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An outline of solar photovoltaic systems impact on environment

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ABSTRACT

The damaging environmental repercussions of energy production are greatly reduced when renewable energy sources are used. Solar photovoltaic (PV) energy is reliable and secure, and it also includes benefits like no noise, no pollution, easy maintenance, and no environmental harm. Solar PV technology has emerged as the renewable energy source with the greatest rate of expansion worldwide since fossil fuels are soon running out and have a negative influence on the environment. PV modules reduce carbon dioxide emissions, preserving the environment and preventing global warming. The solar cell efficiency is one of the key elements in developing this PV technology. To increase solar cell efficiency for commercial use, the type of material used in production is essential. After serving its purpose, a PV module can be recycled, and environmentally appropriate disposal won't have much of an effect on the environment. In this article, the impact of solar PV systems and their most recent advancements for environmental preservation are discussed.

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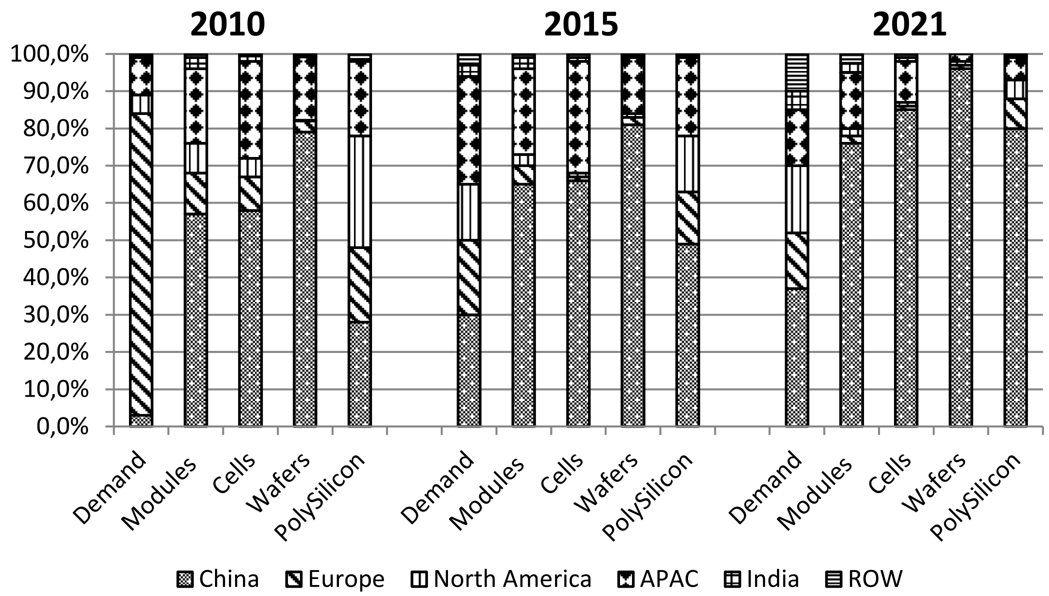
1. INTRODUCTION

The sun continuously sends enormous amounts of energy to earth through radiation. The majority of the sun's energy that reaches the earth is lost and does no good. Over the past five decades, the global energy consumption has significantly expanded from 230 to 606 EJ (nearly 2.6 times) [1]–[3]. The majority of the world's energy needs are met by fossil fuels, which are harming our planet's sustainability while also running out day by day. Because of the use of fossil fuels, pollution is growing every day and contributing to global warming. Government agencies are promoting the use of solar energy by lowering the price of materials and solar equipment in an effort to lessen the impact of pollution. Sunlight is directly converted to electricity by solar cells. Different materials are being incorporated into the creation of solar cells as technology advances in order to increase output and efficiency while lowering solar cell costs and preserving the environment. In order to boost output and decrease cost, this study discusses changes in solar cell materials and technology. Figures 1 and 2 show global solar photovoltaic (PV) module output from 2010 to 2022 as well as solar PV manufacturing capacity by nation and area [4]–[6].

Using PV cells, electricity can be generated by utilising sunshine. A PV cell is a device that produces electricity using sunlight. The choice of materials is important for making solar cells [7]. The kind of PV material, cell temperature, clouds and other shading effects, all affect the efficiency of PV cells. Efficiency is greatly influenced by the inborn characteristics of the semiconductor material [8]. The material used to make PV cells is very important since an accumulation of junk on the surface of PV panels might prevent light from reaching the solar cells, which will reduce the amount of energy produced [9], [10].



*APAC=Asia-Pacific region excluding India, ROW=rest of world

Figure 1. Solar PV manufacturing capacity by country and region, 2010-2021

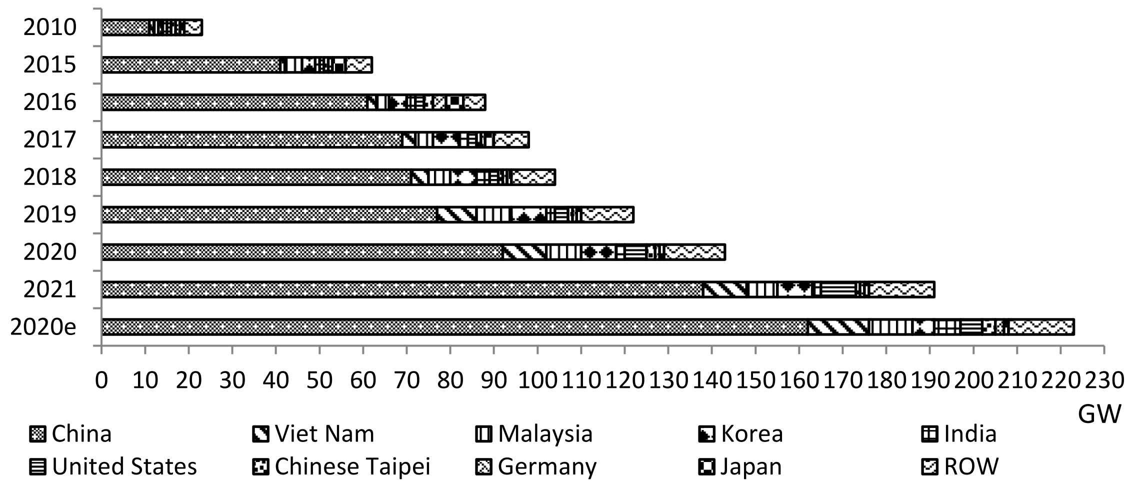


Figure 2. Global solar PV module production, 2010-2022

2. SOLAR CELL MATERIALS

The various solar cell materials utilised today in solar PV systems are presented in this section. The first kind of solar cell was made of silicon. It was discovered that enormous incident radiation absorption and solar cell efficiency both have potential for improvement. To fulfil these demands, amorphous silicon solar cells and thin-film technology were further improved [11]. Solar cells of the first generation, made mostly of single crystals on silicon wafers, were silicon-based. Improvements have been achieved in thin films, dye-sensitized solar cells, and organic solar cells in order to boost cell efficiency. The greatest material to use in the creation of solar cells is silicon because of its high efficiency [12]. Researchers are seeking for a replacement material to reduce material costs despite thin film technology's high efficiency, and they believe this would be a good candidate [13]–[15]. Because thin film technology utilises less material and has layers that are significantly thinner than monocrystalline and polycrystalline solar cells, it is less expensive to create. The solar cells created with this method still have poor efficiency.

Amorphous silicon, CdS/CdTe and cadmium indium selenide (CIS) are the three materials that have received the most attention in thin film technology, although researchers are constantly seeking for ways to increase effectiveness. Amorphous silicon is chosen over materials like CIS/cadmium indium (gallium) selenide copper indium gallium selenide solar cell (CIGS) and cadmium sulphide/cadmium telluride (CdS/CdTe) in thin film technology because of its efficiency [16]–[19]. However, each of these materials has a detrimental impact on the ecology. By utilising polymer or organic solar cell materials, researchers have created a new method for thin film technology. Polymer materials have a variety of advantages, such as cost, low weight, and environmental friendliness.

Thin film technology costs less than crystalline silicon solar cells because it uses less materials and production processes. The thickness of the solar cells produced using this process ranges from 35 to 260 nm [20]–[24]. A substrate could be covered with one or more layers of solar cell as an alternative to the standard manufacturing process. Thin-film PV cell development large-scale production is simpler and less expensive when compared to crystalline-based solar cells, but because they are less effective, they require more space [25]. The performance deteriorates more quickly than solar panels made on mono- and polycrystalline crystals. Their uniform appearance makes them seem more alluring. The effectiveness of solar panels is less affected by shade and higher temperatures [26]. Over the past ten years, the thin-film PV market has grown by about 55–60% yearly. This method uses solid backing materials and thin film solar cells based on semiconductors. Thin-film technology reduces the amount of semiconductor material required, saving money [27]. Due to their high absorption coefficients, CdTe as well as CdS solar cells have efficiencies of up to 15%. These cells can be made quickly and inexpensively, in addition to having a high efficiency [28], [29]. Figure 3 shows common CdTe thin-film deposition techniques.

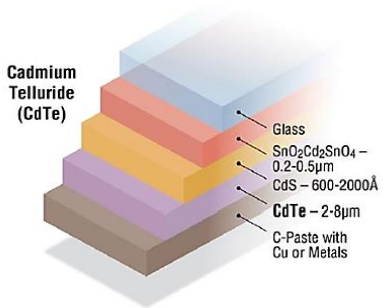


Figure 3. CdTe solar cell

Radue *et al.* [30] conducted an experiment to assess the effectiveness and lifespan of CIGS solar cells [30]. The experiment was conducted both indoors (under STC) and outdoors for four months. It has been noticed that the present collection would shrink as a result of the module's shortcomings. Another test was run by Meyer and Dyk [31] to assess how well CIS and other thin film materials perform. Compared to other thin film materials, CIS only degrades by 10% after 130 kWh/m^2 of outdoor exposure, according to the experiment's results. The absorption coefficient of CuInSe2 is greater than 105 cm^{-1}. The range of wavelengths that can be absorbed from solar radiation increases with a suitable band gap. The most effective thin film solar panels as of yet are CIGS-based [32]. Compared to CdTe cells, these cells contain less of the potentially hazardous metal cadmium [33]. Figure 4 explains a typical CIGS solar cell diagram, and Figure 5 illustrates how it is made. Similar to CdTe modules, photo degradation also occurs when CIGS modules are exposed to sunshine. More barrier coating is necessary to fix this issue [34]–[38].

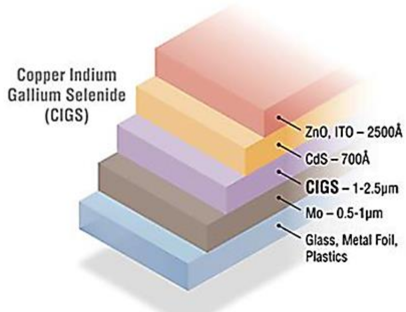


Figure 4. CIGS solar cell

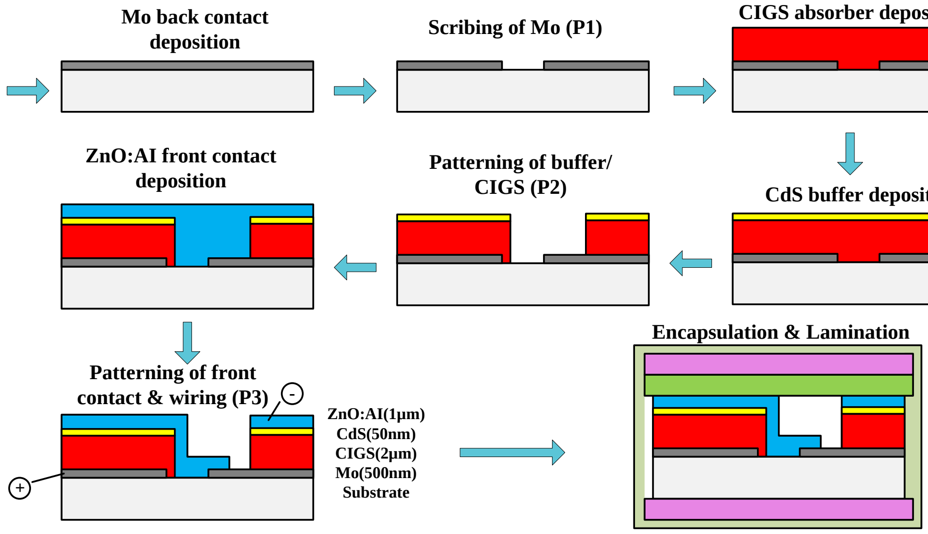


Figure 5. CIGS solar cell manufacturing

3. ROLE OF SOLAR PHOTOVOLTAIC SYSTEMS IN ENVIRONMENTAL PROTECTION

PV modules must first go through some processing steps in order to produce power. The current situation urgently necessitates the use of environmental sensitivity components and fundamental pollution prevention, environmental impact analysis, and life cycle assessment concepts. Each developed technology ought to have an impact on the environment, both positive and negative [39]. Solar cells have certain negative environmental effects throughout the manufacturing and processing stages, but once they are in use, they provide a lot more advantages [40], [41]. When compared to the electricity produced by coal and other fossil fuels, the PV system is clean and safe for the environment. In the fight against global warming and for a safer environment, PV modules lower carbon dioxide emissions. Although the lack of accessible area for PV installations is an important issue, small-scale installations can be handled by incorporating PV into buildings and utilising a roof- or wall-based PV system. When a PV module has served its purpose, it can be recycled, which will have less of an influence on the environment. Therefore, research into recycled PV materials is crucial for minimising the environmental impact of PV technology during the course of its useful life. A great green, sustainable energy choice is solar energy. In addition to saving your electricity expenses, solar energy provides significant environmental benefits [42]. Some of the main environmental advantages of solar energy include the following [7]:

a. Slows down climate change

Due to the increased atmospheric concentration of greenhouse gases like carbon dioxide and methane brought on by the usage of fossil fuels, our planet warms up more quickly than usual. As a result of the rise in global temperature, glaciers melt and sea levels rise, resulting in a variety of natural disasters like cyclones, frequent floods, very hot weather, and drought. However, using solar energy to generate energy has no associated greenhouse gas emissions, which aids in slowing down climate change.

b. Lowers carbon footprint

The term "carbon footprint" refers to the amount of greenhouse gases, primarily carbon dioxide, released into the atmosphere as a result of human activities. The primary contributor to carbon footprint is the use of fossil fuels. Solar energy, on the other hand, is among the cleanest forms of energy. Carbon dioxide emissions are reduced by 0.5 to 1 tonne for every megawatt-hour (MWh) of solar energy produced.

c. Reduces the use of fossil fuels

Coal, oil, and natural gas have historically provided the majority of our energy needs. Fossil fuels are a big source of pollution and cannot satisfy the world's expanding energy needs due to their finite supply. Solar energy, on the other hand, is abundant and can be utilised eternally to satisfy global energy needs, reduce energy costs, and provide a secure energy future.

4. RECYCLED SOLAR PHOTOVOLTAIC SYSTEM EFFECTS ON ENVIRONMENT

End-of-life (EoL) solar panels may produce hazardous waste even if solar energy usage is expanding quickly and has many benefits. Recycling solar panels is currently not a significant problem, but when it comes time to replace solar panels in the upcoming decades, it will. Solar panels can currently be disposed of with other types of common e-waste [43]. The likelihood of recycling-related issues is higher in nations without dependable e-waste disposal solutions. Recycling and disposal of solar panels are significant challenges. Ethyly vinyl acetate (EVA) is frequently used to encapsulate silicon wafers in conventional solar panels. This layer protects the silicon wafer. If modules are not properly disposed of and are put through certain test conditions, leakage could occur. Under typical operating conditions, these compounds cannot be discharged [44]. By 2030, there would be between 1.7 and 8 million tonnes of PV waste, and between 60 and 78 million tonnes by 2050, according to an International Energy Agency assessment from 2017. Growing PV panel waste could have detrimental environmental effects [45]. If EoL from solar PV systems is not properly collected and recycled, it could result in metal leaching. Solar module recycling is currently the focus of research and development efforts in the major nations including Japan, Europe, and the US. The bulk of solar panel recycling programmes concentrate on Si panels and try to salvage and recycle the most important parts [46]. As depicted in Figure 6, there are now three main categories of recycling methods utilised on solar PV panels: physical, thermal, and chemical [47].

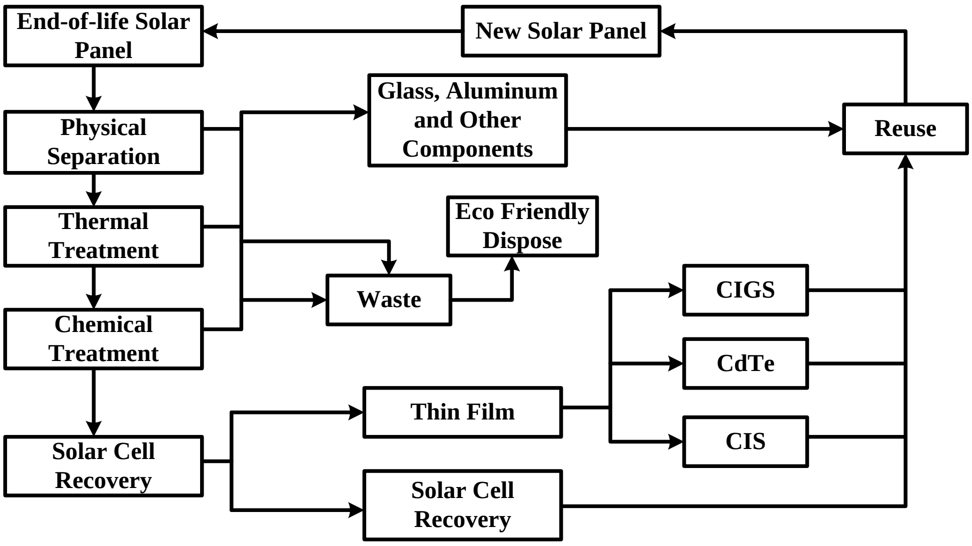


Figure 6. Recycling of solar PV panel

If solar waste management can be done well, there will be certain advantages. It is aware that recycling solar panels has advantages from an economic standpoint. Naturally, a suitable infrastructure for recycling solar panels will need to be built in order to handle the enormous volume of PV modules that will need to be disposed of in the near future. Once it is formed, the economy will go through a variety of positive changes and open up new opportunities [48]. More than £11 billion in recoverable value and additional green job opportunities will be produced through PV recycling by the year 2050. With this injection, 2 billion solar panels will be produced without any investments in raw materials. According to this, it will be able to produce 630 GW of energy using just recycled materials [49]. Due to the solar energy industry's continual price reductions, more and more homeowners and businesses are deciding to invest in solar power systems. As a result, there will be more business and job prospects in the solar cell recycling sector [50].

5. CONCLUSION

The globe uses more energy each year, and new technologies are being implemented to keep up. Today's energy production uses more fossil fuels than ever before, which has resulted in a major rise in environmental pollution. The development of solar PV technology has accelerated recently and may be crucial in meeting the increasing demand for electricity globally. The enormous number of PV systems installed each year demonstrates how committed each nation is to the idea of preserving the environment through the use of renewable energy. In terms of solar cell materials, solar PV systems' current state, their contribution to environmental protection, and the consequences of recycling solar PV systems on the environment are all covered in this study. Every created technology has effects on the environment, both positive and negative. While being manufactured and processed, solar cells have some negative environmental effects; but, while in use, they offer many more benefits. The PV system is clean and environmentally safe compared to the production of power using coal and other fossil fuels. By lowering carbon dioxide emissions into the atmosphere, solar power generation is safe for the issue of global warming. A PV module can be recycled when it has served its purpose, which will have less of an impact on the environment. To lessen the environmental impact of PV technology throughout its useful life, it is crucial to continue conducting research on recycled PV materials. This article clearly gives an overview on impact of material selection in maximum power generation from solar PV systems and impact of recycled solar PV systems on environment.

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