Nature Protects if She is Protected

EU-REI
Creating a Resource Efficient India

Greening the Solar PV value chain

September 2018

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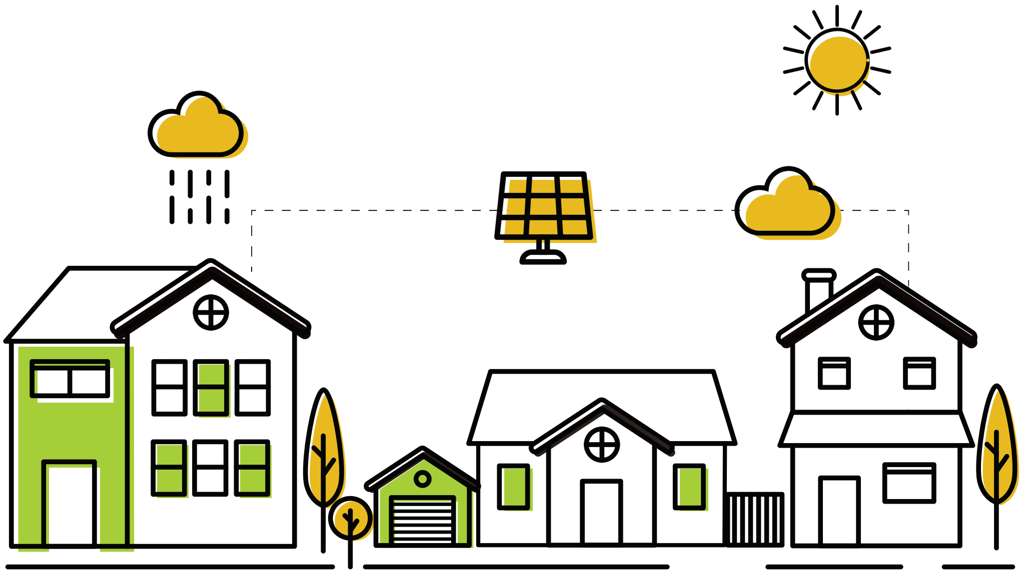

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About the project

Introduction

Economic growth of the 20th and early 21st century has contributed to widespread alleviation of absolute poverty across India. However, the modus operandi of the country's economy is still rested upon a linear "take-make-dispose" logic which extracts resources, transforms them into products and simply discards them at the end of life. Following such linear consumption and production patterns is highly resource intensive and represents a waste of valuable materials. In the light of increasing resource scarcity, promoting resource efficiency (RE) and integrating circular economy thinking becomes imperative and can contribute to the long-term availability of resources for inclusive economic development in India.

Towards an International Resource Efficiency Agenda

Having recognised the urgency of the issue, the Government of Indian (GoI) has actively engaged in international collaboration to implement global RE strategies, e.g. in relation to the 2030 Sustainable Development Goals (SDGs) which recognize the potential of resource efficiency in resolving trade-offs between economic growth and environmental degradation. In fact, RE strategies form a key part of Goal 12 (sustainable consumption and production) and Goal 8 (decent work and economic growth), but also links to other goals-sustainable cities and communities (Goal 11), industry, innovation and infrastructure (Goal 9), climate action (Goal 13), and affordable &clean energy (Goal 7).

Other important activities are carried out under the ambit of the G20 Resource Efficiency Dialogue which was launched in July 2017 by G20's Hamburg Declaration. According to the Declaration, the Dialogue has three core objectives: 1) exchange knowledge on policy options to increase resource efficiency; 2) sharing of best practices on resource efficiency along the entire product life-cycle; and 3) spread awareness on solutions and options to strengthen countries' national policies which reduce overall resource consumption. In addition, RE strategies can make substantial contributions to our efforts towards reaching the 2°C target (on limiting the global warming) and fulfilling countries' Nationally Determined Contributions (NDCs) as part of the Paris Agreement signed in 2015.

At the European level, the transition towards resource efficient economic model is reflected in the European Commission's (EC) Roadmap to a Resource Efficient Europe in 2011. Therein, a key component is the development of policies which encourage management of waste as a resource by means of reuse and recycling. In May 2018, the EC renewed its commitment to aim for more sustainable production and consumption practices by adopting the Circular Economy Package. Mobilising more than six billion EUR in funding under Horizon 2020 and EU structural funds, the Package defines several priority areas to improve the utilisation of critical raw materials which are typically found in packaging and Electrical & Electronic Equipment (EEE), the electric mobility sector (specifically batteries) and renewable energy.

Indo-European Collaboration on Resource Efficiency and Circular Economy

At the national level, the Indian government has given RE lot of priority as is reflected in various policies/programme announcements like Make in India, Zero Effect-Zero Defect Scheme, Smart Cities, Swacch Bharat, and Ganga Rejuvenation Mission. The government also seeks to strategically foster RE on a broader scale, and the country's policy think tank –NITI Aayog has published a national RE strategy paper. In the context of these recent developments, the European Union (EU) is providing support through its Resource Efficiency Initiative in India (EU-REI) in India which aims to facilitate the implementation of the UN global sustainable consumption and production (SCP) agenda by adapting international standards and best practices to the Indian context. More specifically, the initiative seeks to support the Indian government to identify and implement measures which can foster resource efficiency across four priority areas, including waste from plastic packaging and electrical and electronic equipment (WEEE or e-waste), buildings and construction sector, electric mobility and renewable energies (with a focus on solar photo voltaic).

Being implemented over the course of three and a half years (01/2017 to 7/2020), the EU-REI project will focus on assessing the production and consumption trends in selected sectors which are congruent with Indo-European interests and experiences in the above mentioned priority sectors. The project is being implemented on behalf of the EU by a consortium led by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and includes The Energy and Resources Institute (TERI), Confederation of the Indian Industry (CII) and adelphi. TERI analyses the scope and potential for enhancing resource efficiency and integrating circular economy thinking in the solar PV sector in India.

Enhancing Resource Efficiency and Circular Economy along solar PV value chain

Renewable energy, and in particular solar energy, will play a very important role towards achieving sustainable energy for all for India. However, the generation of renewable energy also faces relevant resource constraints. Wind energy, which forms the biggest part of India's renewable energy supply, often requires certain key metals. In state-of-the-art wind turbines with direct-drive permanent-magnet generators, about 550 kg of permanent magnets or 150 kg of neodymium (a rare earth material) is used per MW [Kleijn / van der Voet, 2010]. At the moment, very few wind turbines actually use direct drive systems with permanent magnets. Most turbines use electromagnets in geared generators, which are primarily made of copper and iron. Therefore, neodymium constraints will not only inhibit the large-scale application of wind turbines in general, but it will limit the market share of certain types of wind turbine systems. Other renewable energy technologies also consume highly specialized materials. A study conducted by the Raunhofer Institute suggests that some raw materials used in solar power technologies could become scarce compared to their demand in future scenarios, due to their limited recycling possibilities among other reasons [Angerer et al., 2009].

In 2010, India launched the renewable energy program- 'Jawaharlal Nehru National Solar Mission (JNNSM)', with an objective of deploying 20,000 MW of solar power by 2022 ,and revision in this target was made to 100,000 MW of which 60000 MW has to be grid connected and 40000 MW has to be rooftop solar. This will require supply and use of newer materials for manufacturing different solar PV technologies while maintaining cost competiveness in the sector and in this regard resource efficiency will be a key to achieving these objectives.

Multi crystalline silicon is the leading PV technology. Key materials that are used in manufacturing solar PV include silicon, glass, silver, aluminium and copper. While glass contributes to nearly two thirds of the material requirement, the shares for aluminium frame, silicon and silver are 18 percent, 4 percent and 0.1 percent respectively. Ethylene Vinyl Acetate (EVA) encapsulation takes up 5 percent of the share while the back sheet represents between 1 - 2 percent by weight. TERI estimates show that that by 2030, the solar PV sector will require 12 million tonnes of materials assuming that India adds 170 GW of PV based solar power generation capacity.

Given the scale of deployment of solar power that is envisaged, uninterrupted availability and affordability of materials among others are key for the success of the ambitious program if India becomes a manufacturing hub of solar PV. The PV industry is not immune from economic issues. For example, India depends heavily on imports of the materials particularly silver and copper and any change in prices will have impacts on these products. India produces only a small quantity of silver that is consumed in the country. The average volume of silver produced domestically in recent years has been 400 tons while silver import in recent years has been around 5000 tons. By 2030, the demand for silver in PV sector alone is likely to be close to the current average import of silver. Further, many of the panels that were installed over the last 10 years will be reaching their end of life in a decade posing many new environmental challenges. To avoid wastage of resources embedded in the panels at the end of life or use of recovered high valued materials in low cost applications, it is essential to make the solar PV value chain more resource efficient and circular.

There are challenges with regard to introducing break-through technologies in developing products that use recycled materials. But this is extremely important as demand for secondary raw materials will help reduce the import dependency of raw materials, encourage formalizing management of end of life panels including reverse logistics and reducing down cycling. The closed loop management of wastes/ scrap at intermediate levels, tracing mechanism of critical components through, labelling of resource efficient products, certification of used products etc., will further enhance the use of secondary raw materials.

Within the scope of the EU-REI project, this study presents the opportunities that the PV sector can create for resource savings along the value chain. Process innovation will reduce primary demand of resources. Further efficient recycling can help in recovering these materials, thereby making India achieve material security. Before India becomes a leading manufacturing hub of solar PVs, it is extremely important that an ecosystem is developed that can promote efficiency across the life cycle stages. Apart from improved product design and process re-engineering and a business model that can promote reverse logistics of end of life solar PVs for efficient material recovery, a conducive policy framework is the need of the hour that will further enhance establishing such an ecosystem in place thus making India’s solar PV sector most competitive.

At the same time opportunities can be created in terms sharing of good practices and knowledge between Indian and European stakeholders and in particular businesses.

1. India's journey in Solar PV Sector: Imperative for fostering resource efficiency

1.1 Background

With a total installed electricity generation capacity of 344 GW in 2018, which is significantly higher than the peak demand of 173 GW, India is still characterized by low per capita level energy consumption (670 kgoe and at 1075 KWh/year). India being a rising economy, it has been predicted that in future the energy demand, GDP and population would further increase significantly. As a part of India's pledge to the Paris Agreement India would contribute 40 percent of the installed capacity from renewables.[1,2]

Geographically located near the tropics, India is well endowed with natural and renewable sources such as solar, wind, biomass, small hydro and the like. Renewable energies hold a lot of potential in the context of energy security and decarbonization of the economy. It offers a plausible option to steer the energy system in the direction of sustainability by catering to energy requirements in an environmentally benign way. Consequently, renewables have become a high priority in the energy policy strategies at the national level.

Renewables, particularly wind and solar, have been given tremendous thrust by the Government of India (GoI) in the recent years. With an estimated solar energy potential of about 750 GW, the GoI has set up a capacity target of 100 GW from solar by the year 2022, comprising of 60 GW grid connected solar power projects (large and medium scale) and 40 GW rooftop (MNRE 2017-18). Further, India Energy Security Scenarios 2047 of the NITI Aayog show a possibility of achieving a high of 479 GW of solar PV by 2047[3]. This signifies the potential for the solar photovoltaic power sector to contribute to India's energy security. To capture the benefits of renewable energy, it would require large scale manufacturing and wider adoption of solar photovoltaic.

1.2 Initiatives towards promoting Solar Photovoltaic in India

India, as early as the 1970s, recognized the significant role that renewables can play for meeting its energy needs and transform the energy system to a sustainable path. Policy measures in renewable energy in India at the central level are administered through the MNRE - the apex Indian organization for policy making, planning, promotion, and coordination of various aspects with regard to renewable energy. MNRE has been supporting research, design and development in new renewables for more than two decades. To demonstrate the usefulness of PV technology the Ministry had initiated various field level programmes during the initial periods of PV development in India. To accelerate utilisation

1 Renewable energy sector as a whole is broad, ranging from solar, wind (offshore and onshore), hydro, marine (wave and tidal), biomass and hydrogen among others. The term new renewable energy usually excludes large hydro and traditional biomass as sources of energy.

2 Draft National Energy Policy, NITI Aayog, Government of India (Version as on 27.06.2017)

3 A range of institutions (both within and outside India) partnered with NITI Aayog to develop the tool. The tool is accessible at: http://www.indiaenergy.gov.in/iess/what_IESS.php

and exploitation of the solar energy, MNRE has initiated innovative schemes and incentives like subsidy, soft loan concessional duty on raw materials import, excise duty exemption on certain devices/ systems etc. To promote domestic manufacturing industry in solar photovoltaic, the government is providing incentives like exemption from import duties and making deployment of indigenous modules mandatory in some of the solar power projects. The details of schemes and the component of Central Financial Assistance (CFA) arepresented in table 1.1.

Table 1.1: Selected government schemes for promotingSolar Energy in the country

Sr. No.	Scheme	Central Financial Assistance/Subsidy
1.	Scheme for Development of Solar Parks and Ultra Mega Solar Power Projects	Rs.20 lakhs/MW or 30% of the project cost including Grid-connectivity cost, whichever is lower
		CFA @ Rs 25.00 lakh per park for DPR preparation of solar parks, conducting surveys, etc.
2.	Operationalization of 300 MW Solar PV Projects by defence establishment and para military forces	The bidders selected on the basis of bids for minimum VGF requirement for the project with commitment to supply solar power at Rs. 5.50/KWh for 25 years.
		The upper limits of the VGF are as follows:
		i. Category-I: Rs.2.5 crore/MW for project capacity up to 5 MW or 30% of the project cost whichever is lower;
		ii. Category-II: Rs. 2 crore/MW for project capacity greater than 5 MW up to 25 MW or 30% of the project cost whichever is lower; and
		iii. Category-III: Rs. 1.5 crore /MW for project capacity greater than 25 MW or 30% of the project cost whichever is lower.
		Keeping in view the technology upgradation and economies of scales, the upper limit of VGF was revised on 17.02.2017 to @ Rs. 1.10 Cr./MW for all projects irrespective of sizes for which tenders were not brought out.
3.	Scheme for Setting up of 750 MW Grid-connected Solar PV Power Projects under Batch-1 of Phase-II of JNNSM with Viability Gap Funding Support	The selection of the bidders has been based on the Viability Gap Funding (VGF) required for the project in an ascending order upto the full capacity. Viability Gap Funding (VGF) is limited to 30% of the project cost or 2.5 crore per MW, whichever is lower. Solar Energy Corporation of India (SECI) has signed PPA with such project developers for purchasing entire power from the project for 25 years at 5.45 Rs. per unit (4.75 Rs. per unit for projects availing accelerated depreciation).
4.	Scheme for Setting up of 2000 MW Grid-connected Solar PV Power Projects under Batch-III of Phase-II of JNNSM with Viability Gap Funding Support	The Project developer is provided a viability gap funding based on his bid. The upper limit for VGF is kept at Rs.1.0 Crore/MW for open category (Rs. 1.31 Crore/MW for projects in DCR category).

5.	Scheme for Setting up of 5000 MW Grid-connected Solar PV Power Projects under Batch-IV of Phase-II of JNNSM with Viability Gap Funding Support	The Project developer is provided a Viability Gap Funding based on his bid. The upper limit for VGF is kept at Rs. 1.0 crore/MW for open category and Rs. 1.25 crore/MW for projects in DCR category. SECI will select projects through competitive e-bidding based on minimum VGF sought (quoted in INR/MW), or there may be a provision for quoting a discounted tariff (quoted in INR/kWh).
6.	Grid Connected Rooftop	CFA is 30% of the benchmark cost for general and 70% CFA for North Eastern and Special Category States for residential, social and institutional sector.
7.	Pilot-cum-demonstration project for development of grid connected solar PV power plants on canal banks and canal tops	Financial support of Rs.3 crore/MW or 30% of the project cost, whichever is lower, for Canal Top SPV projects and Rs. 1.5 crore/MW or 30% of the project cost, whichever is lower, for Canal Bank SPV projects. Total CFA of upto Rs.225 crore for 100 MW (50 MW on Canal Tops and 50 MW on Canal Banks) to be disbursed over a period of maximum 2 years post sanctioning of the plants as under: i) upto 40% on sanctioning of the projects. ii) 60% on successful commissioning of the projects. iii) Service charge to SECI @1% of project cost.
8.	Scheme for setting up of 1000 MW of Grid-Connected Solar PV Power projects by Central Public Sector Undertakings (CPSUs) under Batch- V of Phase II of JNNSM	Viability Gap Funding (VGF) provided through SECI at a fixed rate of Rs. 1 Cr/ MW for projects where domestically produced cells and modules are used and Rs. 50 lakh/ MW in cases where domestically produced modules are used. i) 50% on successful commissioning of the full capacity of project (COD). ii) Balance 50% after one year of successful operation of the project.

Source: http://www.pib.nic.in/PressReleaseIframePage.aspx?PRID=1514462

In the recent years, tremendous thrust has been given and ambitious targets have been set to increase the share of renewable energy in the energy basket of India. To achieve the 100 GW target of electricity generation from solar under the National Solar Mission (NSM), the GoI has initiated a large number of policy measures with emphasis on reduction in cost and increase in efficiency.

A significant reduction in cost of solar (and wind power) has been achieved in the recent years through tariff based competitive bidding process with a lowest tariff of INR 2.44 per unit for solar. For transparent bidding and facilitation for procurement of solar and wind power, the government has notified the competitive bidding guidelines in 2017.

To promote renewables in the states having greater resource potential and to create a pan-India renewable power market, the GoI has waived the Inter State Transmission System charges and losses for inter-state sale of solar and wind power for projects to be commissioned by 2022. This would facilitate transmission of excess power generated to the resource poor states without additional financial burden. Consequently, Green Energy Corridor projects seeking creation of grid infrastructure for renewable power evacuation and for reshaping grid for future requirements,are being implemented by eight renewable rich States, and these will set up about 9400 circuit km transmission lines and Substations of total capacity of approx. 19000 MVA by 2020.

To reinforce government's commitment towards renewables the GoI has notified Renewable Purchase Obligation (RPO) trajectory upto the year 2019 and the process of further extending it upto the year 2022 is being pursued. Furthermore, Renewable Generation Obligation (RGO) has also been introduced by the GoI towards mainstreaming renewables by encouraging coal based thermal power generators to diversify into renewable energy portfolio.

The Government started a scheme in 2014 for setting up of 25 Solar Parks, which will be able to accommodate over 20 GW of solar power projects. The target for Solar Parks has been enhanced from 20 GW to 40 GW and 41 Solar Parks in 21 States with aggregate capacity of over 26 GW have already been sanctioned. To encourage participation by private parties and central public sector undertakings in setting up Solar Parks, the GoI has announced the New Solar Park policy.

To harness solar and wind energy potential optimally and address renewable energy variability, the GoI has notified Solar-Wind hybrid policy. Standards for deployment of solar photovoltaic systems/devices have also been notified for quality assurance. To create trained human resources and to generate employment opportunities in the sector, the Suryamitra program was launched by the government of India in 2015[4].

To provide a stimulus to domestic manufacturing of solar cells, efforts have been made to create an ecosystem. Expression of interest for setting up solar PV manufacturing capacities linked with assured off take of 20 GW has been issued. For setting up of renewable energy-based power generation projects and for financial and/or technical collaboration foreign investors can enter into joint venture with an Indian partner. Hundred Percent foreign investment as equity qualifies for automatic approval and foreign investors are being encouraged to set-up renewable energy-based power generation projects on build-own-operate basis. Accordingly, during last four years, over US$ 42 billion investment has been made in renewable energy in India. To boost end-to-end manufacturing of solar equipment - polysilicon, wafers, cells and panels , Viability Gap Funding (VGF) in the form of a financial subsidy is being offered to companies setting up integrated manufacturing facilities. To enable the manufacturers to compete on an even level with their global counterparts ,government if planning to announce a domestic solar manufacturing policy[5] The policy, being prepared by the Department of Industrial Policy and Promotion in association with the MNRE, is in pursuant with the Make in India policy of the government of India which recognizes solar manufacturing as an industry having "strategic importance".

Energy sector being a concurrent subject under the Indian constitution, energy development and environmental regulation is the shared responsibility and powers between the Centre and the states. There are independent regulatory commissions at the centre and in the states. CERC (Central Electricity Regulatory Commission) regulates the tariff of generating companies owned or controlled by the central government, including tariff that state government bodies pay for renewable energy. SERCs (State Regulatory Electricity Commissions) take measures conducive to an efficient electricity system in the state, safeguards interests of the consumers, and provide advice to the State Governments. To encourage rooftop solar plants, SERCs of twenty States have notified regulatory framework on net-metering and feed-in-tariff. So far, 16 Indian States have come out with Solar Policy supporting grid connected rooftop systems.

4. Over 18,631 Suryamitras have been trained under the programme up to 31 March 2018 and around 10 million man day's employment per annum has been created by setting up renewable energy projects in the last 4 years
5. https://www.pv-tech.org/guest-blog/new-government-policies-to-support-solar-manufacturing-in-india

The Ministry of Communications and Information Technology is supporting semiconductor production in the country and is providing investment support for the production of solar cells and devices. Research and technology development in solar energy is being coordinated by the National Institute of Solar Energy (NISE). The institute also conducts skill development programmes. MNRE has been supporting R&D projects undertaken by research organizations of central/state government, autonomous societies, Universities, recognized colleges, IITs and industries etc. on solar photovoltaic technology, and has been supporting the development of photovoltaic systems and components used in manufacture of such systems. Further, to contribute towards the common goal of increasing utilization and promotion of solar energy and solar applications in its member countries, International Solar Alliance (ISA) has become the first international intergovernmental organization headquartered in India.

Several organizations across different Ministry support the commercialization of renewable energy. Technology Development Board (TDB), established in 1996 promotes development and commercialization of indigenous technology and adaptation of imported technology for wider application. The public limited company – IREDA, established in 1987 by the MNRE, has been assigned the responsibility to commercialise PV technology in 1993-94. Since then it has been supporting through appropriate financing mechanisms the commercialization of solar PV technology in India. It provides revolving fund to financing and leasing companies offering affordable credit for the purchase of PV systems. The mandate of Solar Energy Corporation of India (SECI), a company of the Ministry of New and Renewable Energy, has been broadened to cover the entire renewable energy domain and efforts have been made to make it self-generating and self-sustaining by allowing it to own solar power plants generating and selling power and through other activities, including manufacturing of solar products and materials.

1.3 Solar photovoltaic market in India

India had total installed power generation capacity of 331.95 GW in 2017 from all resources. With 60.1 GW installed renewable power capacity, the renewable power has a share of about 18% to the total installed capacity.

Table 1.2: Renewable power installed capacity (MW) in India

	2014	2015	2016	2017
Solar	3062	4879	9013	14772
Wind	22465	25088	28700	32701
Biomass	4165	4678	8021	8182
Small Hydro	3990	4177	4334	4390
Total	33682	38822	50068	60045

Source: Annual Report, MNRE (various years)

Crystalline silicon (c-Si) modules represented 85-90% of the global PV market in 2015 whereas Thin-films accounted for 10% to 15% of global PV market[6]. The Indian solar PV manufacturing sector consists of crystalline Silicon (c-Si) cells and PV module manufacturing. At present, the production capacity in Indian PV industry is based largely on crystalline silicon. Although the manufacturing base of PV has been gradually strengthened so as to become self-sufficient in PV production, manufacturing of solar

6. https://www.nias.res.in/sites/default/files/GTWG.pdf

cells and PV modules has not kept pace with global trends. As per the information available, the installed capacity of Solar cells and Modules in the country is 1.4 GW & 5.7 GW respectively. This shows that there is inadequacy of the domestic cell manufacturing capacity to cater to the 5.7GW module manufacturing capacity. The slow growth trend in cell manufacturing capacity additions may be attributed to unavailability of raw materials, lack of technology know-how, lack of large-scale demand for domestically manufactured cells, and unskilled technical workforce[7].

1.4 Resource use related challenges for solar photovoltaic in India

Given that renewable energy, and in particular solar energy, has significant sustainable development implications, the country has tremendous scope of generating solar energy due to its geographical location. Large scale solar deployment will not only help in reducing the cost of power generation in the country and helping promote energy access, but the promotion of research and development in the context and the related technology transfer can enhance domestic manufacturing capability of components and products.

Silicon is the leading technology in making solar cells. However, due to high cost, considerable amount of research has been undertaken on newer generation thin film low cost technology. Three materials that have been given much attention under thin film technology are amorphous silicon, CdS/CdTe and CIS. Other materials that find application include copper, silver, iron, plastics, etc. There are further research towards development of third and fourth generation technologies using polymer or organic as solar cell materials. Polymer materials have many advantages like they are low cost, light weight and environmental friendly. A brief description of the technologies along with material intensity is provided in Table 1.3.

	First generation	Second generation	Third generation	Fourth generation	Next generation
Technology					
	Crystalline films	Commercial thin-film [a-SH, CdTe, CIGS]	Novel thin-film [NSC, PEC, CZTS, DSSC, OSC]	organics-in-organics [QDPV, PSC]	CNT based, Graphene based
Technology characteristics					
Active cell material	Crystalline silicon based	Amorphous silicon and semiconductor compounds	Semiconductor compounds and emerging/novel materials	Emerging/ novel materials	Emerging/ novel materials
Device structure and architecture	Wafer-based solar cells	Thin-film solar cells	Thin-film solar cells	Thin-film solar cells PSC	
Band gap		CdTe – 1.45 eV CIGS – 1.7 eV			
Efficiency		CdTe [21% - lab cells, 17.5% - modules] CIGS [20% - lab cells]			

7. Challenges to solar cell manufacturing in India (http://www.infracircle.in/category/opinion/policy-window/)

Technology resource/material requirement					
	Silicon (6629)	Amorphous Silicon	Poly phenylenevinylene	Perovskite	
	Silver (35.6)	Cadmium (138) Tellurium (156) Indium (28) Gallium (9) Selenium (161) Copper	Polythiophenes Indium Tin Zinc Copper	Gold	

Source: Compiled from various sources

Note: a-SH – Hydrogenated amorphous silicon; CdTe – Cadmium Telluride; CIGS – Copper indium gallium diselenide; NSC – Nanocrystal solar cells, PEC – Photoelectrochemical cells; DSSC – Dye-sensitized solar cells; OSC – Organic solar cells; CZTS – Copper zinc tin sulphide; QDPV – Quantum dot photo voltaics; PSC – Perovskite solar cells; CNT – Carbon nano tube

Figures in parentheses indicate Material Intensity (t/GW)

Given the scale of deployment of solar power that is being discussed in India, dedicated availability and affordability of materials among others are some of the critical factors for the success of the ambitious program in India. The PV industry is not immune from such issues. For example, India depends heavily on imports of the materials particularly silver and copper and any change in prices will have impacts on these products. There are also significant rooms for improvement of material usage during manufacturing and assembly of solar panels.

Further, many of panels that have been installed will be reaching their end of life in a decade and will pose new environmental challenges. However the PV waste also has the potential to create unprecedented opportunities for value generation for recycling businesses.

India has one of the largest renewable capacity expansion programmes. While it is a significant step towards meeting our NDC, there are challenges that need solutions with regard to tariff discovery, grid integration, storage, and human resources. Issues associated with material requirement are often ignored. Under the 'Make in India' initiatives making panels may get affected due to issues on solar PV material availability at affordable prices. Further, issues related to end of life management of Solar PVs and battery modules would be critical. In this regard, an integrated assessment covering material flow analysis, review of good practices (product and process innovations) in India and abroad on Secondary Resource Management (SRM) on solar PV and End of life polices for better management of wastes would be important.

Given the fast evolving photovoltaic sector in India, it calls for a detailed assessment introducing a resource (material) efficiency framework to answer the above issues in order alleviate existing pressures on natural resources and take advantage of the economic benefits of resource efficient production. The European Union supported resource efficiency initiative (REI) study on "Achieving Resource Efficiency in Solar Photovoltaic in India", will try to address the following questions and suggest elements of a roadmap for creating a resource efficient photovoltaic sector in India.

- What are the major resources that find use in solar PV technologies and how will the demand for these resources evolve in the near future?
- To what extent can secondary material management be achieved under the current scenario?

- What are the current policies (if any) and legislative framework (in India and abroad) that can promote material use efficiency in the sector and the kind of learning that can be drawn for the Indian context?
- What are the different best practices (including those related to technological interventions and use of standards) along the value chain in the solar PV sector existing across the globe and if and how they can be replicated in India?
- How to enhance consumer awareness on the need and role of resource efficiency in solar sector?
- How the issue of circularity and product standards and end of life management be addressed through existing and new policies?
- What would be the essential elements of a resource efficient PV policy roadmap for India?

2. Understanding resource use and efficiency potential in Solar PV sector

2.1 Introduction

This chapter presents a brief introduction of the available solar cell technologies followed by an assessment of the material composition of PV. The assessment is undertaken for a baseline scenario and a possible resource efficient scenario.

2.2 Types of solar panel[8,9]

There are a number of technologies available when it comes to solar cells. The three broad categories are crystalline silicon, semiconductor compounds and emerging or novel materials. The sub-categories for these technologies are listed in Figure 2.1

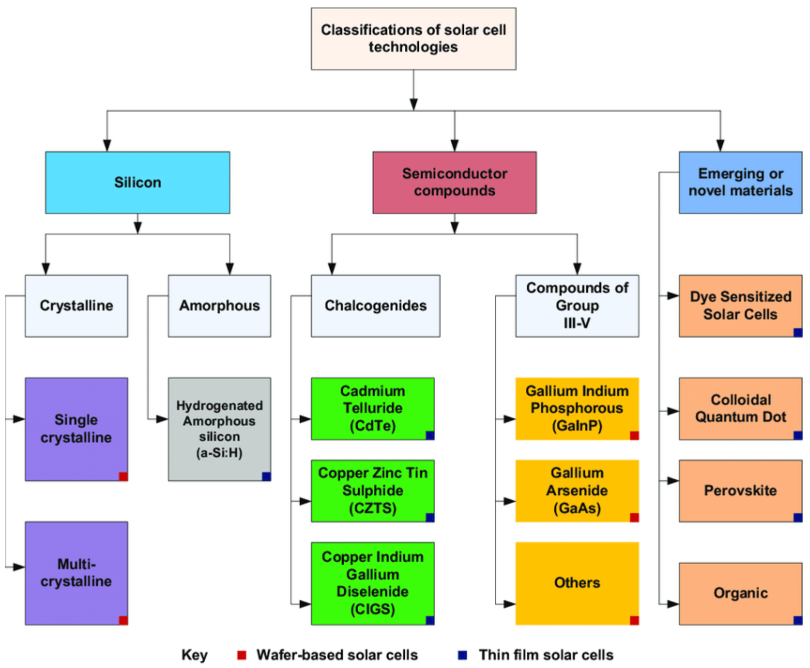

Figure 2.1: Classification of solar cell technologies

Source: https://www.researchgate.net/publication/317569861_Perovskite_solar_cells_An_integrated_hybrid_lifecycle_assessment_and_review_in_comparison_with_other_photovoltaic_technologies/figures?lo=1&utm_source=google&utm_medium=organic

8. Xu, Yan, Jinhui Li, Quanyin Tan, Anesia Lauren Peters, and Congren Yang. 2018. "Global Status of Recycling Waste Solar Panels: A Review." Waste Management.

2.2.1 Crystalline silicon

This is one of the most widely used technologies for building solar panels. The three prominent forms of modules within this include:

- Monocrystalline
- Multi-crystalline
- Amorphous Silicon (a-Si)

The monocrystalline silicon modules exhibit higher conversion efficiency while the multi-crystalline modules are comparatively cheaper and more resistant to degradation due to irradiation. Even though amorphous silicon modules are made up of non-hazardous materials, that make their disposal less problematic, the low efficiency rates and absence of materials of high value have led to the discontinuation of a-Si products. The dominance of crystalline silicon in world markets is primarily due to its reliability and longer service life. However, the main task at hand is improving the efficiency and effectiveness of resources consumed through a reduction in materials, and automation of manufacturing to name a few.

2.2.2 Semiconductor Compound

The semiconductor compounds can be categorized into the following two types:

- **Cadmium Telluride (CdTe)**

This technology is the second most widely used solar PV technology. The main selling point of this is that it can capture energy at shorter wavelengths unlike silicon panels. Their manufacturing costs are low and there is an abundance of cadmium telluride as it is a byproduct of a commonly used industrial element – zinc[10]. A major drawback of this is that cadmium is a toxic material. While it is not harmful for humans presently, disposing off degraded CdTe panels will prove to be problematic. Further, the efficiency levels of CdTe panels is not at par with those of silicon panels[11].

- **Copper Indium Gallium Selenide (CIGS)**

In case of CIGS, high light absorption is used as a semiconductor. Variation in the ratios of different elements in the semiconductor such as gallium, selenium and indium help adjust the light spectrum. They pose a significant competition to silicon panels in terms of efficiency. On the down side, CIGS too contain the toxic element cadmium. However, its presence is lower in CIGS as opposed to CdTe panels. The high production costs of CIGS panels acts as a barrier for them to compete in the market with the other technologies.

- **Concentrator photovoltaics and other technologies**
  - **Organic solar panels**[12]

    It has the potential to supply electricity at cheaper rate than electricity generated from other solar technologies. Different absorbers can be used to build organic photovoltaic (OPV) devices. Some of the benefits include- low manufacturing costs, ample availability of building materials etc.

    OPV cells are of two types-
    • Small molecule
    • Polymer based

10. https://www.energysage.com/solar/101/about-solar-panels/thin-film-solar-panels-amorphous-cadmium-telluride-and-cigs/
11. IBID
12. https://www.energy.gov/eere/solar/organic-photovoltaics-research

- **Hybrid panels**

Hybrid Photovoltaic/Thermal (PV/T) solar system is one of the most popular methods for cooling the photovoltaic panels. The hybrid system consists of a solar photovoltaic panels combined with a cooling system. The cooling agent, i.e., water or air, is circulated around the PV panels for cooling the solar cells, such that the warm water or air leaving the panels may be used for domestic applications such as domestic heating

- **CPV solar panels**

Concentrator photovoltaics (CPV) (also known as Concentration Photovoltaics) is a photovoltaic technology that generates electricity from sunlight. In contrast to conventional photovoltaic systems, this technology uses lenses and curved mirrors to focus sunlight onto small, but highly efficient, multi-junction (MJ) solar cells. In addition, CPV systems often use solar trackers and sometimes a cooling system to further increase their efficiency

- **Dye- sensitized solar panels**

The dye-sensitized solar cells (DSC) provides a technically and economically credible alternative concept to present day p–n junction photovoltaic devices. In contrast to the conventional systems where the semiconductor assume both the task of light absorption and charge carrier transport, the two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band semiconductor. Charge separation takes place at the interface via photo-induced electron injection from the dye into the conduction band of the solid. Carriers are transported in the conduction band of the semiconductor to the charge collector.

When making a choice between crystalline and thin films technology there are pros and cons for both. On one hand, crystalline technology has higher efficiency and requires less roof area (in terms of number of panels to be installed) to generate the same amount of power. They also tend to work better in warmer conditions than thin film technology. On the other hand, crystalline PVs have higher initial costs and in case of partial shading, some of the silicone cells may stop generating electrons and the efficiency of the panel will reduce[13]. Thin film PVs have shorter payback and are not as susceptible to shading issues as crystalline PVs. However, in comparison to crystalline technology, thin films require more land (i.e. more panels need to be installed) for reaching the same capacity level due to its relative lower efficiency. Moreover, their service life is usually shorter than that of crystalline technology[14]. On an average the thin films have a life of around ten years while that of the crystalline technology can be 25 years.

2.3 Assessing Material Composition of Solar PV

For the purpose of analysis, this report focuses on multi-crystalline solar PV technology for assessing the material requirement. This is largely because more than 80 percent of the total installations of solar PV in India are multi crystalline silicon technology, as revealed from interactions with the stakeholders and review of literature. The material flow for this technology is presented in the flow chart in Figure 2.2. The steps involved in the production of silicon modules include:

- Growing ingots of silicon
- Slicing ingots into wafers to build solar cells
- Interconnecting the cells electrically, and
- Enclosing the cells together to form a module.

13. http://switchtosolarnow.com/solar-101/crystalline-vs-thin-film-modules/
14. IBID

Starting from the production of silicon to the assembly of modules, each stage makes use of different product and process input materials.

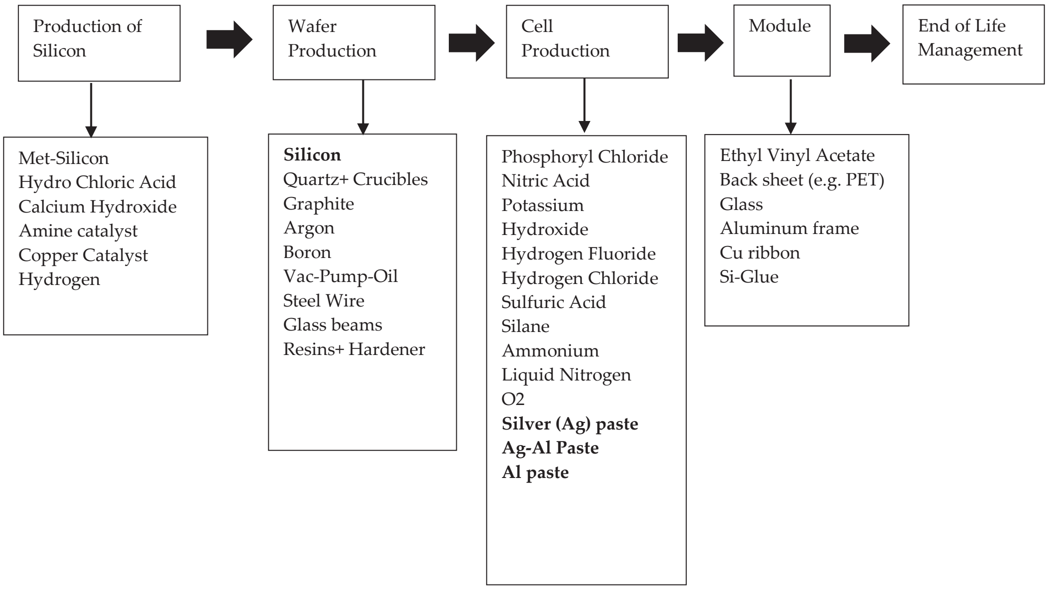

Figure 2.2: Key materials that are used in manufacturing silicon solar PV

Source: Based on interaction with different stakeholders

As is evident from figure 2.2, key materials that are used in manufacturing silicon solar PV are silicon, glass, silver, aluminium and copper. Review of selected literature with regard to this material composition reveal that nearly 70 percent of the mass composition of 1000 Kg of PV weight comprises of glass. The corresponding shares for aluminium frame, silicon and silver are 18%, 3.65% and 0.053% respectively (figure2.3). EVA encapsulation takes up 5.1% of the share while the back sheet represents 1.5%.

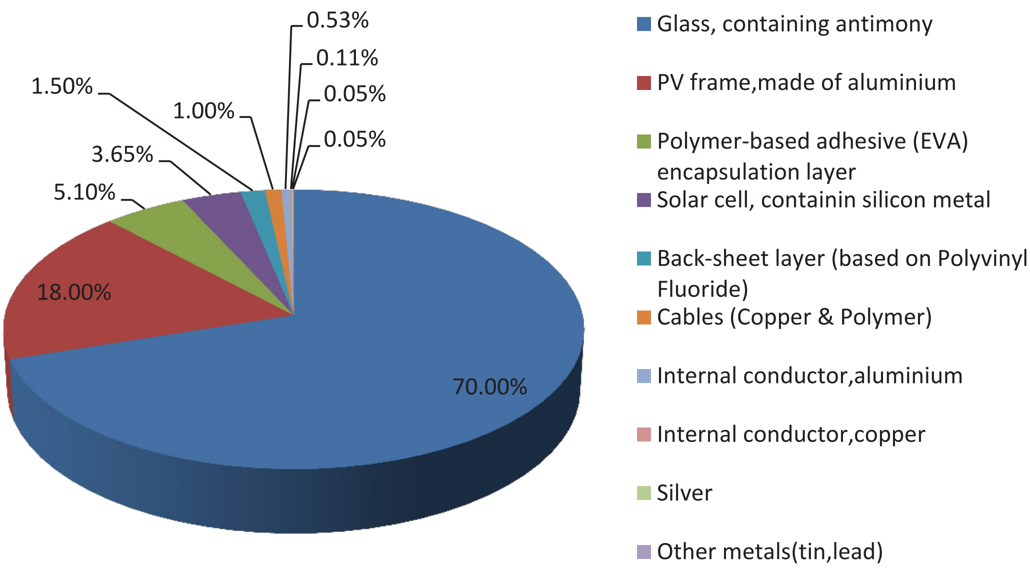

Figure 2.3: Material composition in a crystalline solar PV (by weight percentage)

Source: https://www.scribd.com/document/360791571/1-s2-0-S0927024816001227-main

2.4 Estimated material demand under baseline scenario

According to the estimates arrived at by NITI Aayog[15], India is expected to have an installed capacity of 160-170 Giga Watts (GW) of solar solar PV by 2030, under ambitious RE scenario, as compared to the 5 GW of installed capacity in 2015. The total demand, estimated for different materials, over the period of 2015-2030, for using multi-crystalline silicon PV is provided in figure 2.4.

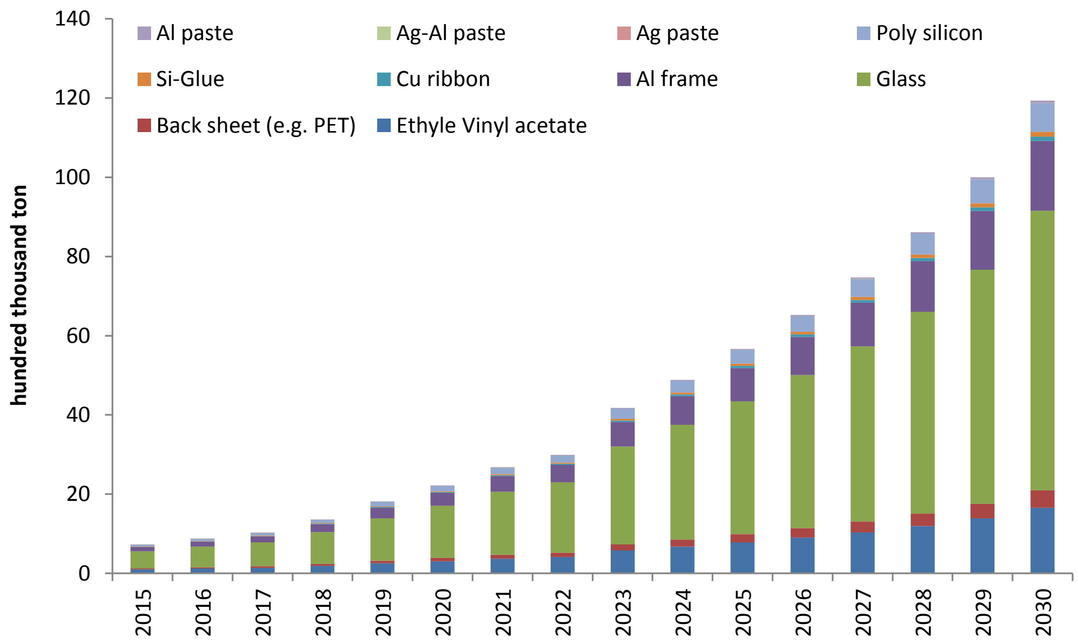

Figure 2.4: Estimated requirement of materials for manufacturing crystalline solar PV in India

Source: TERI calculations

Under the assumptions that there is no improvement in kerf-loss during wafer manufacturing from silicon, average consumption of silver per cell remaining constant at 170mg, having thickness of front glass at 3.5mm and no modification in aluminium frames, the total requirement of key materials is expected to increase from 700 thousand tons in 2015 to 12000 thousand tons in 2030. The relative material share of silver, aluminium, glass and polysilicon (by monetary value) are 47%, 26%, 8% and 11% respectively(International Renewable Energy Agency 2016). An added reason behind the focus on these four materials is their relative importance in terms of price, availability, criticality etc.

As is evident from the graph, the demand for glass will reach 7057 thousand tons in 2030 from 432 thousand tons in 2015. Demand for aluminium is estimated to be more than 1700 thousand tons from its current level of 108 thousand tons. From an initial 233 tons of silver demand is likely to reach 3810 tons by 2030, while poly-silicon consumption estimated to reach 730 thousand tons.

India produces only a small quantity of the silver that is consumed in the country. Most of it is imported from countries such as China, United Kingdom, Australia etc[16]. The average volume of silver produced domestically in recent years was roughly 400 tons[17,18], and the average volume of silver imported

15. http://iess2047.gov.in/pathways/22202222222222220222222222201222220222222221120222020222022222/primary_energy_chart
16. http://www.commoditiescontrol.com/eagritrader/staticpages/index.php?id=75
17. 426443 kgs (2015), 460811 kgs (2016) ; average =443627 kgs ; 489.02 tons.
18. http://www.24hgold.com/english/stat_country_detail.aspx?pays=India&deid=29364B1670

between 2015-2017 was 5000[19] tons[20,21]. Given the ambitious target of reaching 170GW of installed capacity by 2030, the situation of import dependency for silver is not likely to change. By 2030, the demand for silver by the PV sector alone is likely to be close to the current average import of silver.

2.5 Estimated material demand under resource efficient scenario

The resource efficiency opportunities for various materials largely involve process innovation that minimizes wastages, creates opportunities for material substitution or doing away with consumption of materials. In the context of PV cells the same can be achieved by reducing kerf-loss with the use of Diamond Wire Sawing technology, reducing the consumption of silver by substituting it with copper and other alloyed materials, reducing the thickness of front glass and introducing frameless modules to decrease aluminium consumption. The following sections briefly present these opportunities and the expected penetration of interventions between 2015 and 2030.

2.5.1 Slurry based wafering and Diamond Wire Sawing

The standard slurry based silicon wafering technology leads to significant amount of kerf loss. In order to remedy this, Diamond Wire Sawing technology is introduced, which will help reduce the consumption of silicon by 15%, as a result of improved cutting. According to the ITRPV Report[22], between 2015 to 2030, it is expected that the production process will shift from 100 % to 5 % slurry based technology. Correspondingly, the share of production carried out via the electroplated diamonds production will rise from 0% in 2015 to 95% by 2030. The comparison of trends in the consumption of polysilicon between the baseline scenario and the RE scenario can be seen in figure 2.5.

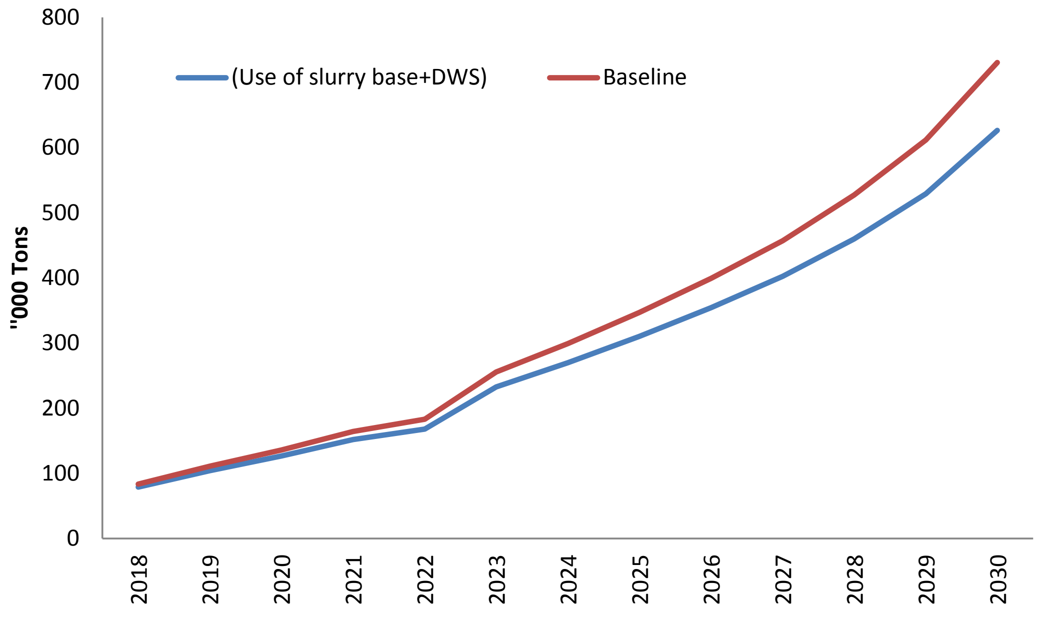

Figure 2.5: Estimated material consumption by moving from slurry based wafering technology to diamond wire sawing

Source: TERI calculations

19. 7955 tons (2015), 2794 tons (2016), 5188 tons(2017); sum total=15937 tons
20. https://www.business-standard.com/article/markets/silver-imports-surge-on-the-back-of-strong-industrial-demand-117112200760_1.html
21. http://www.mydigitalfc.com/companies-and-markets/silver-imports-nearly-doubled-2017-thanks-gst
22. http://www.itrpv.net/Reports/Downloads/

2.5.2 Substituting silver with copper or other conducting materials

The estimated weight of silver used is 170 mg/cell as was the practice in 2015. It has been found in the report by ITRPV, that the median consumption of silver for the year 2017 has come down to 100 mg/cell and is 90 mg/cell for 2018. It is expected that by 2030 the weight will be reduced further to 50mg/cell. Copper (or other alloys), being relatively less expensive materials are expected to be used as a substitutes for silver. The trend in silver consumption between the two scenarios is depicted in figure 2.6.

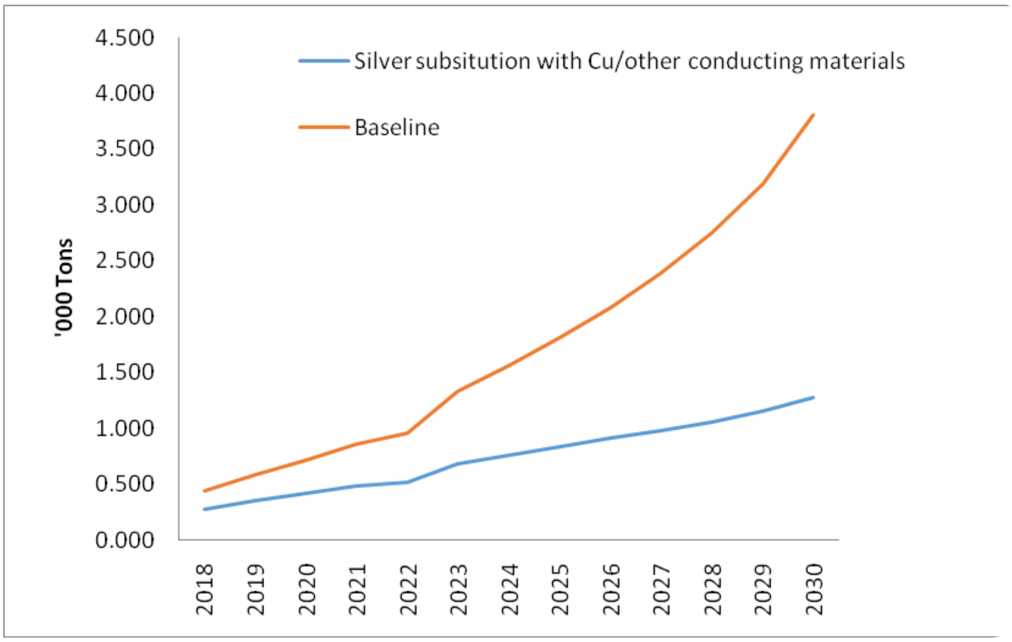

Figure 2.6: Estimated material consumption by substituting silver with copper or other conducting materials

Source: TERI calculations

2.5.3 Reducing thickness of front glass

The average thickness of the front glass used in a panel is 3.5mm. It is expected to reach 2 mm by 2030. Anti- reflective (AR) coatings are commonly used for improving the transmission of the front glass. It is expected that the dominance of AR coated glass will continue even in future for crystalline silicon PV modules, with their market shares in excess of 90%. From an earlier consumption of 100 % glass in 2015, it is expected that by 2030 their consumption would come down to 57%. The comparison with the baseline scenario of front glass thickness of 3.5 mm with the RE scenario of reduced thickness is shown in figure 2.7.

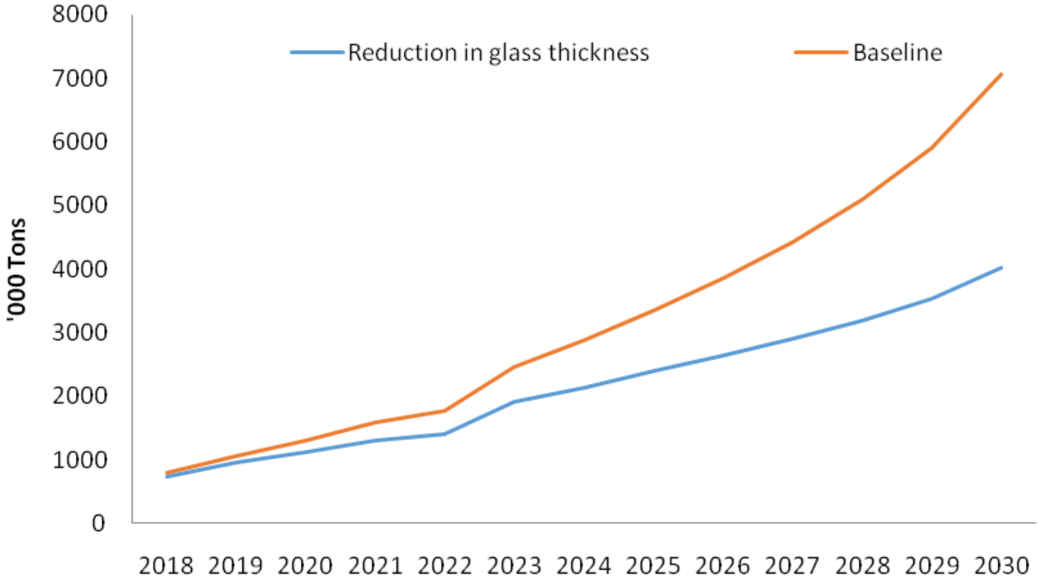

Figure 2.7: Estimated material consumption by reducing thickness of front glass

Source: TERI calculation

2.5.4 Aluminium frames and frameless modules

At present, modules having aluminium frames are dominating the market. It is expected that frameless modules will have a market share of approximately 28% by 2030. The share of frameless modules was very low at 2% in 2015 as reported in ITRPV report and emerged from stakeholder. With increased deployment, there will more production of frameless module and reported to reach 28% by 2030. Hence, 72% of the installations will have use of aluminium frames. Further plastic frames are also likely to emerge as alternate framing materials. Hence, the implication of moving to frameless modules or plastic frame modules implies reduced consumption of aluminium over the years as presented in

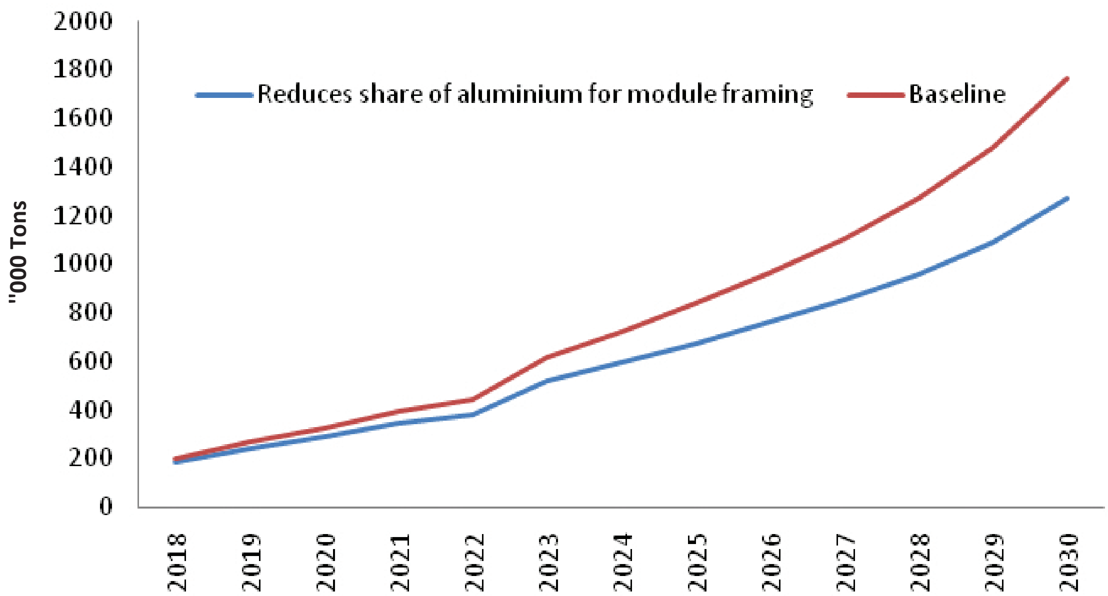

Figure 2.8: Material consumption using frames and frameless modules

Source: TERI calculation

2.5.5 Material consumption under RE scenario

Based on the above estimates, the material consumption in the resource efficient scenario, thus arrived at adding the estimated consumption of materials from the interventions as presented in the earlier sections, will increase from 0.7 million tons to 8.2 million tons.

2.5.6 Comparing estimates for resource consumption between the two scenarios

Comparison of two scenarios, viz. the baseline and that of the RE scenario (arrived at adding the estimated consumption of materials from the interventions as presented in the earlier sections) reveal that an estimated 12 million tons of material will be demanded under the baseline scenario, as compared to the 8.2 million tons under the RE scenario. The latter provides an efficiency of more than 30% by 2030 from an earlier 6% in 2018. This is presented in figure 2.9.

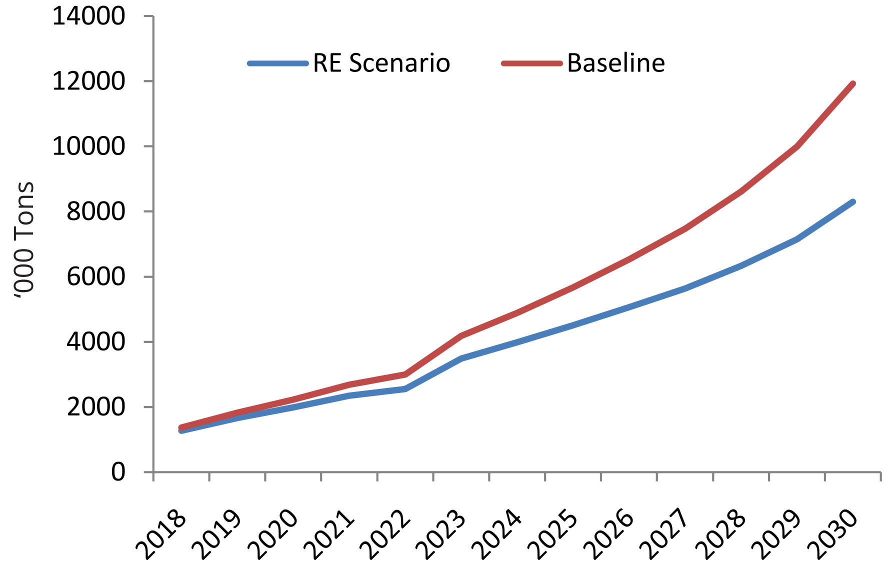

Figure 2.9: Comparison of material consumption under Baseline and Resource Efficient Scenario

Source: TERI Calculation

2.6 Conclusion

This chapter has presented material requirements for the baseline and RE scenarios. The potential respective savings with regard to improved use of silver, aluminium, polysilicon and glass have been highlighted through the differential material requirement in the RE scenario compared to the baseline scenario.

The resource efficiency opportunities for various materials largely involve process innovation that minimizes wastages, creates opportunities for material substitution or doing away with consumption of materials. In the context of PV cells the same can be achieved by reducing kerf-loss with the use of Diamond Wire Sawing technology, reducing the consumption of silver by substituting it with copper and other alloyed materials, reducing the thickness of front glass and introducing frameless modules to decrease aluminium consumption. For example, the standard slurry based silicon wafering technology leads to significant amount of kerf loss. Other possible interventions include substitution of silver with copper or other conducting materials, reducing thickness of front glass, moving to frameless modules or modules that use plastic frames.

Comparison of two scenarios, viz. the baseline and that of the RE scenario reveal that an estimated 12 million tons of material will be demanded under the baseline scenario, as compared to the 8.2 million tons under the RE scenario. The latter provides an efficiency of more than 30% by 2030 from an earlier 6% in 2018.

3. Mapping Resource Efficient practices along the Solar PV value chain

3.1 Introduction

The PV sector has the potential to create unprecedented opportunities for resource savings along the value chain. Process innovation will reduce primary demand of resources. Further efficient recovery of wastes generated at different stages of the life cycle and recycling can help in material security for the sector. Before India becomes a leading manufacturing hub of solar PVs, it is extremely important that an ecosystem is developed that can promote efficiency across the life cycle stages. Apart from improved product design and process re-engineering and a business model that can promote reverse logistics of end of life solar PVs for efficient material recovery supported by a conducive policy framework is the need of the hour that will further enhance establishing such an ecosystem in place. The various stages involved in the life cycle of solar panels include the following:

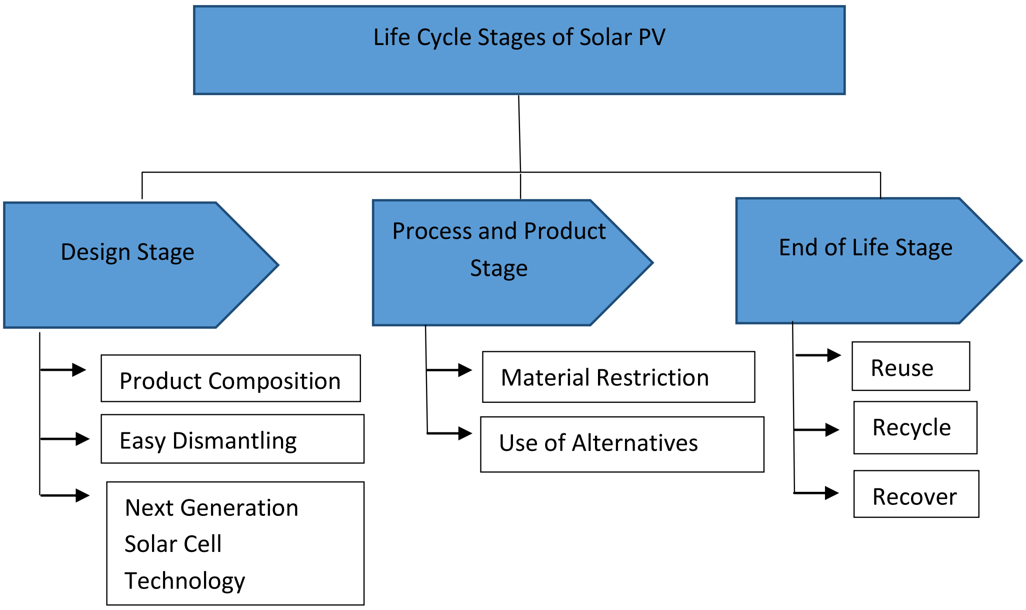

Figure 3.1: Life cycle stages of Solar PV

In the sections that follow, we look at some of the best practices that have been adopted, for attaining resource efficiency across the PV value chain.

3.2 Design Stage

The way the panels are designed is of particular importance, as it plays a central role in how the degraded components of the panel are repaired, refurbished, remanufactured or dismantled, or for extending the use life. In case of a standard module, the cells are connected electrically in a series and then assembled into a module. Suitable power output is ensured by a junction box. The components of the module are attached to each other through lamination and soldering. Thus, any potential recycling involves destructive processes (such as shredding), resulting in inefficient recycling and recovery of contaminated materials that cannot be reused for further purposes[23]. Keeping in mind the need for easy dismantling of the panels at the end of life stage, the panel has to be designed in such a way that:

- Any additional damage to the panel in the course of dismantling, collection or transport is minimized.
- Easy recovery of valuable materials like silver, copper, aluminium etc.
- Labelling for possible product recyclability, content of recycled materials.

(Adapted from IRENA 2016)

3.2.1 Improved design for better dismantling

Apollan Solar has designed a module called New Industrial Cell Encapsulation (NICE) that facilitates easy dismantling[24]. The technology adopted makes use of pressure contacts to interconnect the cells rather than soldering them together. Instead of using EVA (Ethyl Vinyl Acetate) like encapsulation (as is the case with standard modules), NICE modules make use of Poly-Isobutylene (PIB) sealing, that acts as a barrier against moisture ingress[25]. A 'pick and place' system is used for placing the module cells and contacts in a series on the rear glass. A sealant material is applied along the perimeter of the glass and the front glass is placed on top. For creating the under pressure, the module is pressed under partial vacuum and neutral gas. In the end, a junction box is placed and a secondary sealant is applied[26]. Once the modules reach their end of life, they can be opened and disassembled into their components (glass sheets, copper wires, cells)[27]. This enables higher recovery of the materials.

Also the NICE module can be reopened and components not functioning properly due to degradation during operation or due to manufacturing defects, can be repaired or replaced[28]. For the purpose of monitoring malfunctioning or degraded components, efforts are being made to develop a 'cell doctor', that is a fully automated system, that can identify defects in a finished cell and repair the ones that can be repaired[29].

3.2.2 "Twin peak" cell technology

Renewable Energy Corporation (REC), a Norwegian company, has developed a 'twin peak' technology that helps in delivering a power boost to the panel. There are 4-5 key elements related to their invention that we would like to highlight here along with their benefits.

1. A new wafer production technology has enabled REC's "twin peak" cells to have a greater surface area to capture sunlight (greater the surface area of the module that is exposed to sunlight, higher the output that the module will produce[30]). The cells are cut into two pieces ("half cut cells") that helps reduce internal resistance. They are connected in strings and the panel is laid out in a "two twin" section, with identical number of cells connected in a series. Splitting of the cell into two pieces helps reduce the internal current and thereby reduces the power loss. Since power loss is equal to the square of the current flow, the loss is cut by a factor of 4[31].

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23. http://ecosolar.eu.com/project-summary/
24. http://ecosolar.eu.com/project-summary/
25. Dupui, Julien , Etienne Saint Sernin, Oleksiy Nichiporuk, Paul Lefillastre, Denis Bussery, and Roland Einhaus. 2012. "NICE module technology - from the concept to mass production: a 10 year review." Photovoltaic Specialists Conference.
26. IBID
27. http://ecosolar.eu.com/project-summary/
28. IBID
29. https://www.sintef.no/en/latest-news/even-greener-solar-power-on-the-way/
30. http://www.alternative-energy-tutorials.com/solar-power/solar-panel-orientation.html
31. https://www.recgroup.com/sites/default/files/documents/whitepaper_twinpeak_technology.pdf

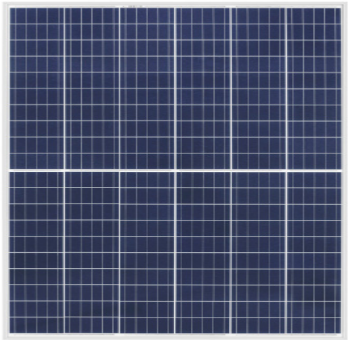

Figure 3.2: Panel layout (1)

Source: https://www.recgroup.com/sites/default/files/documents/whitepaper_perc.pdf

1.1. "Fill factor" which is an indicator of cell quality, increases with the reduction in the aforementioned losses. With improved cell quality and reduced resistance, up to 6 Wp (Watt peak capacity) of additional power can be generated from a 60 cell panel[32].

1.2. When a standard module is placed in a portrait orientation, shading of a single row of cells renders the power generation from the panel to be 0. With its unique layout, the REC panels, under the same conditions can generate at least 50 percent of the output[33].

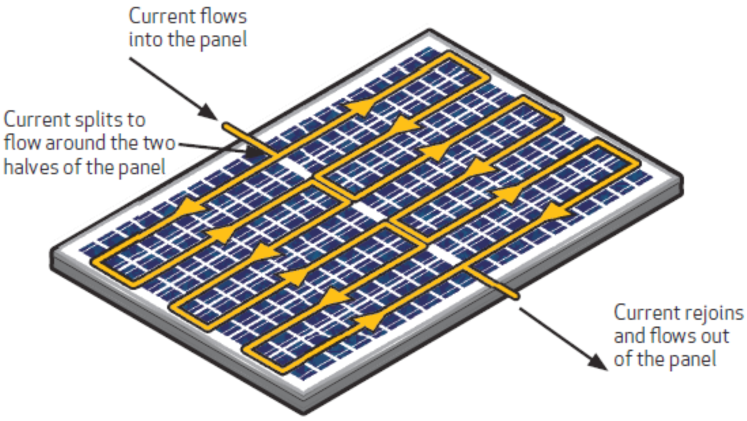

Figure 3.3: Panel layout (2)

Source: https://www.recgroup.com/sites/default/files/documents/whitepaper_perc.pdf

2. Thin rectangular strips of copper or aluminium, placed between the cells that conduct electricity are called bus bars[34]. Most solar cell designs incorporate 3 bus bars on the cell[35]. REC's solar cells make use of 5 bus bars, which helps reduce the distance travelled by the electrons to reach the ribbon. This facilitates faster electron flow and improves panel reliability. Results of the stringent quality control test conducted by REC suggest that panels having 5 bus bars are more durable (particularly in the mechanical load and thermal cycling tests)[36,37].

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32. https://www.recgroup.com/sites/default/files/documents/whitepaper_twinpeak_technology.pdf
33. IBID
34. https://www.solarpowerworldonline.com/2012/03/busbars-101/
35. https://www.powerfromsunlight.com/need-know-solar-cell-bussbar-0bb-3bb-5bb/
36. Mechanical load tests are stress tests where pressure is applied on the solar panels to determine whether the panel can withstand static snow and wind loads. (www.sinovoltaics.com/learning-center/testing/mechanical-load-test-conduction-and-specification/)Thermal cycling tests are conducted to examine whether the panels can withstand rapid changes in temperatures from 85 degree Celsius to – 40 degree Celsius. Hidden defects in the module (such as cracks, poor soldering etc.) can be detected this way. (www.pvtest.cz/en/tests/thermal-cycling-test)
37. https://www.recgroup.com/sites/default/files/documents/whitepaper_twinpeak_technology.pdf

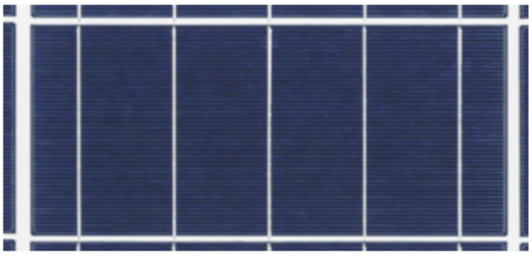

Figure 3.4: 5 bus bar cell

3. A standard junction box consists of bypass diodes and connection options for linking the panel to the rest of the system. REC twin peak products make use of a split junction box, wherein the functions are split between 3 small boxes. This split junction box makes use of lesser metallization, reduces internal resistance and also takes up lesser space. The space thus freed up allows greater spacing between the cells which in turn increases the internal reflection of light from the back sheet to the cell surface[38].

4. A standard cell consists of a base and an emitter, both made of silicon but having different electrical properties. An electrical field is generated where the two layers (base and emitter) meet and that pulls negatively charged electrons into the emitter. Depending on the wavelength of the light that enters the cell, electrons are generated at different levels of the cell structure. They are generated at the front of the cell in case of light with shorter wavelength (blue light). For longer wavelengths (red light), electrons are generated at the back of the cell and at times may pass through the wafer without creation of any current[39].

    4.1. Passivated Emitter Rear Cell (PERC) technology, is a new cell structure that has been developed by REC, which improves the light capture and optimizes cell performance. A conventional solar cell has an aluminum metallized layer, which is connected to the rear of the cell. PERC technology coats the back of the cell with a dielectric layer that has small holes made with the help of a laser. An aluminum metallization layer is added on top of this and contact with the silicon wafers occurs only through the laser made holes[40].

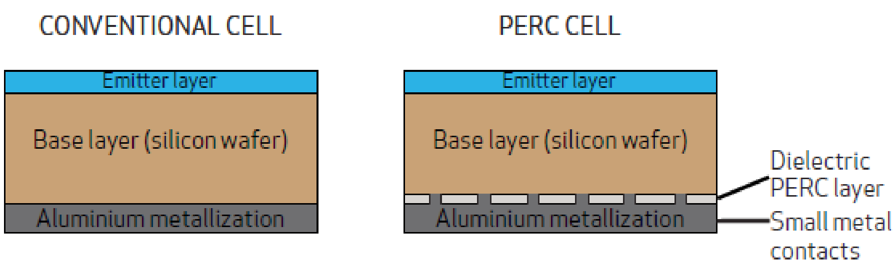

Figure 3.5: Comparison between conventional and PERC cell technologies (1)

Source: https://www.recgroup.com/sites/default/files/documents/whitepaper_perc.pdf

In case of PERC cells, the dielectric layer acts as a reflector for any light that passes through the wafer without generating any current. Between blue light and red light, it is the latter that is harder to absorb by the earth's atmosphere. Cells that can capture more red light are more powerful. Even during weak

38. https://www.recgroup.com/sites/default/files/documents/whitepaper_twinpeak_technology.pdf
39. https://www.recgroup.com/sites/default/files/documents/whitepaper_perc.pdf
40. IBID

light conditions, the reflective properties of PERC technology help in increased absorption of red light, which facilitate higher production, improvement in cell efficiency and augmentation of overall energy yield[41].

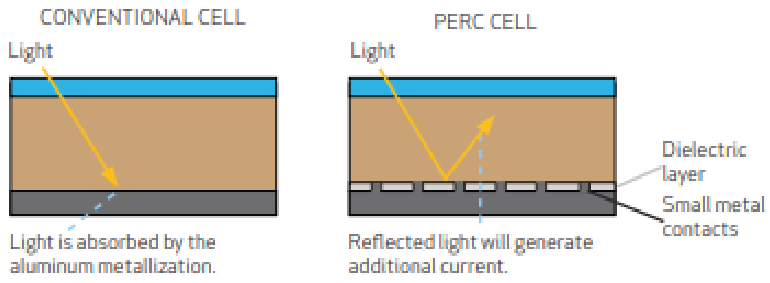

Figure 3.6: Comparison between conventional and PERC cell technologies (2)

Source: https://www.recgroup.com/sites/default/files/documents/whitepaper_perc.pdf

3.2.3 Upgradeable solar energy system: "40 Year Solar"

U.S. based Solergy has developed upgradeable solar energy system, "40 Year Upgradable Solar", that can generate power at a cost of $0.01/kWh. The system makes use of High Concentrating Photovoltaic (HCPV) technology. Compared to the standard PV module, Solergy's 40 Year generates forty percent more power per installed kW, as it uses multi-junction cells (cells having more than one p-n junction)[42], having higher efficiency. Upgradation of the cells helps increase the service life to 40-50 years, as compared to a standard module that has a service life of only 25 years. A longer service life in addition to upgradable design, implies that one can benefit fully from any technological improvement that comes about, without having to worry about the current technology becoming obsolete[43]. The design of the module is such that direct cell upgradation can take place in the field and at a low cost[44].

The "40 year solar" includes[45]:

- Glass concentrating lenses
- Upgradeable, hermetically sealed modules
- Secondary alignment that ensure 0.1degree sun tracking accuracy
- A tracker structure that operates in a variety of challenging climatic conditions (including during 200 km/hr winds).

Solergy CPV maintains a high power generation level that allows it to deliver energy when it is most required. This is of particular importance during times of peak demand (late afternoon or early evening), when traditional PV output begins to drop. Apart from generating electricity, solar CPV can cogenerate heat as well, at no extra cost. A heat exchanger is attached to the tracker pillar that allows transfer of heat towards the required application (e.g.-hot water). The option to use the cogenerated heat can be activated as and when the need arises. This avoids wastage of the co-generated heat.

3.3 Process and Product stage

While there are recent developments in improved process and product manufacturing stages, specific improved process related information are not available in the public domain. However, there are

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41. https://www.recgroup.com/sites/default/files/documents/whitepaper_perc.pdf
42. https://www.suncyclopedia.com/en/multi-junction-solar-cells-more-junctions-more-power/
43. https://www.solergyinc.com/en/index.html
44. https://www.solergyinc.com/en/index.html
45. http://www.solergyinc.com/it/archivio-news/solergy-introduces-the-world---s-first-upgradeable--40--year-lifetime-solar-energy-system_4c5.html

selected research studies that have analysed efficiency potential for several processes based input materials that are used for producing silicon panels. The 'Eco Solar' based project under the European Union's Horizon 2020 Research and Innovation Program, have assessed improvement in input consumption of materials like silicon feedstock, silver, aluminium, cadmium, pure argon gas etc. In this section we discuss the benefits thus achieved through the exercise .

3.3.1 Eco Solar Project

The project is funded by the European Union's Horizon 2020 Research and Innovation Program. The main aim is reducing the consumption of raw materials used in the production of solar cells and reducing the carbon footprint of the modules. The vision behind the project is based on the idea of minimizing the number of resources used, reusing and recycling raw materials.

3.3.1.1 Crystallization of Silicon feedstock

Crystallization is usually done either via Directional Solidification or through Czochralski crystallization. Eco Solar has identified two areas where carbon footprint can be reduced. These are – reusing argon purge gas and reusing crucibles.

3.3.1.1.1 Argon gas recovery

Pure argon gas is used for removing contaminants during crystallization of ingots. Even though argon is abundantly available in the earth atmosphere, production of pure argon gas is costly. A Cleantech company by the name of Gas Recovery and Recycling Limited (GR2L), specializes in recovery, purification and recycling of purge gases that are utilized in photovoltaics, microelectronics and material processing industry sectors. They have developed a technique for recycling argon gas (as well as other purge gases such as xenon and helium) , wherein the recovered gas has a 99.9999 purity level. The method being used is based on a chemical looping combustion process. "ArgonØ", the product developed by GR2L, recycles more than ninety five percent of the furnace exhaust gas, while removing thousands of ppm of contaminants.

3.3.1.1.2 Reusing crucibles

Molten silicon feedstock is contained in crucibles. Given the fact that silicon reacts with everything at high temperatures, there are limited crucible materials that fulfill the purity requirement for manufacturers. Thirty percent of the cost of converting silicon feedstock into as grown ingots is contributed by silica crucibles. Used crucibles are sent to landfills.

STEULER has come up with a concept for reusable silicon nitride crucibles. SINTEF has investigated the technical potential of these crucibles for crystallization of multi crystalline silicon. At present, a single silicon nitride crucible can be used for five consecutive crystallization runs. The quality of the silicon so obtained is similar to what is obtained from standard silicon crucibles.[57]

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46. https://solergyinc.com/en/technology_18c9.html#technology_4
47. https://solergyinc.com/en/applications_26c10.html#applications_1
48. http://isc-konstanz.de/en/isc/institute/public-projects/current-projects/eu/ecosolar.html
49. IBID
50. http://ecosolar.eu.com/project-summary/
51. M.P. Bellmann, R. Roligheten, G.S. Park, J. Denafas, F. Buchholz, R. Einhaus, I. Lombardi, et al. date. "Eco-Solar Factory:40% Plus eco-efficiency gains in the Photovoltaic value chain with minimized resource and energy consumption by closed loop systems." 32nd European Photovoltaic Solar Energy Conference and Exhibition .
52. http://gr2l.co.uk/
53. http://gr2l.co.uk/argono-overview/
54. http://ecosolar.eu.com/project-storyboard-crystallisation/
55. http://gr2l.co.uk/argono-overview/
56. http://ecosolar.eu.com/project-summary/
57. IBID

Secondary applications include ceramic or glass industry, horticulture, building industry, silicon production etc.[58]

3.3.1.2 Cutting and wafering of silicon ingots[59]

Once crystallization is complete, the bottom, top and side parts are removed before cutting the ingot into blocks. The ingot blocks are then wafered. In the process of cutting, a significant amount of silicon is lost. Nearly half of the silicon that one started with, goes into the coolant used for sawing the silicon wafers. Recycling of kerf loss (loss of silicon in the form of sub-micron powder) will help in reducing polysilicon consumption and waste generation. Garbo has patented its silicon recycling process which is knows to remove contaminations and bring purity level of silicon to 99.999%. The purified silicon so obtained is dried and packed under vacuum for getting a stable silicon powder. This powder has to go through a high temperature oxygen degassing process before it is used in producing solar ingots and cells.

3.3.1.3 Processing of solar cells[60]

In the process of converting wafers into solar cells, many wet chemical etching and cleaning procedures are involved, which may have a negative impact on the environment. Through a reduction/avoidance in the use of certain chemicals and metals (like hydrogen fluoride, silver, aluminum, lead etc.) and increased usage of less pure or recycled chemicals, the amount of waste generated can be reduced.

Silver (which is an important component of solar cells) helps in collecting and draining the current from solar cells. Attempts have been made by ISC- Konstanz to conduct experiments to possibly reduce the use of silver.

ISC-Konstanz and SoliTek are in the process of developing an alkaline method for saw damage removal, texturisation and cleaning that is intended to replace the currently used concentrated mixtures of **hydro fluoric acid and nitric acid.**[61]

At the end of each chemical process, the silicon wafers are cleaned with de-ionized, ultra-clean water. The used water that goes down the drain is often of a higher quality than the one coming from the taps. Recycling of waste water will prove to have a beneficial impact. ISC Konstanz is studying the viability of recycling waste water with the aim of saving ninety percent of water that is used in solar cell processing.

For the purpose of avoiding separation of front and rear of the solar cells via wet chemistry, AIMEN is in the process of developing an advanced laser treatment which will help minimize the area cut off from the wafer edges.

Most of the silicon recycling technologies break the silicon wafers once they are removed from the panel. The impurities are then removed with the help of hydrofluoric acid. This substance is not only harmful for the environment but can also cause severe burns to the human skin. Korea Electronics Technology Institute and the Korea Interfacial Science and Engineering Institute, have designed a method to recycle silicon solar panels without using highly toxic chemicals (for e.g. hydrofluoric acid). The panels are heated at 480 degrees Celsius in a furnace to vaporize the glue that holds the cells together. If the temperature is increased by 15 degrees Celsius, none of the wafers break in the heating process. After removing the wafers, the silver electrodes are removed from the top, with the help of

58. K. Wambach, I. Fechner, M.P. Bellmann, G.S. Park, J. Denafas, F. Buchholz, F. Madon, et al. “Eco Solar Factory Establishment of Pan Industrial Material Reuse Opportunities.”
59. http://ecosolar.eu.com/project-summary/
60. IBID
61. K. Wambach, I. Fechner, M.P. Bellmann, G.S. Park, J. Denafas, F. Buchholz, F. Madon, et al 2016. “Eco Solar Factory Establishment of Pan Industrial Material Reuse Opportunities.”

nitric acid. Pulverization of anti-reflexive coating, emitter and p-n junction layers takes place in a grinding machine. The aluminum electrode is then etched away with the help of potassium hydroxide. New solar cells that are built by using the recycled wafers perform almost the same as the cells made from newly acquired silicon.[62]

3.3.1.4 Solar cell repair during manufacturing

In the EU-funded project REPTILE, which AIMEN coordinated and in which ISC and INGESEA participated as beneficiaries, there was preliminary work done on a system that is able to automatically select and cut out or isolate non-defective areas in defective cells and wafers, called the Cell-Doctor. Within the Eco-Solar project a fully operational protoptype is to be built. ISC will evaluate the rejected solar cells with an automated system for defects recognition. AIMEN and INGESEA will further develop the accuracy of the Cell-Doctor prototype, aiming to avoid 50% scrapped cells. Moreover, this technology can be used to evaluate solar cells after end-of-life modules return to the factory for recycling and reuse.

3.3.2 Renewable Energy Corporation (REC)

Norway based Renewable Energy Corporation (REC) has brought in process innovation that can not only reduce material loss while using renewable energy during manufacturing solar PV. The following sections briefly presents some of these interventions.[63]

3.3.2.1 Fluidized Bed Reactor (FBR)

For producing silicon, the company has developed a Fluidized Bed Reactor (FBR) technology which is applied to the depositions of silicon from the gas phase, so that the solid silicon particles float and grow in an upward gas flow in a chamber. The process uses 90% lesser energy than the conventional Siemens reactor.

3.3.2.2 Renewable source of energy used

REC Solar Norway (a subsidiary of REC) extracts and produces silicon which is then used by REC. In Norway, 96% of the electricity is generated via hydroelectric sources. REC Solar Norway makes use of a process that reduces the energy usage at the purification stage to 11 kwh/kg, which is much lower than the energy consumed by Siemens production process (200 kwh/kg).[64]

3.3.2.3 Efficiency of crystallization

For improving efficiency of crystallization of ingots, furnaces that can crystallize more than 1000kg of ingots per cycle (as compared to the standard 400-500 Kgs) are utilized by the company. Efforts are being made to increase the capacity to 2000 kg of ingots per cycle.

3.3.2.4 Wafer Thickness

Wafer thickness has been reduced to 180 µm with the help of thinner wires that are used to produce the wafers. Thus, by making use of thinner wires and wafers, the overall production process has been made more efficient, as a larger quantity of wafers, cells and modules can be produced from the silicon stock.

62. http://ecosolar.eu.com/project-storyboard-solar-cell-processing/; https://www.chemistryworld.com/news/a-bright-future-for-silicon-solar-cell-recycling/9160.article
63. https://www.recgroup.com/sites/default/files/documents/wp_-_recs_class-leading_carbon_footprint.pdf
64. IBID

3.4 End of Life Stage

"End of life" management of solar panels can help in conserving natural resources and lowering the production costs. Extraction of secondary raw materials from degraded panels and their availability in the market will be some of the added benefits. In addition, hazardous components of the panels such as those made of lead, cadmium etc. need to be treated separately. Based on the estimates of the IRENA report, the value of recovered material from PV recycling globally will be close to 450 million US dollars by 2030. Further, there will also be creation of new jobs spread across the private sector (producer, waste management firms etc.) and public sector (public research etc.). At present the issue of waste disposal may not appear to be crucial. However, once the service life of a solar panel comes to an end, managing heaps of accumulated waste will be an issue. By 2050, the cumulative volume of waste from end of life panels for the world is likely to be close to 60 million tons for regular losses and 78 million tons for early losses. (International Renewable Energy Agency 2016)

3.4.1 Life cycle stages for PV

The 3R principle and the circular economy framework can be used in the case of PV panels. The order of preference in terms of waste management options is as follows- Reduce, Reuse and Recycle. Figure 3.8 presents the different life cycle stages and opportunities of the use of 3R principle across the value chain.

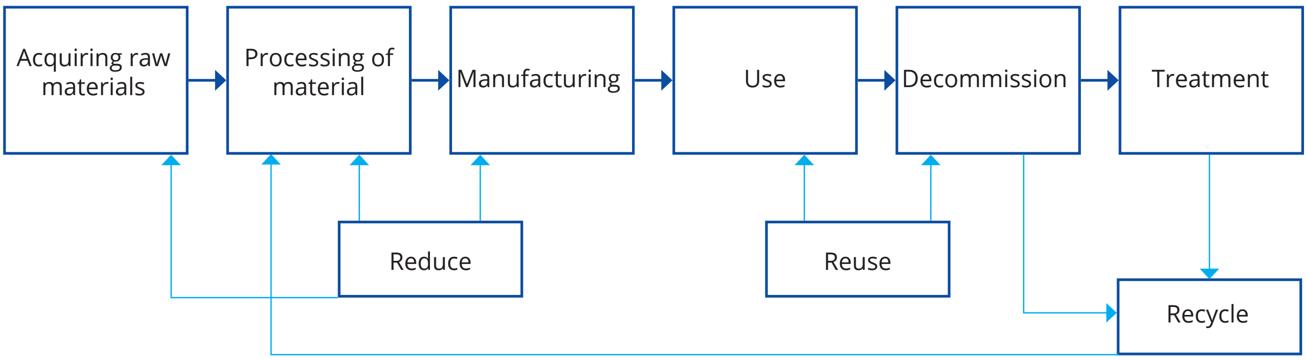

Figure 3.8 Life cycle stages of PV value chain and opportunities of the use of 3R principle

Reduce

There has been ongoing research for finding substitutes for and/or reducing the use of certain components of PV panels that are commonly used.

Reuse

Defective panels are usually returned to the producer for inspection and repair. Quality tests such as wet leakage test etc. are conducted to recover materials of value from the recycled panels. In case repairs are required and feasible, then new frames maybe attached, along with new junction boxes, diodes, plugs and sockets etc. Repaired panels can be sold again as replacements or sold as second hand items at a price lower than the market price.

Recycle

Panels that cannot be repaired or reused are dismantled and sent to treatment facilities for further processing. Due to the low volumes of PV waste in global markets, there hasn't been much incentive to have separate PV recycling plants. The panels are processed in general recycling centers for material recovery. At this stage it is possible that some higher value components are not fully recovered.

- Recycling of crystalline silicon PV panels

The panels are first disassembled into the following components- aluminium frame, conductors, cell recovery and glass structure. The aluminium frame and the conductor is shredded via a shredding mill and then sorted and refined to reach a certain purity level. The cells are sent to the wafer production while the glass is sent for recycling. The recycled materials can then be used to build new panels that have the same output as the original panel. (McKeown 2014)

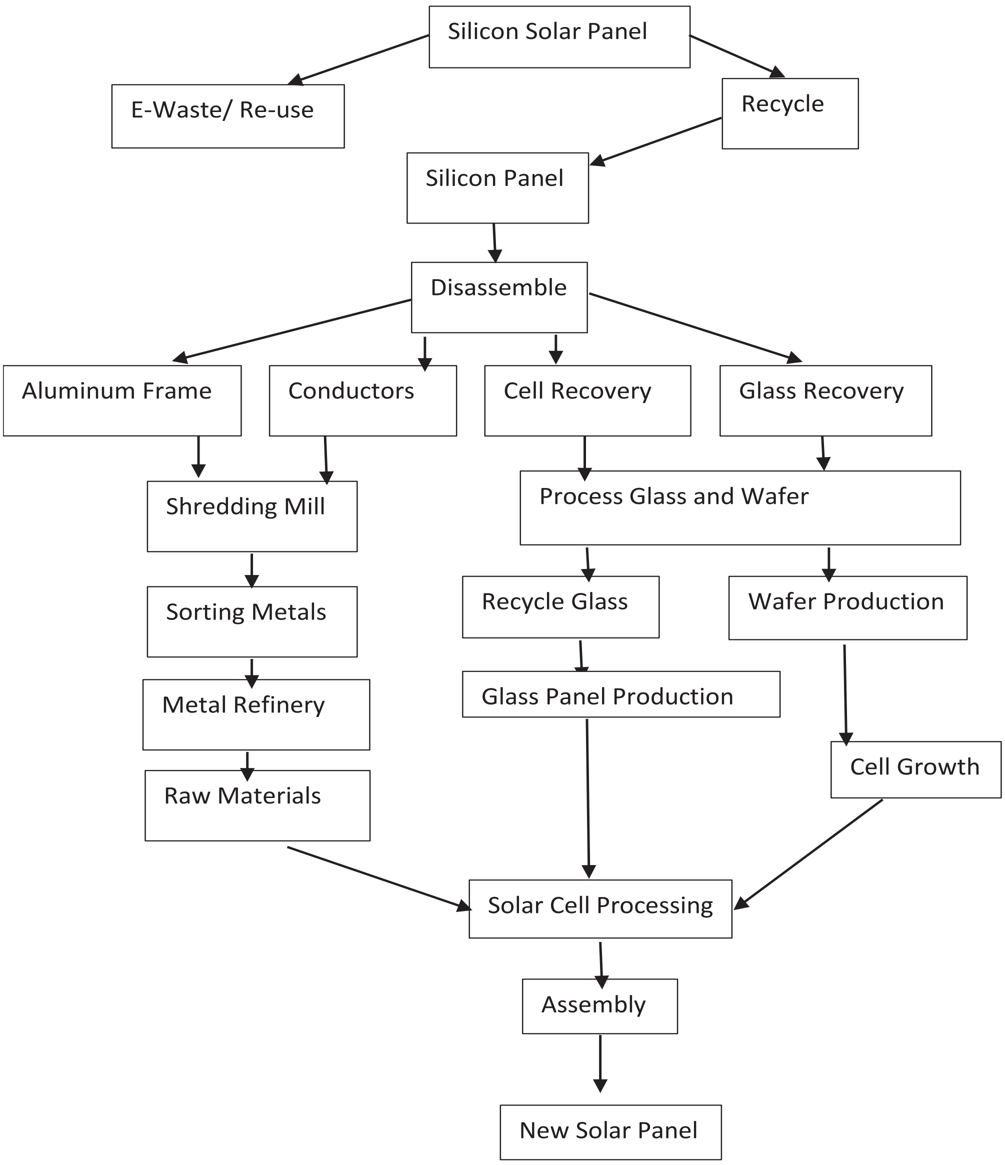

Figure 3.7: Recycling of crystalline silicon PV panels

Source: McKeown (2014)

We discuss here some of the best practices with regard to end of life management of solar PV.

3.4.2 PV CYCLE[65]

Belgium based PV CYCLE has been able to secure a recycling rate of 96% for silicon based PV installations. The remaining 4% that is not recycled due to residues from the glass recovery and EVA foils (used for lamination). The company in association with EU recycling partners for silicon-PV modules have been using new process that combines mechanical and thermal treatment to recycle silicon flakes as well as recycling a combination of EVA laminate, silicon-based semiconductors and metals. The areas looked after by the company include the following:

- PV module waste
- Electrical and electronic equipment waste
- Battery waste
- Industry waste
- Packaging waste

The services provided by PV CYCLE include:

1. Waste Compliance

The company encourages its members to comply with the legal rules of the countries where they operate in. Based on the products sold by its members, it is mandatory to comply with either the WEEE directive, battery legislation or packaging legislation.

2. Waste Collection and Treatment

The European Waste Shipment Regulation is adopted, that indicates the procedures to be followed for shipping waste within EU and to & from other countries. Regulation of waste shipments facilitates environmental protection. PV Cycle has developed a collection network to ensure hassle free discarding and collection of waste.

- Direct pick up services

Items collected from the customers' location are transported to the recycling partners.

- Collection points

It is often the case that PV modules exceed to collection and storage capacities (due to size and weight) of municipal collection centers. PV Cycle has its own collection points that are managed by professions in PV intensive locations.

3. Waste Dismantling

Those in need of help for dismantling can take advantage of the decommissioning services that the company provides for PV installations. The dismantling is carried out by professionals who also offer waste packaging services.

4. Waste Management Programs

Countries outside EU are provided waste management solutions and support services custom made for them. The primary focus is on solar energy and PV production scrap, a few other waste products such as battery waste, packaging waste etc. are also considered.

3.4.3 Reclaim PV Recycling

It is an Australian company that offers a take back scheme for managing waste and recovery of resources in Australia and the oceanic region, through a module drop off and collection network. The company has developed a unique process to retrieve "good" cells from the modules, so as to reduce the energy needed to recycle the solar cells. Reclaim PV Recycling is working together with the Australian government agencies, PV manufacturers and other private agencies through their NannoConnect Program

66. http://reclaimpv.com/

3.4.4 Other Examples

In the United States, companies such as Abound Solar, First Solar, and Suntech have designed panels with end-of-life in mind.

First Solar has a prefunded collection and recycling programme for solar PV cells and modules that they install. Earlier, a trust structure had been set up to guarantee funds available for recovery and recycling regardless of the financial status of First Solar. However, the fund was later discontinued. The company reuses up to 95 per cent of the semi-conductor material in new modules.

Abound Solar has a "cradle-to-cradle" programme. They reclaim both tellurium and cadmium from its modules at end-of-life and reuse the materials. Over 90 per cent of Abound Solar's components are recycled.

Suntech uses easy to recycle, non-resource-constrained materials to ensure that the materials at the end of life of the panels can also be recycled and reused.

3.5 Conclusion

Solar PV system is a versatile technology that generates clean electricity and represents a sustainable solution with the establishment of solar photovoltaic industries globally. Solar sector is an emerging industry in India. The aim of the best practices highlighted in this chapter was to draw attention to the potential for resource efficiency across life cycle stages of the solar PV. Of course, these best practices are not comprehensive analyses of all the resource efficiency options available across the life cycle stages, but they highlight certain areas with considerable potential and possible replication. In India the Ministry of New and Renewable Energy, plans to initiate manufacturing scheme to build up manufacturing capacity of solar PV modules, cells, wafers/ingots and polysilicon. Learning from some of the best practices could mainstream resource efficiency in the domestic manufacturing segment.

Further, if solar PV technology is considered as a sustainable solution for electricity generation, it is important to address the end-of-life of PV modules. The manufacturing of PV solar systems is accompanied with the variety of material usage, technology development and wastage, which calls for a need to identify end of life management solutions that could be cost-effective and lead to efficient material recovery that can be reused within the sector or other sectors with minimizing down cycling possibilities. Many countries across the world including those in the European Union (EU) are looking at this issue. Further, recycling and reuse of discarded PV waste also has the potential to generate business opportunities and new jobs and create a cleaner environment.

4. Regulatory frameworks for promoting resource efficiency: Cross country evidences

Policy Interventions across the solar PV value chain Policy plays an extremely important role in regulating, incentivizing, and promoting resource efficiency for various sectors and PV sector is no different. India has one of the largest renewable capacity expansion programmes in the world. While it is a significant step towards meeting its NDC target, there are challenges faced by the sector that needs solutions with regard to tariff discovery, grid integration, storage, and human resources. Issues associated with material requirement is often ignored. Under the 'Make in India' initiatives making panels may get affected due to issues on solar PV material availability at affordable prices. Further, issues related to end of life management of Solar PVs and battery modules would be critical. An integrated assessment covering material flow analysis and end of life management for better management of wastes are important areas for policy intervention. The following section presents initiatives taken in other parts of the world on developing guidelines and policies for promoting resource efficiency in the solar PV sector with a primary focus towards the end of life management of PV modules.

4.1 Case of European Union

At the heart of the regulatory framework formulated by EU is the principle of extended producer responsibility. Producers supplying products to EU markets are responsible for managing the end of life phase of solar panels regardless of where the manufacturing process is taking place. The initial Waste Electrical and Electronic Equipment (WEEE) document released in 2003 turned out to be ineffective in managing the variety wastes that were being generated. It was later revised in 2012. This included end of life management with special focus on PV panels. By 2014, all EU member states were required to abide by the said directives. Currently the WEEE directives have been implemented in all 28 member states of the European Union.67

The responsibilities bestowed upon the producers include fulfilment of certain criteria. The term 'producers' not only include manufactured of the equipment, but also players involved in bringing the product to the market. The criteria are discussed here:

1. Financial implication

Costs incurred from collecting or recycling products consumed by households are to be covered by the producers. Further, funding of public collection areas and treatment centers is to come from the pockets of the producers.

The WEEE directive consists of dual financing approaches. These are: individual pre funding or collective joint and several liabilities schemes & contractual agreements between the buyer and the producer. Past experience with the initial WEEE directive showed that pre funding approaches work well only for e waste that is sold in small quantities. In the revised version of the directive, a distinction is made between household or business to consumer transactions. Depending on the end use of the product, the WEEE directives indicate the financing approach to be followed.

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67. https://www.take-e-way.com/services/weee-elektrog/weee-transposition-status-eu/

According to WEEE directives, there can be two financing mechanism on the basis of the end use. The first is B2C transactions (private households). Under such transactions the producer cannot enter into contractual agreements with the consumer on financing. However, requirements set by the regulator have to be fulfilled by the producer. In case of B2C transactions, it has been found that it is more efficient and more enforceable when the producer is asked to collect and recycle e waste at their end of life instead of asking the household customers. The second kind of financing mechanism is that of B2B transaction (non-private households). For these transactions it has been found that a regulatory framework overlooking the collection and recycling and allowing for contractual agreements between the consumer and the producer is effective.

2. Reporting

Records of monthly or annual sales of panels, or panels that are taken back or sent to treatment facilities are to be kept by the producers. The corresponding end results from treatment of waste is also required to be presented.

3. Information

Labelling of panels following the WEEE directives is to be carried out by the producers. The buyers have to be informed of the designated centers where the panels are to be disposed-off and are not to be mixed with other waste materials. They must also be duly informed regarding the end of life procedures to be followed. Waste treatment facilities are to be guided on how to deal with the PV when it is being collected, stored, dismantled and treated. This may include information such as presence of hazardous components or possibilities of occupational risks.

The approach of “high value recycling” forms the foundation of WEEE directives. The following aspects have been incorporated in the same

- Hazardous components (such as lead) are removed during the treatment stage
- Materials of value such as silver, indium etc. are recovered and made available for use in the future.
- Components with energy embedded within them are recycled.
- Once an item has been recovered after recycling, the quality of the same will be assessed. (for example glass).

4.1.1 WEEE guidelines on product labelling

In countries where the WEEE directive is implemented, any electrical or electronic equipment falling under the directive that is produced, rebranded or imported has to be marked with:

- A crossed out wheeled bin symbol (to indicate to households that the product is not to be disposed-off with other unsorted household waste).
- Producer identification mark
- a date mark

The above mentioned labelling must be clearly visible, permanent and on the product. In case the product is too small or such markings can hamper the functioning of the product, the information can be printed on the packaging, instructions or warranty.[68]

68. https://www.nibusinessinfo.co.uk/content/weee-rules-marking-your-products

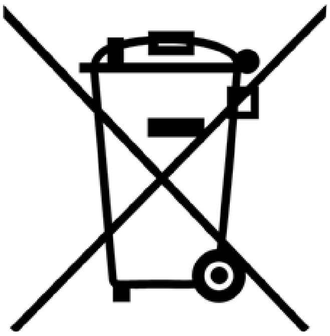

Figure 4.1: Code to represent that a products is not to be disposed-off with other unsorted household waste

Source: http://conformance.co.uk/directives/full_text/l_19720120724en00380071_bookmarked.pdf

4.1.2 End of waste criteria

EU has recently came out with a new Directive (EU) 2018/851, amending its Directive 2008/98/EC on waste. The revised waste legislation sets new recycling targets and defines mandatory extended producer responsibility schemes. Further, suppliers are newly required to inform the European Chemicals Agency (ECHA) about the presence of substances of very high concern (SVHC) in their products. For this, ECHA will establish a new database to collect industry submissions. .As per Article 6 (1) and (2) of the earlier Directive 2008/98/EC, certain waste will no longer be considered to be waste and will be identified as a product (secondary raw material), if it has undergone a recovery operation (including recycling) and fulfills certain criteria. These conditions include[69]:

1. The object or substance is commonly used for specific purposes
2. There exists a market or demand for the substance of object in question
3. The substance or object fulfills the technical requirements for the said purpose and does not violate any standards applicable to the product.
4. The use of the said product will not cause any adverse environmental or human health impact.

The mandate for setting the end of waste criteria was put in place for the purpose of encouraging recycling, reducing the consumption of natural resources and reducing the volume of waste sent for disposal. This was ensured by the creation of a legal framework and the removal of any unnecessary administrative burden. The criteria is not applicable on all wastes but only on certain waste streams for which the criteria can be developed and adopted, while remaining within the purview of the Waste Framework Directive.[70]

So far the guidelines have been laid down for –

- Iron, steel and aluminium scrap
- Glass cullet
- Copper scrap

69. http://ec.europa.eu/environment/waste/framework/end_of_waste.htm
70. http://ftp.jrc.es/EURdoc/JRC53238.pdf

End of waste criteria for copper scrap[71]

The EU wide end of waste criteria for copper scrap is likely to provide benefits as listed below:

1. Improvement in functioning of internal market
2. Clear difference between high and low quality copper scrap. It is only the former that will cease to be waste
3. Reduction in administrative burdens pertaining to shipment and transport

With reference to the requirements mentioned in the waste framework directive:

Copper and copper alloy have a structured market that exists. Scrap copper is traded internationally in large volumes and standards regarding the metal grade have been developed. Varying qualities of copper and copper alloys are used as feedstock in the metal producing industry, depending on the needs of the segments in the copper refining chain. For instance, low quality scrap is used for smelting and refining purposes whereas, high quality scrap and refined copper is used by melters for producing semis (used for making copper products). Moreover, recycling of copper scrap is environmentally beneficial as opposed to its production from ores.

Copper scrap would cease to be waste when:

1. The scrap metal fulfills the industrial standards copper scrap grade for which there is demand.
2. Information regarding the scrap type is mentioned and requirements pertaining to maximum content requirement of foreign materials, oils etc. are not violated.
3. The scrap metal does not have any hazardous properties.
4. All the necessary treatments have been carried out on the scrap metal to ensure that it is suitable for use.
5. Documentation of the fulfilment of the aforementioned conditions is provided by the producer.

The European Standard EN 12861:1991 specifies the characteristics for copper and copper alloy scrap for direct melting. It specifies details regarding the moisture, composition, metal content, metal yield and test procedures. The requirements regarding the metal content and yield also mention the effectiveness of any pre-treatment that takes place and puts limits on the possibilities of diluting the scrap by using other waste material.

Foreign materials as defined under EN 12861:1999 is “Any material other than copper and copper alloys, whether metallic or non-metallic including free iron”.

Those involved in the reprocessing step of the copper chain such as scrap collectors and processors, favor the higher foreign material limits (5-8%), whereas those involved in the lower end of the copper chain (such as users of scrap) prefer a value close to 2 percent.

The EN 12861 specifies a foreign material content limit between 2-5%.

19 grades of copper scrap and copper alloy scrap have been characterized by the EN standard. The codes prevalent for copper scrap are S-Cu-1 to S-Cu-10 and those for copper alloy scrap are S-CuZn-1 to S-CuZn-10. The grade S-CuZn-5 is excluded from end of waste due to the frequent content of oil, grease etc. Out of the 19 grades mentioned, 14 of them have foreign materials less than 2%. These are known

71. http://ftp.jrc.es/EURdoc/JRC64207.pdf

as high purity scrap grades. Scrap grades S-Cu-8, S-Cu9 and S-CuZn-6, S-CuZn-7 exceed the limit of 2 %. Depending on the technical conditions of the furnace that uses this scrap, additional pre-treatment may be applied to improve the quality of scrap. Copper scrap containing foreign materials in excess of 5% is use by upstream steps in the copper chain, often without any additional treatment.

The ISRI specification is another quality reference that covers copper scrap types (including lower quality grade) for smelting and refining that are not included in EN 12861. However, the specifications are not as detailed as the EN 12861 in terms of impurity content limits and testing procedures.

Directive (EU) 2018/851 makes amendments to Directive 2008/98/EC on waste (The Waste Framework Directive) which provides the legislative framework for the collection, transport, recovery and disposal of waste.

EU has recently come up with directive that makes amendments to 2008/98/EC which among other things increase targets for preparing for re-use and recycling of waste; remove substances intended for animal feed from the scope of Directive 2008/98/EC; add a number of new definitions; change cease to be waste conditions and requirements; set out exemptions for separation of waste collection; establish bio-waste separation; establish household hazardous waste collection; and update record keeping requirements.[72]

4.2 Case of Italy[73]

In Italy, the legislative decree No. 49 of 14th March 2014 incorporates the Directive on Waste Electrical and Electronic Equipment. For the purpose of promoting the use of secondary raw materials and for more efficient use of natural resources, the decommissioned solar panels were included in the types of household (plants with power less than 10 kw) and professional (plants with power greater than or equal to 10 kw) WEEE. Panels which are at their end of life stage and that were a part of the plants installed before the 2014 decree came into being are called 'historical' waste, whereas those that entered after the decree are called 'new' waste.

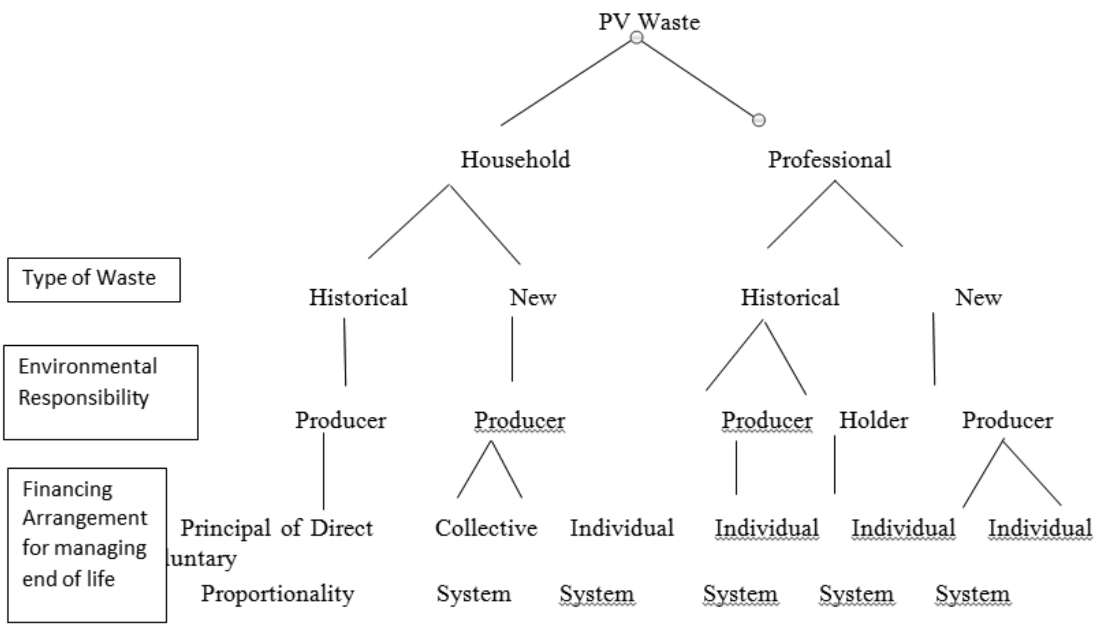

Figure 4.2: PV categorization in Italy

Source: Ornella et. al[74]

72. https://legislationupdateservice.co.uk/directive-eu-2018-851-amending-directive-2008-98-ec-on-waste/
73. Malandrino, Ornella , Daniela Sica, Mario Testa, and Stefania Supino. 2017. "Policies and Measures for Sustainable Management of Solar Panel End-of-Life in Italy." Sustainability.
74. IBID

The responsibility of transporting waste from historical panels to the collection centers from private households lies with the producer. For the new PV waste from private households, the producers calculate the cost of collection and treatment of the modules and then decide whether to carry out the job on an individual basis or collectively. Management of professional panels is funded by the producer only in case of new panels. In other cases, the costs are covered by the holder. New professional waste management is funded by the manufacturer. The producer may enter into voluntary agreements with the users to provide alternative ways of financing the management.

A minimum goal of recovering at least 75 percent and recycling at least 65 percent of the panels has been stated in the decree. The Italian National Institute for Environmental Protection and Research monitors the progress in achieving the targets, each year it submits a report to the Ministry of the Environment and Protection of the Territory and the Sea regarding the volume of electrical and electronic equipment that are present in the market or are prepared for reuse, recycling or recovery. It also includes information about the WEEE that are separated for exports. Once in every three years the Ministry sends a report to the European Commission highlighting the implementation of the Directive of 2012.

An initial Decree was already in place since 5th May 2011 that dealt with the disposal of PV modules for systems that were operating after June 30th 2012. For these modules, a certificate had to be provided by the manufacturer which would then be transmitted to the manager of Energy Services (GSE). GSE is a state owned company supporting renewable energy sources non-compliance, the plant holders are excluded from receiving benefits provided by the Fifth Feed in Scheme. The Technical Regulation was issued on 21st December 2012, which laid down provisions for verifying the requirements of the systems for recovery and recycling of the modules, once they reach their end of life.

The Environmental Provision which was a part of the Stability Law of 2014 stated that all PV panels that have been installed after the Legislative Decree of 2014 came into force, are to be managed by GSE. There are several operators in Italy that have been accredited by GSE and are actively managing recovery and recycling of panels.

The technical and financial requirements for managing PV waste have been defined by GSE for PV modules that have been installed in plants that are operating since 1st July 2012. In addition, those involved in the installations of the panels are encouraged to recover and dispose-off the PV waste and also submit documentation of the same with GSE.

PV Cycle Italy handles the collection and transport of PV waste to the recycling centers. It is affiliated to the non-profit association PV Cycle. The aim of this association is to map the modules at their end of life and to look after the recovery and recycling of materials. The cost of collection and recycling is covered by members of the association through annual financing and payment of a variable fee (estimated on the basis of number of modules that entered the market in the previous year). The role of PV Cycle is limited to collection and/ or transportation of the modules, while the remaining tasks are outsourced.

There are some consortia that make use of technologies that have been developed within the WEEE sector, with minor modifications. There are others who have invented specific technologies for treating PV panels. RAEcycle is one such consortium. Its Solar Glass ML plant can treat 40-60 PV panels per hour while consuming 38kwh of power.

4.3 Case of Germany

Rules governing the collection and recycling of panels have been implemented in Germany ever since the revised WEEE directive was incorporated into German Law in 2015. The National Register for Waste Electrical Equipment regulates the country’s e waste.

Shiftung EAR (national registrar for waste electronic equipment) was founded by producers to act as their clearing house, when WEEE was introduced for the first time. Functions performed by Shiftung EAR include the following: registration of producers suppling electrical or electronic equipment to German markets, assessment of collective producer guarantee systems, coordination of provisioning of containers for public exchange facilities and take back of waste at the public waste disposal authorities, collecting data regarding the electrical and electronic equipment supplied in the market etc.[75]

A financial guarantee has to be provided by the producers against each new panel that is sold. Depending upon the financing approach selected by the producer, the guarantee is calculated. There is a provision for separate collection and treatment of PV panels at the municipalities.

4.3.1 Financing Schemes

4.3.1.1 Business to consumer transactions

Producers selling panels to households have to take care of the end of life obligations for the panels. There is a two level financing supporting the reverse logistic network.

The first level covers the collection system operating costs and other expenses related to collection and recycling. In the second level, it is ensured that sufficient funds are available for collecting and recycling of materials in the future for products that are put on the market today. The costs are calculated at this level by taking into account the average service life, return quota at the municipalities and the costs of treatment and logistics.

A 'pay as you go' system is followed by market participants to cover level 1 costs. Before access to the market is granted, the producers are required to register with a clearing house. In addition to this, they have to declare that they agree to covering the level 2 costs for business to consumer products. Depending on their current share in the market, they must also take full responsibility for the level 1 expenses. Once the aforementioned conditions are met, a registration number is provided to the producer by the clearing house that has to be printed on the products and the invoices.

4.3.1.2 Business to business transactions

It is left to the parties in the contract to decide on the end of life responsibilities mentioned in the WEEE directives by choosing the producer to manage the collection and recycling or by seeking competitive market bids.

The German federal government had set a target in the National Sustainable Development Strategy, of doubling the country's raw material productivity by 2020, relative to 1994 levels. The German Resource Efficiency Program (ProgRess) (2012) aimed at achieving this target. With the publication of the German Resource Efficiency Programme (ProgRess), the "Programme for the sustainable use and conservation of natural resources" in 2012 and its update in 2016, the German Federal Government has set a milestone for further development in this area .The central goal of the program was to ensure that the extraction and use of natural resources is sustainable and also to reduce environmental pollution.[76] The aims of this program include:

- Ensuring a secure supply of raw materials
- Enhance resource efficiency in production
- Reduce resource intensity in production and consumption
- Build a resource efficient circular economy

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75. https://www.stiftung-ear.de/en/about-us/
76. Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). 2012. "German Resource Efficiency Programme (ProgRess): Programme for the sustainable use and conservation of natural resources."

The program covers abiotic resources that are not utilized in energy production such as ores, industrial minerals and construction materials, along with the use of raw materials. Natural resources such as water, air etc. are not included in this program.

The entire value chain, starting from the extraction of raw materials to the disposal of products is something that ProgRess aims to cover. Seven areas where actions need to be taken have been identified by the program. These include: bulk metals, rare earths and critical metals; construction, planning and buildings; photovoltaics; electro mobility; IT and chemicals.

To ensure the smooth implementation of the programme, the government reviews progress every four years and in 2016 the first revision was made which resulted in the publishing of ProgRess II.

4.4 Case of United Kingdom

The market for solar PVs is relatively young. Voluntary producer initiatives, recycling & take back systems prevailed in UK before the WEEE directives were implemented. According to UK legislation a producer is defined as

- A UK manufacturer who sells PV panels under his/her self-owned brand.
- Imports PV panels to UK markets
- UK businesses selling panels that are manufactured or imported by some third party but sold under their brand name.

The producers have to register in a producer compliance scheme and have to submit details of products being sent to households and non-household markets.

4.4.1 Financing Schemes

Requirements for financing under the UK legislation differs from that under the EU WEEE directives.

- Producers need to fund the collection of household panels based on their share in the market.
- Producers are also responsible for financing the collection and recycling of non-household panels if they are replaced simultaneously by newer ones.

An additional requirement has also been incorporated for installers to become a part of a distributor takeback system.

First level treatment of panels (including registering of volumes collected) has to be done within UK. The next stage of treatment occurs abroad. Due to the absence of high value treatment facilities in the UK, waste can be exported to other member states of the European Union, provided those facilities fulfill the UK treatment requirements.

Table 4.1 gives a comparative assessment of PV waste management in EU, UK and Germany.

Table 4.1: comparative view between EU, UK and Germany with respect to PV waste management

Parameter	European Union	UK	Germany
Regulations	Waste Electrical and Electronic Equipment (WEEE) Directive governs the treatment of electrical and electronic waste at the end of life stage. The principle of extended producer responsibility is followed, where in, the producers are liable for any environmental impact that their product has in the course of its service life.	WEEE Directives have been implemented in UK. It became a law in UK in January 2014.	WEEE Directives have been incorporated in German Law in 2015.

Reverse Logistic	Hazardous components (such as lead) are removed during the treatment stage. Materials of value such as silver, indium etc. are recovered and made available for use in the future. Components with energy embedded within them are recycled. Once an item has been recovered after recycling, the quality of the same will be assessed.	First level treatment of Solar panels occurs in UK and the remaining stages occur abroad. Due to the absence of high value treatment facilities in the UK waste can be exported to other member states of the European Union.	CCR RELETRA is a compliance scheme for electrical and electronic equipment. It helps producers and importers meet their extended responsibilities related to their products based on the WEEE Directives.[77]
Financing	The WEEE directive consists of dual financing approaches. These are: individual pre funding or collective joint and several liabilities schemes & contractual agreements between the buyer and the producer. In the revised version of the directive, a distinction is made between household or business to consumer transactions. Depending on the end use of the product, the WEEE directives indicate the financing approach to be followed.	Requirements for financing under the UK legislation differs from that under the EU WEEE directives. -Producers need to fund the collection of household panels based on their share in the market. -Producers are also responsible for financing the collection and recycling of non-household panels if they are replaced simultaneously by newer ones.	There are two financing schemes that are present: -Business to consumer transactions (B2C) -Business to Business transactions. (B2B)
Stakeholder Responsibility	-Financial Costs incurred from collecting or recycling products consumed by households are to be covered by the producers. Further, funding of public collection areas and treatment centers is to come from the pockets of the producers. -Reporting Records of monthly or annual sales of panels, or panels that are taken back or sent to treatment facilities are to be kept by the producers. The corresponding end results from treatment of waste is also required to be presented. -Information Labelling of panels following the WEEE directives is to be carried out by the producers. The buyers have to be informed of the designated areas centers where the panels are to be disposed-off and are not to be mixed with other waste materials. They must also be duly informed regarding the end of life procedures to be followed. Waste treatment facilities are to be guided on how to deal with the PV when it is being collected, stored, dismantled and treated.	The producers have to register in a producer compliance scheme and have to submit details of products being sent to households and non-household markets.	Shiftung EAR is entrusted with the responsibility of registering manufacturers of electrical and electronic equipment. It also coordinates the provision of containers at the collection points and looks after the collection of waste from public disposal companies.[78] The collection points notify EAR when the container is full and with the help of a mathematical algorithm EAR then determines the producer who will be collecting the waste It is the responsibility of the producer to ensure that the logistics company picks up the container immediately and also that the waste undergoes required treatment in certified treatment facilities.[79]

77. http://www.relectra.de/en/home
78. https://www.stiftung-ear.de/
79. http://www.elektrogesetz.com/#ablauf

4.5 Case of US

End-of-life treatment of solar PV products is governed by the Federal Resource Conservation and Recovery Act (RCRA) and various local state policies. As a prerequisite to be governed by RCRA, solar panels must be defined and classified as hazardous waste, a condition to be met by failing the Toxicity Characteristics Leach Procedure test (TCLP test), however most panels usually pass TLCP and are therefore not subject to RCRA.

Hazardous waste can be further subdivided into characteristic hazardous waste and listed hazardous waste. Listed hazardous wastes are wastes from manufacturing and industrial processes or wastes that are generated from discarded commercial products. Wastes exhibiting the properties of ignitability, corrosiveness, reactivity or toxicity are known as characteristic wastes.[80] End of life panels don't fall in the category of listed hazardous waste and are therefore processed based on the characteristic hazardous waste method. An assessment is done to see whether in a waste sample the contaminants present exceed the regulatory levels or not. Different states within US can have separate leaching processes. Provisions for voluntary collection and recycling have been made available by different PV industry stakeholders. (e.g- PV CYCLE USA)

4.6 Case of Japan

The country does not have a specific regulatory framework to manage end of life PV panels. Degraded panels are treated as industrial wastes and are often disposed-off in landfills.[81] The Japanese government has been working with organizations like the New Energy and Industrial Technology Development Organization (NEDO) and other private companies such as NPC Group for developing technologies for recycling solar panels.[82]

The NPC Group has invented a "hot knife method" which can separate panel cells from glass in 40 seconds. Two rollers are placed on either side of the panel, which move along it until it turns into a one-meter-long and 1 cm thick steel blade, which is heated to 200 degrees Celsius after which the cell and the glass are sliced apart. For boosting recycling in Japan, NPC Group has also entered into a joint venture with Hamada (an industrial waste disposal company).[83] A goal was set to process 50000-100000 panels in three years, out of which 80 percent were to be recycled and the rest were to be reused.[84]

Research conducted by NEDO in Japan resulted in the designing of a PV recycling technology in 2014. Automatic separation of different panel types occurs through this technology. The entire process has been shown in figure 4.3.

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80. https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes
81. https://www.eu-japan.eu/sites/default/files/publications/docs/waste_management_recycling_japan.pdf
82. https://recyclinginternational.com/e-scrap/solar-panel-recycling-push-in-japan/
83. IBID
84. https://asia.nikkei.com/Business/Biotechnology/Japanese-companies-work-on-ways-to-recycle-a-mountain-of-solar-panels

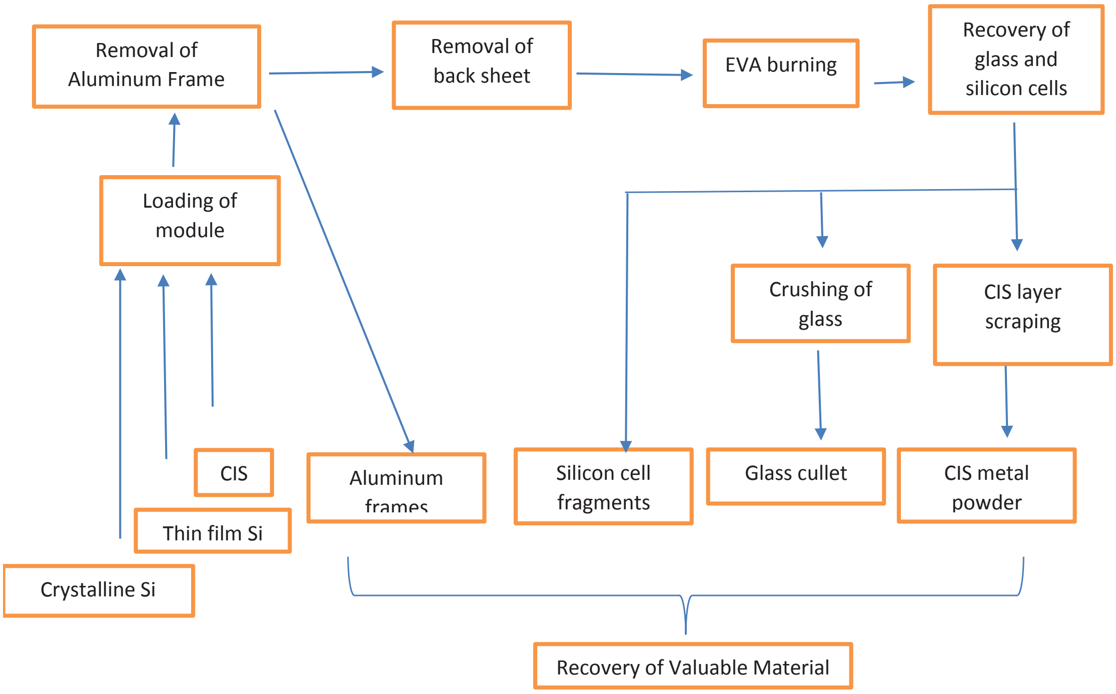

Figure 4.3: Suggested schematic for PV waste management in Japan

Source: https://recyclinginternational.com/e-scrap/solar-panel-recycling-push-in-japan/

There are four processes involved. They include, removal of aluminum frame, removal of back sheet, ethylene-vinyl-acetate resin burning and CIS layer scraping (only for CIS panels). The materials recovered in the end include, aluminum frames, silicon cell fragments, glass cullets and CIS metal powder.

The Promotion of Effective Utilization of Resources Law was enacted in 2000 and came into force in 2001. Establishing a sound material cycle system was the central objective of the law. This was achieved by:

1. Encouraging recycling of goods and resources through collection and recycling of used products by businesses.

2. Reducing waste generation through longer use life of products

3. Implementation of measures for reusing materials recovered from used products.

Some of the resource saving industries that have been identified include:

- Pulp and paper
- Inorganic and organic chemical manufacturing
- Iron and steel making
- Copper smelting and refining
- Automobile manufacturing

The above mentioned industries are expected to reduce the generation of by products through efficient use of raw materials and also through the use of by products as recyclable resources.

The Japanese policy on mineral resources identifies a group of critical metals that are either "geographically rare" or "difficult to recover". Japan maintains stockpiles for the following metals: copper, nickel, tungsten, manganese and a few others.[85]

Japan Oil, Gas and Metals National Corporation (JOGMEC) was set up in 2004 for supporting Japanese companies in securing a reliable supply of natural resources as well as non-ferrous metals in Japan. Within the metals division, the various activities carried out include[86] :

- Mineral exploration
- Research and development for recycling
- Stockpiling of rare metals
- Financing Mine development
- Mine pollution control

JOGMEC along with Sojitz (a trading company), have helped set up long term supply agreements, joint ventures and alliances with producers across countries such as Vietnam, Kazakhstan, Australia, India and Mongolia in exchange for exploration technologies, sharing of technological know-how and financing.[87]

Japan Mining Industry Association (JMIA) is a representative organization, set up in 1948, for mining and smelting companies, who produce non-ferrous metals like silver, copper, gold, lead, zinc and nickel in Japan. It addresses issues ranging from securing a stable supply of non-ferrous minerals, recycling as well as promotion of best practices and technical progresses. Activities directed towards sustainable development of non- ferrous metal industry in Japan include:

- Formulation of mining policies for the government
- Collecting and sharing of information pertaining to demand and supply and new developments related to the industry.
- Promoting best practices
- Interaction with stakeholders such as industrial associations and government bodies in Japan as well as other countries.

In December 2017, Japan acknowledged the repercussions that the decommissioned solar panels could cause. The Japan Photovoltaic Energy Association (JPEA) voluntarily issued guidelines, which are not enforceable yet strongly recommended to the industry, on 'proper disposal' of used solar modules.

4.7 Conclusion

The developed countries across the world have given a serious thought to the resource efficiency aspect of the solar PV sector, particularly the end of life management of the solar PV modules. Infact solar PV recycling is gradually becoming a prominent industry with potential to earn significant profits. Indian policy makers can draw learning from these countries and design a waste management plan including recycling standards for the estimated 77.6 lakh tonnes e-waste that will be generated in the form of used-up solar panels. Presently, India does not have a robust recycling infrastructure as well regulatory framework for solar PV panels. The provision, made under the technical requirements for grid solar PV

85. https://www.wrforum.org/wp-content/uploads/2015/03/Metal-Recycling-Opportunities-Limits-Infrastructure-2013Metal_recycling.pdf
86. http://www.investimentos.mdic.gov.br/public/arquivo/arq1274106828.pdf
87. https://www.merit.unu.edu/publications/working-papers/abstract/?id=5933

power plants MNRE, Government of India has directed all the solar power developers to ensure that all Solar PV modules from their plant after their end-of-life (when they become defective/ non-operational/ non-repairable) are disposed-off in accordance with the 'e-waste (Management and Handling) Rules, 2011' notified by the Government and amended in 2016. Most of the solar panels that are disposed of each year are damaged or defective.

India already has the recycling technologies in-use for the recovery of materials other than precious elements from generated e-waste. Such technologies could be implemented for the recovery of the materials from generated solar PV waste as well in order to avoid flooding of landfills with huge heap of modules and also the leaching of harmful chemicals in the soil and water resulting in contaminating the environment. The regulatory bodies, manufacturers as well consumers should consider the solar PV waste seriously. The concerned authorities should try to make amendments regarding solar PV recycling in existing e-waste rules.

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88. http://www.kogyo-kyokai.gr.jp/category/1850702.html

5. Recommendations for a low carbon resource efficient Solar PV sector in India

Given that India has seen modest growth in solar capacity only in recent years, that too using mostly imported modules, there has not been much thinking of management of solar PV wastes not only during production and installation phase, but also at the disposal stage. In other words, the solar PV modules in the country are far away from reaching their end of life and therefore their recycling in terms of policy and regulatory measures has still not been considered by the Government, as it is perceived that the repercussions of waste from used PV modules are not glaring presently. However, with increased installations under the JNNSM, the projected installation of solar generation capacity can reach 100 GW by 2022, and hence there will be increased volume of PV waste that would be generated. To promote the solar cell manufacturing, India has already initiated dialogue on the policy front with the announcement of a draft concept note on Solar PV manufacturing scheme to build up manufacturing capacity of solar PV modules, cells, wafers/ ingots and polysilicon in India. The concept mentions about a “direct financial support” of Rs 11,000 crore and a ‘technology upgradation fund’, for solar cells and module manufacturing.

An estimate by IRENA (2016) the cumulative PV waste generated in India was between 1000- 2500 metric tons in 2016 which will probably rise to 50,000-320,000 metric tons by 2030, and further culminating into 4.4-7.5 million metric tons by 2050 as a result of country’s solar targets. The ramping up of solar power generation, should address the prospect of used panels that would flood the landfills while leaching toxic waste into the environment. There is a significant thrust on domestic manufacturing under the “Make in India’ campaign. Hence systemic value chain based resource management thinking now will help India in the long term to manage the expected growing value of waste from the sector thus enhancing material security.

Under the scheme of “setting up grid connected solar PV under JNNSM” there is a clause on Safe Disposal of Solar PV Modules that provides the developers to ensure disposal of all Solar PV modules from their plant after their ‘end of life’ (when they become defective/ non-operational/ non-repairable) in accordance with the “e-waste (Management and Handling) Rules, 2011” notified by the Government and as revised and amended from time to time. However, the e-waste rules 2011 does not specifically provide a methodology for safe disposal and management of the solar cells or modules. In the current scenario, it is mostly the unorganized waste collectors who are interested in aggregating e-waste, including panels and batteries. Some companies such as Poseidon Solar Services Pvt Ltd, based in Chennai, provide silicon recycling services for the solar industry and recovers all types of silicon and cell raw material bringing disposed and dead material back to the value chain in a professional recycling way. This call for issuance of guidelines that specifically provide a methodology for safe disposal and management of the solar cells or modules

The aim of this study was to understand the possible scope of enhancing resource efficiency in the solar PV sector in India, with additional focus on end of life management stage. The study has also illustrated some of the best practices and policies used by other countries that if appropriately adopted can play a key role in fostering RE in the sector and also be an effective means of reducing the environmental burdens and simultaneously strengthening India's economy by helping decouple resource consumption and economic growth. It is important to however note that the policy support should promote competition, be implementable and can be monitored and sustained with minimum fiscal burden and maximum impact. Based on the study, we present here few recommendations for the solar PV sector keeping in mind our broader objectives pertaining to resource efficiency for the country in Table 5.1.

Table 5.1: Key recommendations for enhancing resource efficiency in solar PV sector

Objective	Actions	Outcome	Policy instruments	Timeframe
Enhance raw material security of the country	• Encourage standardized and easily dismantled product designs	• Reduced imports • Recovery of secondary raw material	• Financial support through subsidies and other incentives to encourage responsible product design	Medium to Long Term
	• Encouraging manufacturers of solar PV systems to use recycled raw material	• Substitution of virgin raw material with recycled raw material to expand domestic manufacturing of solar cells	• Set up a modest target of use of recycled material in their new products , followed by gradual rise in the target • Provision of additional incentives during manufacturing (such as through GST reduction) for manufacturers for manufacturing solar PVs using recycled raw material • Purchase tax rebates for secondary raw material recovered through PV recycling processes	
	• Set up a proper solar panel recycling infrastructure that can manage the large volumes of PV modules that will be disposed in near future		• Awareness generation through showcasing of innovation and exploring potential for upscaling of the new technologies for end of life solar PV management • Investment in formal recycling set ups; A cluster approach could be considered here since solar PV manufacturing happens in selected locations and these locations could also be those where formal recycling set ups come up	

			• Establishing Reverse logistics network involving PV manufactures distributors networks or third party e-waste management vendors • Realistic and achievable collection target for PV Panels • Issuance of guidelines that specifically provide a methodology for safe disposal and management of the solar cells or modules • Arrangement for skill and training for managing end of life solar PV • Define labelling and standards that could be adopted for recycled/secondary products	
Expansion of technologies for solar PV	• Encourage development of thin-film technologies that use Earth-abundant materials and promise low weight and flexibility • Encourage development of recovery technology for valuable and rare earth elements such as palladium (Pd), tantalum (Ta), indium (In), gallium (Ga), beryllium (Be), etc., present in traces	• Reduced pressure on rare earth materials • More efficient resource utilization	Financial support to R&D of thin-film technologies Financial support to R&D for developing recovery technologies for valuable rare earths from Printed circuit boards (PCBs) which can act as a secondary source of these materials	Medium term to Long term
Implementing Extended Producer Responsibility including that for end of life management	• Developers should be made responsible for handling damaged and unusable modules broken during transit or installation.	• Better end of life management of solar PV modules	Design of an agreement mandating the developers for collection of damaged and unusable modules broken during transit or installation; The cost of take back arrangement need to be specified within the total cost of installation. Enforcement mechanism for such contracts should be designed by the Government in their tenders/schemes or PPA agreements	

	• Designing of Extended producer-responsibility schemes for end of life management		Pay-as-you-go combined with last-man-standing insurance, and joint and-several liability approaches in which producers become responsible for PV panel collection and recycling; the costs of proper treatment and recycling can be included in the production sales price through a modest fee per kilowatt-hour produced	
Resource efficiency standards	• To strengthen and organize the used panels segment by recognizing specialized dealer network or manufacturers	Bring back used, remanufactured, and refurbished panels and sell them through organized channels	• Introduction of appropriate functional criteria and labels • Monitoring and supervision by solar developers	Long term
Capacity development	• Support for R&D in PV end-of-life activities • Support for technology innovations • Training of personnel in resource efficient techniques and processes through different vocational training programmes • Industrial cluster cultivation between the automotive and waste sectors as well as cross-cutting R&D programmes • Accessing human talent across different disciplinary fields, including engineering, science, environmental management, finance, business and commerce.	• Improved technological performance and generation of greater value from the recycling output • Creation of high-value recycling processes for rare, valuable and potentially hazardous materials • Additional environmental and socio-economic benefits • Increased quality for recycling technologies and processes	• Grants for organizing training and workshops • Financial support for R&D	Immediate to Long term

5.1 Conclusion

In an era where economies are striving to achieve ambitious and interconnected global development agenda, the role of a new global partnership has become even more relevant and critical. A successful sustainable development agenda requires partnerships between government, private sector and civil society as reflected in SDG 17.

Business to Business partnerships between India and other countries supported by targeted dialogue and action can help mainstream and institutionalize resource efficiency and lifecycle thinking. There is significant scope for collaboration and information exchange for resource efficiency innovation across the life cycle and promote effective use of applied research and analysis to support innovation.

5.1.1 EU-India B2B cooperation –Scope to exchange learning and explore potential business collaborations

The EU India Circular Economy Mission, under the Resource Efficiency Initiative is an ideal platform to establish new partnerships and strengthen existing ones in renewable energy sector and more so in the solar PV segment. In a world with dwindling resources and increased price volatility, the platform will create unprecedented opportunities for businesses from EU and India and learn from each other's experiences on strengthening resource efficiency and circular economy. The Circular Economy Missions are a series of high-level political and business meetings in third countries to communicate and promote sustainable and resource-efficient policies.

The missions are organised by the Directorate-General (DG) for the Environment of the European Commission and aim to build bridges between European institutions, NGOs, civil society organizations, companies and the relevant stakeholders in those developing countries, in pursuit towards promoting and adopting sustainable consumption and production.

EU a resource constrained region have achieved breakthrough technologies and processes in the PV sector across the different life cycle stages that enhances resource productivity and circularity, while catering to the growing PV requirement in the region in a sustainable manner. India, on the other hand, is an emerging market with high ambition of deploying renewable energy and in particular solar PV. This creates opportunities for technology and know-how transfer between India and Europe. While India can leapfrog others towards a sustainable resource efficient PV sector, at the same time India will provide EU new avenues of collaborative research and development and innovative service delivery to existing and future consumers along the value chain of the PV sector.

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