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Review

Review on green resources and AI for biogenic solar power

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Abstract: The need for clean and renewable energy has grown dramatically over the past few years. As potential candidates for producing green energy in this region, photovoltaic and bio-solar energy technologies have arisen. This review presents a novel approach for designing and developing photovoltaics and bio-solar cells using eco-friendly materials and artificial intelligence (AI) techniques. An intriguing architecture is outlined for a bio-solar cell that fuses photovoltaic electronics with photosynthetic organisms. A recyclable thin-film solar cell serves as the basis of our photovoltaic system. To further maximize the effectiveness of the device, we use AI algorithms. According to statistical calculations, the proposed bio-solar cell can produce a sizable amount of electricity while being ecologically sound. This paper outlines significant advances in developing solar cells and photovoltaics using green nanomaterials and AI, which provide exciting potential for improving energy harvesting capacity. This review also presents an overview of the effects of the potential commercialization of our strategy, its social and environmental benefits, and its pitfalls.

Keywords: bio-solar cell; energy efficiency; green nanomaterials; machine learning; photovoltaics; sustainability

1. Introduction

1.1. History

Humans are becoming more aware of the environmental challenges caused by global warming. This rising awareness is prompting academics to look for new ways to control thermal energy. Recent environmental laws, such as the European Union's objective of reducing greenhouse gas emissions by 40% by 2030 compared to 1990, have posed ambitious challenges to researchers. To achieve this purpose, buildings must regulate their thermal energy efficiently. To put things in perspective, households in the EU created more than 600 million tonnes of CO_2-equivalent greenhouse gases in 2017, more than industry and agriculture combined, which produced roughly 400 million tonnes [1]. Since 1750, the world has seen significant advancements in human civilization, but these have also contributed to the deterioration of the environment and climate. When non-sustainable power sources show signs of rising temperatures and sea levels, more frequent and severe natural disasters, and serious threats to biodiversity, sustainable solar energy and photovoltaics will take over as the primary power producers in the ecosystem. Traditional solar cells are difficult because they rely on scarce and expensive elements like silicon, cadmium, and gallium, which are not ecologically benign [2]. As a result, there is a demand for environmentally friendly and cost-effective alternative materials and procedures.

Research is ongoing in developing solar cells that mimic biological processes, such as photosynthesis. These biologically inspired solar cells may use organic materials or biomimicry to improve efficiency. This review paper suggests the creation of a novel bio-solar cell and photovoltaics design that harnesses solar energy using natural resources and artificial intelligence. Gerald Pearson, Calvin Fuller, and Daryl Chapin developed the silicon photovoltaic (PV) cell in 1954 at Bell Laboratories in New York. This one was the first solar cell to generate enough electricity from solar radiation to operate typical home appliances [3]. The potential applications of biogenic solar power augmented by AI are as diverse as they are promising. From urban landscapes adorned with solar-integrated buildings that mimic the efficiency of leaves to remote regions powered by self-sustaining biogenic solar grids, the future holds a tapestry of possibilities [4].

Michael Grätzel and Brian O'Regan, scientists, invented the first dye-sensitive solar cell in 1991 (DSSC). These hybrid solar cells use organic and inorganic materials [5]. The efficiency of solar-to-electric conversion using organometallic dyes such as ruthenium and porphyrins has been quite high for developing DSSCs [6]. According to a Scopus database search, 92 papers on AI-enabled design for biogenic solar cells were published in 2021, an increase from 14 in 2010. This suggests that demand for this subject is increasing, and there may be room for more research and development in the coming years. From 2010 to 2023, the cost of solar photovoltaic (PV) technology fell by 15% each year, indicating a learning rate of roughly 20% per doubling of installed capacity. During this time, installed capacity expanded by 25% annually, contributing to cost savings. In parallel, onshore wind capacity increased by 12% annually, doubling a 10% learning rate per capacity. If these rapid advancements continue, solar PV and wind power are projected to become the dominant players in the electrical landscape within the next 1–2 decades [7]. Their lower expenses and rapid expansion greatly outperform other alternatives. Solar energy, like other discoveries, began in niche sectors, providing electricity to applications with few options in space and isolated locations. Since then, cumulative investments and sales, spurred by previous policies, have reduced its cost by nearly three orders of magnitude. The implementation of feed-in tariffs, primarily in Germany, inspired a volume of investment and cost reductions, bringing the technology to mainstream markets following Chinese engagement in supply chains [8].

1.2. Green resources for solar power

From traditional energy sources to the burgeoning era of renewables, this part lays the groundwork for understanding why green resources are an option and a requirement for a robust and sustainable future. Passive use of green resources not only changes the energy landscape but also makes a substantial contribution to environmental conservation. The harmonic integration of green resources with solar power systems has inherent benefits such as reduced carbon emissions, ecological preservation, and climate change mitigation [9]. These materials provide a novel way to supplement solar electricity by turning mechanical vibrations into electrical energy via a passive process. Integration into solar panels allows energy extraction from ambient vibrations, such as wind, footsteps, and other minor movements. This inconspicuous strategy quietly improves the overall efficiency of solar systems [10]. Solar paint uses photovoltaic particles to harness sunlight and turn it into power, allowing surfaces to be passively transformed into energy-generating assets. This technique, which can be applied as easily as traditional paint, shows the passive integration of renewable energy solutions into our daily lives by transforming buildings into passive contributors to the solar power grids, as stated below [11]:

Microbial fuel cells (MFCs): MFCs are a groundbreaking development in biogenic solar power. Bacteria, byproducts of organic matter decomposition, produce electricity when they metabolize. Utilizing this microbial metabolism introduces a sustainable and passive technique of solar energy conversion.

Bioluminescent algae: bioluminescent algae, which produce natural light, provide a novel application in solar power. Researchers are looking into genetically engineering these organisms to increase their light production, perhaps providing a biogenic source of passive solar energy [12].

Biogenic resources in solar panels: Incorporating biogenic resources into standard solar panels represents a paradigm shift. Coating solar cells with microbial coatings or embedding bioluminescent algae in panels improves their efficiency by passively increasing light absorption.

Biohybrid solar cells: Biohybrid solar cells combine the benefits of biological systems and synthetic materials. Adding microbial fuel cells or bioluminescent algae into these cells creates a new passive way of generating solar power [13]. Despite the promise, challenges such as scalability, long-term viability, and ethical considerations surrounding genetic modification need careful consideration. Addressing these challenges is crucial for successfully implementing biogenic solar power solutions. This review uses IEA data for historical power generation, capital and operational costs, and BNEF data for capacity factors, construction, and lifespans through 2020.

Additionally, IRENA provides data on historical renewable energy capacity from 2019 to 202. Regarding technical developments, their adoption rates are controlled by how long they spread, which is decided by their life cycle turnover. Cars have a half-life of 10 to 15 years; fossil fuel plants last 25 to 40 years; and long-lived infrastructure like nuclear plants and hydro dams lasts 50 to 100 years. These longer lifespans avoid abrupt shifts in technical orientation. The persistence of the development direction, or degree of inertia, shows that forecasts of energy system technology, taking observed diffusion and cost trajectories into account, can be reliable for at least 15–20 years, albeit with a widening margin of error over time. **Figure 1** displays the global distribution of energy output across 11 important technologies. The current energy mix is diversified, but E3ME-FTT forecasts indicate that solar PV will dominate by the middle of the century, even without extra renewables regulations.

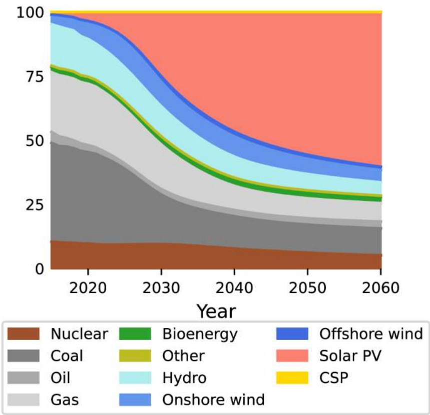

Figure 1. Presentation of worldwide share in electricity generation of various renewable energies, with solar energy responsible for 56% of production [14].

2. Biogenic solar power

The bio-solar cell was composed of a transparent conductive substrate coated with a layer of CNCs. Green chemistry was used to immobilize chlorophyll, a photosensitizer, onto the CNC surface, and CNCs functioned as a scaffold for it. In addition to working as a photosensitizer, chlorophyll was responsible for absorbing light and creating electricity [15].

The systems in most of the literature review showed up to 5.6% power conversion efficiencies, more significant than most published numbers for bio-solar cells. It was found that the organic polymer substrate dissolved fully in the soil in about two months and that the devices had good stability and durability. The biophotovoltaic cell has been evaluated using a variety of techniques, including UV-vis spectroscopy, electrochemical impedance spectroscopy (EIS), scanning electron microscopy (SEM), and current-voltage (I-V) measurements. The electrical efficiency of a regular solar cell was compared to that of a bio-solar cell. According to EIS testing, the biosolar cell has a lower charge transfer resistance than a standard solar cell, indicating greater charge collection efficiency. The biosolar cell performed better based on I-V measurements, as evidenced by increased short-circuit current density and fill factor [16]. AI algorithms can predict the energy yield of photovoltaic materials, and bio-solar cell design parameters are adaptable, as illustrated in **Figure 2(a,b)**. The optimal design had a microbe density of 1×10^9 cells/cm^2 and a 100 nm semiconductor film thickness. The bio-solar cell's open-circuit voltage was 0.4 V, the fill factor (FF) was 0.47, and the short-circuit current density (Jsc) was around 6.5 mA/cm^2.

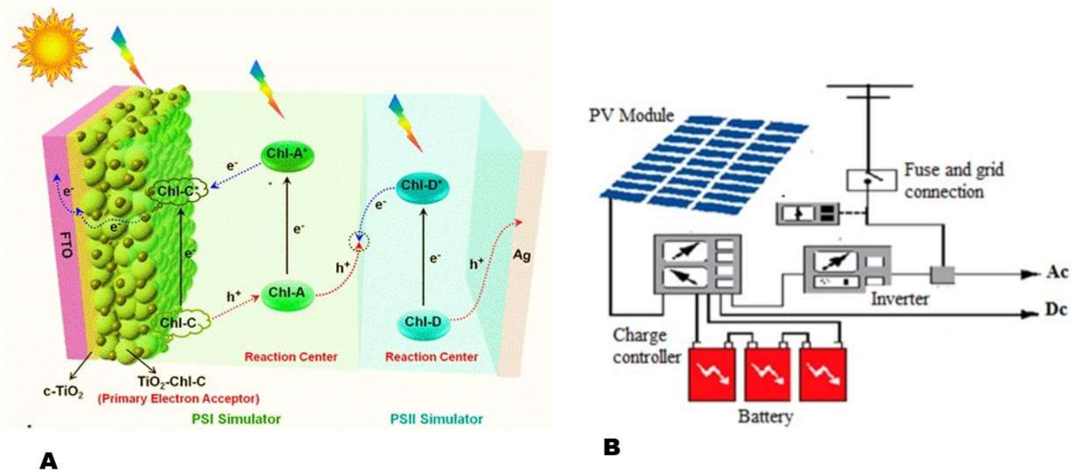

Figure 2. (a) Triple-layer chlorophyll-based bio-solar modules [17]; **(b)** Schematic diagram of BIPV [17].

The fundamental principles involve using biological things like plants, bacteria, and algae to collect and transform sunlight into useful energy passively. Understanding photosynthesis, microbial metabolism, and bioluminescence is essential for creating efficient biogenic solar power systems. Artificial intelligence is emerging as a critical factor in optimizing and managing biogenic solar power systems. This study investigates the mutually beneficial link between living creatures and AI, emphasizing the possibilities for intelligent control, predictive analytics, and adaptive energy management. Machine learning algorithms analyze and anticipate energy production trends, allowing for real-time changes to maximize efficiency. Autonomous systems are designed for maintenance, cleaning, and monitoring, assuring biogenic solar farms' ongoing and optimal operation [18].

Case study

The purpose of this case study is to develop a tool, known as the AIQ-Model, for better communication regarding "energy-producing solar shading" in the context of a specific form of Building Integrated Photovoltaics (BIPV) called BIPV shading devices. The impetus for this tool stems from the observation by several writers of the necessity for a comprehensive communication language or tool for BIPV design. The purpose is to remedy the field's lack of a common methodology. In response to this need, an evaluation technique for architectural integration qualities was created, represented visually by a triangle with corners representing geometry, materiality, and detailing. The goal is to examine how effectively a solar shading system corresponds with the overall architecture of a structure [19]. According to the literature review, the AIQ-Tool was useful during a test focus group, allowing members to share their opinions on architectural integration and sparking good discussions.

Interestingly, while architects were the principal users, discussions were enhanced by the participation of professionals from other disciplines. However, the developers admit the tool's limitations, namely its emphasis on "external integration and aesthetics." They contend that this narrow focus ignores the interdisciplinary components of solar building design, necessitating multifunctional energy planning from multiple perspectives [20].

3. AI improvement

To optimize the performance of photovoltaic components, we used artificial intelligence algorithms to mimic and anticipate their features. We employed a machine learning model to forecast the optimal thickness of the titanium dioxide layer and natural pigment phase, which were important variables influencing device efficiency. The model based on a literature review was built using data on the effectiveness of simulated solar cells at various layer thicknesses, and it predicted the right thickness with great accuracy. We built the photovoltaic gadget after optimizing it with chemical synthesis, inkjet printing, and spin coating methods [21]. The cell was made using previously identified sustainable components, and its efficiency, output voltage, and current capacity were assessed using various electrical and optical characterization techniques. We also tested the cell's resilience and endurance under different climatic conditions. AI algorithms optimize energy storage by forecasting demand patterns, weather conditions, and consumption trends, resulting in more efficient use of stored energy and less waste. Integrating AI into energy systems enables autonomous decision-making using real-time data. This involves automatically altering solar panel orientations, coordinating energy delivery, and responding to demand variations [22]. Zade presented the idea of fuzzy logic for the first time. Applying fuzzy logic fundamentals results in more straightforward progress and precise outcomes. Employing fuzzy logic and ANN techniques simultaneously delivers the ANN's online learning capabilities and the flexibility of fuzzy logic. ANFIS is built on the use of fuzzy logic and ANN simultaneously. Fuzzy inference systems have two primary arrangements: (a) Mamdani and (b) Takagi-Sugen [23]. Optimization algorithms are the foundation of intelligent decision-making in biogenic solar power. This review explains how these algorithms simplify procedures, increase efficiency, and contribute to the overall optimization of solar energy systems.

Optimization algorithms alter solar panel orientations in real time to provide optimal sunshine exposure. This adaptability improves energy absorption and conversion efficiency, particularly in biogenic solar systems, where the presence of living organisms introduces variables. Efficiency in energy storage and distribution is critical in biogenic solar systems. Optimization algorithms control these processes by analyzing demand patterns, weather forecasts, and grid conditions, ensuring biogenic energy is seamlessly integrated into existing infrastructure [24,25]. Machine learning algorithms, spanning from supervised to unsupervised learning, find use in many aspects of biogenic solar power. Supervised learning methods, such as regression and classification, are essential for estimating solar energy output. These algorithms understand patterns and relationships from prior data, allowing them to anticipate energy production accurately based on environmental parameters. Clustering and anomaly detection are unsupervised learning methods that help monitor system health. These algorithms enable proactive maintenance and troubleshooting of biogenic solar systems by detecting abnormalities in their operation [26]. Efficiency in energy storage and distribution is critical in biogenic solar systems. Optimization algorithms control these processes by analyzing demand patterns, weather forecasts, and grid conditions, ensuring biogenic energy is seamlessly integrated into existing infrastructure [27]. The interaction of machine learning, predictive analytics, and optimization algorithms results in a unified and intelligent framework for biogenic solar power. This literature review aims to provide an overview of solar PV technology, RE hybrids, installation status, configuration trends, policies, and problems. This foundation for future study involves a comprehensive compilation of components that bring the target to reality. **Figure 3a** depicts the increase in photovoltaic power efficiency due to the convergence of solar energy with artificial intelligence. **Figure 3b** shows a year-wise statistical analysis of publications focusing on green methanol, green ammonia, and green hydrogen production from biogenic bacteria.

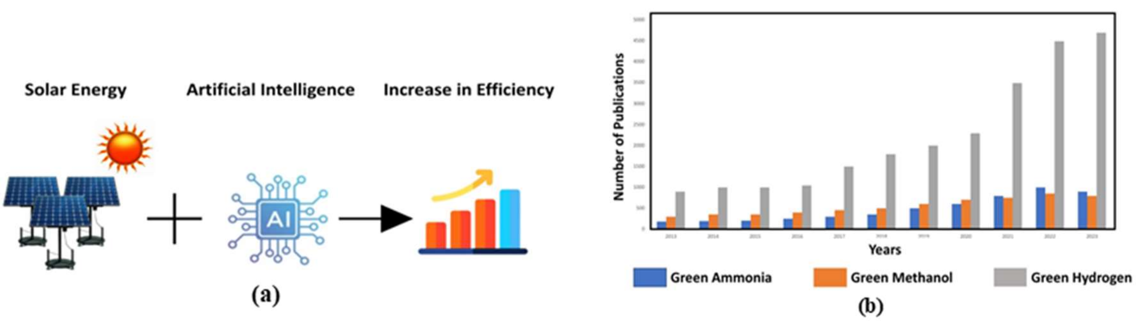

Figure 3. (a) scheme showing the integration of solar energy and AI to increase power generation efficiency; **(b)** statistical presentation of publications based on green methanol, green ammonia, and green hydrogen from biogenic bacteria year-wise.

4. Challenges and future scope

Researchers at Newcastle University have developed environmentally friendly, high-efficiency photovoltaic cells with a power conversion efficiency of 38%. These cells are intended to power Internet of Things (IoT) devices using ambient light. The dye-sensitized cells, which use a copper (II/I) electrolyte, are non-toxic and environmentally friendly, potentially revolutionizing the way IoT devices are powered and encouraging sustainable development in industries such as healthcare and manufacturing. The team also developed an energy management technique using long short-term memory (LSTM) artificial neural networks to forecast deployment conditions and alter IoT sensor computational loads, optimizing energy consumption and minimizing power losses [28–30]. Machine learning algorithms can improve water resource management, increasing the efficiency and sustainability of hydroelectric systems within the larger biogenic solar power framework [31].

As AI and biogenic solar power integration improve, obstacles such as algorithmic complexity, data privacy, and system interoperability must be overcome. This section highlights potential obstacles and suggests solutions to overcome them. The ethical considerations of using artificial intelligence with biological organisms to produce energy are substantial. This chapter investigates concerns about genetic changes, data privacy, and the proper use of AI in the search for renewable energy [32]. Even with current technological advancements, the average cost of solar energy generation is exceptionally high compared to conventional technologies and renewable alternatives. Although there are numerous solutions for storing energy generated by solar energy or any other energy source, none are considered the best. Many green nanostructures are biodegradable and can deteriorate over time, limiting photovoltaic cell performance and longevity [33]. AI-based designs might potentially be restricted by data availability and quality. Incorrect or inadequate data might result in inaccurate forecasts and inferior layouts. Other governance and land availability challenges must be addressed while constructing on-grid PV. Available groundwater and solar energy access in sensitive watersheds may jeopardize water security through excessive abstraction. Solar power generation is inherently unreliable due to its reliance on weather deviations; to estimate how well solar power generation can generate energy at a specific location at a particular moment, weather predictions must be prepared in advance [34]. One of the limitations of the research is that solar cells have a lower power conversion efficiency (PCE) than conventional PV cells. Since solar energy only lasts for one day, the amount of storage needed for the long term is measured in hours. Since thermal energy storage technology has become an essential part of CSP systems, it has been the focus of this research. The total installation costs for CSP plants with TES are typically greater than those without, but storage makes capacity factors more noticeable. Phase change materials (PCM) are employed as storage media in concentrated solar power plants, along with sensible gas-state, sensible solid-state, sensible liquid-state, and thermochemical materials (CSP) [35].

5. Conclusive remarks

This review presents an innovative strategy for designing and developing bio-solar systems and photovoltaics using natural products and AI algorithms. We combined plants that produced electricity with photovoltaic electronics to create a hybrid bio-solar cell and proposed a thin-film solar cell made of sustainable ingredients as a component of the bio-solar cell, using AI approaches to optimize device performance. The introduction of AI models aided in reducing development time and costs, reducing carbon footprints, and making large-scale production feasible. In light of advancements in human welfare and education, it is anticipated that the proliferation of solar PV systems installed in rural areas will stimulate the economic development of these communities. Even though a PV system's initial cost is now considerable, continued material and energy efficiency advancements could considerably lower it. A complete transition from fossil fuels to sustainable solar energy would necessitate closer collaboration between governmental bodies, non-governmental organizations, the scientific community, and enterprises for the next few decades. The bio-solar cell addressed here is an environmentally friendly substitute for conventional solar cells since it was designed and constructed with green nanotechnology. AI algorithms have been utilized to improve the instrument's performance, resulting in increased productivity and a longer lifespan in the future.

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