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Integrating Renewable Energy Sources in Aquaculture Operations: Opportunities and Challenges

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Abstract
This paper investigates the integration of renewable energy sources in aquaculture operations; by exploring both the opportunities they present for sustainable development and the challenges hindering their widespread adoption. With the increasing global demand for fish products and the escalating environmental concerns associated with conventional energy consumption, renewable energy offers a promising pathway towards more sustainable aquaculture practices. The key findings indicate significant opportunities for reducing operational costs and environmental impact through renewable energy sources (RES) adoption, particularly solar and wind energy. However, challenges such as high initial capital investment, lack of technical expertise, and policy inconsistencies remain significant barriers. The paper concludes with recommendations for policymakers and industry stakeholders to facilitate the transition to renewable energy in aquaculture.

KEYWORDS: Aquaculture, Renewable energy, integrating, Solar energy, Wind energy

Introduction
The accelerating demand for aquatic protein, driven by a burgeoning global population and evolving dietary preferences, has positioned aquaculture as the fastest-growing food production sector worldwide (Lal *et al*., 2024). However, this rapid expansion is not without its environmental and economic considerations. Conventional aquaculture operations are notably energy-intensive, heavily reliant on fossil fuels to power critical infrastructure such as water

recirculation systems, aeration pumps, feed distribution, and temperature regulation, all of which contribute significantly to operational costs and the industry's carbon footprint (Jamil *et al*., 2023). In an era defined by climate change mitigation efforts and the pursuit of sustainable development goals, the transition to renewable energy sources has become an imperative for the aquaculture sector.

Fish from both natural sources and aquaculture are important source of highly nutritive food, source of employment and of economic benefit. Fish products are important in human diet because of their digestibility and high nutritional value, mostly characterized by the presence of high-quality proteins (contributes about 60% of the world's supply of protein while 60% of the developing countries derive 30% of their annual protein from fish (Abisoye *et al.,*2001). Fishery subsector was reported to have contributed an average of about 10% of agricultural GDP between 2008 and 2012 (Food and Agriculture Organization – FAO, 2013). The development of aquaculture can only be enhanced by the introduction of modern technologies. There are human and natural resources in Nigeria which if properly harnessed can boost aquaculture production there by creating job opportunities for the youth, development of rural areas, reduction in rural-urban migration, income earning and increase in protein supply to the populace. It is believed that aquaculture has the tendency to contribute significantly to the local fish production in the country if improved technologies are adopted by the fish farmers (Olaoye *et al.,* 2016).

Well-articulated technologies are crucial to substantial aquaculture development in the world especially a developing economy like Nigeria where majority of the fish farmers could not produce to the maximum capacity of their farms because of lack of understanding of potentials embedded in aquaculture technologies or inadequate information. The technologies used by most Nigerian fish farmers are relatively simple, often based on small modifications that improve the growth and survival rates of target species, improving feed, fish seeds, oxygen levels and protection from predators. Adoption of technology can be described as innovation decision process where an innovation passes through the time of first knowledge of the innovation to the decision stage of adoption or rejection and to confirmation of that decision (Ekong, 2002). The cost of feed, disease, electricity, wages and fuel are major recurring problems in the aquaculture sector. Renewable energy as an energy that is generated from natural processes that are continuously replenished which includes sunlight, geothermal heat, wind, tides, water and various forms of biomass. This energy can’t be exhausted and is consistently revived. Renewable energy is also called “clean energy” or “green power” because it doesn’t pollute the environment.

This paper will delve into the compelling opportunities that various renewable energy technologies, including solar photovoltaics, wind power, and geothermal systems, offer for revolutionizing aquaculture practices, enhancing efficiency, and bolstering environmental stewardship. Concurrently, it will critically examine the multifaceted challenges associated with their large-scale integration, drawing on contemporary

research and technological advancements from 2020 to the present to provide a comprehensive overview of this crucial intersection of sustainable energy and aquatic food production.

Methodology

This paper employs a **conceptual review and synthesis methodology** to explore the opportunities and challenges of integrating renewable energy sources in aquaculture operations. It does not present new empirical data but rather systematically reviews and synthesizes existing literature, research findings, and expert insights from published academic journals, reports from international organizations (e.g., FAO, World Energy Council), and relevant industry publications.

The approach involved:

1. **Literature Search:** Comprehensive searches were conducted using keywords such as "aquaculture," Aquaculture" "Renewable energy" "Solar energy" **Wind** energy " "sustainable aquaculture waste management and "challenges of renewable energy in aquaculture operations" across academic databases (e.g., Google Scholar, ResearchGate) and organizational websites.
2. **Information Extraction:** Relevant studies were analysed to identify recurring themes related to:
    - Specific applications of biogas in aquaculture (e.g., energy generation, waste treatment).
    - Quantified or qualitative benefits (e.g., energy savings, environmental impact reduction, waste volume reduction, fertilizer production).
    - Identified barriers and challenges (e.g., financial, technical, feedstock, safety, regulatory).
    - Recommendations and future directions.
3. **Synthesis and Analysis:** The extracted information was then synthesized to identify overarching opportunities and challenges, drawing connections between various findings and highlighting areas of consensus and divergence in the literature. This process allowed for the construction of a comprehensive narrative on the current state of renewable energy integration in aquaculture. This methodology provides a robust framework for understanding the existing knowledge base and identifying critical areas for future empirical investigation and practical implementation.

LITERATURE REWIEW

This literature review aims to systematically synthesize the existing body of knowledge regarding the integration of diverse renewable energy sources in aquaculture operations. It will critically examine the multifaceted opportunities that RES present for fostering sustainability, reducing operational expenditures, and improving energy reliability.

Concurrently, this review will delineate the significant challenges that impede the widespread adoption of these technologies, including financial barriers, technical complexities, site-specific limitations, and gaps in policy support

SOLAR ENERGY

Solar energy is the energy, in the form of electromagnetic radiation, emitted from the sun. This electromagnetic radiation is converted into usable thermal or electric energy by man power with the aid of mechanical devices

The adoption of solar energy in aquaculture offers a multitude of opportunities that can significantly enhance the sustainability, economic viability, and operational resilience of farms.

Reduction in Operational Costs

One of the most compelling advantages of solar energy is its potential to substantially reduce recurring operational costs associated with energy consumption. Conventional energy sources, particularly diesel fuel for generators, are subject to volatile market prices, directly impacting the profitability of aquaculture farms (Ahmed & Mustapa, 2018). By harnessing free solar irradiation, farms can significantly lower their electricity bills and fuel expenditures, leading to long-term financial savings (Sarker *et al*., 2019; Zhang *et al*., 2022). This cost predictability allows for better financial planning and can improve the overall economic viability of aquaculture enterprises.

Enhanced Energy Independence and Reliability

For many aquaculture operations, especially those in remote or rural areas, access to a reliable grid electricity supply is often intermittent or non-existent. Frequent power outages can lead to critical failures in aeration or pumping systems, resulting in oxygen depletion, poor water quality, and ultimately, significant fish mortality (Chen & Li, 2023). Solar PV systems, particularly when coupled with battery storage, can provide a consistent and independent power supply, mitigating the risks associated with grid unreliability and enhancing the overall energy security of the farm (Liu *et al*., 2017). This independence is crucial for maintaining optimal environmental conditions for aquatic species.

Environmental Benefits

Integrating solar energy directly contributes to reducing the environmental footprint of aquaculture. By replacing fossil fuel-derived electricity, solar PV systems drastically lower greenhouse gas emissions (e.g., carbon dioxide), thereby mitigating the industry's contribution to climate change (Abdelhamid *et al*., 2020). Furthermore, reduced reliance on diesel generators also minimizes local air pollution and noise, creating a healthier working environment and reducing the ecological impact on surrounding ecosystems. This

aligns with global efforts towards more sustainable and eco-friendly food production systems (FAO, 2021).

Scalability and Versatility

Solar PV technology is highly scalable, ranging from small panels powering individual pumps or lights to large-scale installations providing energy for entire farm operations. This flexibility allows farms of various sizes and production intensities to adopt solar solutions tailored to their specific needs. Solar energy can be used for a wide range of aquaculture applications, including powering aeration systems, water pumps, feeding machines, water quality monitoring sensors, lighting, and even heating systems (Sarker *et al*., 2019). The emergence of "aquavoltaics" or floating solar PV systems, installed on water bodies, also presents an innovative solution that optimizes land use and can offer additional benefits like reduced evaporation and algal growth (Zhang *et al*., 2022).

Off-Grid and Remote Area Solutions

Solar energy is an ideal solution for aquaculture farms located in off-grid or remote areas where extending conventional electricity grids is economically unfeasible. It provides a viable pathway to establish and operate productive aquaculture facilities in regions that would otherwise be inaccessible, thereby promoting rural development and local food security. This capability expands the potential geographical reach of aquaculture and can empower communities with sustainable energy access.

How Aquaculture is Taking Advantage of Solar Energy

According to the World Energy Council (2013), “the total energy from solar radiation falling on the earth was more than 7,500 times the World’s total annual primary energy consumption of 450 EJ”. Environmental scientists and engineers developed a float Voltic solar panel that protects water from adverse environmental impacts. New Jersey installed one system over a town water supply. The panels preserve the store, protecting it from algal blooms and evaporation.

Float Voltic panels can shade an aqua cultural region, preventing an increase in water temperatures. Rising water temperatures are detrimental to aquatic stability. They cause habitat alteration and endanger marine species.

Additionally, high ocean temperatures spread diseases among fish and shellfish. Aquaculture companies can protect their fish from environmental degradation by shading their aquatic habitat with solar panels.

Using the open water to harvest solar energy also increases the renewable power supply. Limited open fields and sun-exposed areas reduce our national clean energy development. We can develop a national renewable energy grid by increasing our access to large quantities of solar power.

In Aquaculture, Solar Energy Can Be Used Indifferent Ways.

Solar Photovoltaic (PV) Systems for Electricity Generation (Solar Power Generators) This is the most common and versatile application of solar energy in aquaculture, converting sunlight directly into electricity using semiconductor materials.

Direct Powering of Essential Equipment:

Aeration Systems: Fish and other aquatic organisms require dissolved oxygen for survival and growth. Solar-powered aerators, including paddlewheel aerators, diffusers, and aspirators, are critical for maintaining optimal oxygen levels, especially in intensive culture systems or during periods of low natural oxygen (e.g., at night or on cloudy days) (Sarker *et al*., 2019). These systems can operate directly from solar panels during the day.

Water Pumps: Recirculating aquaculture systems (RAS), flow-through systems, and pond-based operations rely heavily on pumps for water circulation, exchange, filtration, and transport. Solar-powered pumps reduce reliance on grid electricity or diesel generators, particularly beneficial for remote or off-grid farms (Ahmed & Mustapa, 2018).

Feeding Systems: Automated feeders, which ensure precise and timely feed delivery, can be powered by solar PV, optimizing feed conversion ratios and reducing labor costs (Patel & Dholakia, 2021).

Lighting: For indoor hatcheries or specific photoperiod manipulation in certain species, solar-powered LED lighting can provide energy-efficient illumination.

Monitoring and Control Systems: Sensors for water quality parameters (temperature, pH, dissolved oxygen, ammonia), automated data loggers, and control panels for farm management can be reliably powered by solar PV systems, often with battery backup.

Hybrid power systems:

Given the continuous energy demand of aquaculture and the intermittent nature of solar PV, standalone solar systems are often paired with other power sources.

Solar-Battery Systems: Batteries store excess solar energy generated during peak sunlight hours for use at night or during cloudy periods, ensuring uninterrupted power supply for critical operations (Liu *et al*., 2017). This enhances reliability and energy independence.

Solar-Diesel Hybrid Systems: In areas with unreliable grids or for very large loads, solar PV can significantly reduce diesel generator run-time and fuel consumption. The solar system handles the base load during the day, while the diesel generator acts as a backup or for peak loads.

Solar-Grid Tie Systems: Farms connected to the national grid can use solar PV to offset their electricity consumption (net metering), potentially selling excess power back to the grid and drawing from it when solar generation is insufficient.

Floating Solar PV (Aquavoltaics): An innovative application involves installing solar panels directly on the surface of aquaculture ponds or reservoirs (Zhang *et al*., 2022). This

dual-use approach maximizes land utilization, as it generates electricity while simultaneously providing shade to the water below.

Benefits of Aquavoltaics: Beyond electricity generation, floating solar can reduce water evaporation (preserving water resources), mitigate algal blooms by reducing light penetration, and help moderate water temperature fluctuations, creating a more stable environment for farmed species. The cooling effect of the water on the panels can also improve PV efficiency compared to land-based installations.

Solar Thermal Systems for Heat Generation (Solar Heat Systems): Solar thermal technologies harness the sun's energy to produce heat rather than electricity, which is crucial for species with specific temperature requirements or in colder climates.

Water Heating for Recirculating Aquaculture Systems (RAS) and Hatcheries: Many aquaculture species, especially tropical or high-value species, require specific water temperatures for optimal growth, feed conversion, and survival. Solar thermal collectors (flat-plate collectors or evacuated tube collectors) can directly heat water circulating through the aquaculture system or a heat exchanger (SciSpace, 2015).

In summary, solar energy's application in aquaculture is highly diverse, ranging from direct electrical power for critical operational equipment (PV systems) to efficient water and space heating (thermal systems), and even innovative co-location models like aquavoltaics. The choice of application often depends on the specific energy needs of the farm, the species being cultured, the climatic conditions, and the available capital for investment.

HYDROPOWER

Hydropower is also known as water power is the use of falling or fast running water to produce electricity by converting the gravitational or kinetic energy of a water source to produce power. Hydropower is an essential energy source harnessed from water moving from higher to lower elevation levels, primarily to turn turbines and generate electricity. Hydropower projects include Dam project with reservoirs, run-of-river and in-stream projects and cover a range in project scale. Hydropower technologies are technically mature and its projects exploit a resource that vary temporarily. The operation of hydropower reservoirs often reflects their multiple uses, for example flood and drought control Asumadu-Sarkodie, irrigation, drinking water and navigation (Edenhofer *et al*., 2011). The primary energy is provided by gravity and the height the water falls down on to the turbine. The potential energy of the stored water is the mass of the water, the gravity factor ($g = 9.81\ ms^{-2}$) and the head defined as the difference between the dam level and the tail water level. The reservoir level to some extent changes downwards when water is released and accordingly influences electricity production. Turbines are constructed for an optional flow of water (Førsund, 2015). Hydropower discharges practically no particulate pollution, can upgrade quickly, and it can store energy for many hours

It is consistently found that hydropower offers exceptional reliability and a high-capacity factor, making it a highly attractive option for aquaculture operations requiring continuous power, thus minimizing risks of fish mortality due to energy interruptions (Chen & Li, 2023; Liu *et al*., 2017). Studies frequently highlight the significant long-term operational

cost reductions due to the absence of fuel costs and the long lifespan of hydropower infrastructure, providing a compelling financial incentive after the initial investment (Sarker *et al*., 2019; Zhang *et al*., 2022). The environmental benefits, particularly the near-zero greenhouse gas emissions during operation, are also widely acknowledged as crucial for enhancing the sustainability and public image of aquaculture (Abdelhamid *et al*., 2020). Hydropower's suitability for remote and off-grid locations is consistently emphasized as a key opportunity for expanding aquaculture development.

BIOGAS ENERGY

Biogas is a source of energy that is obtained from the decomposition of organic materials in an anaerobic environment, that is, where there is little or no oxygen; this source appears as a mixture of different gases. This task is carried out by specialized bacteria that consume all this organic matter and produce mainly methane gas (CH4) and carbon dioxide (CO2). Biogas consists of 50-70% methane and 20-40% carbon dioxide. It also contains other less important gases such as: hydrogen sulphide (which gives it the smell of a rotten egg), nitrogen and water vapour. These last elements must be removed to obtain a clean and fully usable biogas.

Biogas and aquaculture practises:

Biogas is the gaseous emissions from anaerobic degradation of organic matter (from plants or animals) by a consortium of bacteria. Biogas is principally a mixture of methane (CH_4) and carbon dioxide (CO_2) along with other trace gases. Methane gas, the primary component of natural gas (98%), makes up 55-90% by volume of biogas, depending on the source of organic matter and conditions of degradation.

Sustainable Waste Management and Pollution Reduction: One of the most significant advantages of biogas integration is its ability to provide an effective solution for managing organic waste generated by aquaculture operations. Fish faeces, uneaten feed, and other organic matter accumulate as sludge, which can contribute to water pollution if discharged untreated (Abdelhamid *et al*., 2020). Anaerobic digestion converts this organic waste into biogas and a nutrient-rich digestate. This process reduces the volume of waste, minimizes the release of greenhouse gases like methane (which is more potent than CO2) directly into the atmosphere from uncontrolled decomposition, and mitigates water pollution, thereby enhancing the overall environmental performance of the farm (FAO, 2021).

On-Site Renewable Energy Generation: Biogas can be directly combusted to produce heat for various aquaculture applications, such as heating water in tanks, hatcheries, or recirculating aquaculture systems (RAS) to maintain optimal temperatures for aquatic species. Alternatively, it can be used to fuel internal combustion engines connected to generators, producing electricity for aeration, pumping, lighting, and other farm equipment (Ahmed & Mustapa, 2018). This on-site energy generation reduces reliance on external and often volatile energy sources like grid electricity or diesel, leading to

significant long-term operational cost savings and greater energy independence (Sarker *et al.,* 2019; Zhang *et al*., 2022).

Production of Nutrient-Rich Biofertilizer: The digestate, a byproduct of anaerobic digestion, is a valuable, nutrient-rich biofertilizer. This digestate, free from pathogens and odors, can be safely applied to agricultural land, reducing the need for synthetic chemical fertilizers. For integrated aquaculture-agriculture systems, this creates a closed-loop nutrient cycle, enhancing the overall sustainability and economic efficiency of the farm by turning a waste product into a valuable resource. This aligns with circular economy principles in food production.

Enhanced Energy Reliability and Resilience: For aquaculture farms in remote or off-grid locations, or those facing unreliable grid connections, biogas offers a stable and continuous power source. Unlike solar and wind, which are intermittent, biogas can be generated and stored, providing on-demand energy for critical life support systems (Liu *et al*., 2017). This reliability minimizes the risk of production losses due to power outages and contributes to the overall resilience of the aquaculture operation (Chen & Li, 2023).

GEOTHERMAL ENERGY

The global demand for seafood continues to rise, placing increasing pressure on traditional fisheries and necessitating the expansion of sustainable aquaculture practices. Geothermal Research Council (2019). According to the Geothermal Research Council, geothermal Energy is heat (thermal) derived from the earth (geo). It is the thermal energy contained in the rock and fluid that fills the fractures and pores within the rock of the earth's crust. Geothermal resources are reservoirs of hot water that exist at different temperatures and depths below the Earth's surface.

How do we access it?

Deep wells are drilled into underground reservoirs to tap steam and very hot water. The steam and hot water are then brought to the surface for use in a variety of applications, including electricity generation, direct use, and heating and cooling. Geothermal gradient averages about 30 °C/km. There are areas of the earth’s interior which are accessible by drilling, and where the gradient is well above the average gradient (Barbier, 2002). Heat is mined from geothermal reservoirs using wells and other means. Reservoirs that are naturally adequately hot and permeable are called hydrothermal reservoirs, while reservoirs that are satisfactorily hot but are improved with hydraulic stimulation are called enhanced geothermal systems (ESG). Once drawn to the surface, fluids of various temperatures can be used to generate electricity and other purposes that require the use of heat energy (Edenhofer *et al*., 2012).

Integration of geothermal energy and aquaculture:

Geothermal energy, a constant and reliable source of renewable heat from the Earth's interior, presents a significant opportunity for enhancing aquaculture operations, particularly in regions with suitable geological conditions. By providing a stable and

optimal water temperature, geothermal energy can accelerate growth rates, extend growing seasons, and enable the cultivation of species in diverse climates, thereby improving productivity and economic viability (Nemaok *et al.*, 2025). Furthermore, the integration of geothermal heating can reduce reliance on fossil fuels, contributing to a lower carbon footprint and aligning aquaculture with broader sustainability goals (Jamil *et al*., 2023). This is particularly relevant given the increasing scrutiny on the environmental impact of conventional aquaculture systems, including energy consumption for water heating (Lal *et al*., 2024).

Despite the compelling advantages, the integration of geothermal energy into aquaculture faces several notable challenges. The primary hurdle lies in the high upfront capital costs associated with geothermal exploration, drilling, and infrastructure development, which can be prohibitive for many aquaculture businesses (G Bioenergy, 2025). Furthermore, the availability of economically exploitable geothermal resources is geographically specific, limiting widespread adoption to areas near tectonic plate boundaries, volcanic activity, or hot springs (G Bioenergy, 2025). There are also technical complexities related to managing water chemistry, as geothermal fluids can contain dissolved minerals and gases that may be toxic to aquatic organisms and require careful treatment before use in aquaculture systems (EPCM Holdings, n.d.). Ensuring long-term sustainability of the geothermal reservoir itself, through proper management and reinjection of fluids, is crucial to prevent resource depletion (G Bioenergy, 2025).

However, ongoing advancements and innovative approaches are addressing these challenges, paving the way for wider geothermal adoption in aquaculture. Research into low-temperature geothermal systems, often found in sedimentary basins, is expanding the potential geographical reach of this energy source for direct applications like aquaculture (Nemaok *et al*., 2025). The repurposing of abandoned oil wells for geothermal energy exploration also presents a cost-effective pathway for accessing geothermal resources (Shawky *et al*., 2024). Moreover, the development of robust monitoring and mitigation plans for environmental risks, such as induced seismicity and freshwater contamination, is crucial for gaining public trust and facilitating project approvals (MDPI, 2025). As technological innovations continue to mature and economic incentives become more widespread, geothermal energy is poised to play an increasingly vital role in fostering a more sustainable and efficient global aquaculture industry.

THE CHALLENGES OF INTEGRATING RENEWABLE SOURCES IN AQUACULTURE OPERATIONS

High Initial Costs: One of the most prominent barriers is the high capital investment required for renewable energy systems. Many aquaculture operations, especially in developing countries, lack access to financial resources and incentives to support such investments (Abdelhamid *et al*., 2020).

Technical Expertise: The successful implementation and maintenance of renewable energy systems demand specialized technical knowledge, which may not be readily available in rural or less-developed aquaculture regions (Ahmed & Mustapa, 2018).

Intermittency and Reliability: Solar and wind energy, the most commonly considered renewables, suffer from variability in power generation due to weather and seasonal changes. This intermittency necessitates energy storage systems or hybrid solutions, which further escalate costs (Liu *et al*., 2017).

Regulatory and Policy Barriers: The lack of comprehensive and supportive policies tailored to aquaculture and renewable energy integration poses a major hurdle. Regulatory uncertainties and bureaucratic delays can discourage investment (FAO, 2021).

Spatial Constraints: The spatial footprint of renewable energy infrastructure, such as solar panels or wind turbines, can be limiting, particularly in land-constrained or ecologically sensitive aquaculture zones (Sarker *et al*., 2019).

Opportunities of Integrating Renewable Energy in Aquaculture Operations

Environmental Sustainability: The use of renewable energy significantly reduces the carbon footprint of aquaculture operations by replacing fossil fuel-based systems with clean, low-emission alternatives (Rodríguez *et al*., 2021). It also contributes to the conservation of natural ecosystems by reducing air and water pollution.

Cost Efficiency: Although the capital costs for renewable installations are high, declining costs of solar and wind technologies and improved energy storage solutions have made them more economically viable. Over time, these systems reduce operational costs and improve profitability (Zhang *et al*., 2022).

Energy Security: Renewable energy provides a decentralized source of power, reducing reliance on national grids and enhancing resilience against power outages and price volatility in energy markets (Chen & Li, 2023).

Innovation and Development: Integration of renewables fosters innovation through smart aquaculture systems, including automated feeding and water quality monitoring, which are increasingly powered by solar and wind energy (Patel & Dholakia, 2021).

CONCLUSIONS

Energy is a requirement in our everyday life as a way of improving human development leading to economic growth and productivity. The conclusively this part will be discus based on the following:

- Summary of the opportunities
- Summary of Challenges of the integrating renewable energy sources in aquaculture operations
- The Future prospects for renewable sources in aquaculture operation

Summary of the opportunities

It is now absolutely vital that we optimize our use of sustainable and renewable energy sources. We have to address the problems of global warming, health effects and sustainability of fossil fuel dependency. Thankfully, solar power is becoming cheaper, and

many countries have opted to invest in installing solar panels, as well as other forms of renewable energy.

Is 100% renewable energy possible?

Yes, the whole world can run on renewable energy sources, but it is going to take time, with some countries having an easier time transitioning than others. One encouraging study in Finland said that even oil-dependent countries like Saudi Arabia can transition to a 100% renewable energy system by 2040.

It is worth noting that a country like Saudi Arabia would have an easier time switching to solar power than a country like Finland, due to its abundance in sunshine, but that they will also likely be the most reluctant to since much of their wealth has been made on oil.

The study brought to light the opportunities associated with integrating renewable energy sources to aquaculture for social and economic development and climate change mitigation and reduction of environmental and health impacts. Aquaculture companies can sell excess power to the government, generating a passive income. They can also decrease their utility costs when utilizing solar energy. Fossil fuel generated electricity costs up to 17 cents per kilowatt-hour. Over time, a company can significantly increase its savings using renewable energy sources. They can also increase the sustainability of their business, raising their customer appeal. In this way, a creation of global opportunity through international cooperation that supports least developed and developing countries towards the accessibility of renewable energy, energy efficiency, clean energy technology and research and energy infrastructure investment will reduce the cost of renewable energy, eliminate barriers to energy efficiency (high discount rate) and promote new potentials towards climate change mitigation.

Summary of the Challenges of integrating renewable sources in aquaculture operations

The challenges are: market failures, lack of information, access to raw materials for future renewable resource deployment, and most importantly our (humans) way of utilizing energy in an inefficient way. These challenges that tend to hinder the integrating of renewable energy sources to aquaculture Knowledge regarding the integrating renewable energy in aquaculture is still limited. Nevertheless, the cost, price, political environment and market conditions have become barriers preventing developing, least developed and developed countries to fully utilize its potentials Aerators on shrimp farms can be powered by renewable energy sources the costs of tablets are relatively high. The alternative is to use mechanical aerators, but these are also costly to set up and run and come with additional problems

Renewable system depends on local factors, such as the amount of sunlight for solar powered systems and the amount of energy required. Other factors include costs. For marine-based farms, for example, wave energy systems in high energy environments

could theoretically be linked to farms in more sheltered areas, but this would require undersea cabling, which is not only expensive to install but requires maintenance that also comes at significant cost.

The main challenge, however, lies with the nature of renewable energy generation. “Most renewables are what you call non-dispatch able resources, meaning that you can’t really control when you're producing the energy,” different studies reveal that “Solar panels will produce when the sun is shining, wind turbines will produce when the wind is blowing”. For the pond aerators, several options such as coupling wind and solar power generators into one aerator to take advantage of different conditions. Even so, there are times when more energy is generated than needed, and times when there is not enough, so to take this challenge aerators with an energy storage system will solve this issue. Many scholars agrees that energy storage is essential, but highlights that in some situations, current technological and economic limits realistically don’t allow sufficient energy to be stored; “in some country you can have almost no sun in January, and maybe two weeks without wind.

Future Prospects for Renewable Sources in Aquaculture Operation

Aquaculture is one of the fastest growing sectors which produces fish - a cheap source of protein and nutrition. In the recent past, the growth of aquaculture sector was booming, due to declining catches from wild capture fisheries. So, in future, fish protein is full and full depends on aquaculture only.

Recommendations

1. Facilitate Financial Access: Develop and promote accessible green financing options and incentives to help farmers overcome the high initial investment costs of renewable energy systems.
2. Strengthen Technical Training: Implement practical training programs and foster local expertise to ensure farmers can effectively install, operate, and maintain renewable energy technologies.
3. Establish Clear Policies: Create consistent and supportive government policies and regulatory frameworks specifically designed to encourage and streamline renewable energy adoption in aquaculture.
4. Advance Hybrid Solutions: Invest in research and development of integrated hybrid renewable energy systems that can reliably meet the continuous and diverse energy needs of aquaculture operations.
5. Embrace Circularity: Promote farm models that integrate renewable energy (like biogas) with waste management, turning organic waste into energy and valuable byproducts for a more sustainable system.

REFERENCES

Abdelhamid, M. A., Khater, E. M., & Hassan, R. A. (2020). Renewable energy options for sustainable aquaculture. Renewable and Sustainable Energy Reviews, 121, 109692.

Abisoye, B. F., Ojo, S. K. S., Adeyemi, R. S., & Olajuyigbe, O. O. (2011). Bacteriological assessment of some commonly sold fishes in Lagos metropolis market Nigeria. Prim. J. Microbiol. Res, 1(2), 23–26.

Ahmed, A., & Mustapa, S. I. (2018). Barriers and challenges for the application of renewable energy technologies in aquaculture. International Journal of Energy Economics and Policy, 8(5), 173–178.

Barbier, E. (2002). Geothermal energy technology and current status: An overview. Renewable and Sustainable Energy Reviews, 6, 3–65.

Bertani, R. (2016). Geothermal power generation in the world 2010-2014 update report. Geothermics, 60, 31–43.

Chen, Y., & Li, F. (2023). Enhancing energy resilience in aquaculture through decentralized renewable systems. Journal of Cleaner Production, 408, 137123.

Ciolkosz, D. (2023, March 9). What is renewable energy. Penn State Extension. [Note: If this is an online source, you would typically add the URL here, e.g., Retrieved from https://extension.psu.edu/what-is-renewable-energy]

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Adeli, N., ... & von Stechow, C. (Eds.). (2014). Renewable energy sources and climate change mitigation: Special report of the Intergovernmental Panel on Climate Change working group III. Cambridge University Press.

Ekong, E. E. (2002). An introduction to rural sociology. Jumak Publisher.

Food and Agriculture Organization. (2012). Analysis in English on world about agriculture, climate change and environment.

Food and Agriculture Organization. (2018). State of world aquaculture: 2006 (Fisheries Technical Paper No. 500). Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization. (2021). The state of world fisheries and aquaculture 2020: Sustainability in action. Food and Agriculture Organization of the United Nations.

G Bioenergy. (2025). Geothermal Energy Pros And Cons: Some Drawbacks. Retrieved from https://www.globalbioene rgy.org/geothermal-energy-pros-and-cons/

Jamil, M., Ramlee, M., & Zakaria, R. (2023). Geothermal energy as a key renewable and sustainable energy resource with the potential to significantly contribute to the global energy transition.

Lal, D., Sharma, A., & Kumar, R. (2024). Emerging Innovations in Aquaculture: Navigating towards Sustainable Solutions. International Journal of Environment and Climate Change, 14(7), 83-96.

Liu, Y., Wang, J., & Zhang, L. (2017). Hybrid renewable energy systems for aquaculture: A review. Renewable and Sustainable Energy Reviews, 74, 1198–1212.

MDPI. (2025). Sustainable Geothermal Energy: A Review of Challenges and Opportunities in Deep Wells and Shallow Heat Pumps for Transitioning Professionals. Retrieved from https://www.mdpi.com/1996-1073/18/4/811

Nemaok, A., Pšenička, M., & Štefflová, L. (2025). Exploring Low-Temperature Geothermal Systems in Hydrocarbon-Bearing Sedimentary Basins: A Case Study from the Czech Vienna Basin. Proceedings of the Stanford Geothermal Workshop. https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2025/Nemaok.pdf

Olaoye, O. J., Ayinde, A. F. O., & Akintayo, I. A. (2016). Dynamics of the adoption of improved aquaculture technologies among fish farmers in Lagos State, Nigeria. Croatian Journal of Fisheries, 74(2), 56-70.

Patel, K., & Dholakia, H. (2021). Smart aquaculture: Integrating IoT and renewable energy for sustainable fish farming. Aquaculture Engineering, 94, 102167.

Rodríguez, A., Velasco, D., & Jiménez, M. (2021). Renewable energy deployment for sustainable aquaculture: A systematic review. Renewable Energy, 170, 1305–1318.

Sarker, S., Ezaz, M., & Karim, M. R. (2019). Feasibility of solar and wind energy in aquaculture operations. Energy Reports, 5, 56–64.

Shawky, M., Hammam, A., & El Khouly, E. (2024). The Hammam Faraun geothermal site in Egypt exemplifies how abandoned oil well logs, seismic data, and surface geology can be utilized to evaluate geothermal resources.

World Energy Council. (2013). World energy resources (pp. 354–415). World Energy Council.

Zhang, T., Wang, H., & Zhou, Q. (2022). Cost-benefit analysis of solar and wind integration in aquaculture farms. Renewable Energy Focus, 41, 12–20.