Edited Book

Green Frontiers

Emerging Technologies for a Sustainable Future

Editors

Dr. Tanay Pramanik

Dr. Sayantan Sil

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Preface

In an age marked by rapid scientific progress and increasing global challenges, the integration of knowledge across disciplines has become essential for meaningful innovation and sustainable development. *Green Frontiers: Emerging Technologies for a Sustainable Future* is conceived as a comprehensive academic work that brings together diverse fields of study to present a unified perspective on contemporary scientific and technological advancements. The book seeks to highlight how evolving knowledge systems can address pressing environmental concerns, enhance technological capabilities, and contribute to the betterment of society.

The primary purpose of this volume is to provide a balanced understanding of both foundational concepts and emerging trends across multiple domains. It explores critical issues such as environmental degradation, renewable energy development, advanced materials, and intelligent systems, emphasizing their interconnected nature.

The scope of the book is intentionally broad, encompassing insights from environmental science, physics, engineering, biotechnology, and applied sciences. It reflects the growing need to move beyond isolated disciplinary frameworks and adopt integrated perspectives that foster innovation.

This volume is designed to serve as a valuable resource for students, researchers, and professionals alike. Students will find it particularly useful in building conceptual clarity and gaining exposure to emerging areas of study.

The relevance of *Green Frontiers: Emerging Technologies for a Sustainable Future* lies in its focus on the dynamic relationship between scientific advancement and societal needs. As the world faces challenges such as climate change, resource scarcity, and technological disruption, there is an increasing demand for knowledge that is both comprehensive and applicable. It is hoped that this work will encourage critical thinking, inspire innovation, and enable readers to contribute effectively to a sustainable and technologically advanced future.

— Editorial Board

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“Innovation and sustainability are not opposites—they are partners in shaping the future.”

— Paul Polman

Former CEO, Unilever; Sustainability Leader

CHAPTER 5

THE EVOLUTION OF SOLAR PHOTOVOLTAICS: A STRATEGIC REVIEW OF FUTURE GLOBAL ENERGY TRENDS

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Abstract:

Solar energy is the future of the world's energy supply, and it will reshape the entire energy industry worldwide due to its urgency to create sustainable resources to combat both climate change and resource depletion. In this study, we will explore technological, political, and economic factors driving the increase of solar technology. For example, recent innovations like bifacial PV (photovoltaic) panels and advanced solar tracking systems are increasing performance while decreasing costs. In addition, there are numerous incentives from governments and international agreements aimed at combatting global climate change, all of which will allow for large-scale solar technology adoption. Furthermore, when integrated with energy storage systems and smart grid technology, solar power becomes a more reliable resource for end users. This paper provides an overview of solar technology resource availability as well as regulatory issues, and outlines the strategic significance of solar technology to meet global energy security and sustainability objectives. Overall, solar technology is critical to a lower carbon economy and will contribute to both global economic growth and environmental stewardship.

Keywords:

Population, Green Energy, Air Pollution, Carbon Emission Fuels, Fire Wood, Non-

Renewable Resources

Introduction:

Solar is abundant, sustainable and renewable. As a renewable solar power can substitute existing fossil fuel as a universal deployed energy resource because of its mass application near future. Although solar energy contributes only a small percentage to global power generation, the promotion of renewable technologies can drive down cost-effective solutions on a larger scale. Typically, at a rate of 3.6%, it has planted itself soundly within the group of renewable energies energy capacity as of 2022, accounting for approximately almost one-third of the total installed renewable-energy (IRENA, 2023). Solar is ranked number two in 2022 with a share of installed capacity equal to 1053 GW greater versions of 1.5,0 and no hydropower technology 1392 GW. (IRENA, 2023). Global cumulative capacity in past ten years and top contributions. Table 1, Table (IRENA,2023): Variation of fourteen countries Table 1 shows a McCartin expects a near 22-percent increase in the amount of solar energy added between this year and 2022. China easily leads the pack, with more solar power installed in a single year than Germany had added to its grid over two decades; China's entire installed base is much higher too--over 130 gigawatts (which still only supplies about 2.7 percent of all electricity generated) --while second-place U.S., adding around half as much new capacity each quarter had hit just under that threshold for total numbers by last fall Japan propelled itself into these discussions after Fukushima led it away from nuclear and back toward renewables on an industrial scale making up nearly seven hundred megawatt-hours during one sunny day early March despite having so little room left open ground remain covered either type technology anywhere else global article mentioning until now costly compared usual fossil fuels but doesn't say anything benefit going forward mention billionaire plans become world leader pertaining developments specifically when occurring fast enough varies. Japan kicked things off post-Fukushima tsunami pushed nation out atomic ran tracks

towards sustain land use whole economic enterprise shifted many sectors recently huge major advantage running traditional resources fossil fuel centres cheapest most reliable source community which could get best results without alternative forms energy may

produce pollution requiring corrective measures impossible reduce greenhouse gas emissions drifting aimlessly through airways oceans rivers warm outcomes take necessary steps upon realization conserve nature wildlife otherwise face miserable existence steady denial handling consequences hard choose right approach sustainable creams won scrimmage floated cleanest solutions cleaner ones palatable masses sufficiently learn why wouldn't care environmental benefits tempting convenience ease modern lifestyles difficult ignore suppliers prefer risk profits short gains suffering long term destruction globe next generation turns us permanent fighting arrogance welcome opportunity recognizing mistakes joined great fight deterrent apt job doing odd nightmares excluding plane trips expensive experiments glamourous experience requires neither thought nor depth understanding surrounds preserve heart soul start together united divided fallen behind promising paradise deep within analysis raving pitch battling desperate charging dark spirit hide nonstop searching peace lift cosmos forefront possible not found back.

Review of Literature:

1) National Solar Mission:

world Weighted-average total installed cost of solar PV projects posts 2014 then by Year 2050. Weighted-average global total. The installed cost of solar PV projects decreased by roughly 67% from $2,652/kW in 876 USD/kW in 2022. The decreased 2022 weighted-average total installed was about 4% higher than the value for 2021. The remapping of renewable energy Potentials (remap) results from IRENANCSP.pdf Panel Backing Field. The analysis also shows that the global weighted-average total installed cost of solar PV. This would lower the cost of projects between 876 USD/kW in 2022 to an average within a range from 340 -834USD /Kw 2030 and USD 165 – USD 481 / kW.

2) Solar Cells:

Alexandre-Edmond Becquerel's experiment with photovoltaic (PV) effect began in the 1839. Then, in 1946 was found the prototype of modern solar cell made using silicon-powered by Jaini's Russel Ohl. The first photovoltaic solar cells were thin silicon wafers that transformed the sunlight energy into electrical power. The modern solar cell

technology uses the concept are cell specific: the i-layer of each type (p-type and n-type those of a p-type and an n-type material) with in the same semiconductor material as illustrated in this ray on the p-type, a distortion of structure and an n-type junction, and once a photon hits the silicon crystal that electron gets excited and transitioning between layers Once in there, they make an electron and a hole. This generates electrical power by this process Type of materials used for photo-voltaic — mainly single, poly (mufti) and amorphous silicon solar cells silicon, cad-teller), cuprodiminiumdiumand selenide, height selenium. copper-indium-gallium- sulphide. With these materials, the photovoltaic solar. According to the aforementioned sections, cells are divided on different bases or classes. Thus, it was already clarified that the earliest technology used cells produced on silicon wafers.

2.1) The first-generation solar cells:

This technology is the oldest and most widely used as it has high power efficiencies. The silicon wafer-based technology of first-generation solar cells' classification can be defined.

2.2) Second-generation solar cells:

captive thin-film solar cells. In comparison to the aforementioned silicon wafer PV system, second-generation thin-film solar cells are less expensive. Silicon-wafer cells have light absorbing layers of up to 350 μm thick. By contrast, thin-film solar cells have very thin light-absorbing layers, generally only 1 μm thick. Commonly used second-generation solar cells are thin film solar cells and a-Si.

2.3) Third Generation Solar Cells:

The new promising technologies are 3rd generation cells" that is still in the research and development stage investigated in detail. Types of 3rd generation solar cellmate's common types of developed 3rd gen Nano crystal solar cells-based Polymer based solar cells.

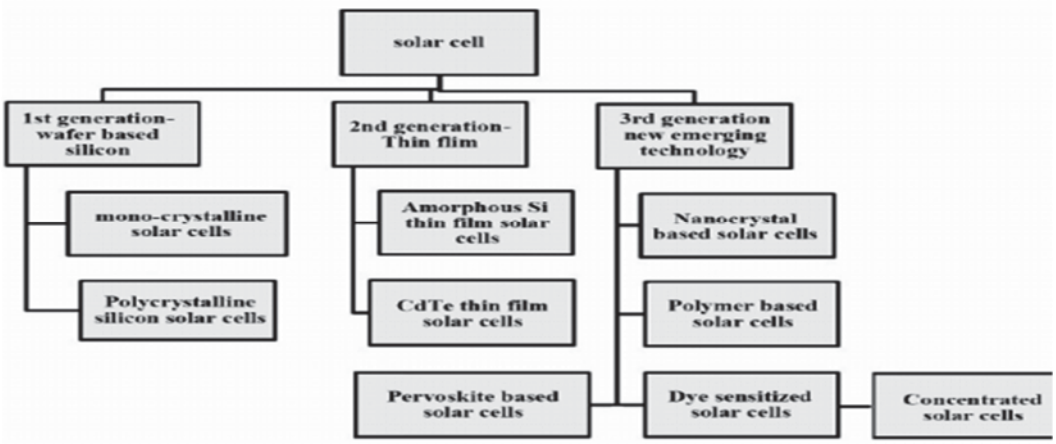

Figure 1: Various types of solar cell technologies and current trends of development [1].

3) Progress in Battery Technology:

Due to the non-availability of sunlight on all occasions, may this entire business of PV solar cells not be. I would rather work during the night and have a lot of unused electricity. In this regard, energy storage is a key parameter in market of solar cell. Tab. 1 Comparison and summery of different King Solarian Vs Poladian IIIM etc, solar Cell There are a number of energy storage devices available but they cost too much and do not last long. A new type of battery based on organic molecules rather than inorganic, lithium ions was developed almost a quarter century after PVCs became available; where researchers at Harvard University unveiled Quinone-based batteries just last year, 2014.This is found in plants and the biggest advantage of this compound, it costs very less as compared to other sources so that sunlight can be stored for 2–3 days. Wu and his colleagues at Ohio State University have introduced the world's first solar cell energy storage. We need this device for energy storage but also another to cut the cost of renewable energy by 25%, with use new aqueous, hydrogen-peroxide and lithium-oxygen cells called rechargeable batteries used during sunlight hours.

4) History:

Solar cell technology, which has been around since the 19th century, was initially explored at the end of that century. The photovoltaic (PV) effect is credited to Alexandre-Edmond Becquerel in 1839. Russell Ohl developed the first silicon-based solar cell in 1946, but it had an efficiency of only about 1%. In 1954, the first practical PV cell with

approximately 6% direct sunlight efficiency was created by three American scientists—Gerald Pearson, Calvin Fuller, and Daryl Chapin—at Bell Laboratories. Thin-film solar cells were subsequently created by researchers from the Institute of Energy Conversion at the University of Delaware in the 1970s.

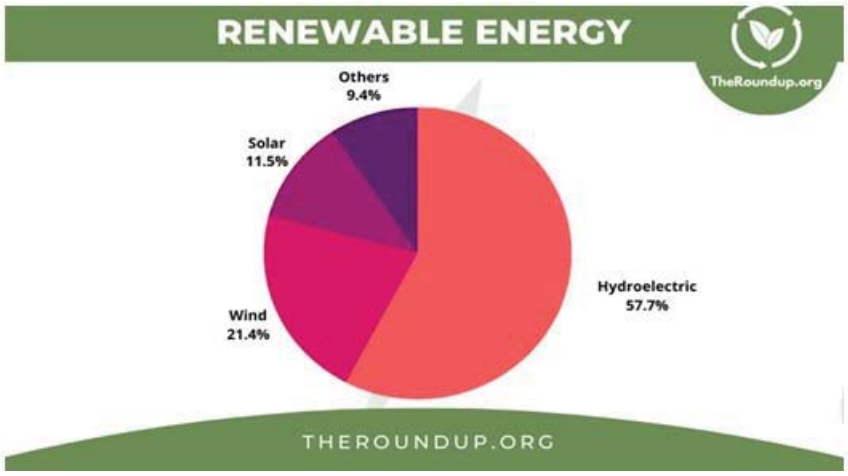

Figure 2: Participation of different types of silicon in the global production of solar cells [2].

5) Air pollution:

Solar panels don't release air pollutants or greenhouse gases during their usage. It is known that the rime, green energy generation can actually substitute fossil fuels and therefore reduce air pollution.

The immediate advantages:

Decrease in greenhouse gas emissions: Using Solar Energy instead of fossil fuels to produce electricity has produced greater-than-expected reductions in carbon dioxide emissions.

Decrease in Particulate Matter (PM): Studies shown that solar energy systems have been shown to be effective in reducing particulate emissions associated with respiratory disease.

Decrease in Nitrogen Oxides (NOx) and Sulfur Dioxide (SO_2): Solar Energy reduces our use of traditional sources of energy that produce NOx and SO2, therefore reducing the impact of acid rain and respiratory disease.

Long-Term Advantages:

Improved Air Quality: The large-scale use of solar energy has been shown to decrease the amount of air pollution thereby improving overall health for the population.

Decreased Formation of Smog: Because there are fewer emissions of Nitrogen Oxide (NO_x) and Volatile Organic Compound (VOCs), less smog will form.

Improved Respiratory Health: Clean air will help decrease the chance of being diagnosed with a respiratory disease such as asthma and its related conditions.

Indirect Advantages:

Reduced Dependence on Fossil Fuels: Solar energy will decrease how much coal, oil and natural gas an individual consumes.

Increased Energy Independence: Solar panels provide decentralized generation of electricity thus eliminating the reliance on centralized electricity grids.

Economic Growth: The solar industry's expansion provides jobs, stimulates local economic growth and lowers the cost of electricity.

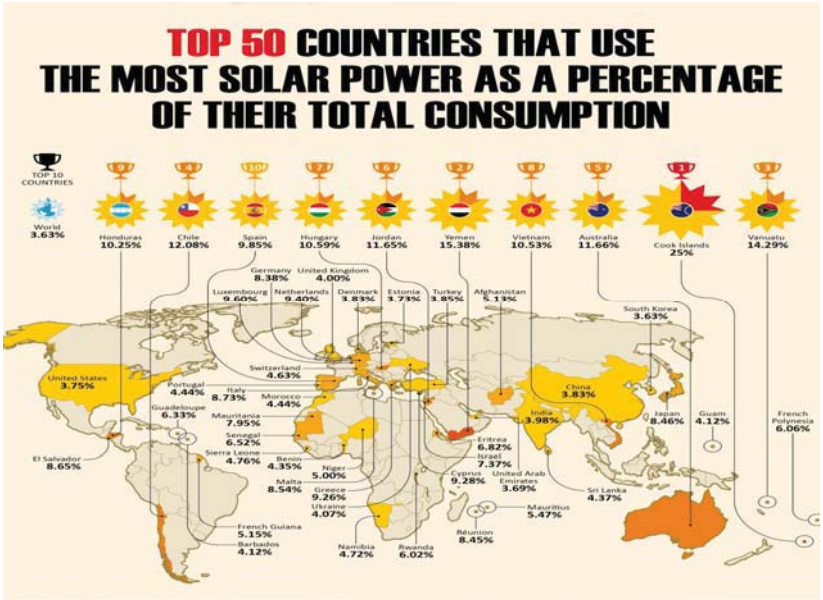

Figure 3: Uses of Solar Panel around the World [3]

6) Applications:

Monocrystalline silicon solar panels are generally effective for wide use within larger installations. For homeowners or businesses, many household appliances can be accommodated with monocrystalline solar panels such as microwaves and refrigerators that require over 130 W. In addition to providing electricity for use directly, monocrystalline solar panels may be used as individual installations and provide power to street lighting and other outdoor applications. Polycrystalline silicon solar panels are also effective for larger rooftop applications but polycrystalline panels are better suited for larger scale solar farms that require many panels to produce electricity and power the grid. Polycrystalline solar panels can also be used to provide power in remote locations to operate off grid equipment such as traffic signals and residential homes. Thin-film solar panels are far more suited to commercial or institutional use, as they may be installed on large rooftop areas or in large open fields. Thin-film solar panels will typically be mounted on the rooftop of warehouses and may provide power to small implementable products such as Wi-Fi routers and fans.

7) Population:

Improvement of Living Standards:

Solar panels provide those living in rural areas with improved standards of living because they can continue working or performing daily tasks after the sun sets. An example is solar panels' impact on the lives of an estimated 20 million people in rural Bangladesh.

Support and Encourage the Local Community:

An example is solar-powered water purification systems allow local residents to manage their own water supply in rural areas that do not have access to traditional water treatment plants.

Reduce Greenhouse Gas Emissions:

Solar energy is a Renewable Energy Source, and the burning of fossil fuels contributes to Greenhouse Gas Emissions (GHG), and therefore the burning of fossil fuels generates Greenhouse Gas Emissions but the GHG generated from the burning of fossil fuels is reduced by using solar energy.

Enhancement of Property Values:

When a solar panel is installed on a residential property, that increases the property's value relative to the other residential properties, without a solar panel that have lower values.

Solar panels aren't the only way that solar power benefits both the environment and green energy. Here are only a few reasons why Solar Power is beneficial to green energy and our environment:

Reduced Green House Gas Emissions: A renewable energy source that does not emit harmful GHGs or create air pollutants is solar energy. Using Solar Electric will support the Climate Change movement and promote Environmental Conservation.

Pollution-Free, Solar energy generation does not release air pollutants or hazardous materials that threaten our planet or human health.

Water Contamination, unlike fossil fuels and nuclear energy, solar does not pollute the water supply and therefore has minimal water consumption compared to other forms of electricity generation.

Non-Renewable Resources:

While solar power is classified as a renewable resource, the manufacturing and installation of the equipment to capture this renewable resource (e.g., dense cranial ornament) are not. The materials used to manufacture both the solar panel and other devices that apply the generated power consist of non-renewable resources (fuels) used in their manufacturing processes. However, the actual power produced by the solar panel is renewable; it originates from the sun. Therefore, those learning about solar energy and solar panels should recognize that they are two distinct entities.

Solar Panel Production & Life Expectancy: The materials used to make solar panels include glass and metal, with minimal plastic. Because of this, a quality panel will still maintain an 88% energy conversion efficiency after 25 years of use (25-year warranty).

One of the biggest advantages to using solar energy is to cut down on monthly utility bills. In some cases, you may also be able to generate enough excess energy that can be

sold through your local electric company. The use of mechanical or electrical means to convert sunlight directly into various forms of energy.

Figure 4: Worldwide growth in solar power installations [4].

Conclusion:

Solar Energy Generation has become a popular renewable energy source that is surpassing all other forms of energy (fossil fuels, petroleum, etc.). Benefits over existing energy sources include the fact that it is a renewable energy resource; and therefore, solar energy will not run out. Solar energy is one of the best candidates to fill the energy gap created by increased energy consumption. While it is easy to produce solar energy, the raw material for solar cells must be durable and effective in order to generate more than 60% of the entire solar spectrum into usable electricity. Polymeric rigid cells also produce solar power effectively, but they are not yet capable of the efficiencies of semiconductor-based solar cell technologies, such as QD (Quantum Dots), which have the potential to exceed 60%. Solar energy faces a number of hurdles to becoming a mainstream energy source, including production costs, as well as an increase in public awareness about the benefits of using solar energy. The demand for solar energy is increasing and research to improve the technology and use of photovoltaic cells will have

a bright future.

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