Received: 24 July, 2024 | Revised: 28 July, 2024 | Accepted: 30 July 2024

MANUSCRIPT ID: CoAS_V2IS2_02

POPULAR ARTICLE

Chronicle of Aquatic Science

Green Energy in Blue Waters: Photovoltaic Systems Enhancing Aquaculture Efficiency and Environmental Stewardship

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The authors assert that the manuscript was developed without any commercial or financial associations that could be interpreted as a potential conflict of interest.

Authors Contribution

All listed authors have contributed significantly, directly, and intellectually to the work and have endorsed it for publication.

Abstract

Aqua-PV systems combine aquaculture with solar panels to produce both food and clean energy. This innovative concept involves the cultivation of aquatic organisms beneath solar panels, optimizing the utilization of water bodies. The integration of solar panels provides shade, reducing water evaporation and algal growth, thereby improving water quality for aquaculture. These systems offer benefits like water conservation, improved water quality for fish, and potential for ecosystem restoration. Challenges include reduced light penetration for plankton and biofouling on panels and equipment. While aqua-PV holds significant promise, challenges such as the initial investment, technological advancements, and environmental impacts require careful consideration. Further research is needed to optimize light and develop anti-fouling methods. Through careful planning, research, and development, Aqua-PV has the potential to revolutionize the way we utilize water bodies, contributing to a more sustainable and resilient future. By harnessing the power of the sun and the productivity of aquatic ecosystems, this integrated approach offers a compelling solution to global challenges.

KEYWORDS

AQUA-PV, Desert Aquaculture, Aquaculture, Solar Photovoltaic, Renewable Energy

INTRODUCTION

Aquaculture constitutes a significant element within the global food economy, contributing an impressive 43% of all aquatic foodstuffs consumed by humans (Bostock et al., 2010). According to the FAO 2022, world aquaculture production reached another record high of 185.4 million tons (FAO 2024). Conventional energy sources, such as oil, diesel, and fossil fuels, power most aquaculture operations. However, the high energy costs and resulting carbon emissions associated with these practices are increasingly under scrutiny (Bostock et al., 2010). Electricity plays a significant role in powering aquaculture production systems. Aquaculture production is inherently energy-intensive, requiring significant inputs at every stage. This applies across the board, from stocking fingerlings in hatcheries to final harvest, and encompasses all production intensities, from semi-intensive to intensive systems. Essential processes like aeration, water treatment, pumping, and recirculation all rely heavily on dependable energy sources. This dependence can be costly and leaves farms vulnerable to energy price fluctuations. Solar energy is environmentally benign and does not contribute to global warming, making it one of the most sustainable energy sources. It is used instead of petroleum and coal [10]. The sun emits electromagnetic radiation, which is the basis of solar energy. Mechanical systems transform electromagnetic radiation into heat or electric power equipment (Bharathi et al., 2019). A growing number of nations across the globe have installed solar power systems as an alternative energy source. This includes prominent countries such as China, Taiwan, South Africa, the United States, and Australia, among others (IRENA, 2020).

SOLAR PHOTOVOLTAIC (PV)

Photovoltaic (PV) systems represent a distributed approach to generating electricity that relies on the combustion of fossil fuels. These systems harness the sun's abundant radiation and convert it directly into usable electrical power through the photovoltaic effect. Among sustainable and clean energy sources, solar photovoltaic (PV) technology stands out for its remarkable accessibility (Granovskii M et al., 2007; Pearce JM et al., 2002). This technology offers inherent scalability, positioning it as a potential solution to meet the ever-growing energy demands of humanity. This technology falls under the umbrella of renewable energy sources, offering a sustainable alternative to conventional methods that contribute to environmental concerns.

PV systems are classified as: Off-grid systems & Grid-connected systems.

A) Off-grid systems operate independently of the electrical grid. They use a battery bank to store extra solar energy during the day and provide electricity when sunlight is absent, such as at night. Essentially, the battery bank serves as both a reference power supply and a storage device.

B) Grid-connected systems operate in cooperation with the utility grid. When solar energy is inadequate, the grid functions as the energy source, providing almost infinite backup while preventing the requirement for a huge battery bank. Excessive solar energy generated during daylight can be sent back towards the grid, potentially providing credits for the user.

Components of PV system

PV modules: Photovoltaic modules, often known as solar panels, are the primary components of a PV system. These panels hold the PV cells, which are actual power converters. Silicon is the most frequently found element used in these cells, although additional alternatives include cadmium telluride (CdTe) and copper indium gallium selenide/sulfide (CIGS). Well-made PV modules have amazing lifespans, often ranging from 25 to 30 years. There are three varieties of solar panels that are often used in photovoltaic systems: monocrystalline, polycrystalline, and amorphous thin film.

Inverter: An inverter converts the direct current (DC) generated by PV modules into alternating current (AC). The produced current is either released into the grid or utilized within it.

Module Mounting Structure: The PV panels are supported by the mounted framework (rack system). PV modules are frequently mounted atop support structures to better capture solar insolation, increase power, and assure structural integrity.

The balance of the system: Cables, switchboards, junction boxes, meters

Aquavoltaics:-

Aqua-PV systems are a double win for sustainable food production. They combine fish farming with solar panels, allowing farms to raise aquatic life while generating their own clean energy. This reduces dependence on outsidepower sources and maximizes the use of land and water. The neat thing is that Aqua-PV works for both big industrial farms and smaller, off-the-grid operations. It presents a unique solution that is scalable for both industrial-sized aquaculture farms and individual farmers in remote, off-grid locations. This adaptability signifies its potential for widespread application across the aquaculture industry (Pringle et al., 2017).

Components of Aqua-PV system

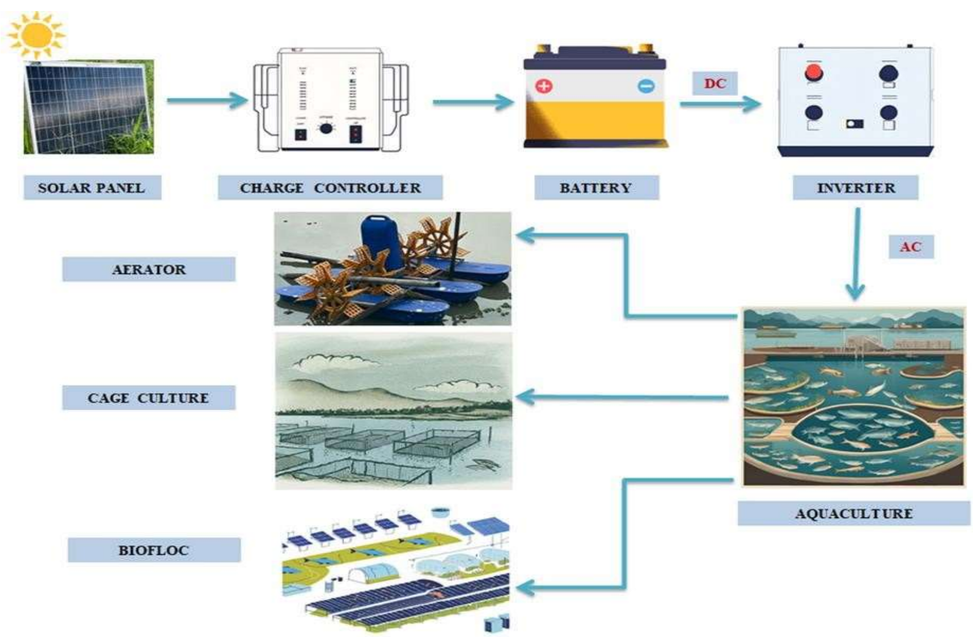
An Aqua-PV system comprises two main units:

1. Photovoltaic (PV) Unit:

A photovoltaic (PV) system is comprised of essential components that work in concert to convert solar energy into usable electricity. The core elements include solar panels, a charge controller, a battery, and an inverter. Solar panels function by capturing sunlight and transforming it into direct current (DC) electrical energy. This DC electricity then undergoes regulation by the charge controller to ensure proper management. Subsequently, the controlled DC power is stored within the battery for later utilization. Finally, the inverter plays a critical role by converting the stored DC electricity into alternating current (AC) power, the form compatible with powering a wide range of devices (Meitei et al., 2022).

2. Aquaculture Unit:

Within an aquaculture unit, the primary component is the water body itself. This can be manifested in various forms such as ponds, tanks, raceways, biofloc systems, cages, or pens, all designed to cultivate aquatic organisms like fish and shrimp. To ensure optimal living conditions for these organisms, the unit is further equipped with supporting technology. Pumps and aerators play a crucial role in maintaining suitable water quality parameters. (Meitei et al., 2022).



DESERT AQUACULTURE AND AQUA-PV SYSTEM

Deserts typically seen as unproductive, actually offer significant opportunities for sustainable growth. One promising approach is the integration of photovoltaic (PV) power generation with aquaculture. This presents a novel solution for producing clean energy and cultivating food in these harsh environments. Deserts, with their intense sunlight, are ideal locations for solar power generation. By setting up PV panels, these dry regions can become significant energy producers. This clean energy can then fuel aquaculture operations, decreasing dependence on traditional power sources. Additionally, the shade provided by the solar panels helps reduce the desert's extreme heat, creating a more suitable environment for aquatic life.

Farming aquatic organisms can be a vital source of food in water-scarce deserts. By carefully managing water supplies and using advanced technology, it's possible to cultivate fish, shrimp, and other aquatic organisms. Combining this with solar power ensures a reliable energy source for tasks like water pumping and maintaining water quality.

Despite challenges like extreme heat, water shortages, and limited infrastructure, the potential benefits of combining solar power and aquaculture in deserts are substantial. This approach can boost food production, drive economic growth, and protect the environment in these arid regions (Vo et al., 2022).

CURRENT STATE OF SOLAR ENERGY IN AQUACULTURE

The utilization of solar energy in aquaculture has witnessed a recent surge, driven by a compelling set of advantages. Solar energy boasts a remarkably low operational cost, translating to long-term financial benefits for aquaculture operations solar power is an environmentally friendly solution, producing no harmful CO2 emissions and minimizing soil contamination (Al-Saidi et al., 2019). Solar energy is proving to be a versatile tool for aquaculture, offering a range of applications to improve efficiency and sustainability (Bharathi et al., 2019) (Huh et al., 2017), such as solar power generation, solar aerators to oxygenate the water, solar feed dispensers, solar pumps, and solar water heat systems (UNHCR, 2019). (Applebaum et al., 2001) developed the first ever photovoltaic aeration system in Israel. This system used solar power to generate electricity, which then drove a paddlewheel that maintained optimal oxygen levels for fish in ponds. (Prasetyaningsari et al., 2013) designed another solar-powered aeration system for fishponds in Indonesia. Their system utilized a 1 kW solar photovoltaic panel (PV) to generate electricity. This electricity was stored in eight 200 Ah batteries and then converted to a usable form by a 0.2 kW inverter to power the aeration system, ensuring adequate oxygen levels for the fish. Tanveer and Mayilsamy designed a large-scale (up to 100 kW) solar aeration system for fish farms. It uses solar panels, batteries, a converter, and an aerator to keep the water oxygenated (Py et al., 2013). (Liu et al., 2016) created an innovative machine for freshwater fishponds. Powered primarily by solar energy, this machine tackles two tasks: regulating water quality and collecting sludge from the pond bottom. (Hendarti et al., 2018) found ideal illuminance levels for grouper in cages to be between 200 and 1150 lux. They also discovered that transparent solar cell film panels are best for these cages, allowing for sufficient light penetration for grouper growth.

ADVANTAGES OF AQUA-PV

The following section explains the advantageous aspects of the Aqua-PV system.

A. As Sustainable Solution for Water Conservation in Aquaculture:-

Aqua PV systems, which combine aquaculture with solar panels mounted overhead, offer a promising approach for water conservation. The shade from the panels can reduce water evaporation from ponds, a significant water loss in traditional aquaculture. Studies suggest reductions of 70-85% compared to unshaded ponds (Ferrer-Gisbert et al., 2013) .This can be a major benefit in areas with water scarcity or high evaporation rates. This dual-use system not only conserves water but also generates clean energy to power the aquaculture operation. While more research is needed to optimize its effectiveness, Aqua PV holds potential as a sustainable tool for reducing water usage and improving the environmental footprint of aquaculture (Pringle et al., 2017).

B. As a Tool for Maintaining Aquaculture Environments:-

Aqua-PV systems offer a unique approach to maintaining the culture environment in aquaculture. It improves water quality with the shade provided by the solar panels helps regulate water temperature, reducing algae growth and promoting a more stable environment for aquatic life. Within the context of an aquaculture environment, Aqua-PV systems offer the capability to achieve optimal cultivation parameters. This optimization encompasses critical water quality metrics such as pH, temperature, salinity, dissolved oxygen (DO), and photoperiod. The implementation of this system facilitates the enhancement of both the oxygenation zone and the capacity for nutrient mixing within the culture environment (Meitei et al., 2022).

C. As a tool for Ecosystem restoration:-

Aqua-PV systems can be designed to mimic healthy aquatic ecosystems, unlike traditional closed systems that require high energy for maintenance. By generating their own solar power, these systems can be located anywhere with sunlight and potentially even help restore habitats by creating artificial reefs and deterring predators with the panels. This approach allows sustainable aquaculture development even in remote areas.

CHALLENGES IN AQUA PHOTOVOLTAIC SYSTEM

Aqua-PV systems, while promising for sustainable aquaculture, can have unintended consequences. Shade from the solar panels limits light penetration, harming plankton and the entire food chain. Additionally, challenges exist regarding maintenance difficulty due to the combined system and the lack of research on potential impacts on fish welfare. Aqua-PV systems can be used globally with sunlight and suitable conditions for aquatic life. However, biofouling (organism buildup) is a major challenge due to the complex interplay of various environmental factors. Research on biofouling prevention in both solar panels (FVs) and aquaculture needs to be combined to address biofouling in Aqua-PV systems. LEDs with photocatalytic titanium dioxide (TiO2) can be used as a less harmful antifouling method (Pringle et al., 2017).

CONCLUSION

Aqua photovoltaic (APV) systems offer a novel and advantageous approach to solar energy production. They can utilize underused water surfaces, potentially increase efficiency through cooling, and reduce land use compared to traditional solar panels. However, challenges remain. Research is needed to ensure long-term durability in water, mitigate biofouling, and reduce costs. Additionally, the environmental impact on aquatic ecosystems requires careful study. Despite these challenges, APV technology has significant potential for the future of renewable energy. Continued research and development can unlock its full potential, making APV systems a key component of a sustainable and secure energy future.

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How to cite this article: Debbarma K and Sarmah P. Green Energy in Blue Waters: Photovoltaic Systems Enhancing Aquaculture Efficiency and Environmental Stewardship. Chron Aquat Sci. 2024; 2(2): 6-11