



Current situation analysis of solar PV waste management in India

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ABSTRACT

Due to the current situation of coal extinction and over exploitation across the world. The energy demands of the world are to be fulfilled by the renewable energy sources. Among this solar energy has the maximum potential to be exploited to the maximum level to full fill the energy demands of the world. Since ages Sun has been praised as vitalizer of life. Per year 5000 trillion kWh energy falls on the India and most of the parts receive 4–7 kWh per sq. m per day. India has huge robustness for solar energy harnessing power. Solar energy is the most secure and ubiquitous source of energy to meet the power needs after coal exploitation. The growing installations of solar panels will lead to increased waste management. The paper presents core reality of existing solar waste management in India and barriers obstructing the managerial policy. DPSIR approach is utilized to effectively manage the end life of the solar panels. Comparative analysis between existing solar waste management policies in India and other countries across the globe has been established. Solar waste management strategies across the world have been evaluated and solar waste management policy has been proposed here for India. Further the operating success of the proposed policy has been evaluated on the basis of vigor, vulnerability, convenience and risk involved for future prospects. Utmost vigor and outcome of the proposed policy will be observed if they are implanted on every niche of waste generation through all collaborators.

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1. Introduction

Production of electricity with the usage of solar photovoltaic technology is the most promising after wind and hydro technology. With the availability of increased installations of solar panels, the energy production has risen to drastic a level in India and other developed countries [1]. Per annum 5000 trillion (kWh/year) solar radiations are received in India. Due to its location on tropical region India receives approximately 300 clear sunny days on yearly basis. If all the incident solar radiations are harnessed than India can procure surplus electricity to meet National power requirements. Solar holds extreme potential to meet the maximum energy requirements of India in context to other energy sources. With the increasing coal crisis across India solar energy can be explored to generate electricity. Numerous policies have been initiated by MNRE, NISE etc. in India to ensure quick development of electricity [2]. International solar alliance launched in the year 2015 aimed at

establishment of association with high insolation receiving countries. Through this energy requirement can be met up to huge extent. India has ranked fifth across the globe in grid connected solar power sector. Major achievements are established in the rural areas to provide them with electricity with the help of solar photovoltaic system. Indian government has initiated various schemes to upsurge the solar energy sector [3]. With the rising installations the solar waste accumulations will also rise to huge extent on their life cycle completion. Rising installations hold the due diligent crisis of waste management in terms of primary and secondary waste generated during and after their end life attainment. Components utilized in the PV system are under the waste generated in primary category.

2. Methodology:

Detailed approach analysis is established to understand the growing solar panel waste management scenario in India and further a framework of regulations is established. To know the existing realities of solar waste management in India the evaluation of

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exact problem and study of existing measures to handle the solar panel waste is executed in the study. To carry out this study existing available literature consisting of government organization reports, research articles, newspaper articles and other international agency reports were analyzed etc. Establishment of understanding the solar photovoltaic installations and their dissolution and further the challenges, barriers and opportunities in context to end life management of solar panel waste management. Through the literature complete life cycle analysis in terms of the inventory strings, constituent outpouring, infrastructure setup and other working setup to manage the solar panel waste of the nation.

Validation of the accumulated knowledge related to the ground reality of the solar panel waste in India is lured out with consultations of experts and through publications. Collection of data for the study was achieved through DPSIR (drivers, pressure, state, impact and response) design [4]. This specific design provided a comprehensive acceptance of the end life solar panel waste management of India. This will help in understanding the dire need of concern towards this issue before it is gathered as a havoc. The comprehension established would lead to the administrative fabrication of policies to look into this concerning matter. Governing approaches by the other countries for the regulation and management of end life solar panel waste management were analyzed critically. Through this analysis preferable and economically appropriate resolution for India could be enacted. Ceaseless pursual in context of keywords related to solar panel waste management was put forward to establish the understanding towards existing measures of solar panel waste management in different continents.

Various research papers were analyzed to yield out the concept of existing measures been practiced by the other countries. Strategies being run in other countries on the basis of their objectives and estimated potential outcomes to tackle the solar panel waste were thoroughly pulled together. This had helped in establishing a solar waste reclaiming policy for the Indian context. Presently available commercial recycling technologies were reviewed so that any of them could be initiated for Indian context. Different literature was analyzed to get detailed insight of the governing policies, inculcated key objectives, targets, obligations, enclosed benefits at levels of involvement of different stakeholders in different continents. Lastly the governing policies were analyzed to so as to upgrade them for practicality in India. The conducted evaluations were thoroughly looked over to establish a management strategy of regulations for solar PV waste pertaining in India. The framed strategies will take the involvement of each stakeholder in the supply chain to manage the solar PV waste. After the policies were established their vigor, vulnerability, convenience and risk factors will be evaluated to search for their continuing practicality.

3. Results & Discussion:

3.1. Core reality of Indian solar PV waste Management:

By 2022 estimation of 100 GW solar power plant installation target is setup 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 [5]. The increasing installations are only giving a message that the main focus of the Indian government is on the installations and not much in the waste management approach at the onset of end life of particular solar PV plant. Core realities of solar waste management in India are highlighted in this study using DPSIR plan of action analyzed through literature and consultation by expertise suggestions. DPSIR plan for Indian sce-

nario has been put forward here in Fig. 1 to effectively understand the management of solar panels at their end life.

Approximately 2.95 billion tons of solar panel waste consisting the solar panels and the balance of system will be accumulated from 2020 to 2047 [6]. For tackling this imminent waste amount an effective strategic planning is the utmost need of the approaching times. Rapid industrialization, increased standard of living, urbanization, raised energy demands of people and the availability of indispensable amount of solar energy in India are the promoting features or enablers for increased installations of solar power plants in India. These driving forces are promoting the way of Indian government to move towards the achievement of 100GW installation capacity by 2022 [7]. Besides the skyrocketing solar photovoltaic installations there is a prominent and dire need of identification of enablers related to resource recovery and management of solar photovoltaic waste. Solar PV installations in India are dependent on import from other countries due to zero commercialization of solar manufacturing [8]. Due to this the cost of the product on its end life treatment is increased as their lies uncertainty in the product import.

Utilization of semiconductor materials like Silicon, Germanium and alkali metals like lithium are cost consuming. Further the utilization of Silver in the manufacturing of solar panels is a major confrontation prevailing in the solar PV sector. These confrontations are also to be taken care at the end life management of solar panels. Synchronized and well-ordered approach needs to be applied for the reduction of resource availability at the end life management. Circular economy needs to be developed for the obtaining the utilized resources at end life management. 60% to 90% recoverability has been projected from the end life of solar panels [9]. Literatures accessed and the expertise views has revealed that there is a lack of commercial facility of recycling aluminum and glass utilized in solar panels. It is highlighted that the solar PV recycling sector is not even in its infancy stage. In India under the Extended Producer Responsibility guidelines the 2016 E -waste management rules were put forward for handling the solar PV waste [10]. Vagueness and absence of managerial regulatory framework in the collection, regulation, recycling and recovery from solar panel waste is putting a next level burden on the Indian solar waste management agenda. Major portion of the generated waste is dumped into the barren lands without treating it. Throwing away of the garbage in such a disorganized manner is an indication of lack of cooperation and responsibility among the personals involved in 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 nation [11]. 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 term of commercial policy making has to be practiced.

The same was projected though the expertise responses and by literature review. Extended producer responsibility, collaboration of solar panel manufacturers with the recyclers and collectors from the recycling centers at the end life are various governance approaches to be implemented as effective strategies. At this hour establishment and implementation of regulatory framework for tackling the solar PV waste is a concerning issue. Establishment of effective supply chain among the managerial sectors of solar industry, solar panel installing authorities, authorities which surpass the tenders of solar installations, manufacturing units of solar panels are utmost necessary for practicality and effective implementation of solar panel end life waste management policies in India.

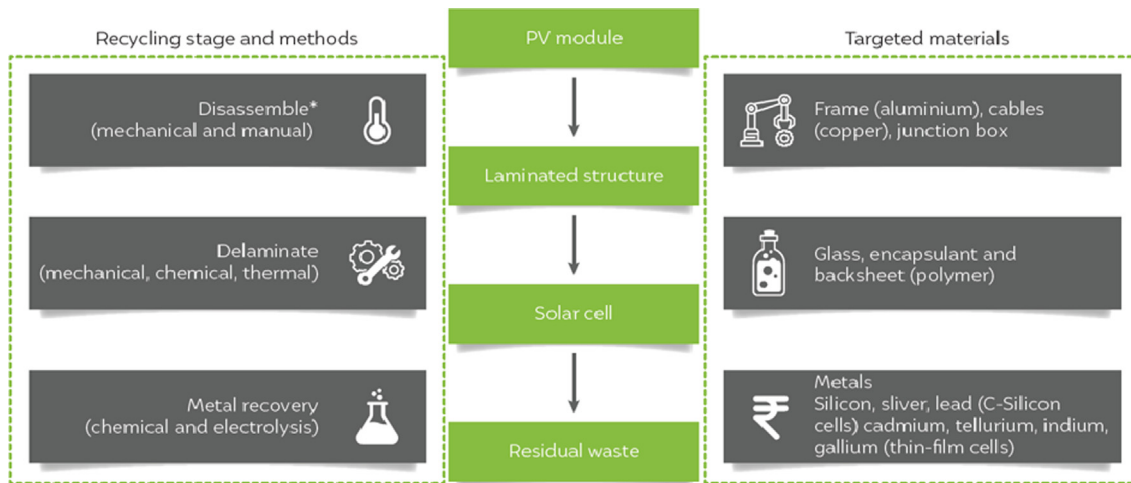


Fig. 1. Recycling of solar modules in multiple steps[14].

3.2. Solar PV waste management across the Globe:

Solar panels on reaching their end life are usually thrown away in barren areas or undergo casual recycling to obtain glass and aluminium. Supply of resource materials for the manufacturing panels is dependent on the naturally available metals. Resource recovery is quite an important prospective which is to be fulfilled so as to establish circular system. This can be achieved by establishing the concept of 4R which are reduce, reuse, recycle and recover. Through this sustainable agenda of development is to be achieved

[12]. The range of recycling material output in solar photovoltaic sector is 60 % to 90% [1]. 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 the 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 100GW 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.

2. Types of enablers:

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 [13].
- 2) Lack of conscious handling of solar panels has also contributed to the waste generation in process of

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.
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3. 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.
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4. 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 [14].
 - 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.
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5. 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
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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 centres 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
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Solar PV waste handling on larger aspect was sought after on 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 the solar waste for commercial treatment. Across the globe only 10% of the accumulated solar panel waste is undergoing any kind of treatment. This clearly 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 gain 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 end life of solar PV systems. Environmental damages occur due to disposition of solar panel waste in open areas resulting in leaching of harmful substances into the soil and water.

Mechanical, chemical and thermal recycling methods are prevalent at present. Removal of the laminating sheets, separating the integrated materials and further purification will extract the metals. These adopted methods are in pilot phase only. The given figure below depicts the present recycling management of the solar modules at their end life attainment. Across the world recycling of solar waste is at its nascent stage. To adopt the commercialization of recycling various business models are to be developed for economic level. Only a handful of the commercially available technology have been able to procure a good state in recycling business models. Approximately 90% of the solar PV installation market is ruled by the c-Si [13]. Fig. 1. shows the recycling of solar modules in multiple steps which can be adopted for Indian context.

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 into the lower usage of advanced solar panel technologies in developed countries. Along with this regulatory framework is to be developed so as to manage the end life solar waste management. In the entire study regulatory approach and policies for waste regulation were analyzed throughout the world. Fig. 2. depicts the overall regulatory approaches across different nations.

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 for adoption of WEEE directives 2012/19/UE was done by European Union. The effort has laid founda-

tion to promote the resource usage effectively by practicing recycling and reuse. Dumping of the waste in barren lands is discouraged substantially. The main work is performed through 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 [15].

After 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 canters after its end life is completed. USA and Japan have not developed any regulatory framework for solar waste end life management. Regulatory framework for the 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 the Senate bill 489 through 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 has initiated recycling approach. US originated company First Solar has commercialized recycling at large scale. Ministry of Economy, Trade and Industry (METI) together with Ministry of Environment (MOE) in Japan has developed end life management plans in 2015 [9].

It includes effective solar panel waste management through collection and recycling. Research and Development promoted in Japan have work towards end life management. In 2016 basic information to deal with end life management of solar panels was published for the first time. However, the developing countries are more attracted towards power generation through solar power plants than towards the end life management of the rising solar panel waste. Korea and China have initiated law to handle solar PV waste by recycling but this is still in the infancy stage and is on 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. Manufactures have only adopted Extended Producer Responsibility to handle solar waste. This will surely reduce amount of solar waste dumping into the landfill. This very similar regulatory strategy is to be adopted for Indian context. (See Figs. 3-5.)Fig. 6..

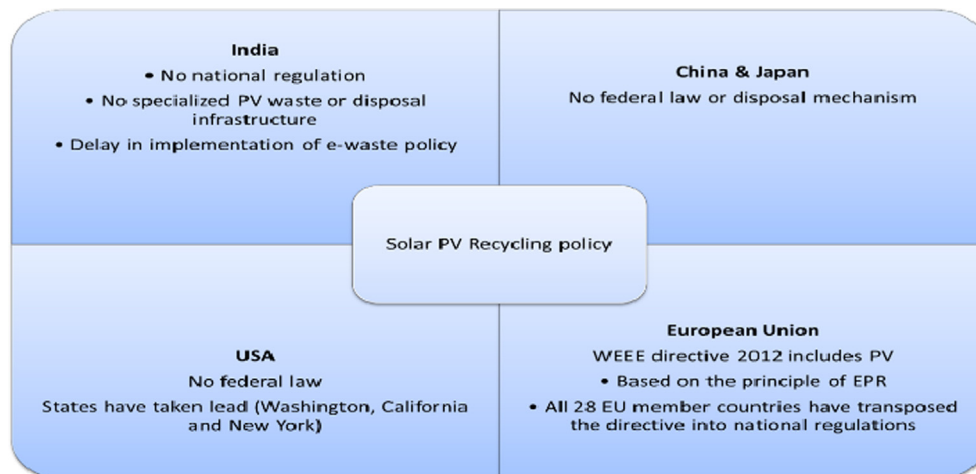


Fig. 2. Regulatory approaches across different nations.

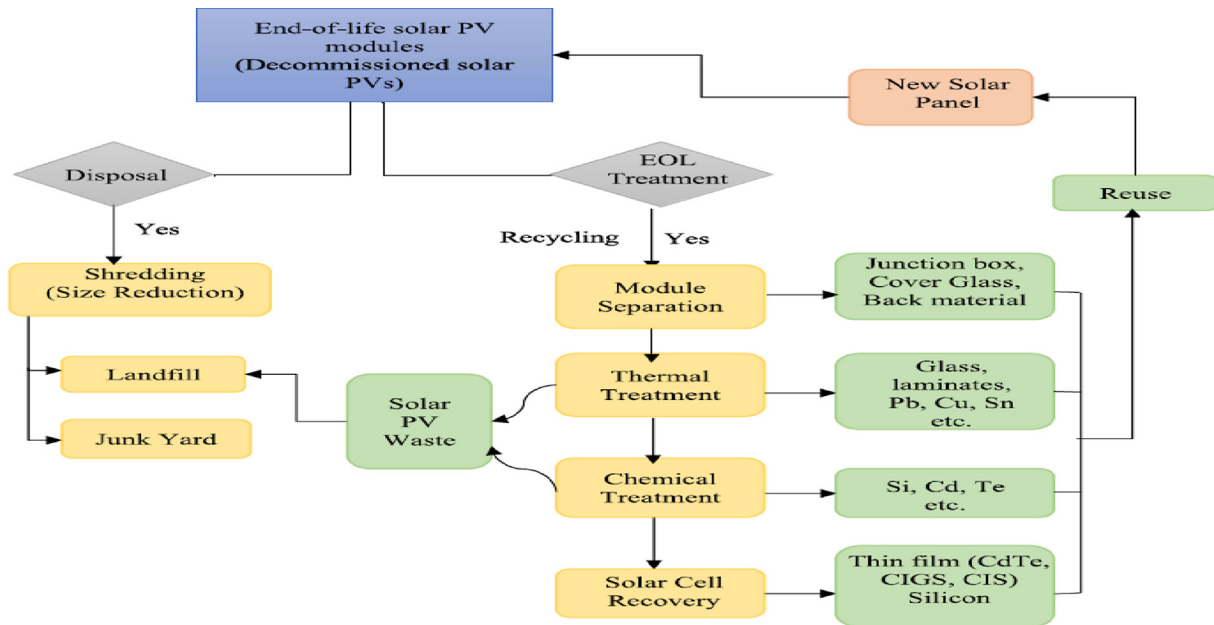


Fig. 3. Fate of solar PV modules at their end of life [16].

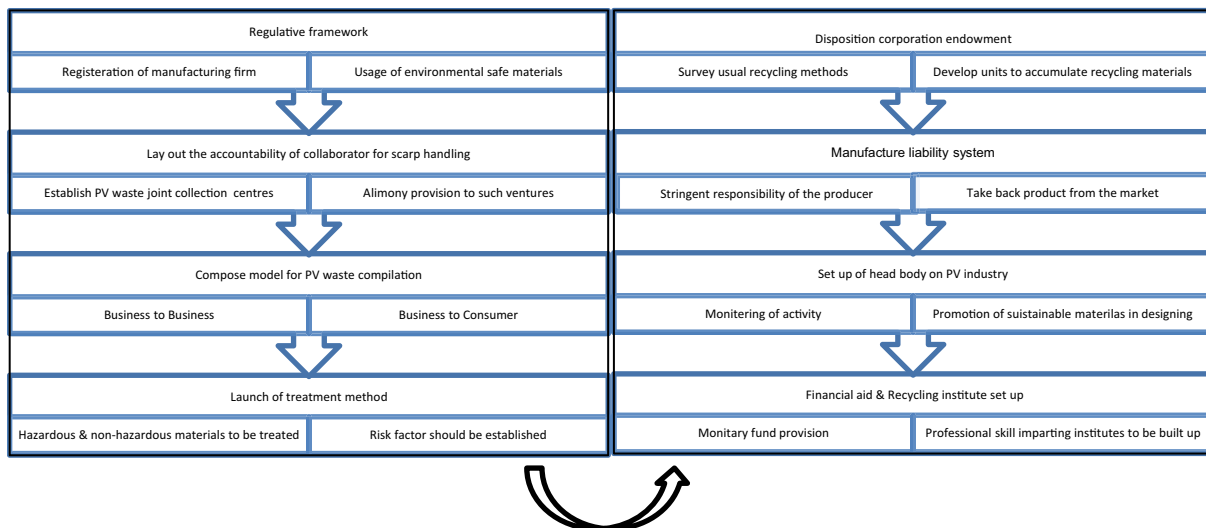


Fig. 4. Proposed solar PV regulatory framework for India.

Solar PV waste management in India through regulatory approach: Among the WEEE directives and the Indian landscape there is 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 upon Extended Producer Responsibility through directives of WEEE European and Indian E waste handling rules of 2016. Consumer based electronic waste is focused based upon 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 EU and India [17]. 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 the E-waste. This informal recycling system is a hindrance to the circular economy of solar panel waste management. Inclusion of Balance of 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 disorganized handling of solar panels in India. European Union holds integrated WEEE directives. These includes 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 upon. The present study highlights the proposed regulatory framework for India.

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

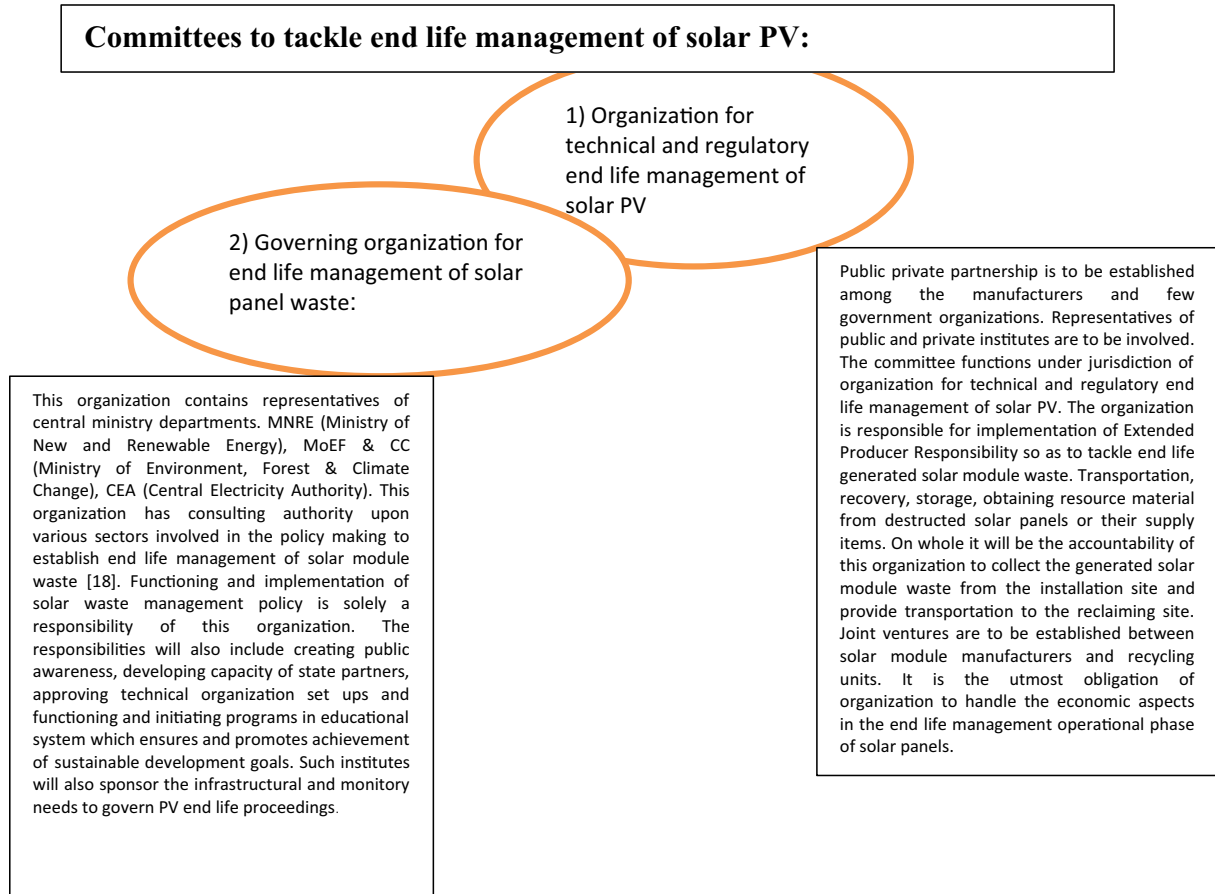


Fig. 5. Committees to tackle end life management.

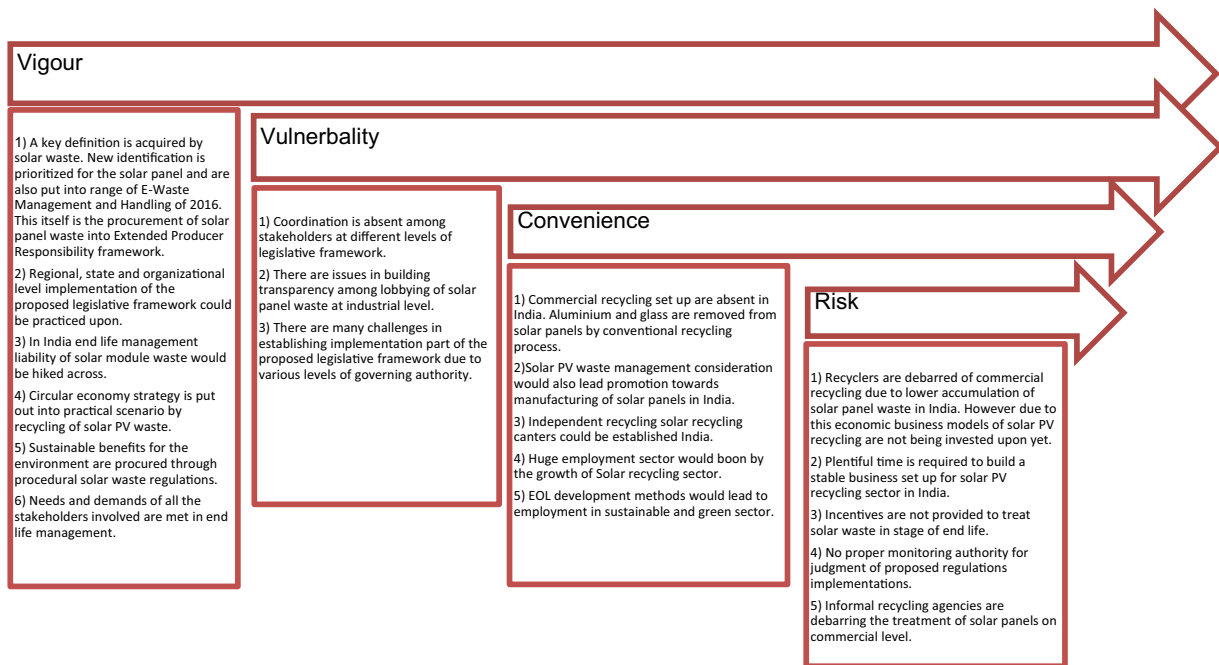


Fig. 6. VCCR analysis: Indian Solar PV waste management regulatory framework.

section provides detailed End Life management working concept to tackle the solar module waste. The Government of India has stressed upon the Extended Producer responsibility to be implemented at the stakeholders and agencies involved in 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 stream line the waste. Stakeholders at different stages will also be provided with incentives, to provide clear demarcation to their responsibilities. To tackle the end life management two committees are presented as follows.

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 with 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 European Union to manage the end life of solar panels. Extended producer responsibility concept is the main key feature towards end life management of solar PV system. Governing organization 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 [18]. It is the manufacturers only who will be in elixir duty towards solar panel waste management in solar industry. This governing body is fully envisaged with the Extended Producer Responsibility in recovering material by efficient business models. Proposed framework here depicts the Indian approach to handle solar PV waste.

Regulatory framework proposed here can be adopted at regional or industrial level. Taking into consideration the complexity and vastness of the system these policies should be first practiced at small pilot scale. After initial testing this could be applied over the entire Indian solar sector. Further vigor, vulnerability, convenience and risk involved were analyzed fully to foresee its applicability in India. On the basis of VVCR analysis carried through available literature and expert consultation it was concluded that the proposed regulatory framework has potential to effectively tackle out the accumulated solar PV waste. Extended regulatory approach should be developed and adopted fully to deal with the waste [19]. 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 formal multi stakeholder approach in the system. Sustainable opportunities to provide jobs and establishing circularity in the industrial sector of solar. According to the expert analysis it was projected out that the proposed regulatory framework will follow lack of coordination and functionality due to inequivalent 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 legislations so proposed.

4. Conclusion:

To know the ground realities of end life management of solar PV waste sector of India extensive qualitative evaluation was performed. This has helped in proposing forward the regulative framework as shown here in this paper. 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 build up yet. The waste generated is left out in barren lands in an unscientific man-

ner. This undisciplined management of the waste has put forward environmental deteriorating effects in terms of leaching of toxic substances into land and soil. Human health is also being affected. The proposed legislative framework here is motivated from the initiated regulations prevailing in the developed countries. Consultation from the experts and DPSIR strategy was a great helping hand to assess the Indian situation of solar PV waste management. Legislative framework so proposed here could be effectively practiced at regional and national level to flourish the engagement of diverse stakeholders. These are involved in the supply chain into 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 very initial stage by enabling the Extended producer responsibility.
- 2) Research & Development is to be established at the technical levels so as to enhance the waste management programs at the country level.
- 3) Skill enhancement and educational precision is to be set up to tackle the waste at governing organization 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 national and regional level so that effective take back system is established to reclaim materials from the worn-out panels.
- 6) Landfill treatment to the solar waste is to be reduced or avoided and procurement of green ways to tackle the waste should be put forward.
- 7) Approach to manage the solar waste can be adopted for the stakeholders at the various levels.

On the wrap 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 functional legislative framework in India. This would be a great aid to regulate the end life management of solar waste in India. Afore mentioned legislative framework would be genuine enough to reduce health effects on the biotic components of ecosystem originating due to impulsive scrapping of solar module waste.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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