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IEEFA.org

Recycle to Repower: Accelerating India's Clean Energy Transition Through Circular Decarbonisation

The Role of the Circular Economy in India's Clean Energy Transition

Executive Summary

> *"Life itself has existed for billions of years and has continually adapted to use materials effectively. It's a complex system, but within it, there is no waste. Everything is metabolised. It's not a linear economy at all, but circular."*
>
> – Dame Ellen MacArthur, Founder, Ellen MacArthur Foundation

Two decades ago, it was hard to imagine that the share of renewables (including hydro) in global electricity generation could touch 28%.[1] The energy transition in India has been inspirational, thanks to supportive policies and a push from the central and state governments. India has already crossed 100 gigawatts (GW) of installed renewable energy (RE) capacity.[2]

A big factor in this journey has been optimum usage of resources that has deep cultural roots in our society, be it innovative recipes to reduce food waste, the unregulated scrap waste industry or passing a piece of cloth from one generation to another. Most of us have seen this while growing up but have lost touch owing to aggressive modernisation and "use-and-throw" culture.

The world now witnesses the same pattern with the usage of electronic and electrical equipment (EEE) and clean energy technologies that include solar, wind or batteries. The impacts are evident globally. In 2019, the world generated a striking 54 million tonnes of e-waste, an average of 7.3 kilograms per capita. The global generation of e-waste has grown by 9 million tonnes since 2014 and is projected to grow to 75 million tonnes by 2030.[3]

This level of waste threatens to not only divert resources from the deployment of renewables, but also to increase carbon emissions from the manufacture of new materials used in wind, solar, and battery projects.

So, how do we achieve deep decarbonisation while ensuring GDP growth and enhanced socioeconomic development of the country?

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[1] IEA. Global Energy Review. April 2020.
[2] The Economic Times. India's renewable energy capacity crosses 100 GW; R K Singh says 'landmark day'. August 2021.
[3] United Nations University. Global E-Waste Surging: Up 21% in 5 Years. 2 July 2020.

There is no easy answer to this question, but a very effective start could be the adoption of circularity in various sectors. We often say, "What goes around, comes around," and it's time to move beyond the traditional linear approach of produce-use-dispose to the circular approach of reuse-and-recycle.

A linear production and consumption cycle does not consider emissions generated when the consumed product is thrown away. Here lies a huge opportunity to ensure economic growth and meet the Nationally Determined Contributions (NDC) targets.

The logical first step is recycling and reusing. Recycling aims to eliminate waste and ensure continual use of resources. India does not yet have a dedicated photovoltaic (PV) waste management and recycling policy. Limited clarity exists on ownership of a solar panel once its life cycle is complete. One can draw from the European experience of the Extended Producer Responsibility (EPR) framework. Another key discussion is the financial viability of recycling and the factors that contribute to the cost. The estimated recycling cost is currently US$20 to US$30 per solar panel as compared to US$1 or US$2 to send it to landfill.[4]

With the aim to achieve Atmanirbhar Bharat (Self-Reliant India) in a true sense and balance the supply and demand for raw material, a holistic understanding of the end-of-life management process of clean energy solutions is crucial. Research and development, as well as private sector participation can make domestic PV recycling a reality while accelerating the path to decarbonisation.

Extended Producer Responsibility (EPR) schemes, for example, have become a powerful tool for promoting effective waste management solutions in a number of countries. The objective of EPR is to push producers (including thermal power generators, renewable energy developers and manufacturers) to factor in environmental costs as part of their project planning – both technical and financial.

This report highlights the need to move forward based on the principles of a circular economy and responsible recycling by taking the following actions:

- **Policy and Regulatory Clarity:** A strategic clean energy transition based on the principles of circular economy would require policy and regulatory clarity from the Ministry of New and Renewable Energy (MNRE) and the Ministry of Environment, Forest, and Climate Change (MoEFCC). Structured guidance on standards for PV waste collection, treatment and disposal is needed.

- **Producer Responsibility Organisations (PRO) Take the Lead:** The Central Pollution Control Board (CPCB) has a list of 57 registered PROs.[5] A program to strengthen the capacity of the PROs to include RE waste collection, segregation, dismantling and recycling needs to be developed and executed. One can also conduct awareness programs, aligning with the National Skill Development Corporation, along with motivating energy

[4] PV Magazine. Solar panel recycling in the US—a looming issue that could harm industry growth and reputation. 3 December 2020.
[5] CPCB. List of Registered PRO. 2 August 2021.

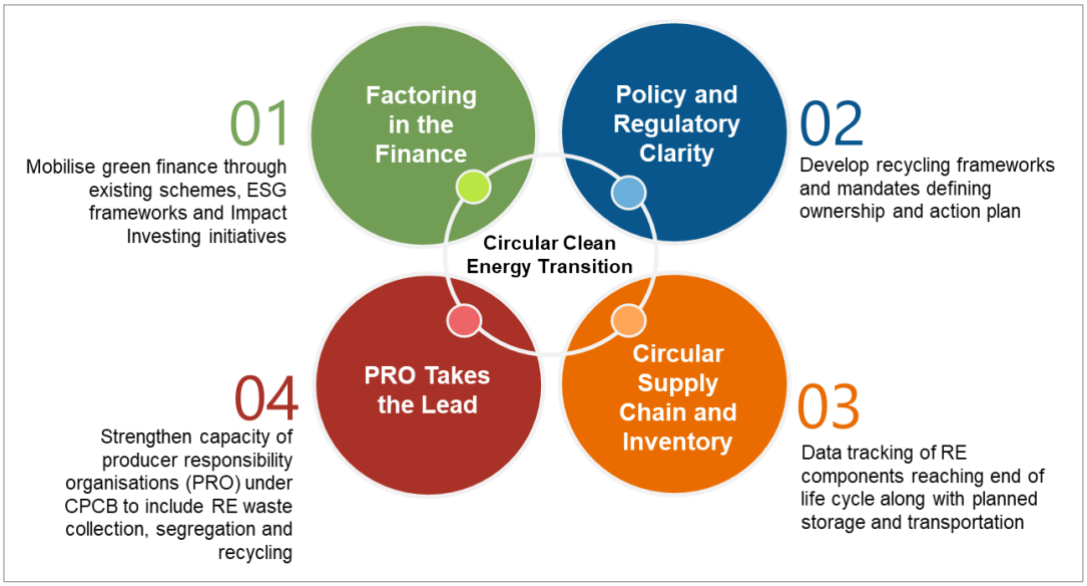
entrepreneurs to explore innovative business like EPR consulting based on responsible recycling.

- **Circular Supply Chain and Inventory:** MNRE and MoEFCC need to track and monitor PV installation, performance, and life to quantify the number of panels reaching end of life. One key solution is to create storage spaces for degraded panels instead of throwing them in landfills.

- **Factoring in the Finance:** Recycling will become economical when India achieves the required quantum along with cooperation from all stakeholders including government, think tanks, manufacturers and consumers. Innovative financing mechanisms motivated by ESG frameworks, along with alternative revenue streams for waste utilisation, could be a game changer.

The economic, social, and developmental viability of India's clean energy transition strongly depends on circularity.

Figure 1: Circular Clean Energy Transition



Source: Author's analysis.

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Introduction

The year 1860 witnessed the invention of the world's first solar energy system by French inventor Augustin Mouchot. He predicted that our coal supply would run out and power would be produced from solar energy. More than 160 years later, the share of renewables (including hydro) in the global electricity generation touched 28%.[6]

This clean energy transition is necessary because of climate change. The last few months have witnessed extreme weather impacts—record-breaking heat waves in parts of India, the U.S. and Canada; floods triggered by heavy rainfall in Europe, China, and the U.S; droughts in Africa; and forest fires in Turkey. A recent Intergovernmental Panel on Climate Change (IPCC) report shows that emissions of greenhouse gases from human activities are responsible for approximately 1.1°C of warming and estimates global temperatures will reach or exceed 1.5°C of warming within the next 20 years.[7]

This is a wake-up call for global leaders to take urgent action, be it net zero targets or deep decarbonisation goals. Almost 137 countries have now committed to achieve carbon neutrality by 2050, confirmed by pledges to the Carbon Neutrality Coalition. Carbon neutrality, or net zero, aims to nullify the addition of new emissions to the atmosphere, moving towards a balanced "give-and-take" relationship with the planet.

There is no denying the need for strong commitments. Both developed and developing countries need unique strategies to reduce carbon emissions. But are we missing something by not considering the huge developmental gap in the starting points of each country? Unlike wealthy nations, developing countries are still struggling to supply basic food, electricity, health, education, and livelihood opportunities to their people.

India reached a milestone achievement of 100 GW on 12th August 2021, amidst the pandemic panic.

So, shouldn't the path to the future be reflective of past learning and ownership of past actions? This highlights the need to align common but differentiated responsibilities when it comes to action by different countries on their low-carbon pathways.

India has made significant progress over the last decade—reduced dependency on fossil fuels, increased RE generation, and improved access to reliable and quality

[6] IEA, *op. cit.*
[7] IPCC. Climate change widespread, rapid, and intensifying—IPCC. 9 August 2021.

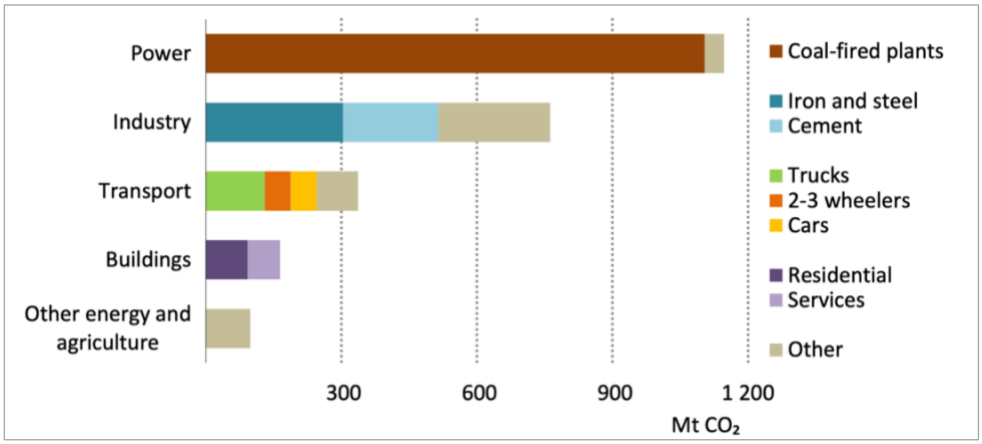
electricity for all. Further, India has the target of achieving 175GW of renewable energy by 2022, and then expanding it to 450GW by 2030.

The key to achieving these targets lies in efficient and effective resource utilisation, along with an analysis of long-term socioeconomic impacts of the decisions made now.

Bearing the Impacts of Fossil Burning

Fossil fuels have been a primary source of energy for centuries. There is no denying that the power sector is the largest generator of carbon emissions. The sector must be decarbonised.

Figure 2: Carbon Emissions - Sectoral Split 2019



Source: India Energy Outlook 2021, pg. 55.

The transition from fossil fuels to renewable energy is the only way to ensure sustainable growth. Fossil fuel-powered homes, industries, and cars are the main contributors of poisonous carbon monoxide and nitrogen oxide, which produces smog (and respiratory illnesses).

An example: India produces about 258 million tonnes of fly ash per annum, a byproduct of coal-fired power plants. About 78% of the ash is utilised and the balance remains in ash dykes.[8] The effects of thermal power generation are witnessed not only during the burning of coal but also by the pollution caused by the waste and byproducts.

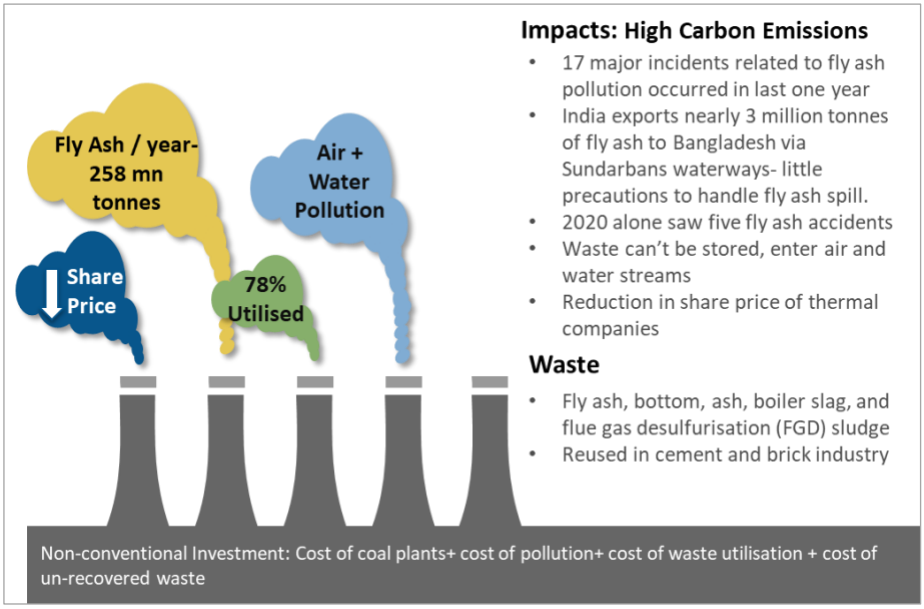
While reducing mining and coal burning has been a focus of the energy transition, one cannot ignore the dangers of coal ash and the consequences of its unmanaged disposal. In terms of land use, the conventional disposal of ash in the form of slurry requires 40,000 hectares of land and 1.04 billion cubic meters of water annually.[9]

[8] Business Line. Fly ash has a new story to tell. March 21, 2021.
[9] Ministry of Environment, Forest and Climate Change. Fly ash management: legal requirements and other issues. 2019.

The report "Coal Ash in India – Vol II: An environmental, social and legal compendium of coal ash mismanagement in India" documents 17 major incidents related to fly ash pollution that occurred in Madhya Pradesh, Tamil Nadu, Odisha, Chhattisgarh, Jharkhand, West Bengal, and Maharashtra.[10]

Every year, India exports nearly 3 million tons of fly ash to Bangladesh via Sundarbans waterways but there are few precautions to handle fly ash spills. In 2020 alone, five fly ash accidents have occurred in the region.[11]

Figure 3: Impacts of Dependency on Fossil Fuels



Source: Author's analysis.

The transition to clean energy solutions does not just reduce the carbon emissions produced while coal is burned. It also spares the world from the effects of the waste generated. Although efforts have been made to reuse fly ash in other industries, the quantum and efficiency is still marginal. The implications can be witnessed in the reduced share prices of thermal giants.

A transition to clean energy solutions is not a choice but a necessity to ensure sustainable socioeconomic development.

Share Prices Not Just Determined by Profits but Also Environmental, Social and Governance (ESG) Impacts

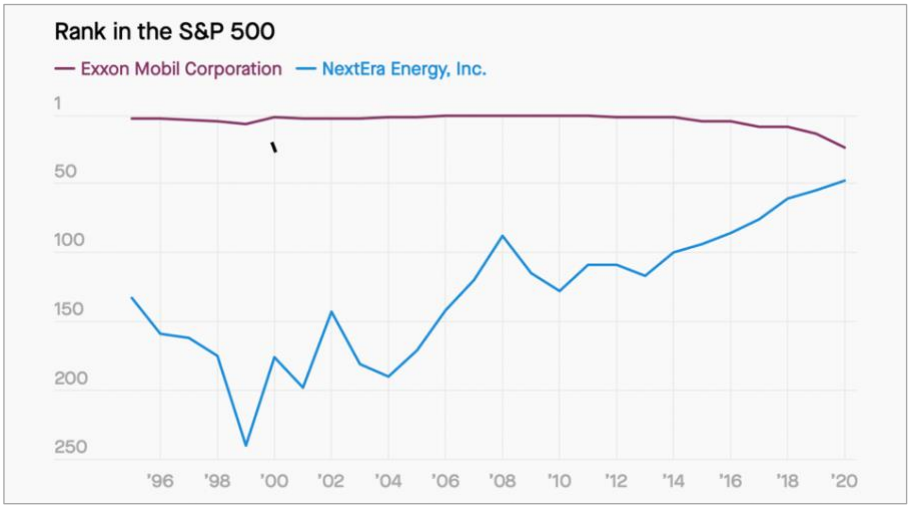
ESG assesses how a company performs in tandem with nature. This is now a key parameter being considered by investors, distributors of financial products and

[10] Health Energy Initiative and Community Environmental monitoring. Coal Ash in India – Vol II: An environmental, social and legal compendium of coal ash mismanagement in India. July 2020.
[11] Acharya.N. Fly ash in India: A free movement of toxicity to Bangladesh. Mongabay. 21 October 2020.

financial advisers. IEEFA notes the increase in green and sustainable lending and investment globally. Companies, despite generating high profits, can lose over multiple investment horizons if they have low ESG scores or damage the environment.

NextEra Energy's (NEE) exponential growth, which saw it briefly take the throne of America's most valuable energy company from ExxonMobil Corp in 2020, is driven by its transition to renewable energy.

Figure 4: The S&P Race Between NextEra Energy and Exxon



Source: Quartz.

NEE was one of the first U.S. power companies that went big on renewables. No company has done more to add zero-carbon electricity to the U.S. grid, which accounts for more than one-quarter of the country's carbon footprint. And it accomplished that feat while churning out cash for investors: shareholder returns bloomed 530% over the last decade, more than double the Standard & Poor's 500-stock index.[12]

The NEE stocks also saw a 100% increase as compared to Duke Energy's (DUK) 18% increase since early 2017.[13] DUK is one of the largest electric and gas utilities in the U.S. serving about 7.7 million electric customers. While DUK revenues are higher, NEE revenue growth is much stronger than Duke's, averaging over 6% over the last three years versus about 3% for Duke. A big credit for this growth goes to the high renewable energy share of NEE.

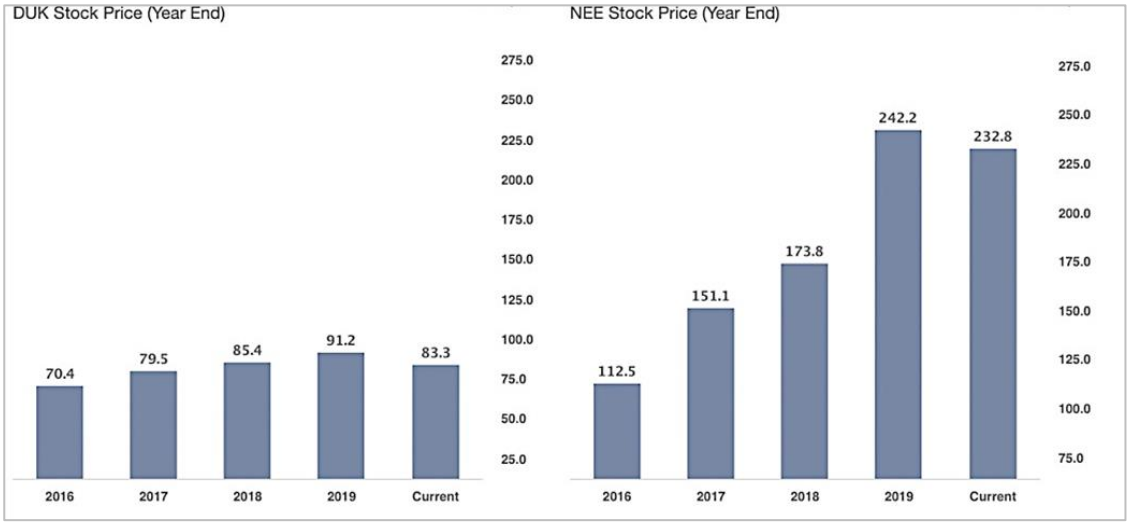
NEE share prices have grown five times faster than Duke's because of aggressive renewable energy investments. Meanwhile, Duke has fought to resolve the issue of coal ash management in North Carolina, absorbing US$1.1 billion in anticipated

[12] Quartz. How wind and solar toppled Exxon from its place as America's top energy company. 30 November 2020.
[13] Forbes. Why NextEra's 5x Price Rise Versus Duke Energy Is Not Justified. 22 May 2020.

cleanup costs between 2015 and 2030.

The total cleanup cost for eight of the utility's coal-ash retention ponds has been projected at between US$8 billion and US$9.5 billion. More expenses will occur after 2030 and may require a new settlement agreement

Figure 5: Stock Price Comparison of NEE and DUK



Source: Forbes.

This is a great example of how the choices made today could impact the future performance and revenue of companies (and countries). The unplanned end-of-life cycle management of thermal plants has left a huge impact on global thermal giants, motivating other power companies to adopt cleaner solutions.

The linear production and consumption cycle does not consider emissions generated when the consumed product is thrown away.

The clean energy transition based on the principle of circular decarbonisation will ensure that countries can achieve their net zero targets.

At present, the linear production and consumption cycle does not consider emissions generated when the consumed product is thrown away. Here lies a huge opportunity to ensure economic growth and meet the Nationally Determined Contributions (NDC) targets.

The transition to RE empowers the world to reduce dependency on coal and nullify environmental damage such as that caused by fly ash. As part of the transition, there is an urgent need to adopt circular strategies.

Designing for Circularity While Decarbonising

The growth of RE depends on availability of raw materials that can be easily recycled and reused. In addition, a circular approach strengthens the economy of a nation by making it resilient to economic shocks such as the COVID-19 pandemic.

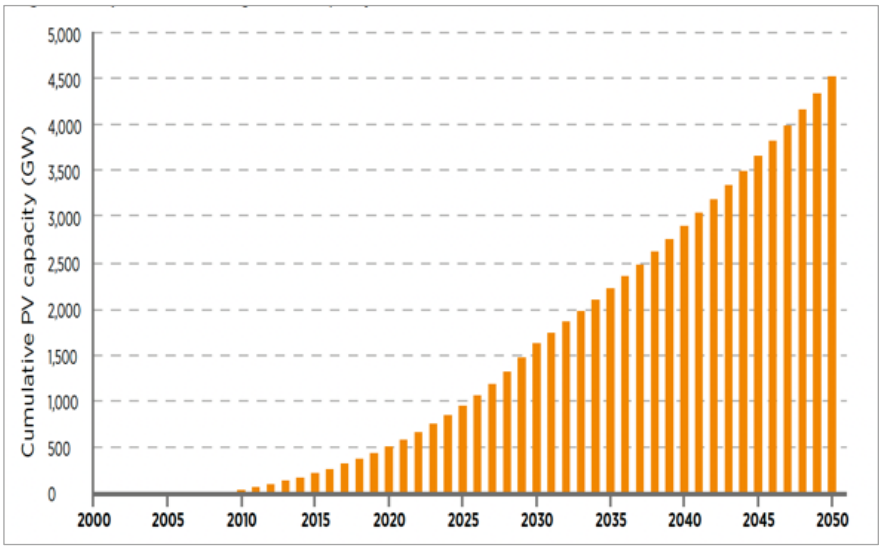
A circular economy values everything. All resources are utilised to their full potential through the reduction, reuse and recycling of waste. This approach not only reduces carbon emission but also builds climate change resilience. In addition, it opens the door for innovative businesses to reduce raw material requirements, optimise costs and enhance resource utilisation.

A circular economy has the potential to accelerate the path to achieve carbon neutrality and deep decarbonisation while reducing the dependency on imports of raw materials, reductions in waste generation, energy use and emissions to the environment. As per the recent Circularity Gap Report, switching to a circular economy could reduce greenhouse gas emissions by 39% and ease pressure on virgin materials by 28%, saving 23 billion tonnes of carbon emissions.[14]

The declining cost of solar energy has paved the way to install more solar capacity and also reduce reliance on fossil fuels. However, as the number of solar installations increases, so do the number of panels that reach their end of life. Figures 6 and 7 capture the increase in global cumulative PV capacity and increase in solar PV capacity in India.

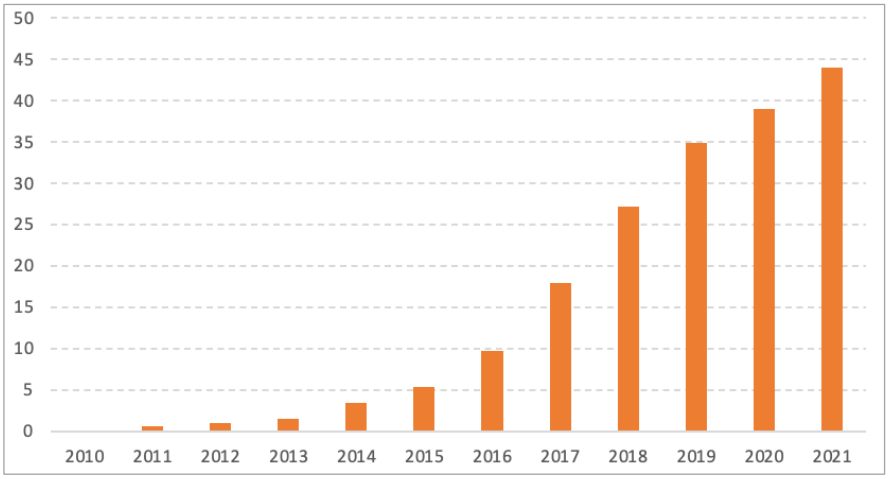
[14] Circle Economy. The Circularity Gap Report. 2021.

Figure 6: Projected Cumulative Global PV Capacity



Source: IRENA (2016) and IEA (2014).

Figure 7: Cumulative Solar PV Capacity (GW) in India



Source: IRENA and IEEFA.

With the aim to decarbonise one of the largest carbon-emitting sectors—the power sector—India is on its energy transition path. India has set a target to achieve 450GW of renewable energy addition by 2030 while decarbonising various industrial sectors, electrifying the transportation fleet, revamping energy efficiency, and strengthening the domestic manufacturing sector.

The growing use of renewables and energy storage has the potential to introduce new challenges for recycling and waste processing, which requires innovative solutions from thought leaders, followed by regulatory and policy action.

The energy transition in India has been remarkable due to supportive policies and a push from the central and state governments. As of July 2021, the nation has 44GW of solar and 40GW of wind installed capacity.[15]

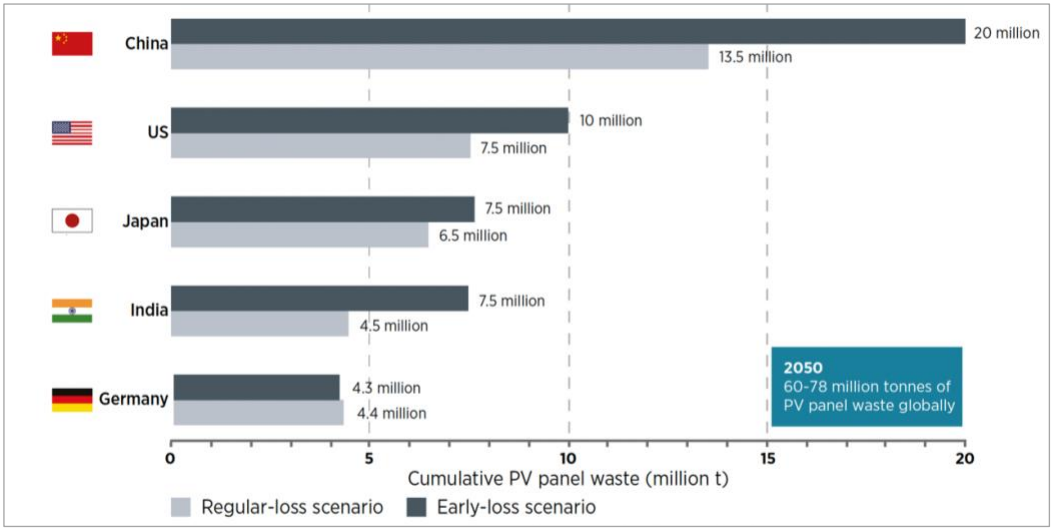
In 2019, the world generated a striking 54 million tonnes of e-waste, an average of 7.3 kilograms per capita.[16] The global generation of e-waste has grown by 9 million tonnes since 2014 and is projected to grow to 75 million tonnes by 2030.

It is estimated that the business opportunity for extracting gold from e-waste could reap between US$700 million and US$1 billion.[17] The gold is mostly dumped or burned rather than being collected for treatment and reuse.

A circular approach undertaking life cycle analysis of decarbonisation pathways will give India the holistic picture of long-term carbon emission generation.

Figure 8 points out a crucial study by the International Renewable Energy Agency (IRENA), which estimated 78 million tonnes of solar PV waste will be accumulated by 2050.[18] The amount of PV waste in India is estimated to grow to 200,000 tonnes by 2030 and to around 1.8 million tonnes by 2050.[19] These estimates may increase as India moves towards its clean energy target of 450GW of RE by 2030.

Figure 8: Cumulative Solar PV Waste Volume of Top Five Countries in 2050



Source: IRENA.

[15] CEA. Installed Capacity Report. July 2021.
[16] The Global E-Waste Monitor. 2020.
[17] FICCI. Accelerating India's Circular Economy Shift. 2018.
[18] IRENA. End-of-life management: Solar Photovoltaic Panels. June 2016.
[19] Bridge to India. Managing India's PV Module Waste. 2019.

Thus, critical materials mined from e-waste—including rare earth elements needed to manufacture EEE products, solar panels, electric vehicles, and batteries—offer a great opportunity for securing their future availability. In India, a lack of domestic reserves makes a circular economy even more important for domestic manufacturing.

Shifting to a circular economy model will not only deliver climate and other ESG benefits but will also provide significant new and better growth opportunities. For example, adopting circular economy principles in Europe in mobility, built environment, and food could offer annual benefits of US$2 trillion by 2030.[20]

Financing of the Circular Economy

As the world starts considering profitability through a lens of conscientious investment, more industries are adopting circular principles to reduce costs, increase revenues, and manage risks. A great example is the circular economy as a key pillar of the European Green Deal. Circular economy roadmaps and legislation also have been considered in China, Chile, and France.

A circular economy holds the power to utilise the growing RE investment efficiently by reducing wastage and converting the produced waste to wealth.

The circular economy is attracting the attention of global financiers. The last 18 months have witnessed a steep increase in the creation of debt and equity instruments related to the circular economy. While no such fund existed in 2017, 10 public equity funds focusing partially or entirely on the circular economy have been launched by leading providers including BlackRock, Credit Suisse, and Goldman Sachs.[21]

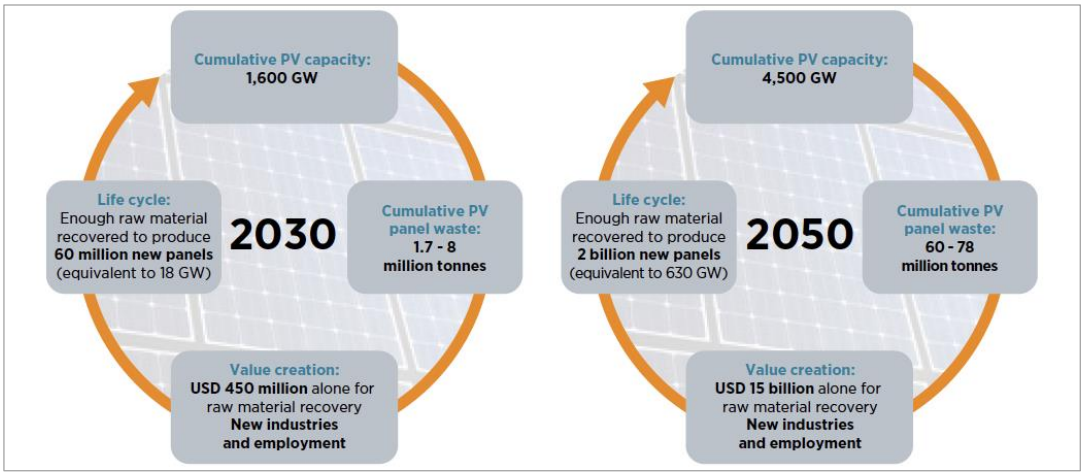
A similar trend is visible in bank lending, project finance, and insurance. Intesa Sanpaolo has launched a US$6 billion credit facility, and the European Investment Bank (EIB) has partnered with five of Europe's largest national financial institutions to launch a US$12 billion loan and investment initiative dedicated to the circular economy.[22]

Central banks have also established platforms like Network for Greening the Financial Systems (NGFS) and Task Force for Climate-Related Financial Disclosure (TCFD). The Reserve Bank of India (RBI) recently echoed the need for such disclosures.

[20] McKinsey Sustainability. Europe's circular-economy opportunity. 1 September 2015.
[21] Ellen MacArthur Foundation. Financing the circular economy. 2020.

Conversations on circular economies do not include clean energy waste, considering the limited amount. The percentage of global circular investment that would target the circular transition of the power sector is a wait-and-see game. (Figure 9 highlights the huge recovery and savings potential of the clean power sector.)

Figure 9: Potential Value Creation through PV End-of-Life Management



Source: IRENA.

Recycling: The First Step Towards a Circular Economy

One method to enhance resource efficiency and reduce waste is basing the energy transition on the foundation of a circular economy. The logical first step is recycling and reusing.

Recycling aims to eliminate waste and ensure continual use of resources. With approximately 44GW solar installed capacity and 40GW wind installed as of July 2021,[23] it is time to create an ecosystem for recycling solar panels and other electric components. Considering the long-life cycle of RE resources and technologies—wind blades, PV, or batteries—there is an immense opportunity to optimise usage, reduce carbon emissions and ensure minimum waste. This is crucial to reduce the long-term effects of an accumulation of electronic waste.

The good news is that most waste is a combination of reusable raw products that can be recycled. In short, adoption of a circular manufacturing and recycling approach can prevent dumping millions of dollars in landfills, reduce long-term land and water pollution, and truly achieve a sustainable net-zero economy. This forms a very important aspect of discussion for the growth of green taxonomy and climate finance.

IRENA's analysis indicates that many technical barriers must be overcome before a closed-loop circularity is possible for solar panels. But raw materials can already be

[23] CEA. Installed Capacity Report. July 2021.

treated and recycled at a rate of 65% to 70% by mass. By 2030, solar panel raw material recovery could represent an opportunity worth US$450 million.[24]

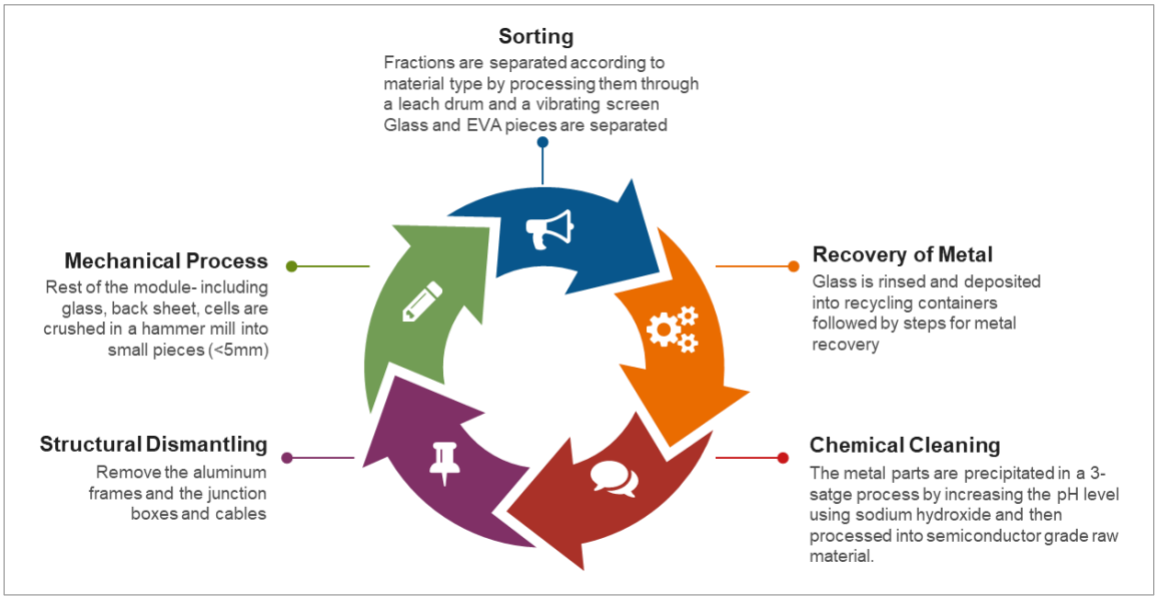
Recycling Process

Solar technology innovation and R&D have taken the centre stage globally. This has led to reduced costs and increased production. As innovation continues and leads to more deployment, the probability of replacing older PV panels with new higher efficiency panels even before they reach end of their lifetime is becoming an issue. In addition, panels destroyed during production, transportation, testing, installation, and climate disasters are reaching the landfills.

The volume requiring recycling or disposal is currently low, except for very early generations of PV panels and small numbers broken during the installation process or damaged in storms. However, options for recycling and disposal need to be addressed as PV production continues to increase. And while a larger recycling need may not come for another decade, an infrastructure and policies should be put in place now to accommodate future needs.

The International Energy Agency's Photovoltaics Power Systems Programme recently released research on the safety of disposing of PV panels in landfills.[25] The main pollutants of concern for each of the major PV modules to be crushed are lead for crystalline silicon panels; cadmium for cadmium telluride (CdTe) panels; and selenium for copper indium gallium selenide (CIGS) panels.

Figure 10: Cyclic Recycling Process



Source: Author's analysis.

[24] IRENA. End-of-Life Management: Solar Photovoltaic Panels. June 2016.
[25] IEA. Photovoltaics Power Systems Programme: Publications.

There are some recycling options currently available for PV panels, but their efficiency depends on the panel type. The most prevalent type of panel, crystalline silicon, can be easily handled in municipal glass, metal, or electronic waste facilities. However, these facilities have limited capacity to extract materials and, due to the infrequent supply of PV panels that need recycling, little incentive to design or install custom processes.

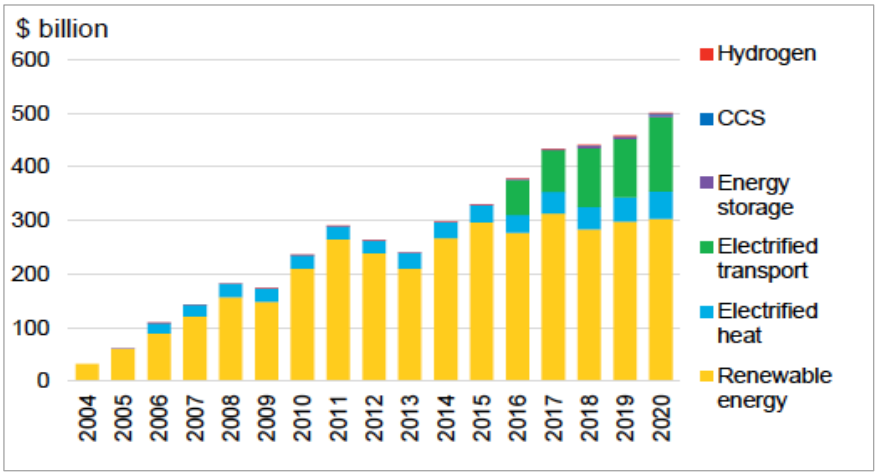
As much as 90% of a module's glass and 95% of the semiconductor material can be recovered during recycling. Aluminium frames can be recycled and processed into usable raw material for furniture, cell phones or new solar panel frames. The silicon cells can be re-cycled as raw material for new solar cells

Non-silicon PV modules, such as thin-film modules, basically need to undergo chemical treatment to separate the various semiconductor materials, allowing as much as 95% recovery of the materials.

Is Recycling of Solar PV Economical?

Investments in clean energy have increased substantially over the years. According to the Bloomberg NEF report, "Energy Transition Investment Trends 2021," a cumulative Rs37 lakh crore (US$501 billion) was invested in 2020 to support a low-carbon energy transition including renewable power, energy storage, electric vehicles (EV) charging infrastructure, hydrogen production, carbon capture and storage (CCS) projects, as well as low-carbon energy devices. This is a 9% increase from 2019 investment value of Rs34 lakh crores (US$459 billion) and 53% increase over the Rs17 lakh crores (US$235 billion) in spent during the last full decade.[26]

Figure 11: Global Investment in Energy Transition by Sector



Source: Bloomberg NEF.

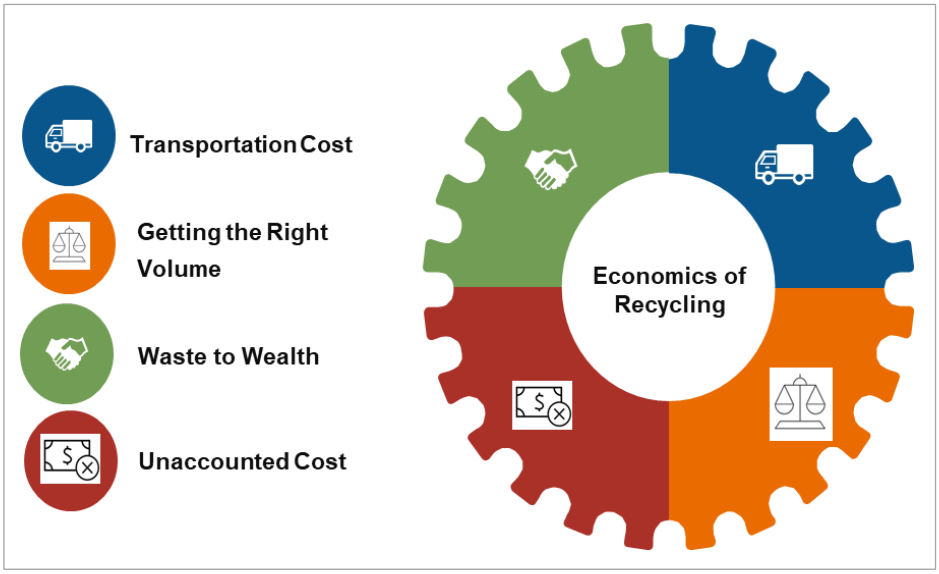
Relevant questions remain about the economics of recycling. According to a report by Bridge to India, PV module recycling is still not commercially viable. Recycling

[26] Bloomberg NEF. Energy Transition Investment Trends. 2021.

costs are US$20 to US$30 per solar panel; it costs between US$1 and US$2 to send it to a landfill.[27]

IEEFA analyses the various factors that contribute to the recycling costs:

Figure 12: Factors Contributing to Recycling Costs



Source: Author's analysis.

Recycling solar PV components, however, has benefits. It can create new and expanded PV market opportunities, new jobs, and domestic supply chain stability. All stakeholders including policy makers, regulators, manufacturers, assemblers, EPC players and consumers need to reduce recycling costs.

Total estimated costs, including transportation, can vary between US$400 and US$600 per tonne, far exceeding the value of the recovered material.[28] The biggest barriers are the reluctance of developers and consumers to give away solar panels for free for recycling, and the lack of a structured policy or regulation that defines the ownership of the used panels. The barriers prevent volume from becoming sufficient for a recycling plant.

In addition, transporting the degraded panels from the site to the recycling plant is a cost that no one wants to bear unless recycling generates additional revenue sources. Dumping old panels into nearby landfills is an easier (and more polluting) option.

Recycling, however, can nullify transportation costs with ancillary markets that utilise the recycled products. Some recycled glass might not be of the quality to be reused in a solar panel manufacturing unit, but it can act as raw material in other

[27] PV Magazine, *op. cit.*
[28] Bridge to India, *op. cit.*

industries. Recovered silicon also can be used to produce renewable energy storage components.

In other words, one industry's waste can be the raw material and wealth for another.

Conducive policies and business models, along with financial planning, are needed to make recycling economical. Collaboration amongst the developed and developing countries is needed.

The development of a domestic manufacturing ecosystem is highly dependent on the future availability and cost of raw materials. A holistic approach while implementing the Atmanirbhar Bharat scheme could be a game-changer. Instead of reinventing the wheel every decade, a structured recycling industry can work with manufacturers, save transportation costs, and set rules for dealing with e-waste.

Global Learning: PV Waste Management

India has yet to develop a dedicated PV waste management and recycling policy. One can draw learning from the European experience of its Extended Producer Responsibility (EPR) framework. EPR has grown as a powerful tool for promoting effective waste management solutions in number of countries.

Penalty approach—The EU Waste of Electrical and Electronic Equipment (WEEE) directive requires PV producers and suppliers to finance the costs of collecting and recycling PV panels or face large fines.

Centralised management—The WEEELABEX organisation in the Czech Republic is responsible for the preparation of standards and the awarding of certification with respect to collection, storage, processing and reprocessing of e-waste, as well as the monitoring of waste-processing companies.[29]

Annual monitoring and reporting—The Italian National Institute for Environmental Protection and Research (ISPRA) issues annual reports to the Ministry of the Environment, Land and Sea Protection about the quantities and categories of electrical and electronic equipment located on the market, prepared for reuse, recycled, and recovered.[30]

Government support—South Korea has been supporting initiatives for PV waste recycling. In 2017, the Ministry of Trade, Industry, and Energy planned a facility to recycle PV module waste in North Chungcheong province.[31]

Private sector participation—A U.S.-based solar panel manufacturing company, First Solar, has established factories in the United States, Germany and Malaysia. The company uses recycling methods with recovery rates of 95% for Cd and 90%

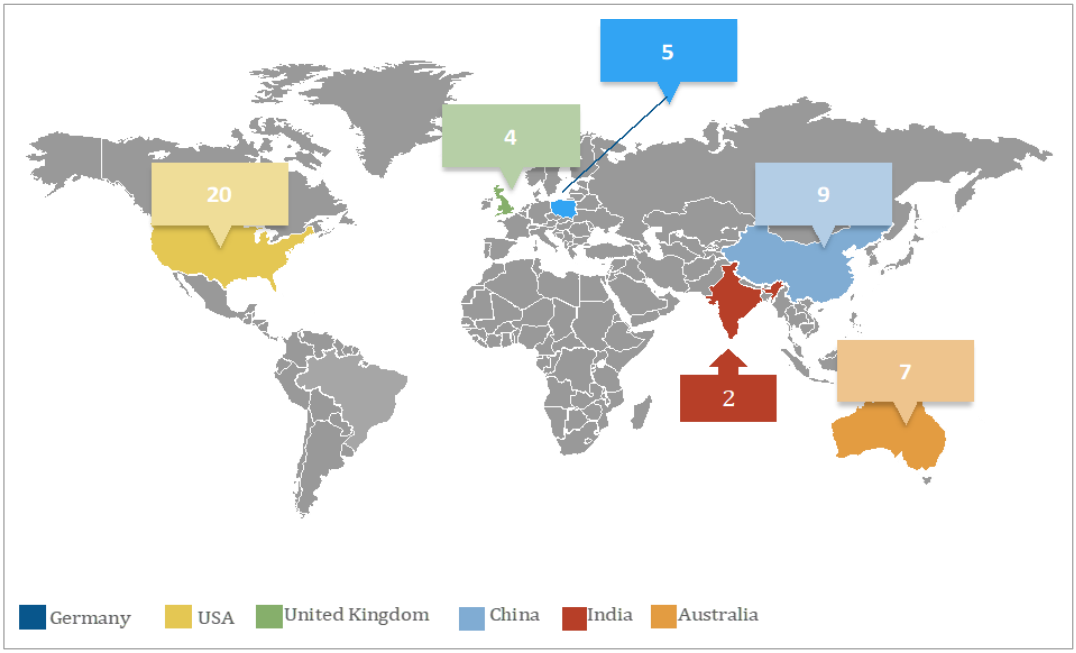
[29] WEEELABEX. 2021.
[30] ISPRA. The Italian National Institute for Environmental Protection and Research.
[31] Ministry of Trade, Industry, and Energy.

for glass[32].

The Solar Energy Industries Association (SEIA) has a national PV recycling program that seeks to lower the cost of recycling panels by aggregating services provided by selected vendors.[33] Individual companies are also ramping up their recycling activities.

Pilots—The Solar Waste Action Plan (SWAP) project in India is looking to investigate both the technical and economic feasibility of a PV module recycling system with support from the Signify Foundation and the Doen Foundation.[34]

Figure 13: PV Recycling Facilities Across Six Key Geographies



Source: IEEFA.

We Recycle Solar has the capacity to process up to 4,536 kilograms of solar equipment daily in each of their 10 facilities across the U.S., Japan, South Korea, and Belgium.[35] The company's current focus is on large-scale recycling best suited for sourcing from manufacturers, utilities, or installers, rather than individual customers. The company recycles all related equipment, including batteries, which streamlines the disposal process and helps companies meet end-of-life requirements from local or state authorities.

Veolia, a French water and waste company, opened Europe's first solar panel recycling plant in 2018. The plant's supply is provided through a contract with the

[32] Energy Strategy Reviews. An overview of solar photovoltaic panels' end-of-life material recycling. January 2020.
[33] SEIA. National PV Recycling Program.
[34] Sofies Leading Sustainability. SWAP.
[35] We Recycle Solar. National PV Disposal Provider.

solar recycling organisation PV Cycle France. Materials extracted from the recycled panels are used directly in new panels.

In January 2019, the Ministry of New and Renewable Energy (MNRE) proposed a new framework for recycling PV panels. It is expected to be mandatory for solar power developers. Producers would be responsible for ensuring recycling of end-of-life glass panels as part of their extended responsibility, as in the case of e-waste that covers used lead-acid batteries, packaging materials, etc.

Steps to Make Recycling a Reality

India needs to learn from the experience of other global initiatives and develop policies and regulations to define the recycling responsibilities and financial ownership of green waste by manufacturers, project developers and consumers.

A holistic approach while implementing the Atmanirbhar Bharat scheme could be the game changer. Instead of reinventing the wheel every 10 or 15 years, a structured recycling industry should be established. Another innovative concept worth exploring is waste trading. The byproduct or waste of one industry could be the raw material for another industry.

Extended Producer Responsibility (EPR) schemes, for example, have become a powerful tool for promoting effective waste management solutions in a number of countries. The objective of EPR is to push producers (including thermal power generators, renewable energy developers and manufacturers) to factor in environmental costs as part of their project planning – both technical and financial.

IEEFA notes other potential ways to encourage the recycling sector in India:

Policy and Regulatory Clarity: A strategic clean energy transition based on the principles of a circular economy will require policy and regulatory clarity from the Ministry of New and Renewable Energy (MNRE) and the Ministry of Environment, Forest and Climate Change (MoEFCC). At present, the e-waste regulations by MoEFCC do not include solar waste, hence the ownership is not defined.

Along with the roadmap to achieve a 450GW target, a framework for RE waste recycling needs to be developed. The framework should:

- Establish standards for PV waste collection, treatment, and disposal.
- Encourage developers and manufacturers to include the cost of decommissioning and recycling of PV panels in the bidding process, power purchase agreements (PPAs), and operation and maintenance negotiations.
- Require government tenders and contracts to include clear directions regarding the treatment of existing panels and clear directions for their disposal.

Producer Responsibility Organisations (PRO) Take the Lead: The Central Pollution Control Board (CPCB) has a list of 57 registered PROs.[36] A PRO is created by the producers (brands or retailers) to meet EPR obligations. PROs develop and execute program plans to comply with legislative and regulatory requirements such as EPR.

The CPCB states that the installed capacity of registered e-waste recyclers and dismantlers in the country is only about 400,000 tonnes per year, 22% of the estimated e-waste volume. It is estimated that less than 4% of the e-waste generated in the country was sent to formal, registered recyclers between 2015 and 2017.[37]

There is an urgent need to:

- Strengthen the capacity of the PROs to include RE waste collection, segregation, dismantling and recycling.
- Ensure proper reverse logistics. Reverse logistics is defined as the process of moving goods beyond their typical final destination for things like re-use, capturing value, or proper disposal.
- Conduct awareness programs, aligning with the National Skill Development Corporation. In addition, motivate entrepreneurs to explore innovative businesses such as EPR consulting based on responsible recycling.

Circular Supply Chain and Inventory: Data forms the foundation for the successful implementation of many policies and frameworks.

- Track and forecast the solar PV waste to develop a roadmap for a smooth roll-out of recycling infrastructure. Leverage the Approved List of Models and Manufacturers (ALMM) initiative by MoEFCC and MNRE to track the solar panels that are reaching end of their lives.
- Encourage mutual recycling responsibility agreements between module suppliers, project developers and power purchasers.
- Create collection areas to store degraded panels instead of throwing them in landfills. Storing degraded panels can reduce transportation costs by piggybacking on the domestic manufacturing initiative.

Factoring in the Finance: Recycling can become economical when India achieves the required quantum, along with cooperation from all stakeholders including government, think tanks, manufacturers, and consumers. Innovative financing mechanisms motivated by an ESG framework, along with alternate revenue streams for waste utilisation, could be a game-changer.

[36] CPCB. List of Registered PRO. 2 August 2021.
[37] Centre for Science and Environment. Report E-waste management: generation; collection and recycling. 19 May 2018.

- Develop ancillary markets and pricing mechanisms to use recycled products. The Micro, Small & Medium Enterprises (MSME) sector could play a huge role in developing a structured recycling industry.

- Create a mechanism for adoption of environmental, social and governance (ESG) frameworks to enable domestic manufacturers to attract green finance to set up recycling plants alongside their manufacturing units.

- Identify investment and technical requirements for dedicated PV recycling facilities that focus on high-value recovery and create mechanisms to utilise existing funding flows like Atmanirbhar Bharat.

- Mobilise capital to circular economy investments. Investors can play a key role in providing financial support that can help accelerate a transition to a net-zero circular economy.

The economic, social, and developmental viability of India's clean energy transition strongly depends on implementing a circular economy.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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Saloni Sachdeva, an energy and finance consultant at IEEFA, has a master's degree in renewable energy engineering and management from TERI School of Advanced Studies, as well as an electrical engineering background. Saloni has worked with Shakti Sustainable Energy Foundation, focusing on policy, regulatory, technical and capacity-building interventions to support the development of renewable energy in India. Along with research, Saloni has more than five years of experience working in the philanthropic world.