

## Chapter 6

### PROPOSED SOLAR PV RECYCLING POLICY FOR INDIA

This chapter outlines the proposed recycling policies for solar panel recycling in India. Despite the increasing PV installations, recycling of solar photovoltaic waste presents a supreme and uncommon platform for recovering valuable materials from the PV waste and harboring the recycling industry on large scale across the world. PV installations across different regions of the world are approximated and the waste generated from them is calculated. Further, their policies are analyzed for the recycling of solar PV waste in the present times core reality assessment of the proposed policies along with their VVCR analysis is laid out.

#### 6.1 Introduction

To use renewable energy in a sustainable approach a recycling platform has to be established on a large scale for the increasing solar PV installations. The overall PV waste figured out by 2050 will be 1.8 million tons while it was estimated to be 200,000 by 2030. This calculated PV waste accounts due to the increased solar PV installations. The installations will be touching 4.7 terawatts in 2050. Existing recycling strategies of the different regions of the world are studied in both commercial and non-commercial solar PV technologies. The PV waste at the end of life needs to be treated cautiously to reduce the harmful effects on the biotic and abiotic components of the ecosystem. With the increasing solar PV installations and the waste so generated from them, there is an indispensable urgency to proceed in the direction of shaping and executing the policies for the commercial level recycling of solar PV across the globe. Emphasis has been laid upon recycling in the Indian scenario.

#### 6.2 Solar Panel Waste Management across the Globe

The solar energy global installation was 39,603 MW in 2010 and it was hiked to 480,357 MW in 2018 (Weckend et al., 2016). With the increasing solar PV installations, the amount of waste generated will also increase. Global PV waste will be between 43,500 and 50,000 metric tons by the end of 2016. The amount of trash produced ranges from 0.1% to 0.6% of the total mass of the installed panels in the same year (Sharma et

al., 2019). The estimated life span of a solar PV panel is 30 years. With the growing technology advancements by 2030 solar panel installation will further rise. By 2050, 5.5-6 million tons of PV waste will be accumulated (Seo et al., 2021).

The annual e-waste has reached 41.8 million metric tons in 2014, whereas the contribution of solar PV waste was 1,000 times less than the above data. In 2016, 44.7 million tons of e-waste were outlined (Ilankoon et al., 2018). Further, the increasing PV installations are also contributing to this data. However, by the year 2050, the annual PV waste will exceed the 10% record of e-waste in 2014. This work projects a layout of global solar PV waste till the year 2050. The waste so generated is estimated through a life cycle assessment of the commercial and non-commercial solar panels (Lamnatou & Chemisana, 2017). The PV waste generated is outlined in two ways:

- a) Regular loss
- b) Early loss

The regular losses include the waste generated after the life cycle of the solar panels is over. The life cycle of solar panels is estimated to be 30 years. Whereas the early losses include the PV waste generated during the operational phase of the solar panels. This phase includes the infancy lifetime to the middle life, up to the completion of a life span of 30 years.

The early loss of PV waste in the year 2016 was 250,000 million tons whereas the regular loss was 43,500 million tons. In 2030 the regular loss was 8 million tons and the early loss was 1.7 million tons. By the extreme of 2050 regular loss was estimated to be 78 million tons and the early loss was 60 million tons.

This work provides comprehensive knowledge of the recycling policies practiced in regions of the world. Silicon Valley toxic coalition has stated solar energy as a clean source of energy and has put on the complete liability on the producers for the recycling of solar photovoltaic modules. However, substances like aluminum, glass, and semiconductors can be reused after their recovery in the formation of new solar photovoltaic modules. For effective recycling program initialization on a large industrial scale, the amount of the waste for processing has to be in bulk volume for the significant quantity recovery from the solar photovoltaic waste (Larsen, 2009). Monocrystalline solar panels are considered commercial solar panels due to their wide

use in the Indian Scenario, whereas polycrystalline silicon panels, thin film solar panels like CdTe, CdS, and concentrated solar panels are regarded as non-commercial solar panels due to their lesser use in the market currently due to greater cost requirement in the manufacturing process (Choi & Fthenakis, 2010).

c-Si panels contain a majority ratio of the content as glass, aluminum, and polymer. These are categorized into non-hazardous waste. A minority of the contents in the c-Si are composed of lead, silver, silicon, and tin. These are included in the hazardous waste category. Thin film solar photovoltaic panels also contain a majority of non-hazardous waste like aluminum, glass, and polymer. These also contain a minute quantity of the transition group elements like zinc and copper which are hazardous to the environment (Azeumo et al., 2019). Semiconductor materials like cadmium, indium, lead, gallium, tellurium, and selenium also possess detrimental effects on the environment. These metals can be recycled further (Graedel et al., 2011).

The components of both the commercial and the non-commercial solar photovoltaic panels can be classified into hazardous, non-hazardous, and inert waste based on the legislation at the international and the national level on the control of the movement of hazardous waste in transboundary fashion and their disposal. The double Green Process is used for the recycling of commercial and non-commercial solar panels with lower environmental effects (Marchetti et al., 2018). The flow of materials for the manufacturing of commercial and non-commercial solar panels is to be regulated and more focus should be given to recycling (Licht et al., 2015).

Countries across the world are planning for the effective management of the waste caused by the solar photovoltaic system. Countries are planning for the sustainable management of waste, for these contributors at each level should undertake the responsibility of waste management. A sustainable approach toward the management of waste should be the utmost priority. The PV panels' waste is largely allocated to ordinary waste. However, European Union has included solar panel waste in the e-waste category under the WEEE guidelines (Cucchiella et al., 2015). Waste Framework Directive 2008/98/EC is also related to the waste directives through the legitimate scheme. This particular scheme safeguards the risks associated with human health and the environment. European Commission 2000 entrenched the wastes checklist. Table 6.1 shows the waste categorization as mentioned in the EU waste list. Through this

standard nomenclature has been laid down for the up gradation of the activities of management of waste.

**Table 6.1** Waste Codes Relevant to PV Panels from the EU Waste List (IRENA 2016)

Type of waste	Code for waste	Remark
All	160214	Electrical and electronic equipment from industrial waste
	160213	Hazardous components of discarded equipment
	200136	Electrical and electronic equipment, municipal waste
	200135	Discarded electrical and electronic equipment with hazardous components
a- Silicon panel	170202	Construction and demolition waste –glass

The collection of the waste PV modules, their transportation, and further reprocessing are executed. Upon information, the PV CYCLE also provides the facility of collecting the waste. This program also provides the platform for the research on the recycling of the solar photovoltaic panels of both commercial and non-commercial solar photovoltaic panels. PV CYCLE has also established various units across Europe for the accomplishment of the process of waste collection (Peeters et al., 2017). Moreover, the focus is also to be laid on the end-life point of the PV panels.

### 3. Supervisory approach:

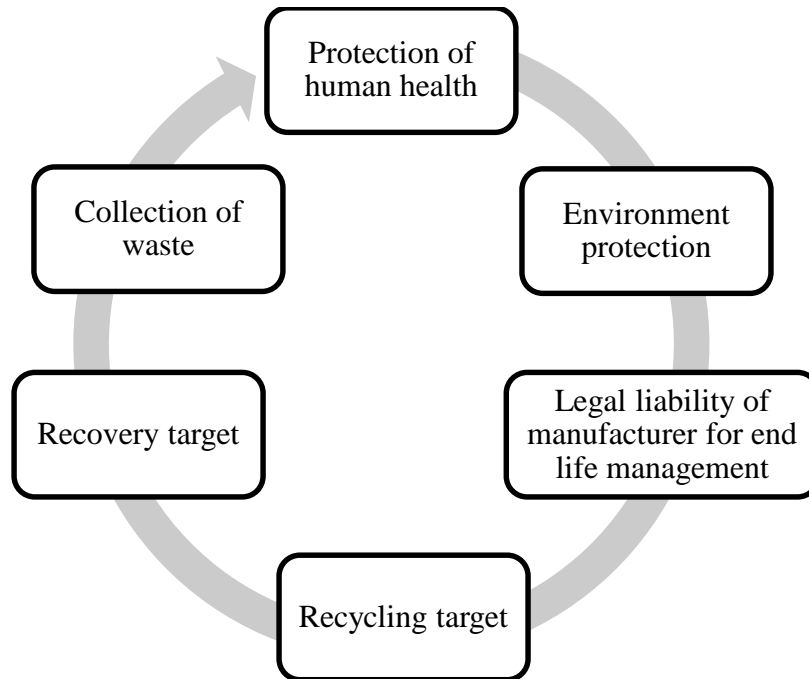
To date, only the European Union has shaped the legislation for the treatment of PV waste after the end of life is achieved.

### WEEE approach:

Solar panel waste is also considered in the category of electrical waste due to the similar composition of elements (Bakhiyi et al., 2014). Hence the legislation initiated by the European Union is influenced by the directives established by the WEEE. The establishment of these legislations is solely done on keeping track of the principle of extended producer responsibility. Only the installers who are floating the product for installation into the market are responsible for the end-life management according to the European Commission.

The main attributes for the management of waste across the world are shown in Fig.6.1.

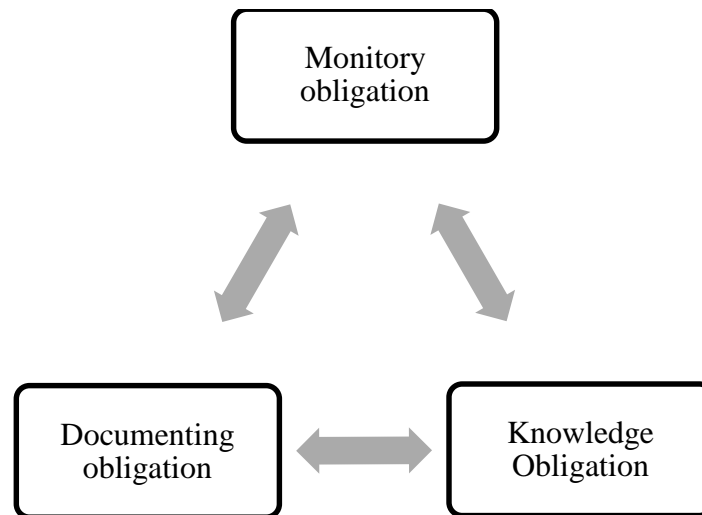
1. Protection of human health
2. Collection of waste
3. Recovery target
4. Recycling target
5. Legal liability of the manufacturer for end-life of product.
6. Environment protection



**Fig.6.1** Attributes for the Management of the Waste Across the World

The history of the WEEE directives dates from February 2003 but due to the inefficient handling of the increasing waste, the directives were amended and finalized in 2012. These amendments were carried out into practice by the European Union in the year 2014.

The amended WEEE legislations are more focused on the principle of the extended responsibility of the manufacturer. And they are responsible for the expenses occurring during the acquisition, operation, and supervising steps. Certain fundamental obligations need to be attained for this as shown in Fig.6.2.



**Fig.6.2** Fundamental Obligations for WEEE legislative

1. Monitory obligation:

It is the responsibility of the manufacturer to hold on to the affairs of money at the point of acquisition and reprocessing. This can be handled by a private firm. This needs to be financed by the collection points at public venues and also at the operation point. This can be preceded by a scheme to fulfill the desired.

2. Documenting obligation:

The overall number of solar panels sold out in the months of a year has to be compiled and documented. Documentation should also be made for the solar panels which are wasted or damaged and henceforth to be reported to the authority. Proper estimation of all the categories of waste should be maintained and recorded.

3. Knowledge obligation:

All the information of the particular solar panels after the manufacturing should be labeled on them so that their categorization is be done based on the WEEE guidelines, and they are to be kept separate from the other waste. It's the responsibility of the manufacturer to intimidate the customers with end-life management.

The manufacturer can also establish the facility of the acquisition from the doorsteps of the customer. This can be established by considering the legal framework. It becomes the responsibility of the manufacturer to guide the recycling companies on the handling of the solar PV waste and its treatment. Knowledge about the handling of hazardous

waste should also be imparted to the firms involved in the recycling of solar panel waste. Risks involving electrocution should also be highlighted during the treatment phase.

Legislations of the WEEE also call for the amendment process on grounds of effectiveness in cost, quality of the material for the treatment, and the recovery of the material after the recycling. A legal framework should also be established for the transportation of solar panel waste on a large scale to avoid any unlawful supply. Customers should also be provided with the knowledge of the detrimental effects associated with solar panels at the end of their lifetime.

Monetary scheme of WEEE:

For the treatment of the waste monetary demand has also to be kept on hold, the following ways have been implied.

1. Funding to individuals
2. Contract establishment between the customer and manufacturer.

The scheme of funding provided to the individuals was not much fruit-full. PAYG scheme was too used. The regulation of solar PV waste is achieved currently according to the WEEE directives. The article outlines the solar PV waste management across the various regions of the world; these are Asia, Europe, Africa, North America, South America, the Middle East, and Australia. The waste management of the solar installations in these regions for every country is studied and the currently going on the procedure is analyzed and reviewed.

European Region:

In the year 1990, the European market started growing. Rooftop PV systems, grid-connected, and residential PV systems were installed to a vast level. In 2000 rooftop solar installation grew to a great extent (Schmela, n.d.). In the year 2015, 6% of the total consumption of electricity in Europe was met by solar photovoltaic technology and it was the largest market in the world for the coming two decades. 1.5 million PV power was supplied from 40 GW distributions. Europe will be the largest market for the recycling of solar photovoltaic technology.

Regulations at National Level:

In 2015 through the revision of the Electrical and Electronic Equipment Act, the

European Union WEEE legislations were switched to German Law. The management of e-waste is monitored by the National Register of the Electrical and Electronic Equipment Act. By the onset of this act, the recycling of solar PV panels came into existence in the same year. Under the Electrical and Electronic Equipment Act of 2005, the other works involved in the functioning task like the collection of the PV waste, their separation, dismantling, and their final disposing part are all governed by the manufacturers.

WEEE legislation implementation:

In 2015 the new WEEE legislative was set up. Under these legislations, the cost of each of the sold panels is further analyzed. Here the business-to-business panels are analyzed. The management of e-waste is monitored by the National Register of the Electrical and Electronic Equipment Act. By the onset of this act, the recycling of solar PV panels came into existence in the same year. Under the Electrical and Electronic Equipment Act of 2005, the other works involved in the functioning task like the collection of the PV waste, their separation, dismantling, and their final disposing part are all governed by the manufacturers (Chowdhury et al., 2020).

WEEE legislative & National Financing Scheme: Based on the type of the transaction of solar PV waste in the market the national financing scheme was established, Business to consumer (B2C) transactions. Under this, the e-waste is sold to the private sector. There are two levels to this;

1. Level 1: Under this, the functioning of the collection procedure and their cost analysis is done, PAYG was used here.
2. Level 2: This makes sure that plentiful finance is available for the treatment process of the recycling procedure. The expense of the finance is estimated by considering the mean life, collection point cost at municipal, treatment, and management costs.

In the United Kingdom, the legislation of the WEEE was implemented in the year 2014. Before the implementation of the WEEE legislative, the PV CYCLE program for the reprocessing of the increasing solar PV waste was established. Business to Business transactions of the solar PV waste was occurring here. Under the WEEE guidelines of the United Kingdom the manufacturers of PV were listed as the ones who will fulfill the under-mentioned requisite:

1. Manufacturers of the PV panels selling them by their brand names.
2. It should be involved in the import within the state's market.
3. Selling PV panels to some other company by its brand.

Here also the manufacturer has to take back its product either through B2B or by B2C. The financing process for the PV waste collection in the UK works based on the shares present in the market for the B2C, whereas in the B2B transaction the manufacturer is providing finance for both the collection of the PV waste and its recycling. The UK government has also launched a distributor take-back plan. Both these are offering the services at the same wages according to the Environment Agency of the UK. The solar PV waste so collected needs to be registered first and then treated within the state only. According to the Department of Business, Innovations, and Skills 2014, a sustainable approach has to be kept for the treatment process of PV waste.

In Italy, the WEEE legislative was implemented in the year 2005. But due to the lack of availability of finances, it wasn't implemented effectively. For the working of the operating system, there was no implementation of a head body to look after all this. Due to this, there was a feeble strategic organization in the collection and solar PV recycling. Italy was the first country to inculcate the legislative of WEEE into its national guidelines for framing the recycling policy in 2014. The principle of extended producer responsibility was fully applied and imparted the financial responsibility of collection and recycling (Malandrino et al., 2017). For the first time, the manufacturers of PV were registered nationally to procure the finances. Organizations like Decree held a little of the feed-in tariff provided by the government to invest in the collection, recycling, and disposal of PV panels. The hostage amount is only available if the disposal of the collected PV waste is done effectively.

In Switzerland, SENS was established in 1991 before the establishment of the WEEE legislative. This organization was involved in the recycling of electrical appliances. SWICO RECYCLING and SENS collectively got adhered to the WEEE legislative by the extreme of 2014. SWICO RECYCLING was regulated by the Swiss Industrial Association for the provision of the funds. Earlier in 2015, the PV waste was collected through email submission to SENS. Now it has been upgraded for the collection and recycling processes too.

In Norway, WEEE legislation was adopted in 1998. By the European Economic Area agreement, the WEEE legislative was adopted into the national regulations in the year 2006. EE -The registered agency was established to put WEEE legislation into effect. This agency provided complete data on the import of solar PV panels and the export of waste PV panels. Waste collection points were established at the municipal level and further sent to the recycling firms for material recovery.

The Czech Republic introduced the WEEE directives in 2013. Through this financial aid is provided for the PV waste operation. It made mandatory for the manufacturers to register themselves with the waste collection centers in 2014. There were specific guidelines that 70% of material is to be recycled; reuse to be done of 80% of the material and 20% be landfilled. A joint venture was established for the revival and recycling of solar PV modules.

Asia Region:

Ministry of Economy, Trade, and Industry (METI) and the Ministry of Environment (MOE) have worked in Japan for the end-life management procedure. In 2015 a scheme was established for the compilation, management, recycling, and operation of solar PV waste. Further in 2017 guidelines for disposal of PV waste were issued by the Japan Photovoltaic Energy Association as the installations were increased. In the same year Ministry of Public Management, Posts, Telecommunications, and Home Affairs circulated information regarding the procedure of waste disposal by the waste handling parties at the native level. Hazardous substances are to be removed by the agencies and also to provide prior information on such composition. Recycling technologies are under the exploratory process for the increasing waste to be accumulated in the time to come.

In India, due to the increasing installations of solar photovoltaic technologies, PV waste has also risen during the last few decades and this demands an effective policy framework to tackle the PV waste scenario. Ministry of Environment, Forest, and Climate Change is responsible for the waste management till now in India covered in the Solid Waste Management Rules. This is also regulated by the Management and Trans boundary Movement Rules under the surveillance of the Ministry of Environment, Forest, and Climate Change. Hazardous wastes are looked after in this

institute. Amendments were made to the rule which was dealing with the management of hazardous waste. The procedure of leaching and its characteristics are also included in it. State Pollution Control Board is involved in the authorized transfer of hazardous waste. Ministry of Environment, Forest and Climate Change 2016. In 2016 the e-waste management and handling rules by the Ministry of Environment, Forest and Climate Change has taken into consideration only electronic items. Solar photovoltaic waste was still not included in this.

In China solar photovoltaic modules are not yet included in the WEEE waste category. For the recycling of photovoltaic panels, National High-tech R & D and the safe disposal research program have highlighted the PV waste management challenges for the framing of the guidelines to recycle the PV. Waste Electrical and Electronic Product Recycling Management Regulation came into force in 2011 by the State Council of China based on guidelines developed in 2009. This regulation of 2011 has mandatory consideration for the establishment of a centralized waste processing system. For management of the end life of solar panels, their recycling and the finance needed are all necessary for the establishment of a PV recycling framework. Focus is also laid upon the advanced photovoltaic technology for the utilization of less material in the fabrication of solar cells.

Korea is also lacking in the establishment of PV waste regulations. Ministry of Trade, Industry, and Energy had issued guidelines for the disposal of PV waste by the encouragement of Promotion of the Development, Use, and Diffusion of New and Renewable Energy. This also highlighted the need of involving Manufacturers more in the procedure. In 2016 ventures were subsidized by the Korean government for the effective recycling of PV waste. These ventures had the capacity of treating two million tons of PV waste. An additional research development program was built up for the effective management of PV waste. These centers need further up-gradation for the effective recycling of solar PV waste. Waste management action is also taken in Thailand (Faircloth, 2019).

North America Region:

Presently there is no specific framework for the collection, handling, and recycling of solar panel waste in North America. Only California and Washington have started

taking initiative for the PV waste regulation and the recycling process. In 2014-2015 a Senate Bill numbered 489 was put forward in the legislative session which enabled the Toxic Elements Control Department to classify the PV module waste under the hazardous waste category. This bill is now transformed into law and is under the procedure of implementation effectively within a year. Senate Bill numbered 5939 was put into progress for relaxation in taxes on renewable energy and also for establishing a structural framework of solar PV recycling. Through this law, the manufacturers can join the national program for recycling if their objectives are coinciding with that of the state to recycle PV waste. Financial provision should also be ascertained. Only those PV manufacturers will be allowed to sell their products that are providing the recycling scheme from 2021.

In 2016 a committee called Corporate Social Responsibility was established which kept an eye on the PV exercise program at the national level. Through the establishment of this committee, Solar Power Industries Association came out with economic and green management for the solar PV modules. SEIA has also planned to make a strategy by which the landfilling of the waste is avoided by the industries. This can be achieved if both manufacturer and customer are aware of the recycling processes of the solar PV waste at the national level (Sica et al., 2018).

**Table 6.2** Solar PV EoL Management Strategies across the Globe

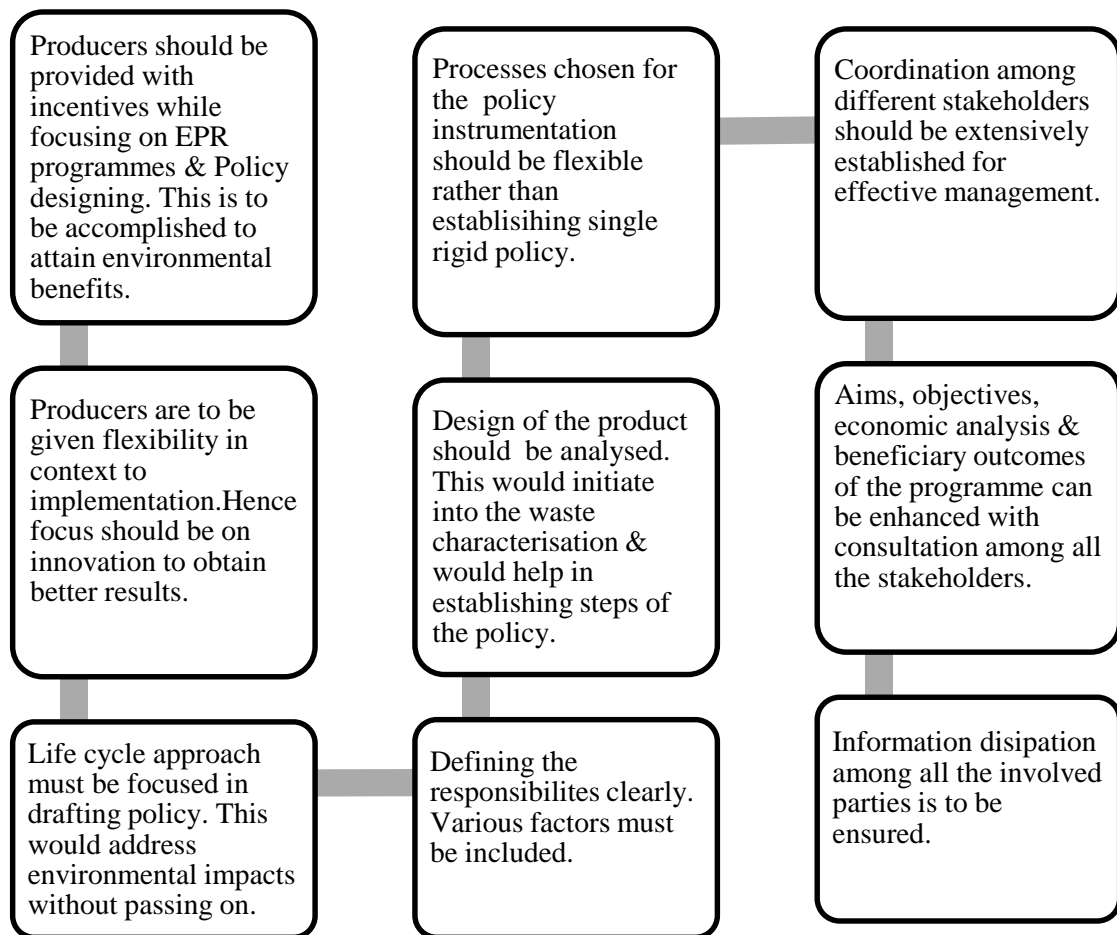
Country	Regulatory Approach	Solar PV Waste Management Approach	Current Status
European Union-U. K, Germany, Italy	EU WEEE directives as a regulatory approach	<ol style="list-style-type: none"> <li>1. Solar waste management is considered for the recycling process for effective management.</li> <li>2. Registration of importers &amp; producers of the materials under the product scheme to project whole information on the solar panel.</li> <li>3. State members are in charge to make a collection and treatment framework for decommissioning solar PV waste.</li> <li>4. Specific goals are put on the manufacturer for collection &amp;</li> </ol>	EPR approach

		<p>recovery from solar PV waste through recycling.</p> <p>5. R&amp;D drive is to be promoted across the European Union for developing recycling technologies at a reduced cost.</p>	
U.S.A	Resource Conservation & Recovery act,1976	<p>1. Lack of federal regulations for solar PV waste handling.</p> <p>2. Absence of legal framework to handle the solar PV waste issues.</p> <p>3. Individual states are free to adopt their own rules to avoid the toxicity caused by solar PV waste.</p> <p>4. Other than California &amp; Washington all over the U.S.A general waste regulations are run to tackle PV waste.</p> <p>5. First Solar itself is only a single unit till now which has dealt with industrial-level commercial recycling of solar modules.</p> <p>6. The corporate social committee of the Solar Energy Industry Association is persistently studying the approaches involved in recycling.</p>	Few factories have been established by the First Solar company for handling solar PV waste.
Japan	The Waste Management Law & Public Cleansing Act, The Construction Waste Recycling Law	<p>1. Solar PV waste is considered general waste due to the lack of any legal regulative framework.</p> <p>2. METI &amp; MOE together provided a framework in 2015 to tackle EoL management of solar modules.</p> <p>3. After R &amp; D in 2016 the regulative roadmap was published first giving a scheme for collection, recycling &amp; treatment of solar modules</p>	Manufacturers of solar panels by the local companies participate in the recycling of PV modules as practiced in Europe
China	No regulatory approach	1. No regulatory approach toward Solar waste EoL management.	Waste Electrical and Electronic Product Regulation, 2011

		<p>2. From 2012 to 2015 National High-tech R &amp; D programmed for recycling of c-Si panels and safety disposal research in China.</p> <p>3. Regulations were under consideration for EoL solar PV waste management. This lays more emphasis on rates of recycling &amp; financial framework establishment.</p>	<p>by the State Council of China.</p> <p>Consideration for the establishment of a centralized waste processing system</p>
Korea	No regulatory approach	<p>1. No regulatory framework to tackle solar PV waste</p> <p>2. Policy framework establishment is under consideration from 2015 for solar PV waste handling.</p> <p>3. Programs of research &amp; development are in the process to establish recycling of Solar PV waste on a commercial level.</p>	<p>Ministry of Trade, Industry, and Energy had issued guidelines for the disposal of PV waste by the encouragement of Promotion of the Development, Use, and Diffusion of New and Renewable Energy.</p>
Norway	WEEE legislative was adopted in 1998	<p>1. WEEE legislative was adopted into the national regulations in the year 2006.</p> <p>2. Waste collection points were established at the municipal level and further sent to the recycling firms for material recovery.</p>	<p>European Economic Area agreement</p>
Czech Republic	No regulatory approach	<p>1. Financial aid is provided for the PV waste operation.</p> <p>2. Mandatory for the manufacturers to register themselves with the waste collection centers in 2014.</p>	<p>WEEE directives in 2013</p>
California and Washington	No specific framework	<p>1. In 2014-2015 a Senate Bill numbered 489 was put forward in the legislative session which enabled the Toxic Elements Control Department to classify the PV module waste under the hazardous waste category.</p>	<p>In 2016 a committee called Corporate Social Responsibility was established which kept an eye on the PV exercise program</p>

		2. Financial provision should also be ascertained. Only those PV manufacturers will be allowed to sell their products that are providing the recycling scheme from 2021.	at the national level.
India	No regulatory approach	In 2016 the e-waste management and handling rules by the Ministry of Environment, Forest and Climate Change has taken into consideration only electronic items. Solar photovoltaic waste was still not included in this.	Ministry of Environment, Forest and Climate Change covered by the Solid Waste Management Rules

The analysis highlighted that only European Union has predominant non-regulatory approaches for solar waste management at end life management. Based on the Extended Producer Responsibility concept countries like Italy, Germany, UK have adopted the WEEE directives. Inaugural adoption of WEEE directives 2012/19/UE was done by European Union. The effort has laid a foundation to promote resource usage effectively by practicing recycling and reuse. Dumping of waste in barren lands is discouraged substantially. The main work is performed through the recovery, collection, and recycling of solar panels. On August 13, 2012 WEEE directives were implemented and on 14 February 2014, these were mandated in all the twenty-eight states of European members (Weckend et al., 2016).



**Fig. 6.3** Principles to Focus on Extended Producer Responsibility

The majority of the solar manufacturing companies across the world are being imposed the responsibility to handle the end-life solar waste under the preset of extended producer responsibility. This has resulted in the lower usage of advanced solar panel technologies in developed countries. Along with this regulatory framework is to be developed to manage the end-life solar waste management. In the entire study regulatory approach and policies for waste, regulation was analyzed throughout the world.

### **6.3. Core Reality of Indian Solar PV Waste Management:**

By 2022 estimation of a 100 GW solar power plant installation target is set up by the MNRE. Among this target 60 GW grid-connected solar power plants and 40 GW rooftops are to be targeted for installations. Solar Power parks are also to be installed

for up to 40 GW capacity till 2022 (Ndzibah et al., 2022). The increasing installations are only giving a message that the main focus of the Indian government is on the installations and not much on the waste management approach at the onset of the end life of a particular solar PV plant. Core realities of solar waste management in India are highlighted in this study using the DPSIR plan of action analyzed through literature and consultation with expert suggestions. DPSIR plan for the Indian scenario has been put forward here in to effectively understand the management of solar panels at their end of life. Approximately 2.95 billion tons of solar panel waste consisting of the solar panels and the balance of the system will be accumulated from 2015 to 2047 (Rathore & Panwar, 2021). For tackling this imminent waste amount effective strategic planning is of the utmost need in the approaching times.

In India, under the Extended Producer Responsibility guidelines, the 2016 E-waste management rules were put forward for handling solar PV waste (Markert et al., 2020). The vagueness and absence of a managerial regulatory framework in the collection, regulation, recycling, and recovery of solar panel waste are putting a next-level burden on the Indian solar waste management agenda. A major portion of the generated waste is dumped into the barren lands without treating it. Throwing away the garbage in such a disorganized manner is an indication of a lack of cooperation and responsibility among the personnel involved in the solar panel manufacturing industry and installation. Such negligence by the higher authorities has made it difficult to establish rightful control and order following the footsteps of Extended Producer Responsibility commercialized among European nations (Curtis et al., 2021).

On analyzing the present solar industry scenario of India with the rising installations the accumulated waste will be hiked drastically. Through the DPSIR approach, it was pulled out that a systematic regulatory approach in terms of commercial policy making has to be practiced. The same was projected through the expert responses and by literature review. Extended producer responsibility and collaboration of solar panel manufacturers with the recyclers and collectors from the recycling centers at the end of life are various governance approaches to be implemented as effective strategies. At this hour establishment and implementation of the regulatory framework for tackling solar PV waste is a concerning issue. The establishment of an effective supply chain among the managerial sectors of the solar industry, solar panel installing authorities, authorities that surpass the tenders of solar installations, and manufacturing units of

solar panels are of utmost necessity for practicality and effective implementation of solar panels' end-life waste management policies in India.

Solar panels on reaching their end life are usually thrown away in barren areas or undergo casual recycling to obtain glass and aluminum. The supply of resource materials for the manufacturing panels is dependent on the naturally available metals. Resource recovery is quite an important perspective that is to be fulfilled to establish the circular system. This can be achieved by establishing the concept of 4R which are to reduce, reuse, recycle and recover. This sustainable agenda of development is to be achieved. The range of recycling material output in the solar photovoltaic sector is 60 % to 90% (Chowdhury et al., 2020). The prominent recyclable output from the solar panel waste has put forward a huge capacity of commercial recycling in the solar panel at their end life. Commercialization of solar panel recycling will promote circular economy growth to enhance the resource availability for the material flow.

DPSIR Approach:

1. Types of drivers:

General drivers:

- 1) Energy demands have risen drastically due to industrialization and modernization.
- 2) Solar installation was targeted to reach 100 GW by 2022 as it is environment friendly.
- 3) Increasing solar installation through government initiatives

Specific drivers of waste management:

- 1) Waste generation from solar panels during transportation, operation and installations or due to natural weather conditions.
- 2) Waste yields out with the damage to balance of system consisting of wires, inverters, transformers etc.
- 3) Exactly reliable data of solar panel waste generated is also hard to gather.

Economic enablers:

- 1) Dependency of India on imports of solar panel manufacturing material.
- 2) Enumerable job opportunities in end life waste management of solar panels.

Availability of resources:

- 1) Affordable resources should be available for solar PV manufacturing.
- 2) Excessive usage of materials available and thus putting excursion on them.
- 3) Dis ordered supply chain.
- 4) Economic recovery of precious metal like Tellurium, Gallium, Ruthenium and Indium.
- 5) Substantial economic recovery of solar panel material would contribute towards circular recovery.

Waste generation:

- 1) Expected waste generation will reach up to 2.95 billion tonnes in India including panels and balance of system.
- 2) Lack of conscious handling of solar panels has also contributed to the waste generation in process of transportation, installation, working phase and natural calamities.

Health related factors:

- 1) Hazardous materials present in solar panels upon leaching contributes to the water and land pollution.
- 2) CdTe, CIGS containing Cd and Te have huge toxic impacts on human health and surroundings.

2. Pressure:

Pressure related to resource availability:

- 1) Supply of critical metals like Germanium, Lithium, Tin is critical in supply chain for panel manufacturing.
- 2) Stringent supply of products at end life is a contributing factor to hiked cost for treatment and supply chain of resources.
- 3) Greater demands for the raw materials utilized in solar panels.

### 3. State:

#### State:

- 1) Solar panel waste is not yet clearly defined in the waste management rules of India. Even the E waste rules are not yet so developed to treat the accumulated E waste. All this is looked after the Ministry of Environment, Forest and Climate change.
- 2) No defined regulations to treat the solar panels in India. They are only disposed of in unscientific manner.
- 3) No Policy to regulate the collection, recycling and recovery of waste solar panels.
- 4) Glass and recycling of aluminum is not yet commercialized.
- 5) Balance of system is yet to be included in the E- waste 2016 rules.
- 6) Lack of accountability to treat end life waste within the solar industry.
- 6) Zero coordination among the various involved authorities in solar industry like the stakeholders in the manufacturing field, tender issuing authority and ministry personals.
- 7) No incentive provision to the recyclers involved at end life or the ones being involved in recycling business.
- 8) No public awareness towards attainment of sustainable development by solar PV recycling.

### 4. Impact:

#### Impact:

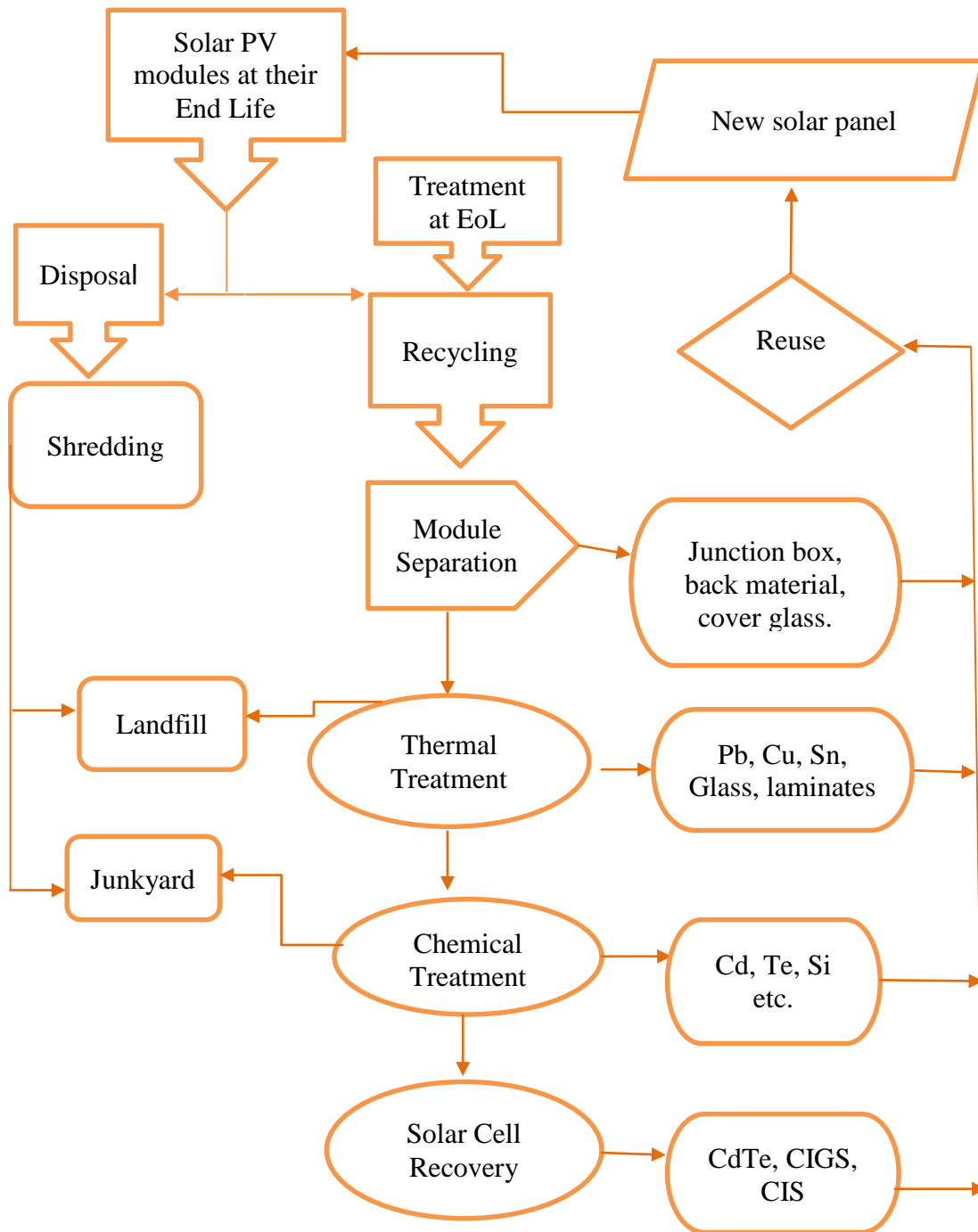
- 1) Air pollution occurs due to waste incineration.
- 2) Increased incineration has led to rising greenhouse gaseous emission.
- 3) Human health is at greater risk due to leaching through landfill deposited waste.

6. Response:

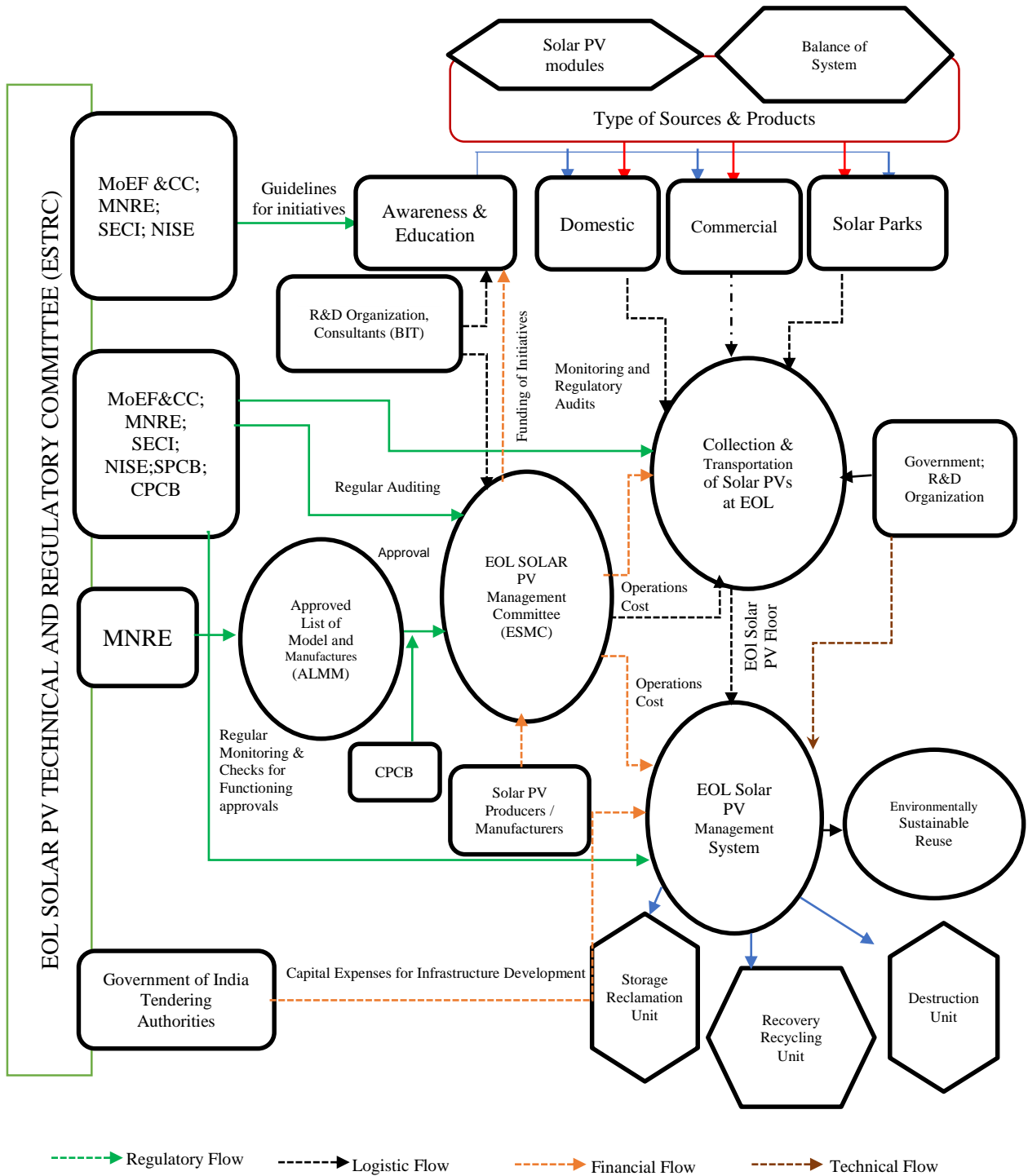
Response:

- 1) Regulatory framework is needed to manage the waste solar panels in circular economy form.
- 2) Strategies like Extended Producer Responsibility, joint waste collection and recycling centers should be built.
- 3) Innovative management programs like establishment of business models which is set up to procure circular business models including take back, refund deposition system and product service for industry.
- 4) Effective designs and solar PV technology should be under research development to carry out End Life Management effectively.
- 5) Layout for the manufacturing, disposal, utilization was laid out by the MNRE in April 2019. However no practical implementation of the same has occurred.

Solar PV waste handling on a larger aspect was sought after on the pretext of the rising waste. Even the so far accumulated volume of waste solar panels is not in a significant amount to be treated commercially. That's why the regular recycling units have not explored solar waste for commercial treatment. Across the globe, only 10% of the accumulated solar panel waste is undergoing any kind of treatment. This indicates that there is no availability of commercial recycling operational infrastructure. In European Union closed loop models for solar waste management at end of life is in occurrence and has the same outcomes. Recycling has gained due awareness in context to pressure on material availability and scarcity of resources. To tackle this research is carried out to extract the materials at the end life of solar PV systems. Environmental damages occur due to the disposition of solar panel waste in open areas resulting in the leaching of harmful substances into the soil and water.



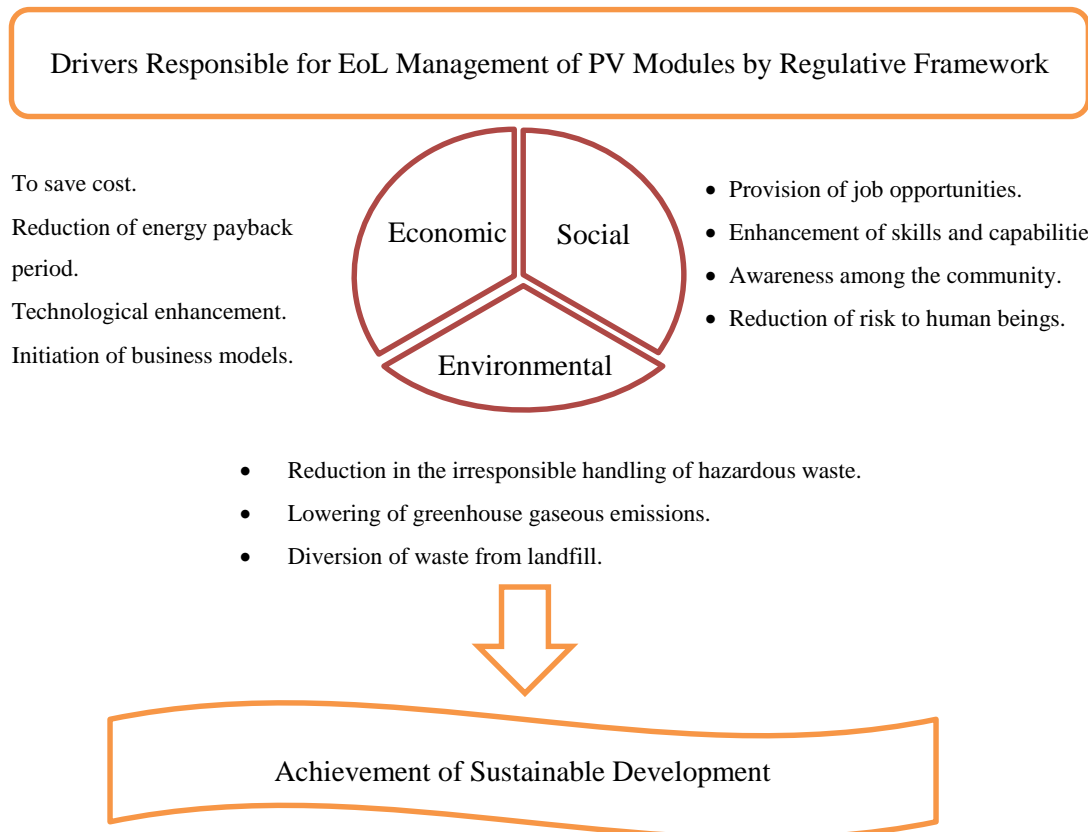
**Fig.6.4** Fate of Solar PV Modules at their End of Life (Jain et al., 2022)



MoEF& CC: Ministry of Environment; Forest & Climate Change. MNRE: Ministry of New & Renewable Energy; **SECI**: Solar Energy Corporation of India; **CPCB**: Central Pollution Control Board, **NISE**: National institute of Solar Energy; **SPCB**: Pollution Control Board; **BIT**: Bridge of India

**Fig. 6.5** Overall Indian Management Approach of Waste Solar PV Module.

It includes effective solar panel waste management through collection and recycling. Research and Development promoted in Japan have worked towards end-life management. In 2016 basic information to deal with end life management of solar panels was published for the first time. However, developing countries are more attracted to power generation through solar power plants than to the end-life management of the rising solar panel waste. Korea and China have initiated laws to handle solar PV waste by recycling but this is still in the infancy stage and is on a loose framework of finance. Hence evaluation of the policy and regulatory approaches across the globe has revealed that only in European Union substantial steps are ruled upon towards solar waste management. Manufacturers have only adopted Extended Producer Responsibility to handle the solar waste. This will surely reduce the amount of solar waste dumped into the landfill. This very similar regulatory strategy is to be adopted for the Indian context.



**Fig.6.6** Drivers Responsible for EoL Management of PV Modules by Regulative Framework

Solar PV waste management in India through regulatory approach:

Among the WEEE directives and the Indian landscape, there is a resemblance. Based on the European Union Directives an effective policy and regulatory framework can be established for the nation. Consumer-based electronic waste is focused based on Extended Producer Responsibility through directives of WEEE European and Indian E-waste handling rules of 2016. Consumer-based electronic waste is focused based on Extended Producer Responsibility through directives of WEEE European and Indian E-waste handling rules of 2016. "One product, One equipment" is the consideration for solar panels in the EU and India (McDonald & Pearce, 2010). Hence PV component system is excluded from the waste management regulations. Circularity is established by the Extended Producer Responsibility approach. Take back system is to be established by the producer through recycling, collection, storage, recovery, and disintegration of solar modules.

In India, unofficial recyclers are already prevalent to tackle E-waste. This informal recycling system is a hindrance to the circular economy of solar panel waste management. Inclusion of Balance in the system is not yet practiced in India. Industrial Solid Waste Rules are prevalent in India. Solar panels are regarded as non-hazardous wastes and are not included in those and it had led to the disorganized handling of solar panels in India. European Union holds integrated WEEE directives. These include rules to regulate the waste generation from solar panels, recycling procurement of waste, and reduction in the landfilling of the solar waste. Hence to ensure the PV waste regulations in India EU should be followed. The present study highlights the proposed regulatory framework for India.

#### **6.4. Proposed Solar PV Recycling Policy for India**

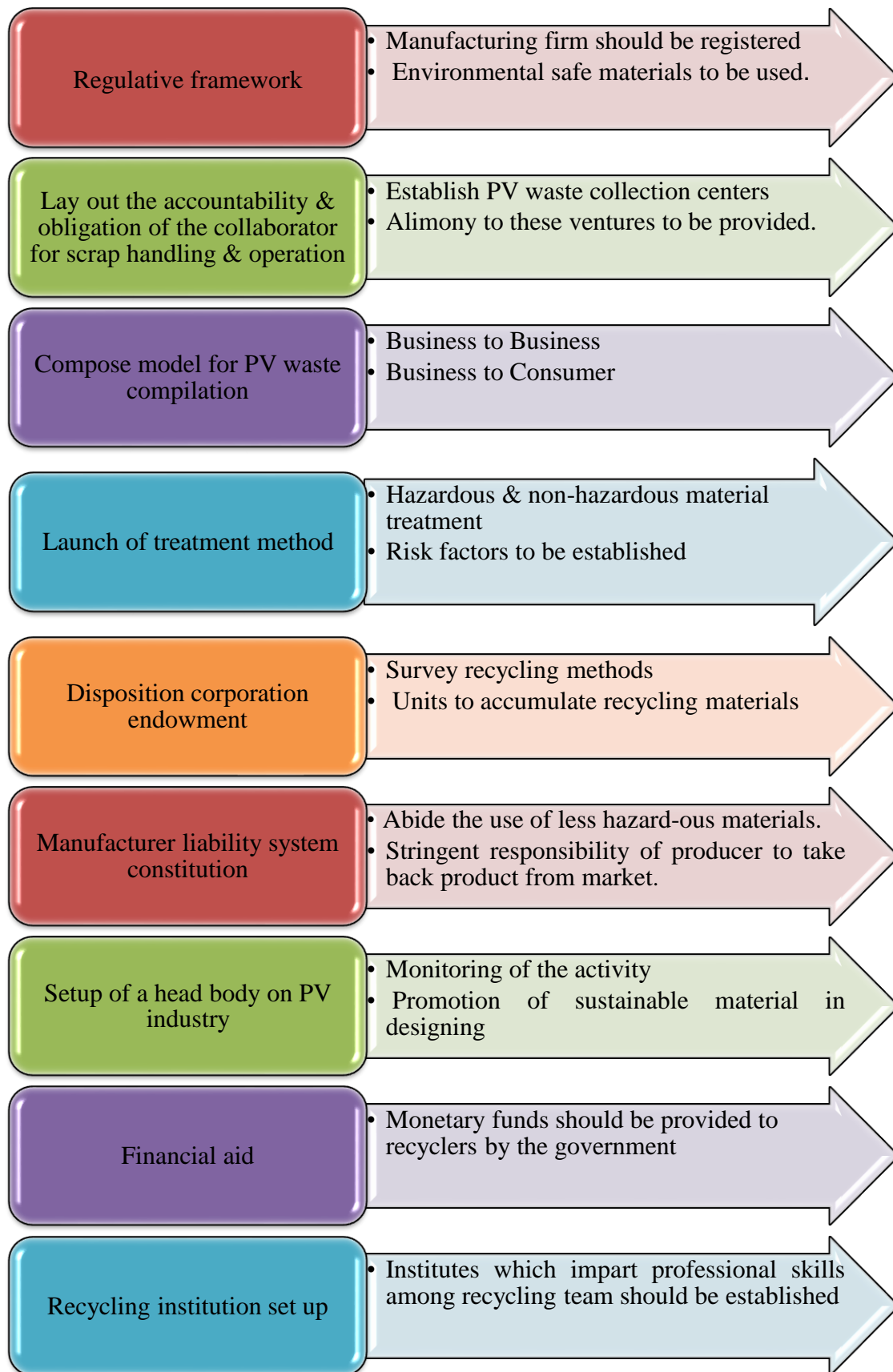
It has become imperative to create a PV scrap management and recycling policy due to the macroscopic proliferation of photovoltaic solar panel trash (PV material waste) in our nation. Solar photovoltaic material recycling is a young industry in India (Sharma et al., 2019). India currently lacks laws for the mandatory assembly, restart, and recycle of PV material over its lifetime. According to the managing committee of Bridge to India, the solar industry would grow significantly from just 3 gigawatts in 2014 to about 28 gigawatts in 2019.

The management of solar waste is currently not transparent in India. To separate the PV scarp from the general waste systemization, the sustainable energy pillar act must be endowed. Recycling of solar PV material is still exempt from odd legislation (Karthikeyan et al., 2018). The Ministry of Environment, Forestry and Climate Change is in charge of managing other waste and hazardous waste in accordance with 2016 solid waste management regulations as well as trans boundary movement regulations. Hazardous compounds are used in the production of solar PV materials; if these are not treated or recycled, the environment will suffer.

Solar energy is crucial in the transition to renewable energy, but recycling solar panels is neither simple nor profitable. To stop a solar waste wave, a recycling solution for the panels is urgently needed. The National Solar Energy Federation of India (NSEFI) estimates that by 2030, India will have produced tones of solar waste overall. The NSEFI serves as an umbrella organization for all Indian solar energy stakeholders. It is a national pathway towards addressing all problems related to the expansion of solar energy in India and works in the area of policy advocacy. 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.

Recycling is still in its infancy, and some parts of PV panels are not yet recyclable, even though it might be a useful way to manage waste and provide an economic opportunity as well. India is expanding its solar power capacity, but it currently lacks a solid framework for handling trash generated during the manufacturing process or from used solar panels. India now lacks both a policy framework and the barest operational foundation to protect the recycling of PV scrap using the old-fashioned recycling methods.

India now lacks both a policy framework and the barest operational foundation to protect the recycling of PV scrap using the old-fashioned recycling methods. India is forced to lean toward a solar PV recycling legislative framework due to the skyrocketing PV scrap. Legislative suggestions for solar PV recycling can be encouraged by members all over the world. The Indian government can address the inevitable PV scarp conundrum by implementing the legislative policy for recycling as depicted in Fig. 6.7.



**Fig.6.7** Proposed Solar Recycling Policy for Indian Scenario

The above proposed solar PV recycling policy framework is described in a detailed manner;

**1) Regulative framework:**

For the establishment of policy to deal with the recycling of solar waste of commercial and non-commercial photovoltaic panels, certain guidelines are to be kept under consideration for the recycling process.

a) The manufacturing firm should be registered with a license:

For the regulative framework to be effective, all the solar manufacturing firms need to be registered. Through this step, a track can be set upon what the manufacturing is going on in the firm. A check can be established on the number of panels established every year. After the registration of the firm, the license is provided for the further production of solar panels.

b) Constituent components utilization should also be familiarized:

The registered manufacturing firm needs to be assured about the components they are utilizing in the commercial and non-commercial panels. Familiarity about each of the components used is to be with the firm, its source; its fabrication, etc. needs to be well known with it.

c) Prohibit the use of low abundant elements:

The manufacturing of solar panels utilizes many elements. Elements of the representative group, transition group, etc. are utilized in them. All these elements are extracted from the earth's crust. The extraction process is cumbersome and utilizes multistep. Among these are included concentration of ore, extraction of metals, and further reduction procedure to extract the metal from it. All elements in the earth's crust are not in equal distribution; some are in abundant amounts whereas the rest are in very less quantity or are in negligible quantity. If any particular element is already in low abundance in the earth's crust and that is an essential component of solar panels, which should be either prohibited from use in the making of that particular type of PV material or some substituent element needs to be used in place of it.

d) Warranty of accomplishing environmentally loyal materials:

The materials which are to be used in the solar panel should be diagnosed analytically

with the deep learning of their effects on the ecosystem, and biotic and abiotic components prevailing in the manufacturing area. Upon analysis of the materials, knowledge about their effects will be established and demarcation can be made based on their behavior towards the environment. To further avoid the harmful repercussions, the use of environmentally loyal materials should be promoted. During the registration procedures also, proper checks should be made on the materials which the firm is going to use in the manufacturing process. The license should also be given to that firm only which ensures the use of environment loyal materials. The use of such amiable materials should strictly adhere to the manufacturing.

e) Provision of an end-life sketch for retiring panels:

After the life cycle of the solar panels is over by the end of 30 years from its operation period, a legitimate end-life sketch needs to be processed by the manufacturer. By ensuring the manufacturer's liability at the end of life, issues on the piling up of solar waste will be handled effectively (McDonald & Pearce, 2010). If end-life procedures are predefined, then it becomes uncomplicated for treatment of PV waste.

f) Comprehensively manufacturing should be amiable to nature:

The overall manufacturing process of the PV panels upon utilization of non-toxic materials is ascertained as amiable and hence is beneficial in an overall manner. The end life of such products will also be a positive point for recycling.

g) Provision of analytical testimony from birth to retirement:

Complete analytical testimony of the different types of solar panels needs to ascertain in a convenient manner which will provide the wholesome detrimental effects of each material to be in use in the solar panels.

h) Gross production & import of all PV material trading routes should be monitored:

The overall production of the solar panels needs to be tracked; the number of materials used, and exported for the fabrication in the manufacturing process should be fed into a directory. Further, the data on total imported solar panels from the manufacturing firm is also to be kept for record. This will ensure the effective monitoring of the trading routes of a manufacturing firm.

i) The user manual should contain possible negative impacts of the PV materials:

The user manual needs to be formulated for the solar panels, inside it each component of the solar panel is to give mention its effects during the operation period and its handling during use.

**2) Layout the accountability & obligation of the collaborator for scrap handling & operation:**

a) Establishment of joint collection ventures across India for the retired and distorted solar panels between the producer and the recycler (Xu, 2018):

At the onset of the end life of the solar panels, the working efficiency is reduced and panels after their retirement are to be collected from the operation site. This process requires effective management. The collection centers should be established for the waste compilation. This accountability needs to be established from the operator's side and the ones who are collecting the waste from the operation site. For the accomplishment of this, a joint venture has to be set up between them.

b) Consumers should be provided some incentives for waste deposition in collection centers:

The utilizing party of the solar panel system should be provided with a stipend for the depositing of their solar plant waste after its end life is over. This will encourage the solar plant installers to be active in the end-life treatment processes, and the waste so generated will directly arrive at the collection centers and less piling up of the waste will be localized in open land areas. Such consumers should be provided some incentives for the act so that they are motivated for recycling.

c) Collected waste material can then be auctioned for the recyclers or tenders can be directed:

The solar waste materials which got concentrated in the collection centers need to be further sent to the recycling firms. This procedure can't be directly accomplished, for this tender needs to be directed to recycling firms or a further auction procedure is to be carried out so that the whole procedure of the recycling becomes economical and near at hand.

d) Collection centers should have familiarity with waste disposal regulations:

The established waste collection centers are required to be well aware of the regulations

governing the endeavor for better accomplishment of waste disposal in the particular storage house. Awareness is also to be made with the WEEE legislative so that acquaintance about the hazardous and non-hazardous waste materials to the recyclers is provided.

e) Alimony to such joint ventures should be provided:

The waste collection ventures are to be provided with alimony from the government of the particular state in which it is located. This will enhance the process of waste collection, by providing alimony to such institutes new job employment sector can be enhanced which will be a boon to the economy of the country.

### **3) Compose model for PV waste compilation:**

Models for the compilation of PV waste are to be established. This can be practiced on a large scale for the development of recycling firms at a large commercial scale. For the fulfillment of the requirement of the model, waste compilation models are to be established. The following two models are discussed here as below.

a) Business to Business (B2B):

In this model, the Business-to-Business approach is followed. It requires that the solar plant manufacturer after the completion of its life cycle transports its waste to the solar waste recycler. This will be directly accomplished as a business setup between the solar panel manufacturing industry and the recycler. This will ensure an exchange of solar panels on a large scale. This model only ensures that the waste isn't thrown in the open yard without any hassle to the surroundings.

b) Business to Consumer (B2C):

This model provides a platform for the transfer of waste generated from the solar PV plant to the consumer only. It ensures that after the complete utilization of the solar plant it's the wholesome responsibility of the consumer only. It depends on the consumer how it is transferring the PV waste for recycling. The waste can be transported to the recycler or the recycler will take the waste from the consumer. In both cases, it's the responsibility of the consumer only to ensure safe and effective dealing with the recycler for the PV waste. The recycler will provide finance to the customer for providing them with raw material to run its firm on the PV waste. Here it

becomes the wholesome responsibility of the customer. This is also helpful for individual users of the residential PV systems. The B2C method can also be applied (the producer sells the waste to recyclers). The B2C method can also be applied by a producer to sell the waste to recyclers.

c) Utilization of a municipal collection point:

For the collection of solar PV waste, a municipal point is to be established. This will ensure the appropriate collection of the PV waste from either the manufacturer or the consumer for the effective working of the recycling firm.

#### **4) Launch of treatment method:**

a) A combination of both mechanical & thermal methods should be registered commercially:

To procure the material from the old and decommissioned solar PV panels efficient recycling methods should be applied to get the maximum output. According to the wide literature survey, it was concluded that for obtaining the maximum output PV material a particular method needs to be launched, which will deal with the hazardous and non-hazardous material during the recycling process. Mechanical and thermal methods upon combination are to be used for obtaining output economically. Though the thermal method possesses little environmental repercussions due to the high output in recycling, it is utilized more in comparison to the chemical method of recycling. The chemical method involves greater risk factors during treatment due to spilling of chemicals, after the utilization of this method chemicals are to be discarded which imparts greater health risk to the one who is handling it. While in a thermal method of recycling high temperature is utilized for the recycling procedure, the gaseous emissions can be handled by applying adsorbing materials to the outer walls of the vessel used for the treatment.

b) Risk factors of waste treatment should be established for the recyclers:

Before treating the PV waste, it becomes the topmost responsibility of the recycler to be aware of the waste it has received. Risks involved in the waste treatment should be well aware to them; measures to tackle the hazards are also to be analyzed and actions are to be formulated for them. Different category waste should be stored separately based on the risk involved. This procedure can be applied strictly after the

decommissioning of the waste solar panels.

c) Standardized infrastructure for the treatment should be available:

For carrying out the recycling procedures a standardized infrastructure is to be established with the ability to tackle all the risk factors involved. Such an infrastructure is to be set up away from the populated area so that lower risk is spread to the surroundings.

d) Optimal treatment method should be established and further registered:

An optimal method needs to be developed and registered so that from time to time up gradation can be made in the method for better results.

### **5) Disposition Corporation Endowment:**

A corporation is to be set up for the supervision of solar PV waste. It will deal straightway after the recycling process is done. This corporation will deal with the following tasks for the build-up of an effective corporation.

a) Survey usual recycling methods:

The usual recycling methods will be surveyed for looking into their process. Detailed analysis will be made on the governing recycling methods to find out their working efficiency for the treatment of waste.

b) Analyze the expenditure and industrial need for the efficient PV recycling system:

This corporation will analyze the expenditure of each recycling step so that account is to be established for the overall expenditure on recycling. On this basis, the feasibility of each procedure is to be evaluated.

c) Develop units to accumulate recycling materials:

After the recycling of material is finished, the recycled material is to be collected from the units and stored separately so that it can be supplied to the industries capable of utilizing it as raw material. In this way, profit can be earned from the recycled waste and will bring a new opportunity for bringing in finance to run the recycling firm.

d) Start-ups should supply recycled glass, aluminum, plastic, etc. to further industrial use:

Separate firms are to be established to supply recycled materials to other industries. Glass, aluminum, plastic, etc. can be exported to the needful sectors.

e) Hazardous material needs to be recycled separately and is to be stored in cement-based tanks where they can be acting like inert materials. Further, their disposal is a debatable issue and it can be solved by carrying out research work.

#### **6) Manufacturer Liability System (MLS) constitution:**

a) Abide the manufacturer to ensure the lesser impact of hazardous materials:

Manufacturers should hold responsible for the materials it is using in the manufacturing of commercial and non-commercial solar photovoltaic panels. It should be strictly tracked in the liability system at the manufacturer's end only to restrict the use of hazardous materials. Strictly actions to be taken against manufacturers who are not utilizing safe materials, such firms can also be knocked out from the registration list for failing the use environmentally safe category sources.

b) Utmost stringent responsibility of the producer to take back its product from the market after its complete life end:

This MLS system establishes the utmost responsibility of the manufacturer only to tackle the product it is manufacturing after the onset of its end lifetime. This can be carried out by the Business to Consumer approach.

c) PV waste treatment act should be in action:

After the set-up of the MLS system, a waste treatment act can be laid out which will further ensure the proper dealing of the PV panels and the waste generated from them. This act can be further linked to the currently practiced waste treatment acts in India for the treatment of components of solar panels. Firms that are failing to abide by the rules of the PV waste act are subjected to face the legal aftereffects.

## **7) Set up of a head body over all the solar PV industry:**

A head body is to be established in the solar PV industry so that monitoring of all the manufacturing firms involved in the solar sector is ensured legally under the guidelines issued. It will monitor the overall activity of the solar firms from manufacturing to decommissioning and recycling. Offenders will be strictly demarcated from the industry. This organization should also promote the use of sustainable materials in the design steps. The role of the head body will be very important in the recycling policy framework in the Indian scenario. It will keep surveillance on all the firms involved in the solar industry.

## **8) Financial aid:**

a) A federal government agency should be set up for the financial assessment of the PV industry:

For the effective working of the solar firms, the government should provide a financial assessment to enhance the responsibility of every firm associated with the solar industry apart from the manufacturer too.

b) Indian government should inculcate various monetary schemes for recyclers:

The financial provision can be better granted by initializing schemes to provide funds to recyclers. This will ensure the growth of the recycling sector to a new level. This way hazardous effects of the clean energy source have culminated in the environment.

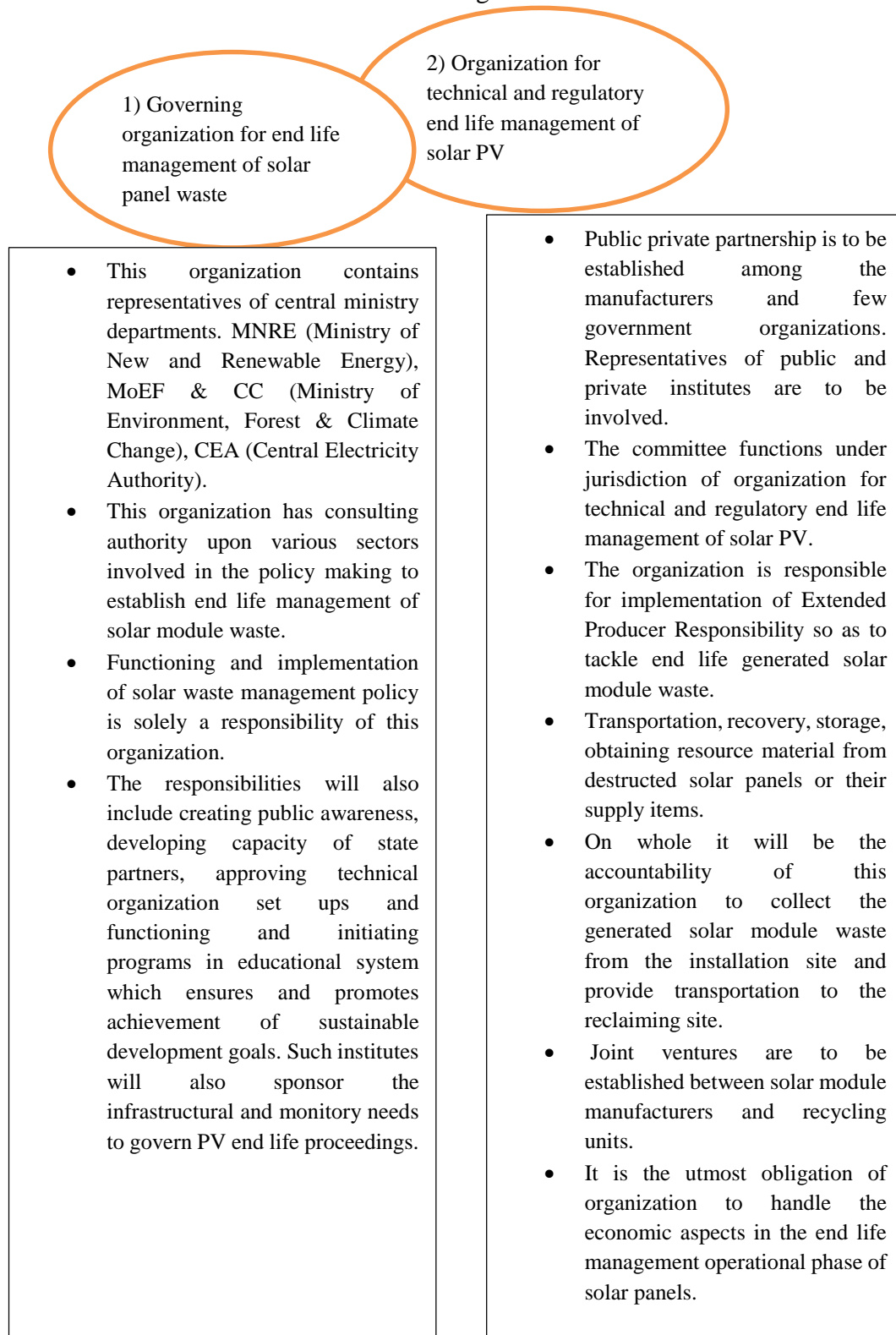
## **9) Recycling institution set up:**

a) India should establish institutes that will impart professional skills among the people involved in this field: With the growing PV waste and e-waste, separate recycling institutions are to be set up depending on the type of PV waste. By the end of 2050 millions of tons of PV waste will be piling up and this would require a huge land area. To tackle this treacherous amount of PV waste recycling institutes are to be set up across the corners of India to lessen their ill effects on the ecosystem. Such a step will be a boon for employment to the inhabitants.

b) Efficient implementation of the regulatory framework is to be ensured by coordinating the existing solar waste management policies of other countries and

analyzing literature. The following section provides a detailed End Life management working concept to tackle the solar module waste. The Government of India has stressed the Extended Producer's responsibility to be implemented by the stakeholders and agencies involved in the supply chain. Regional, national and local stakeholders all will be involved under this approach. The PV waste management is established in rhythm with the existing measures and legislation to streamline the waste. Stakeholders at different stages will also be provided with incentives, to provide a clear demarcation of their responsibilities. To tackle end-life management two committees are presented as follows.

## Committees to Tackle End Life Management of Solar PV



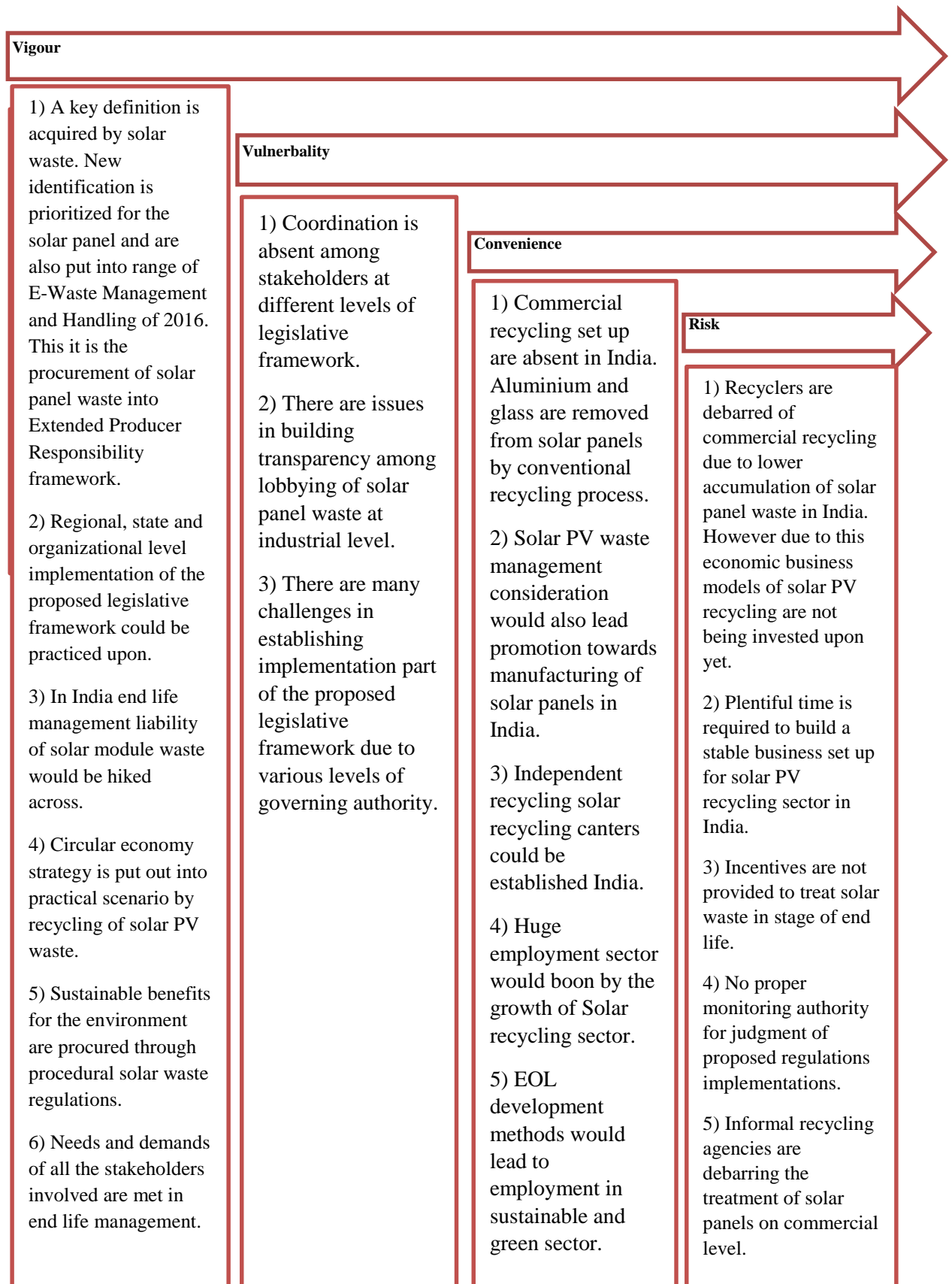
**Fig.6.8** Committees to Tackle End Life Management

The economic matters will include the costs at functioning stages of producer level, recycling level and destruction level, and collection of solar module waste from generation site. It will be the authority of only the producer to finance, report, and

provide information to the Organization for technical and regulatory end-life management of solar PV and Governing organization for end-life management of solar panel waste. This will be depicted as listed in the WEEE directives of the European Union to manage the end life of solar panels. The extended producer responsibility concept is the main key feature of the end-life management of solar PV systems. Governing organizations for end-life management of solar panel waste will deal with the overall economic matter further including the manufacturers and the suppliers of solar panels.

It is the manufacturers only who will be on elixir duty towards solar panel waste management in the solar industry. This governing body is fully envisaged with the Extended Producer Responsibility in recovering material by efficient business models. The proposed framework here depicts the Indian approach to handling solar PV waste. The regulatory framework proposed here can be adopted at the regional or industrial level. Taking into consideration the complexity and vastness of the system these policies should be first practiced at a small pilot scale. After initial testing, this could be applied to the entire Indian solar sector. Further vigor, vulnerability, convenience, and risk involved were analyzed fully to foresee its applicability in India. Based on VVCR analysis shown in Fig. 6.9 carried through available literature and expert consultation it was concluded that the proposed regulatory framework has the potential to effectively tackle the accumulated solar PV waste. An extended regulatory approach should be developed and adopted fully to deal with the waste.

With the rising waste amounts so anticipated the proposition here is of practical application. The framework proposed here pulls out the complete liability on the producer to ensure a formal multi-stakeholder approach in the system. Sustainable opportunities to provide jobs and establish circularity in the industrial sector of solar. According to the expert analysis, it was projected that the proposed regulatory framework will follow a lack of coordination and functionality due to in equivalent participation and sincerity from all the stakeholders involved in the process. This lagging coordination could hinder the implementation and running of the framework to ensure amendments in the legislation so proposed.



**Fig.6.9** VVCR analysis: Indian Solar PV Waste Management Regulatory Framework.

## **6.5. Conclusion:**

This article has outlined the global solar photovoltaic installations and the amount of estimated waste generation from them. After the adoption of WEEE directives in the European Union, these were put as national laws and scheduled upon all solar PV manufacturers to withdraw their product from the market or to make it reachable for recycling centers after its end life is completed. USA and Japan have not developed any regulatory framework for solar waste end-life management. The regulatory framework for solar waste collection, processing, and recycling is still lacking. These countries focused on research and development to regain the utilized outsources efficiently. California is processing regulations under Senate bill 489 through the California Department of Toxic Substances Control.

The Senate bill in legislative session 2014-2015 has established waste solar as universal waste. Senate Bill 5939 passed in July 2017 Washington state implemented the compulsion to withdraw the solar panels at their End of Life and to give them into recycling centers. However, there is still no National regulatory framework. Few manufacturers of solar panels themselves have initiated a recycling approach. US-originated company First Solar has commercialized recycling on a large scale. Ministry of Economy, Trade, and Industry (METI) together with the Ministry of Environment (MOE) in Japan developed end-life management plans in 2015 (Jariwala & Soni, 2021).

Recycling strategies that are prevailing in the current time for the installations across the different regions of the world are analyzed. WEEE directives have also been assessed and the waste materials so included in them have been investigated. Based on the directives of the WEEE, waste management of the solar photovoltaic modules has been carried out. Countries have adopted measures to tackle the compiled solar photovoltaic waste. The existing policies and recycling strategies practiced in the present times are discussed for the commercial and non-commercial solar PV modules. In the European region recycling of PV modules is practiced through the Business to Consumer and Business to Business processes.

In Business to Consumer process, it's the utmost responsibility of the manufacturers to sell their goods to the customers by abiding them to tackle their end-life treatment. While Business to Business process has quite a different approach for end-life

management depending on the fabrication of the PV solar cells and their size. According to the WEEE legislative in the UK all the manufacturers should possess registration for providing details regarding the Business to Business and Business to Consumer transactions. Financial support is provided for the transportation and PV recycling in Italy, for availing these incentives WEEE legislatures should be followed. Countries like Norway have implemented the compilation procedure to be followed at the Municipality. It has to arrange for all the requirements. Obtaining high recovery rates is the prime objective.

Also, the treatment of hazardous waste should be carefully executed. End-life issues of the solar photovoltaic modules are looked after by the Ministry of Environment and Ministry of Economy, Trade, and Industry. In the USA Senate bills have been passed for the initialization of PV recycling in California and Washington. It should also be the moral responsibility of the manufacturers, that if they are introducing some technology into society, it should also be laced with proper planning execution at its end of life for taking back the product in a clean sustainable manner.

China, India, USA still does not have any guidelines for the solar PV recycling policy. Though Research and Development Programme is taking some initiatives for policy making in the field of solar PV waste recycling. Companies from various niches of the globe like Solar World AG, First Solar, etc. have started some recycling frameworks for both commercial and non-commercial solar panels. Adoption of the recycling framework can be done from these. For effective management of the solar PV panels at their end life legislative policy should be constituted with attractive long-term business goals. European Union region countries have taken a little step in the recycling of PV panels. The rest of the regions of the globe should also take measures for framing sustainable solar PV recycling policies for a safer mother planet.

To know the ground realities of end-life management of the solar PV waste sector of India extensive qualitative evaluation was performed. This has helped in proposing forward the regulative framework. The solar PV waste management sector is deeply neglected and is left only in the hands of the informal sector dealing in scrap. Infrastructure to recycle and reclaim the materials from the solar panels is lacking. Also, a proper institute to handle this process commercially is not built up yet. The waste generated is left out in barren lands in an unscientific manner. This undisciplined

management of the waste has put forward environmental deteriorating effects in terms of the leaching of toxic substances into land and soil. Human health is also being affected. The proposed legislative framework here is motivated by the initiated regulations prevailing in developed countries. Consultation from the experts and DPSIR strategy was a great helping hand to assess the Indian situation of solar PV waste management. The legislative framework so proposed here could be effectively practiced at a regional and national level to flourish the engagement of diverse stakeholders. These are involved in the supply chain in cooperation at different levels.

Privileges of the proposed regulatory framework are as under:

- 1) Management of the solar panel waste should be incorporated at the level of the manufacturer so that this matter is handled at the levels of the very initial stage by enabling the Extended producer responsibility.
- 2) Research & Development is to be established at the technical levels to enhance the waste management programs at the country level.
- 3) Skill enhancement and educational precision are to be set up to tackle the waste in governing organizations in the nation.
- 4) Solar waste management drives should be established among the natives of the country.
- 5) With a proper managerial and operational set up a waste collection center should be established at the national and regional levels so that effective take-back system is established to reclaim materials from the worn-out panels.
- 6) Landfill treatment for solar waste is to be reduced or avoided and procurement of greenways to tackle the waste should be put forward.
- 7) Approach to managing solar waste can be adopted by the stakeholders at various levels.

On the wrapped corner present study has endeavored upon the analysis of gaps prevailing to rule out the solar waste management procedures in other nations and establishment of the functional legislative framework in India. This would be a great aid to regulate the end-life management of solar waste in India. The aforementioned legislative framework would be genuine enough to reduce health effects on the biotic components of the ecosystem originating due to impulsive scrapping of solar module waste

## **Chapter 7**

### **CONCLUSION**

Due to the end-of-life waste that solar photovoltaic panel mass production generates, which is expected to reach millions of tones by the middle of the century, there is a socio-environmental risk. Poor management of the world's PV waste can lead to a lack of access to renewable energy, hence neutral sustainability practices should be used. Adoption of sustainable PV waste requires combined effort towards environmental, economic, and social elements of PV waste. According to life-cycle-environmental studies, recycling PV can lessen these effects, with a considerable drop in human toxicity and freshwater Eco toxicity of about 78%. According to a social market survey, the local populace is ready to support recycling. Programs for mass training are advised for social acceptance.

EoL solar PV waste management is appropriate under self-standing EPR regulations. The rapid and widespread deployment of photovoltaic modules causes a significant amount of solar waste to be produced 2050. Resource recovery, circular economy, and consequent environmental impact reduction necessitate a rigorous recycling methods for recovering resources from PV end life. The recovery of tellurium, indium, selenium, and gallium from second-generation PVs and silicon, silver, copper, lead, and tin from first-generation solar cells are the key targets. The development of regulatory frameworks and guidelines, creative business models, and the expansion of local institutions' capacities as well as the PV recycling sector have all been found to be crucial towards PV end life management system.

Some nations that are only beginning to address the difficulties associated with PV recycling can benefit from the EU's experience in building legislative frameworks and best practices while also working closely with PV manufacturers. To significantly lessen the damaging effects of the production and recycling of solar panels on the environment, a closed-loop management system must be implemented. As was already said, the present processes for recycling solar panels are laborious and time-consuming. PV panels are made of materials such as gallium, indium, and germanium, but only silicon, which is used in the panel terminals, can be recycled. The subsequent release of solvent pollutants, another issue with recycling operations, can be lessened by using an activated carbon fiber adsorption recycling condensation device. To promote

economic growth throughout the chain comprising both production and consumption stakeholders, many measures are required. This brief review examined the viability of managing PV panel waste and offered several directions for future research and development in the PV industry to address the numerous challenges that still face this field's growth. The novel policy designed hereby can be successfully implemented for BSDU Solar Photovoltaic Plant to tackle the end-life waste generation and to establish it as a sustainable setup.

To understand models that might enable systematic change for economic purposes, policy officials, institutions, and the business community must work together. It is advised that stakeholders use a variety of tools within a regulatory framework to collaborate effectively on recycling agreements. PV module development should involve the usage of environmentally friendly materials. Manufacturers of modules should emphasize using high-quality materials throughout production. The LCA is crucial for designing the next panels in a way that minimizes the effects of recycling and increases recovery. In addition to the solar PV industry's rapid development, it is suggested that an appropriate strategy be used to recover and recycle EoL wastes.

To further protect the environment, Asian nations should build eco-friendly companies for handling and removing such trash. Therefore, it is advised that recycling become a requirement for all manufacturing firms following their EoL. In conclusion, the government must enact such regulations to make sure that all firms take the environmental impact of their waste into account. It is crucial to mandate that the entire solar manufacturing industry practice responsible behavior and recycle, reuse, and recover their products. Users must be made aware of PV recycling through the media and governmental institutions.

To deal with these suggestions are concluded as: when developing various PV plant components, all module makers should take the EoL stage for panels into consideration. Each stakeholder involved in the treatment of these wastes should have their obligations and responsibilities clarified. Collection, treatment, and disposal standards for PV waste are necessary. To handle waste, it is important to strengthen groups like producer responsibility organizations. It is important to promote agreements like reciprocal recycling between module makers, developers, and buyers. Surveys on recycling treatment could be used to raise awareness. Promotion should only be given to PV

recycling facilities that concentrate on high-value waste recovery.

The assessment of the sustainable management of solar PV panels is aided by this study. Future academics will be better equipped to understand the problems associated with recycling solar energy, which will help to promote sustainable development. The current study filled in the gaps between various stakeholders by examining their perceptions of the management of end-of-life solar waste and brought the issue of end-of-life photovoltaic waste before the government, policymakers, and waste regulators. The results unequivocally show that the key elements influencing the treatment of end-of-life panels are self-take-back collection and recycling facilities, material recovery, and recycling incentives. Understanding the results of the current study on consumers and manufacturers attitudes toward the problem of solar waste and their readiness to engage in recycling efforts is important for policymakers.

The study will serve as a database for the creation of a closed-loop supply chain, economic feasibility assessments, and life-cycle analyses, as well as aid decision-makers and researchers in their field research. For the efficient collection, disassembly, and recycling of e-waste, this study could be expanded to perform classifications of the metals present, a material flow analysis, and a cost-benefit analysis. International organizations, decision-makers, and communities are concerned about the deployment of PV waste management strategies. This has to do with making a long-term plan and putting it into action. It also has to do with life cycle environmental consequences. Last but not least, developing a global monitoring system that systematically tracks the quantity of PV waste and treatments on different scales, including microscopic, macroscopic, and mesoscopic levels, may aid decision-makers, investors, and businesses in developing more dependable solutions and potential management strategies.