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Renewable Energy-Powered Fish Farms: Solar–Wind Hybrid Systems

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The rapid expansion of aquaculture has intensified energy demand, particularly in intensive systems such as recirculating aquaculture systems (RAS). Conventional fossil fuel-based energy sources increase operational costs and carbon emissions, undermining sustainability goals. Solar–wind hybrid energy systems have emerged as a viable solution to address energy intermittency and improve system reliability in fish farming operations. This article critically evaluates the integration of solar photovoltaic (PV) and wind energy in aquaculture, focusing on system design, performance, techno-economic feasibility, and environmental implications. Hybrid configurations enhance energy self-sufficiency, reduce greenhouse gas emissions, and improve farm resilience. However, challenges related to variability, storage, capital investment, and ecological impacts persist. Future research must prioritize intelligent energy management, storage integration, and site-specific optimization to fully realize the potential of renewable-powered aquaculture.

Keywords: Aquaculture; Solar energy; Wind energy; Hybrid systems; Renewable energy; RAS; Sustainability; Energy optimization

Introduction

Aquaculture has become the fastest-growing food production sector globally, but this growth comes at a cost energy. Modern fish farms, especially intensive systems like aeration units, pumping systems, and temperature control mechanisms, are highly energy-intensive. In many developing regions, unreliable grid supply further complicates operations, increasing dependency on diesel generators (Turlybek et al., 2025). This not only inflates operational costs but also contributes significantly to greenhouse gas emissions, challenging the sustainability narrative of aquaculture (Nugraha et al., 2025). In response, renewable energy integration has gained momentum, particularly solar and wind systems due to their widespread availability and scalability. However, relying on a single renewable source is inherently unstable because of temporal variability. Hybrid systems especially solar wind combinations offer a complementary solution, where solar energy dominates during daytime and wind energy compensates during low solar periods. This synergy forms the backbone of next-generation energy-efficient fish farms, ensuring reliability while minimizing environmental footprint.

Energy Demand in Aquaculture Systems

Aquaculture systems require continuous and stable energy supply. Critical operations include water circulation, aeration, filtration, feeding automation, and environmental monitoring. In RAS, energy consumption can exceed 5–10 kWh per kg of fish produced, making energy one of the largest operational costs (Bujas et al., 2022). Renewable integration becomes essential because energy demand is non-negotiable any interruption can result in mass fish mortality. Hybrid renewable systems are particularly suitable as they provide continuous power supply through complementary energy generation patterns (Ramos et al., 2025). Studies highlight that hybrid energy integration improves self-sufficiency and reduces reliance on grid or fossil fuels.

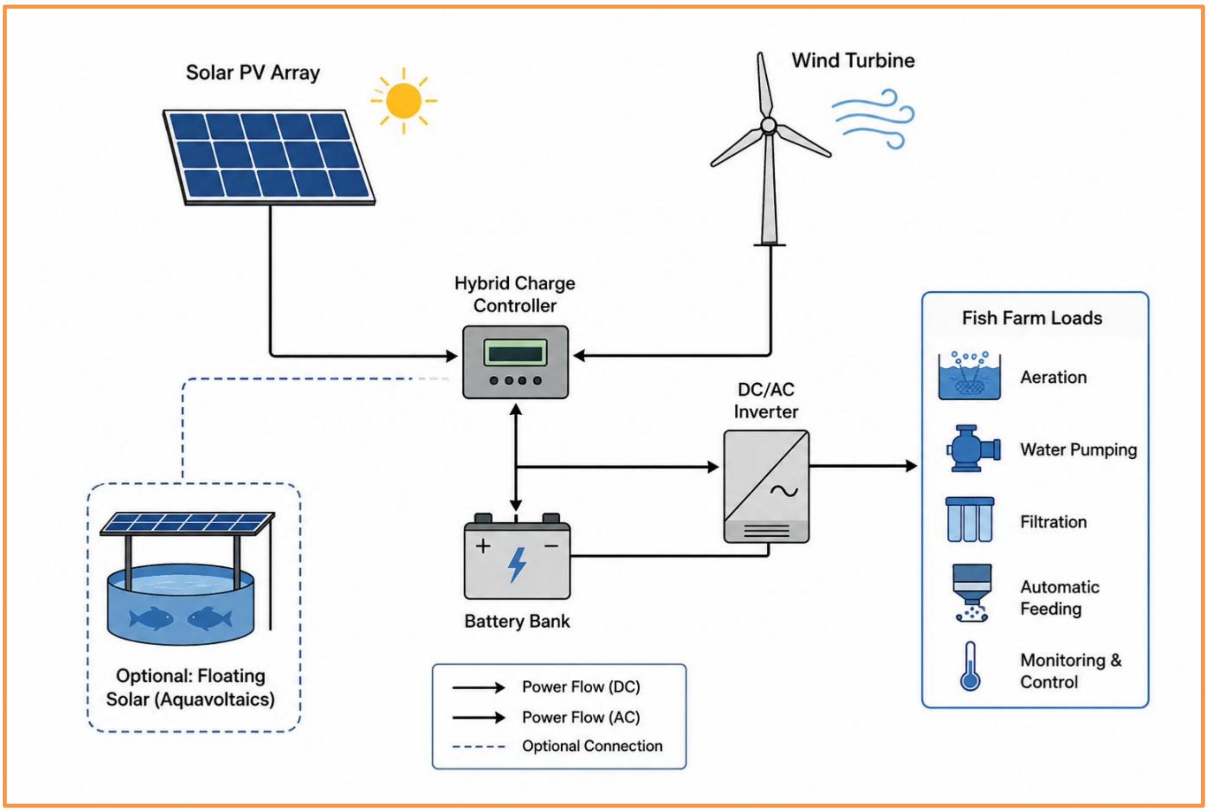

Figure 1. Energy flow architecture of a solar–wind hybrid system in fish farms

Solar–Wind Hybrid Systems in Fish Farming

System Design and Components

A typical solar–wind hybrid aquaculture system includes:

- Solar photovoltaic panels (floating or land-based)
- Wind turbines (horizontal or vertical axis)
- Energy storage systems (batteries)
- Power converters and controllers
- Load management systems

Floating solar panels (aquavoltaics) installed above fish ponds not only generate electricity but also reduce water evaporation and control temperature. Meanwhile, wind turbines provide energy during cloudy or nighttime conditions. Hybridization ensures energy complementarity solar energy peaks during the day, while wind energy can be available at night or during seasonal variations (Pringle et al., 2017). This reduces intermittency, a major limitation of standalone renewable systems.

Case Studies and Applications

Recent studies demonstrate successful implementation of hybrid systems:

- A solar–wind powered aquaculture system (SWPACES) significantly reduced greenhouse gas emissions and improved water management efficiency (Kassem et al., 2025).
- Offshore integrated systems combining wind turbines, solar panels, and fish cages have been proposed for large-scale sustainable production.
- Hybrid renewable-based aquaculture systems show improved economic returns, with internal rates of return up to 42% and payback periods as low as 4 years (Soehlemann et al., 2025).

These examples confirm that hybrid systems are not just theoretical they are already shaping real-world aquaculture.

Environmental and Economic Benefits

Environmental Advantages

- Reduction in CO_2 emissions through fossil fuel replacement
- Improved water quality and reduced thermal stress due to solar shading
- Lower evaporation losses in pond-based systems
- Enhanced nutrient cycling in integrated systems

Renewable-powered aquaculture also supports climate-resilient food systems by reducing dependency on external energy sources.

Economic Feasibility

Hybrid systems reduce long-term operational costs despite high initial investment. Key economic benefits include:

- Reduced fuel and electricity expenses
- Increased energy independence
- Improved farm productivity and reliability

Optimization models indicate that hybrid systems can achieve favorable economic performance when properly designed, particularly in remote areas with limited grid access.

Challenges and Limitations

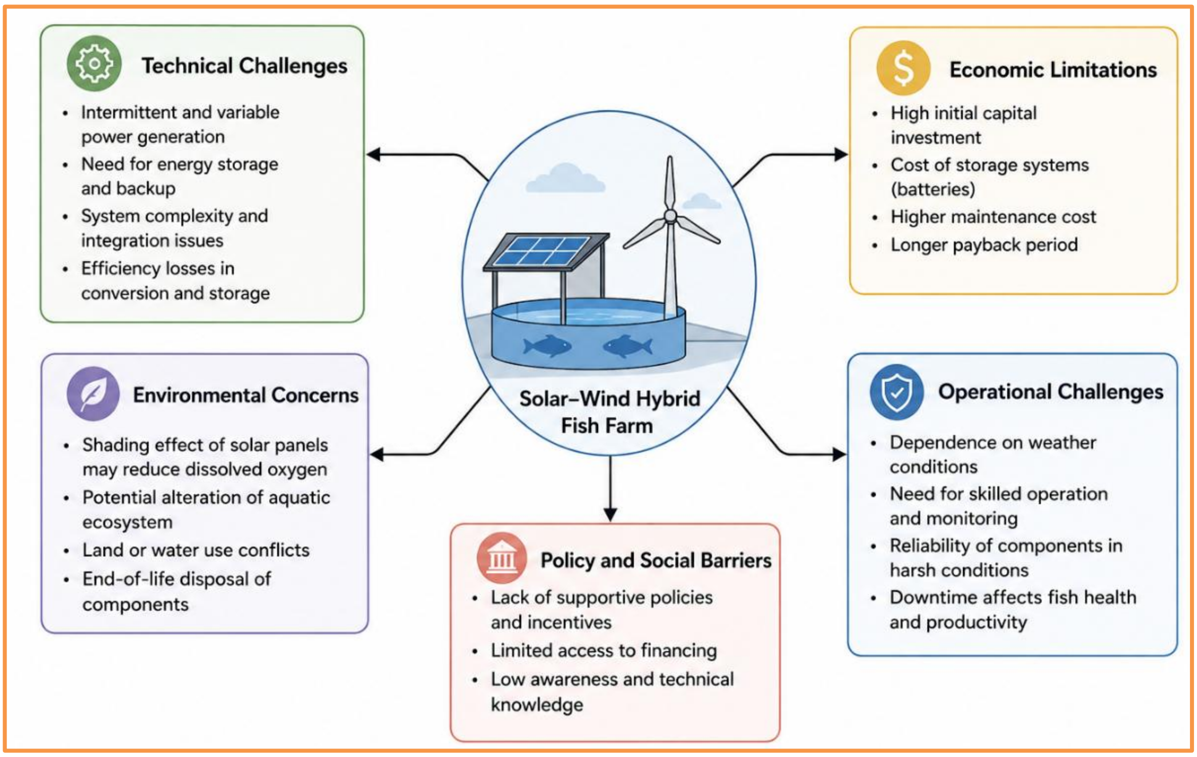

Figure 2. Challenges and limitations of solar wind hybrid system in energy powered fish farm

Technical Challenges

- Intermittency and variability of renewable sources
- Need for efficient energy storage systems
- Complex system design and integration

Economic Barriers

- High initial capital cost
- Limited access to financing in developing regions

Environmental Concerns

- Potential reduction in dissolved oxygen under excessive solar panel coverage
- Alteration of aquatic ecosystems due to shading
- Structural challenges in offshore installations

Even hybrid systems can suffer energy losses (up to ~27%) if not optimized properly (Selj et al., 2025).

Future Perspectives

The future of renewable-powered fish farms lies in smart integration:

- AI-based energy management systems for demand forecasting
- Integration with IoT for real-time monitoring
- Advanced battery and hydrogen storage technologies
- Development of offshore multi-use platforms combining energy and aquaculture

Emerging concepts like aquavoltaics and floating hybrid platforms are redefining how space, water, and energy interact in food production systems.

Conclusion

Solar–wind hybrid systems represent a transformative shift in aquaculture energy management. By combining complementary renewable sources, these systems address the critical challenge of energy reliability while reducing environmental impact. Although technical and economic barriers remain, advancements in energy storage, optimization algorithms, and smart monitoring systems are rapidly bridging these gaps. The integration of renewable energy into fish farming is no longer optional it is essential for achieving sustainable, climate-resilient aquaculture.

References

1. Bujas, T., Koričan, M., Vukić, M., Soldo, V., Vladimir, N., & Fan, A. (2022). Review of energy consumption by the fish farming and processing industry in Croatia and the potential for zero-emissions aquaculture. *Energies*, *15*(21), 8197.
2. Kassem, Y., Gokcekus, H., Camur, H., & Alsakhni, G. A. A. (2025). Innovative Solar-Wind powered Aquaculture System: A Sustainable Solution for Aquaculture in Karbala, Iraq. *Engineering, Technology & Applied Science Research*, *15*(3), 23649-23658.
3. Nugraha, I. M. A., & Desnanjaya, I. G. M. N. (2025). Energy efficiency in aeration systems for aquaculture ponds: a comprehensive review. *Jurnal Riset Akuakultur*, 1-25.
4. Pringle, A. M., Handler, R. M., & Pearce, J. M. (2017). Aquavoltaics: Synergies for dual use of water area for solar photovoltaic electricity generation and aquaculture. *Renewable and Sustainable Energy Reviews*, *80*, 572-584.
5. Ramos, H. M., Soehlemann, N., Bekci, E., Coronado-Hernández, O. E., Pérez-Sánchez, M., McNabola, A., & Gallagher, J. (2025). Challenges in Aquaculture Hybrid Energy Management: Optimization Tools, New Solutions, and Comparative Evaluations. *Technologies*, *13*(10), 453.
6. Selj, J., Wieland, S., Tsanakas, I., van Sark, W., Roosloot, N., Otnes, G., ... & Micheli, L. *Floating Photovoltaic PowerPlants: A Review of Energy Yield, Reliability, and Maintenance. 2025*.
7. Soehlemann, N., Pérez-Sánchez, M., Coronado-Hernández, O. E., McNabola, A., Quintino, A., & Ramos, H. M. (2025). Optimization Tool of Hybrid Energy Systems Toward a New Integrated Solution to Improve the Fish Sector's Effectiveness. *Water*, *17*(22), 3242.
8. Turlybek, N., Nurbekova, Z., Mukhamejanova, A., Baimurzina, B., Kulatayeva, M., Aubakirova, K. M., & Alikulov, Z. (2025). Sustainable aquaculture systems and their impact on fish nutritional quality. *Fishes*, *10*(5), 206.