling industry to thrive in the long run, it will require supportive policies and laws. This article provides that the solar photovoltaic (PV) panel cells produce more toxic materials like CdTe, chromium, lead, copper, glass, silver, aluminium, cadmium, and ethylene-vinyl acetate. These materials can cause cancer, skin diseases, and some other deadly diseases; the government should be concerned for the recycling of solar cells and safe disposal of solar panels. There is no rule or regulation that requires any solar module to be sent for recycling. An immediate bylaw is required to ensure that all future solar modules manufactured or imported in India include a cost of recycling as part of the EPR (extended producer responsibility).

The adoption of the present proposed techniques for the safe disposal of dead solar panels will reduce the accumulation of the solid waste. Apart from this, the issues such as soil contamination, underground water contamination, and release of toxic components to the soil and air can be drastically reduced by following the proposed disposal methods. Apart from this, useful material such as silicon, aluminium, and glass can be extracted for reuse to make new solar panels and other necessary components.

Abbreviations

CdTe: Cadmium telluride
EHF: Electrohydraulic fragmentation
EoL: End of life
EPR: Extended producer responsibility
HVF: High voltage fragmentation
LCS: Life cycle symbiosis
PV: Photovoltaic
WSB: World Solar Bank.

Data Availability

The data is available in the manuscript.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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