



## ROLE OF CIRCULAR ECONOMY IN THE SOLAR ENERGY SYSTEM: AN ASSESSMENT

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**Abstract:** This paper presents an assessment of the role of the circular economy in the solar energy system, with a particular focus on solar panel recycling, repairing, and refurbishing. The circular economy principles emphasize sustainability, resource efficiency, and waste reduction, aligning well with the goals of the solar energy sector. The assessment explores how the circular economy approach can contribute to resource conservation by promoting the use of renewable materials and designing solar panels for long lifespan and easy repair. Furthermore, it examines the importance of proper end-of-life management for solar panels, highlighting the value of recycling and recovering valuable materials to minimize environmental impact.

### 1. Introduction:

In a circular economy, sharing, renting, reusing, repairing, and recycling already made commodities are given priority when manufacturing and consuming goods. A circular economy concept aims to bridge the gap between industry and the natural ecosystem cycles that ultimately support humanity [1]. To do this, waste needs to be reduced first by composting biodegradable rubbish or, in the case of converted non-biodegradable trash, by reusing, remanufacturing, and finally recycling it. On the other hand, it also requires giving up the use of chemicals (a technique to help the regeneration of natural systems) and betting on renewable energy sources [2]. Figure 1 shows the framework of the circular economy with solar energy system.

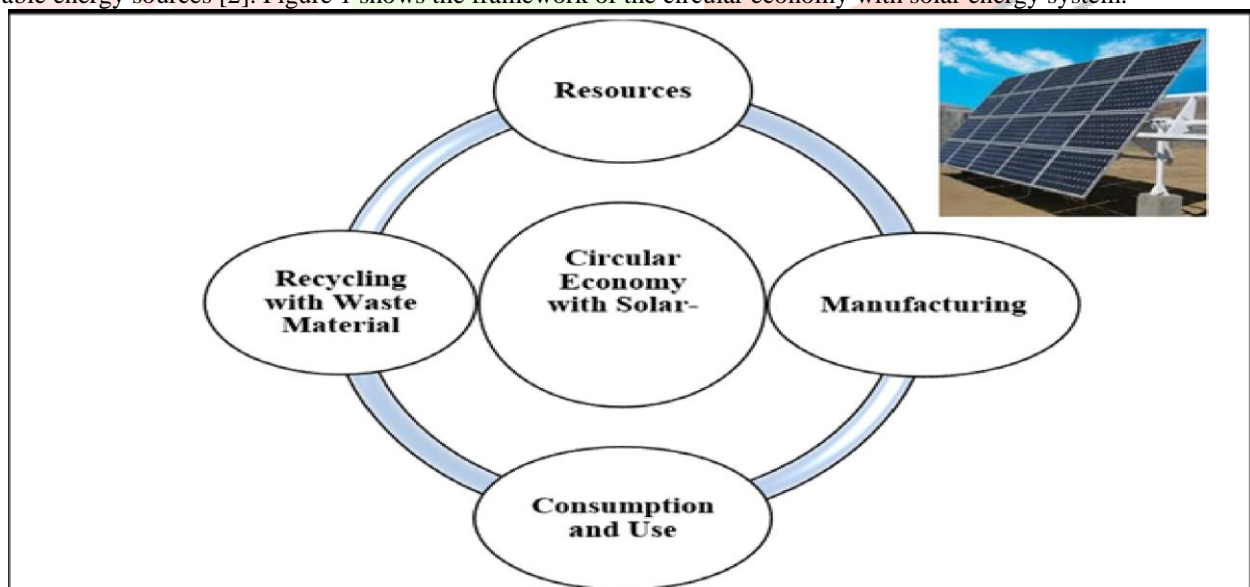


Figure 1: Circular Economy with Solar Energy System

**Khan et al. [3]** describes in what way, circular economy is related to the emission analysis. The thorough development of emission control model requirements is necessary for the transition to the circular economy setup. Policymakers will be able to better plan the strategy for reducing environmental challenges with the support of the full insight provided by the circular economy. **Reich et al. [4]** describes how to measure the circular economy. Working groups establishing a CE policy monitor may find guidance in the framework. Applying the technique ensures that the monitor includes environmental and social data in addition to material flow. The approach highlights important indicators, may be applied at various policymaker levels, and offers immediate feedback on implemented policies. **Kusumo F. [5]** et. al. describes different indicators of circular economy in the field of biological systems. This research also presented a system for measuring and quantifying the CE through the analysis of diverse literary sources. Measurement criteria, level monitoring practices, and the impact of CE make up the framework's first three steps. The suggested structure will speed up the implementation of CE and help spread knowledge among stakeholders, industries, and stakeholders across regions. This paper shows the role of the circular economy in the field of solar renewable energy systems.

## 2. Solar Energy System:

Solar energy system is one of the prominent sources of electricity generation as a renewable energy source. If we want to assess the solar energy system, with the concept of circular economy, it is necessary to identify the way in which materials, products, and services are in circulation for as long as possible. Reducing global warming requires a circular economy. Action must be taken to confront the climatic calamity, and material recovery is essential [6]. Nearly half of all greenhouse gas emissions worldwide are attributed to the extraction and exploitation of natural resources, according to the UN's International Resource Panel. When carefully and comprehensively designed, the circular economy has the potential to advance social justice, improve economics, and protect the environment. Sustainability depends on social justice [7]. How we get, use, and dispose of our resources may have a disproportionately negative effect on communities who are already at risk. The annual production and installation of photovoltaic (PV) modules will rise as solar energy continues to gain popularity as a source of electricity. In order to decarbonize its power system, the United States may have installed 1,600 gigawatts (or more) of PV by the year 2050, which is around 20 times as much as is currently installed. Many of these PV modules can start losing their operational status even before 2050 [8]. Figure 2 shows the solar module with circular economy. Figure 3 shows the features of solar energy system with circular economy. Figure 4 shows the parameter which is used to the assessment of solar energy system with circular economy.

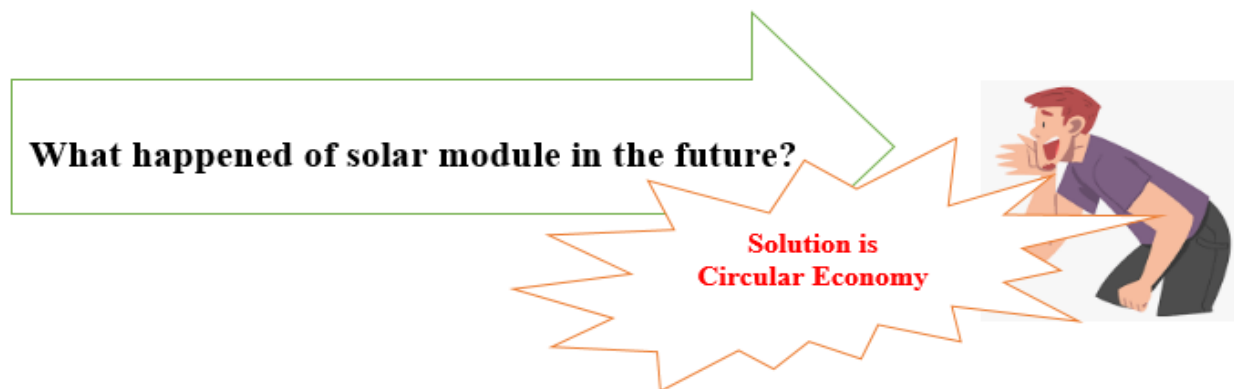


Figure 2: Solar Module with Circular Economy

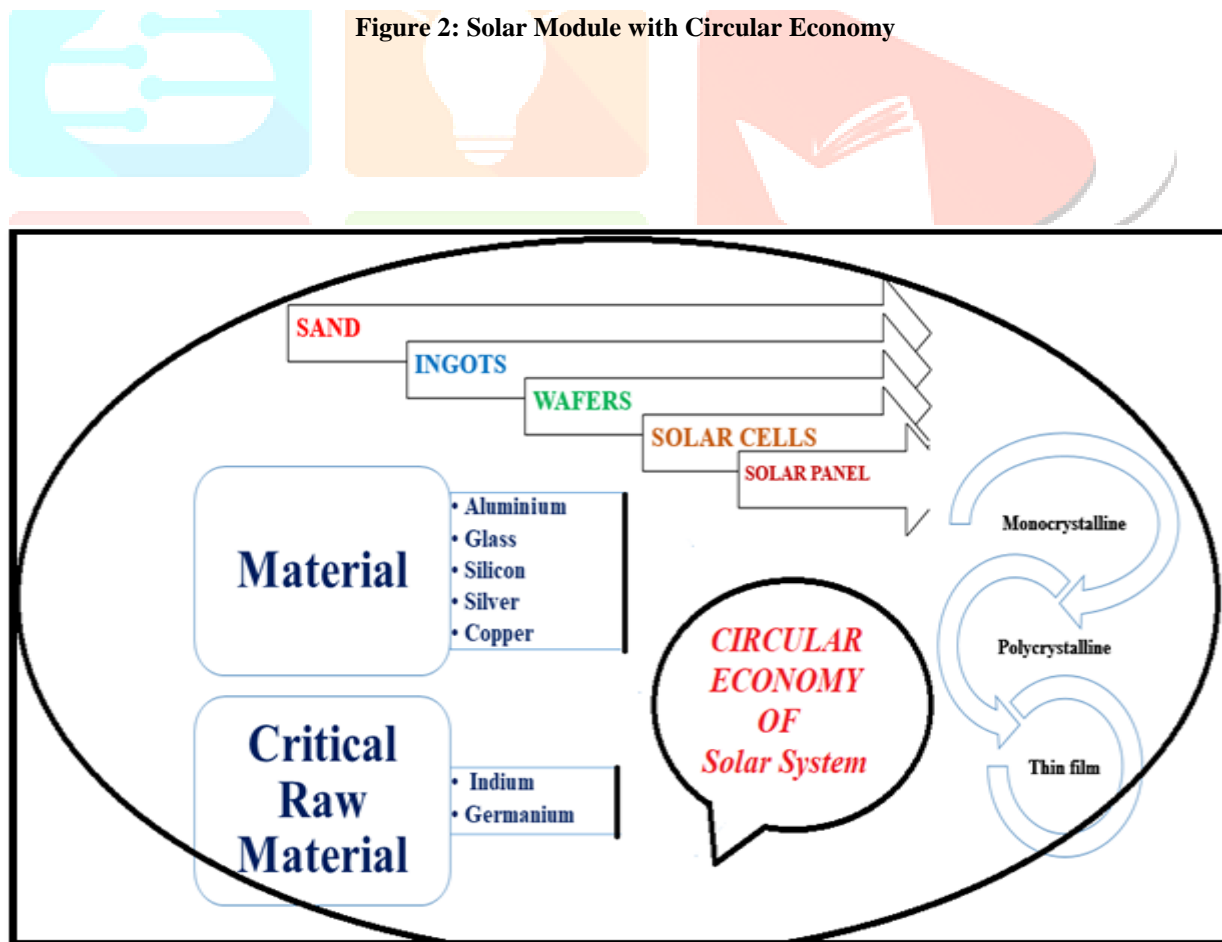
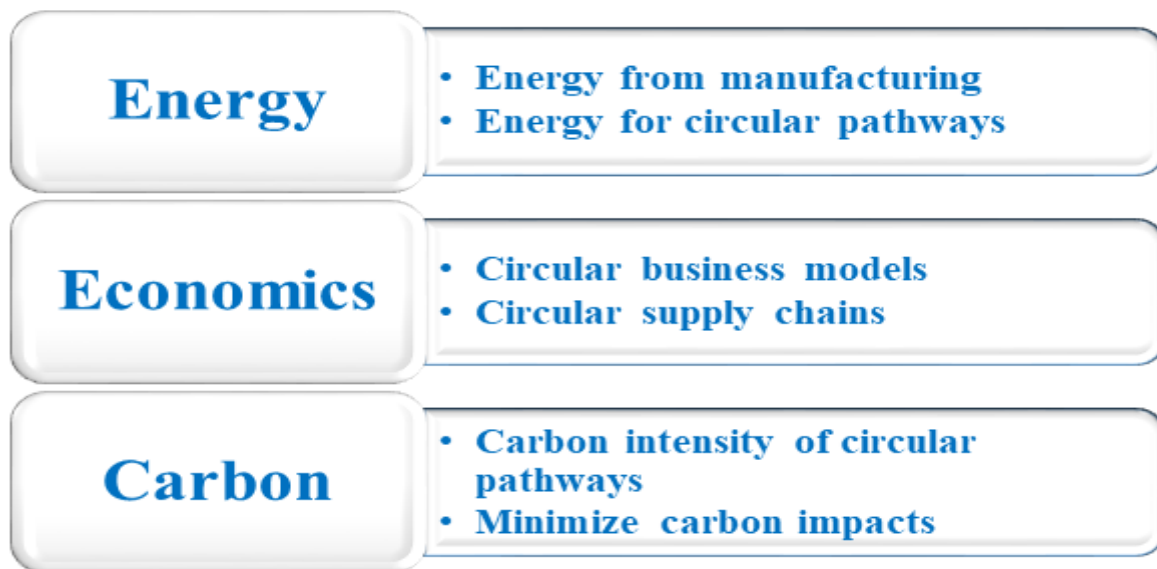


Figure 3: Circular Economy with the Solar Energy System



**Figure 4: Parameter of Solar Energy System with Circular Economy**

A circular economy for solar energy has the potential to lower emissions and the strain on the environment, pave the way for cutting-edge net-zero economies, spur sustainable economic growth and job creation, and lower supply chain risk. From project owners and financiers to manufacturers, a circular economy for solar PV materials will involve everyone throughout the value chain, according to Curtis [9]. By working together, the sector can make sure that liabilities like hazardous chemicals are avoided and that end-of-life management maximizes economic value while minimizing environmental effect. By initially developing materials and products with reuse, recycling, and upcycling in mind, a circular economy for energy materials lowers waste and protects resources [10].

### 3. Solar Panel Recycling:

The electricity capacity of solar panels may drop by 20% over their lifetime. The largest efficiency loss occurs between the first 10 and 12 years and increases to 10% and 20% by 25 years. The majority of manufacturers offer guarantees for these numbers. However, history indicates that after 25 years, efficiency actually only decreases by 6 to 8%. As a result, solar panels may last a lot longer than they are supposed to. High-quality PV panels can last up to 40 years and continue to function after that time, albeit with declining efficiency [11]. To ensure that solar panels do not harm the environment, the makers of solar cells are required by law to adhere to certain regulatory criteria and recycling norms. At that time, solutions for recycling solar panels first appeared. Since all PV cells contain a certain quantity of harmful compounds, that would truly turn into an unsustainable method of obtaining energy by the year 2050 if recycling procedures were not put in place. Currently, there are 60 million tonnes of PV panels waste that are languishing in landfills [12].

There are two primary types of solar panels, and each requires a distinct method of recycling. Both kinds based on thin films or silicon can be recycled using various industrial procedures. Although silicon-based panels are more prevalent right now, materials used in thin-film based cells could still have significant significance. Numerous technologies have been developed as a result of research on solar panel recycling. Although some of them even manage to recycle at an astounding 96% efficiency, the goal is to set a higher threshold in the future [13].

The disassembly of the genuine product and separation of its aluminium and glass components is the initial stage in the silicon-based PV panel recycling process. The external metal parts are all used to make new cell frames, while the glass can be reused almost entirely (95%) of the time. The remaining components are heated to 500 °C in thermal processing equipment to reduce the bonding between the cell elements. The extreme heat causes the plastic covering the silicon cells to vaporise, freeing them up for further processing. Even this plastic is not wasted because of the enabling technology; rather, it is used as a heat source for additional thermal processing. On the other hand, thin-film-based panels go through more rigorous processing. They need to be first put through a shredder. In order to ensure that no particles are larger than this size before it can be removed, a hammermill is employed to ensure that the lamination holding the inner components together breaks at a diameter of 4-5 mm [14]. The leftover substance, in contrast to silicon-based PV panels, consists of both liquid and solid elements. They are separated by a rotating screw, which effectively keeps the solid parts spinning inside a tube as the liquid drips into a container. Liquids go through a precipitation and dewatering procedure to ensure purity. Depending on the specific manufacturing method used to create the panels, 95% of the semiconductor material is typically reused in the final step [15, 16].

This implies that the solar panel simply cannot be thrown into the recycling bin at the recycling station. However, the various materials would need to be separated when it arrived at the recycling facility. Recycling facilities use specialized separation equipment to thoroughly separate the materials in order to do this. However, not all recycling facilities have this kind of machine for separation. And without it, solar panel recycling is impossible. Figure 5 shows the recycling process of material of solar panel.

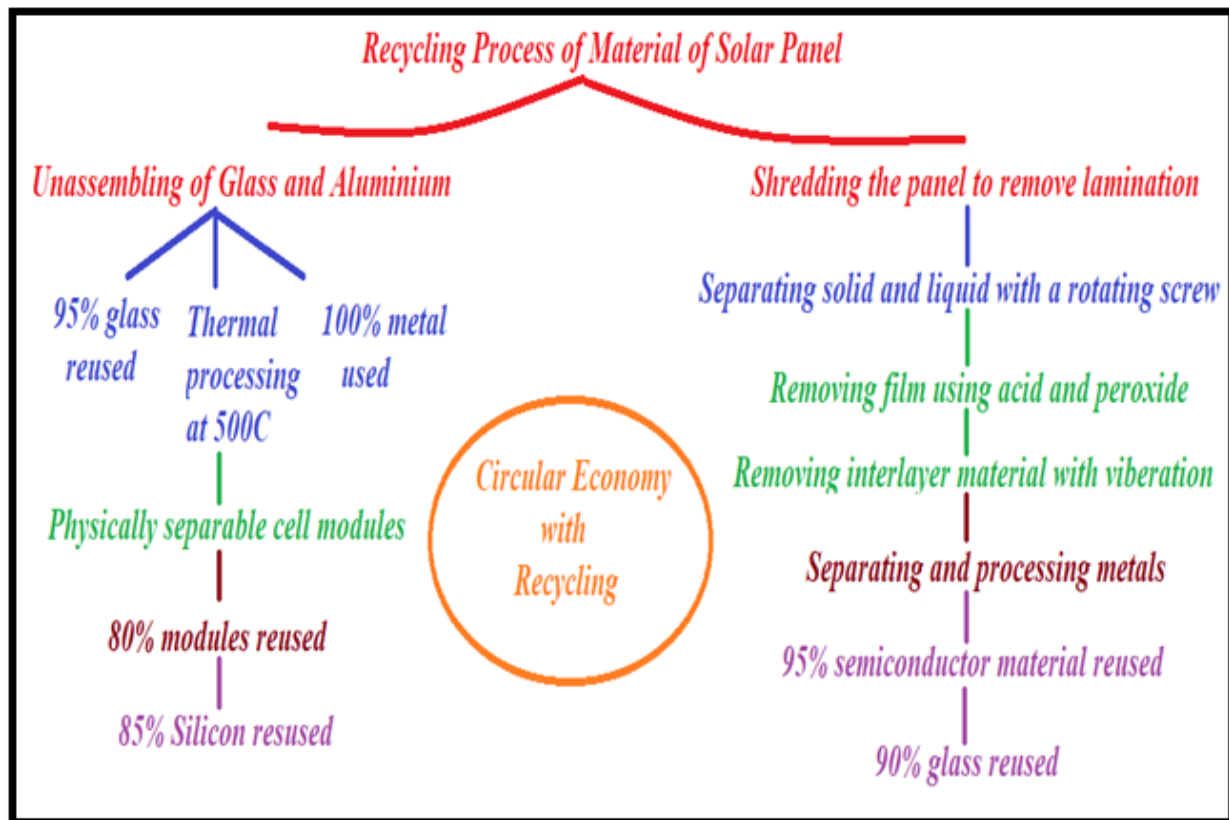


Figure 5: Recycling process of material of solar panel

#### 4. Solar Panel Repairing and Refurbishing:

In the face of expensive and quickly diminishing energy sources, solar panels and the parts that make them up are practical tools. In order to be used in homes and businesses, they convert solar energy into heat and electricity. Solar panel components are susceptible to damage much like any other energy-generating equipment. Their malfunctioning parts are simple to spot because they cause the solar system to produce fewer yields and less energy. As long as they are carried out promptly by industry specialists, repairs for solar panels can aid in the settlement of the majority of typical issues that affect solar panels. On the surface of solar panel glass cells, microscopic fractures, hot spots, and cracks can develop; with time, they can grow in size and impair the efficiency of solar cells. Despite the flaws, the solar system's waterproofing, panel frame, and lamination may still be in fine shape.

**PID Impact:** Voltage variations between the voltage produced by the panel and the earthing of the solar panel are what cause PID, or potential induced deterioration. This causes the main power circuit's discharged voltage to vary in proportion. To stop solar panels from aging more quickly and stabilize their function, the problem can be fixed by experts in solar panel repair.

**Faulty wiring:** Loose cables in the solar power system could cause unforeseen power generation problems. Individual PV cells are connected by these cables to inverters and household solar batteries; even the tiniest wiring error may result in failed connections. Meters and other wire performance checking instruments are used by installers with experience in solar panel repairs and maintenance to assess such issues and provide timely remedies.

**Inside-of-module damage:** Solar panels may sustain internal defects as a result of poor production or component selection. Snail trails, delamination, discoloration of solar connectors or cells, fading of the back-facing sheets, browning of EVA films, staining of the PV cells, unintended inclusions in the PV laminates, burning out of the back and/or front of the solar modules, etc. are the results of these factors.

#### 5. Outcome:

The circular economy plays a crucial role in the solar energy system by promoting sustainability, resource efficiency, and reducing waste throughout the lifecycle of solar energy technologies. Following are the key aspects of how the circular economy contributes to the solar energy system:

**Resource Conservation:** The circular economy aims to minimize resource extraction and maximize resource efficiency. In the solar energy system, this translates into using renewable materials and designing solar panels and related components for long lifespan and easy repair. By extending the lifespan of solar panels and other equipment, it reduces the need for raw material extraction and minimizes waste generation.

**Recycling and End-of-Life Management:** Solar panels have a lifespan of around 25 to 30 years, after which they can still retain a significant portion of their functionality. When solar panels reach the end of their life, a circular economy approach encourages their proper recycling and recovery of valuable materials. This helps reduce the environmental impact of disposal and allows for the reuse of valuable components and materials, such as silicon, aluminum, glass, and other metals.

**Reuse and Refurbishment:** The circular economy promotes the reuse and refurbishment of products. In the context of the solar energy system, this can involve repurposing older solar panels for applications that don't require maximum efficiency, such as in off-grid systems or for community projects. Refurbishing and reusing solar panels can extend their lifespan and reduce the demand for new panels, thereby reducing the overall environmental footprint of the solar energy system.

**Eco-Design and Innovation:** Circular economy principles encourage eco-design, which focuses on designing solar energy technologies with the entire lifecycle in mind. This includes considering factors like material selection, ease of repair, recyclability, and modular design. By integrating these principles into the design phase, solar energy systems can be optimized for longevity, efficiency, and recyclability.

**Local Energy Production and Grid Integration:** The circular economy promotes decentralized energy production, which aligns with the distributed nature of solar energy systems. Solar energy allows for the generation of electricity at or near the point of consumption, reducing the need for long-distance transmission and associated losses. This decentralized energy production contributes to a more resilient and efficient energy system.

#### 6. Conclusion:

In conclusion, the assessment highlights the positive impact of circular economy principles, particularly solar panel recycling, repairing, and refurbishing, in the solar energy system. By adopting these practices, the solar industry can contribute to a more sustainable and circular energy future, reducing waste, conserving resources, and minimizing environmental impact. The findings underscore the need for collaboration among stakeholders, including policymakers, manufacturers, and consumers, to drive the adoption of circular economy principles in the solar energy sector and accelerate the transition towards a more sustainable and circular energy system.

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