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Innovative renewable energy solutions for the sustainability of Egypt's aquaculture

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Innovative renewable energy solutions for the sustainability of Egypt's aquaculture

Authors

Alaaeldin Baioumi, Malcolm Dickson, Ahmed Nasr-Allah and Mohamed Fathi Eliwa.

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Contact

WorldFish Communications and Marketing Department, Jalan Batu Maung, Batu Maung, 11960 Bayan Lepas, Penang, Malaysia. Email: worldfishcenter@cgiar.org

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List of abbreviations

CeREA	Center for Renewable Energy in Aquaculture
CIB	Commercial International Bank
CO_2-eq	Carbon dioxide equivalent
EETC	Egyptian Electricity Transmission Company
EGP	Egyptian Pound
FAO	Food and Agriculture Organization
FIT	Feed-in tariff
GAFRD	General Authority for Fisheries Resources Development
GHG	Greenhouse gas
GW	Gigawatt
IPRS	In-pond raceway system
KIIs	Key informant interviews
KW	Kilowatt
MW	Megawatt
NGO	Non-governmental organization
PV	Photovoltaic
USD	United States Dollar

1. Executive summary

The rapid growth of the tilapia aquaculture sector in Egypt over recent decades has provided an important source of nutrition, income and economic activity for fish farms, feed mills and communities. However, this important industry faces a number of threats, including those caused by climate change.

In June 2023, WorldFish partnered with the Royal Norwegian Embassy in Cairo to establish the Center for Renewable Energy in Aquaculture (CeREA) project to refine, test and scale innovative renewable energy solutions over a 4-year period. The project commissioned a baseline scoping study to identify critical factors, map key stakeholders and recommend opportunities for adoption of technologies.

The study carried out field data collection by interviewing fish farmers, retailers, feed companies and other important stakeholders, such as renewable energy technology companies. Field data was compiled and analyzed along with the results from focus group discussions and key informant interviews (KIIs).

The scoping study highlighted that very few fish farms currently make use of renewable energy technologies. Most depend on diesel-powered pumps to move water through their ponds, and many are not connected to the electricity grid. There has been little capital investment in Egyptian fish farm zones, as land has usually been leased for short time periods and farmers are discouraged from building permanent structures. Farmers generally understand the potential for renewable energy to reduce their operating costs but are worried about the installation costs for renewable energy systems. Short lease periods also mean that that they would prefer transportable systems that could be moved to a new site, if required.

Service providers of renewable energy solutions are keen to provide appropriate technologies but they lack basic information about the aquaculture business. Their most widely applied system for agriculture in Egypt is solar power for pumping water. Other technologies such as biogas, wind turbines and hydrogen would need more research. Finance could be provided for green technologies through existing banks and microfinance institutions, while NGOs could also play a role.

The main conclusion from the study is that there is a clear case for increased use of renewable energy in Egyptian aquaculture. It also has the potential to significantly reduce the greenhouse gas (GHG) footprint of the sector. However, there has been very little capital investment in Egyptian fish farms because of short lease periods. There is also little space available for deployment of solar panels while access to night-time renewable electricity supplies would need additional investment in battery systems.

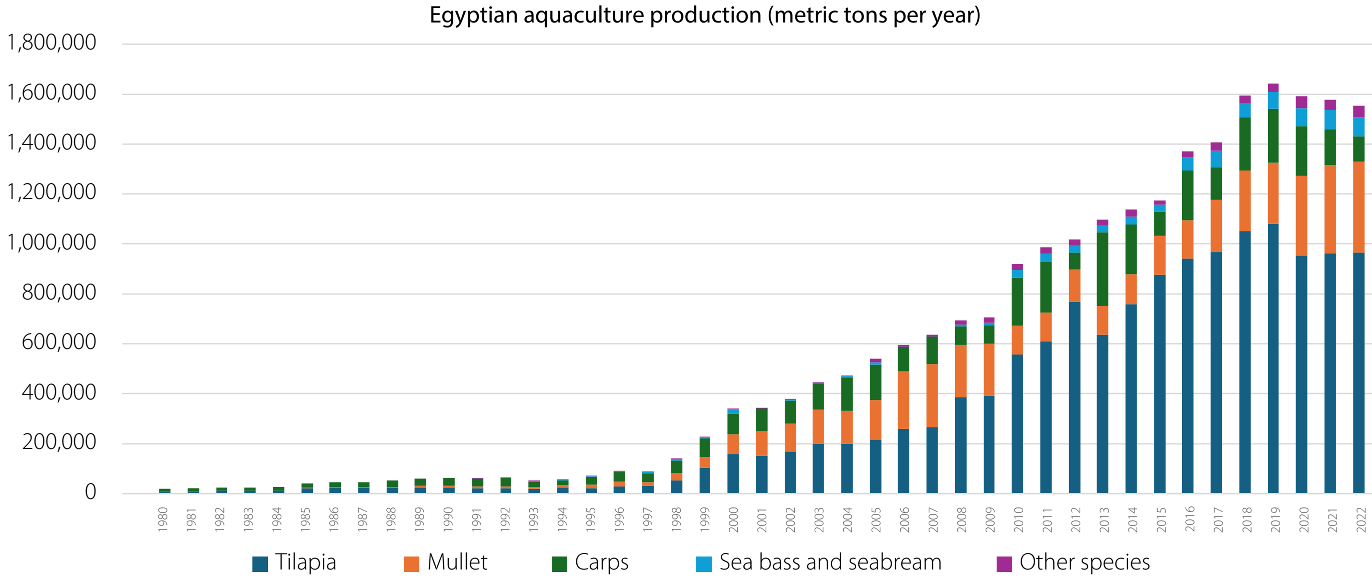
Companies supplying solar and battery technologies as well as financing institutions are already operating in Egypt, but they need to better understand the specific needs of the sector. The study support the on-farm testing of various renewable energy technologies by the project to build the case for more widespread adoption by the sector.

Women working in retailing and processing activities of the value chain face difficulties in transporting and marketing fish. The study suggest the use of a portable solar vending with chest cooler/freezer could alleviate some of their challenges.

The study recommended the 10 most promising, commercially viable, gender-transformative and climate-smart renewable energy solutions for the Egyptian aquaculture value chain, including a ranked list. These solutions aim to enhance performance, strengthen resilience and reduce GHG emissions.

2. Introduction

Egyptian aquaculture production has grown rapidly over the past three decades (Figure 1). This followed the establishment of a regulatory body, the General Authority for Fisheries Resources Development (GAFRD), which leased land to farmers in designated production zones, including Kafr el Sheikh, Behera and Fayoum, as well as managed the first hatcheries and feed mills. Techniques for profitable tilapia farming and tilapia/mullet polyculture were spread among fish farmers in response to booming demand for farmed fish in the main population centers. This growth has established Egypt as the top aquaculture producer in Africa, accounting for 71 percent of the continent's output, and the third-largest tilapia producer globally, after China and Indonesia (FAO 2024). Aquaculture production plays an important role for Egypt's national economy and food security, as production is almost exclusively sold for local consumption (Macfadyen et al. 2012).



Source: FAO, 2024

Figure 1. Egyptian aquaculture production statistics, 1980–2022.

The total area dedicated to fish farms in Egypt was estimated at 122,000 ha in 2021. This comprised 102,000 ha in privately managed farms and 20,000 ha in governmental farm areas. Rossignoli et al. (2023) concluded that semi-intensive polyculture of tilapia was the dominant farm system; only 18 percent of the tilapia produced came from monoculture systems, while 82 percent came from polyculture systems where tilapia were grown together with mullets and other species. The ownership structure included privately owned farms, farms leased from the government and government-managed farms, with production dominated by private farms ranging from small-scale to larger intensive operations (FAO 2020).

Egyptian fish farms face a number of threats. Profitability has been squeezed by increasing input costs, particularly for feeds, while farmers have little control over selling prices as markets and distribution are controlled by wholesalers (Dickson et al. 2016a; Dickson et al. 2016b). By law, farms must re-use water from lakes and irrigation drainage canals, this means fish farms do not place a burden on Egypt's scarce freshwater resources. Most farms pump large quantities of water through their ponds to maintain oxygen levels. Meanwhile, most fish farms operate on short leases, discouraging investment in physical infrastructure. This means they lack access to the electrical grid or paved roads and operate diesel-powered pumps to pass large volumes of water through their ponds. Until around 10 years ago, diesel was heavily subsidized. But as these have been gradually withdrawn, farmers face rising energy bills. Fish farms also face threats from climate change through the impacts of extreme weather events. Higher summer temperatures increase the risk of disease, and yet more re-use of water further up in the agricultural irrigation system will result in even poorer water quality.

Global warming has become an important issue over recent decades as the consequences are being felt and countries commit to GHG emission reductions. Egypt ratified the Paris agreement in 2017 and has committed to reduce emissions from the electricity and fossil fuel sectors by 37 percent and 65 percent by 2030, respectively.[1] To date, the country's total installed capacity of renewables amounts to 3.7 gigawatts (GW), including 2.8 GW of hydropower and around 0.9 GW of solar and wind power. The Egyptian government set a renewable energy target of 42 percent of the electricity mix by 2035 (IRENA 2018).

The aquaculture sector in Egypt needs to address its responsibility to contribute toward these targets by adopting innovative practices and technologies. A study by Henriksson et al. (2017) showed that GHG emissions from Egyptian tilapia farming could be reduced by up to 23 percent if improved genetic strains and better farming practices were adopted. Meanwhile, WorldFish established demonstration units for solar pumping of water and in-pond raceway systems (IPRS) at its Abbassa Research Center, both of which have the potential to reduce emissions from water pumping while the efficiency of feed conversion can be significantly improved by using IPRS (Fantini-Hoag et al. 2022) Widespread adoption of renewable energy could help Egyptian fish farmers reduce their GHG emissions. This will be easier for farms and value chain actors such as feed mills that are connected to the electricity grid as the country gradually replaces large-scale fossil fuel electricity generation with low-carbon technologies. However, fish farmers and others in the aquaculture value chain should also be able to benefit from renewable energy technologies at the farm or business level.

2.1. Overview of renewable energy sources

Solar

On a smaller scale, such as a farm or for personal use, solar energy can be harnessed through photovoltaic (PV) panels. These panels can be installed on rooftops or in open areas to generate electricity for direct use. This setup is particularly beneficial for remote locations where connecting to the grid is challenging. In these cases, solar energy can power essential appliances, pump water and provide aeration to ponds via paddle wheels. Additionally, the excess energy can be stored in batteries for use when sunlight is not available.

In contrast, large-scale solar energy is typically deployed through solar farms. These extensive arrays of PV panels feed electricity directly into the grid. They can cover several hectares and can generate substantial amounts of power, often equivalent to traditional power plants, depending on the time of day and weather conditions. These installations require significant investment and infrastructure but can contribute significantly to the overall renewable energy capacity of the national grid,[2] supplying electricity to thousands of individual locations that are connected to the grid.

There is great potential for advancing solar energy in Egypt, both on small-scale and large-scale projects, given the many sun hours and available land. Small-scale initiatives like the Egypt PV project and the Small-Scale Grid-Connected Solar System project have promoted rooftop solar systems across households, businesses and heritage sites, reducing carbon emissions and boosting local energy generation.[3,4] On the larger scale, Egypt is developing major solar plants, such as the 200 megawatts (MW) Kom Ombo plant and several projects, aiming to generate 42 percent of its electricity from renewable sources by 2035 according to the World Bank.[5]

Wind

Small-scale wind energy makes use of wind turbines that are typically between 40 and 200 kilowatts (KW) in capacity.[6] These turbines can be installed on individual properties, like tilapia farms, to supplement energy needs. They are particularly effective in areas with consistent wind patterns. Small wind turbines can be used for tasks like pumping water, charging batteries or providing electricity to outbuildings. Large-scale wind farms, in turn, are made of many large turbines (3–12 MW each) installed in parallel in areas with strong consistent wind patterns. These turbines can be onshore or offshore and can generate a substantial amount of electricity, enough to power entire communities.[7]

Egypt already has some operation wind parks, such as the Gulf of Suez wind farms with capacities of 263 MW and 500 MW,[8] but wind and solar combined constituted less than 1% of the overall electricity mix in 2021 (IEA n.d.). However, Egypt is set to begin construction of one of the world's largest wind parks, a USD 11 billion project that aims to generate 10 GW by 2030, contributing substantially to Egypt's commitments in reducing GHG emissions. This project is expected to offset approximately 23.8 million metric tons of carbon dioxide equivalent (CO_2-eq). annually, or approximately 9% of Egypt's overall GHG emissions.[6,9]

Biogas

At a small scale, biogas systems convert organic waste from households, farms or small businesses into biogas through anaerobic digestion. This biogas can be used for cooking, heating or generating electricity on-site. Small-scale biogas systems reduce waste and provide a renewable source of energy that can be used according to demand.

In large-scale operations, biogas plants process large volumes of organic waste, including municipal waste, agricultural residues or industrial organic waste. These plants can generate substantial amounts of biogas, which is then purified and injected into the natural gas grid or used to produce electricity and heat in power plants.[10] Egypt is currently building its first biogas factory in Sadat City, a facility capable of processing 85,000 t of cattle manure annually, from which 1 MW of electricity could be produced alongside fertilizers.[11]

2.2. Other (hydroelectric, biomass energy, hybrid systems)

Small-scale applications of other renewable sources, like hydroelectric systems, might involve micro-hydro setups in streams or small rivers, generating electricity for individual farms or small communities. Biomass energy, such as wood or crop residues, can be used for heating or cooking, but not generally used for electricity generation at smaller scales.[12]

Large-scale hydroelectric power involves constructing dams and reservoirs that can generate substantial amounts of electricity, but with limited possibilities for upscaling in Egypt. Biomass energy in large-scale scenarios often involves industrial-scale production of biofuels or electricity generation through burning organic materials (e.g. wood products) in power plants. In 2021, hydroelectricpower constituted 1.2 percent of the overall electricity mix in Egypt, while biofuels and waste accounted for 3.5 percent (IEA n.d.).

In June 2023, WorldFish partnered with the Royal Norwegian Embassy in Cairo to establish the CeREA project to refine, test and scale innovative renewable energy solutions over a 4-year period (Box 1).

Box 1. CeREA key interventions.

Refine, test and scale innovative renewable energy solutions that enable fish value chain actors in Egypt to increase their productivity and income leading to improved food and nutrition security, reduced food waste and loss, and more adaptation to energy-efficient and climate-smart systems.

Deploy appropriate renewable energy technologies for aquaculture, along with efficient planning and capacity building for scaling the Egyptian aquaculture sector in a sustainable, climate-friendly and inclusive manner to support both economic growth and the protein needs of the country's rapidly expanding population.

The project commissioned a study to provide baseline information:

- An overall baseline (scoping) study by Dr. Alaaeldin Baioumi to assess the status of using renewable energy in the aquaculture value chain, identify the critical factors limiting its use, map the key stakeholders and recommend opportunities for adoption.

3. Methodology

A farmer survey was used as the primary data collection tool, complemented by focus group discussions targeting fish farmers. A stratified randomized sampling methodology was used to ensure that the main types of farms were represented, while clustering was carried out in the target governorates of Kafr el Sheikh, Sharkia, Behera, Port Said, Damietta and Fayoum (Figure 2) in order to cover farms using different energy sources. Assuming a total farm population of 5000, the aim was to survey (KIIs) 500 farms. However, this was later adjusted to 239 due to time limitations and poor weather:

- Kafr el Sheikh – 120 farms, average total pond area 8.57 ha, including seven hatcheries
- Port Said – 41 farms, average total pond area 10.3 ha, including three hatcheries
- Beheira – 31 farms, average total pond area 8.8 ha
- Sharkia – 29 farms, average total pond area 9.5 ha, including five hatcheries
- Damietta – 9 farms, average total pond area 10.1 ha, all marine fish farms
- Fayoum – 9 farms, average total pond area 34 ha, including two very large farms.

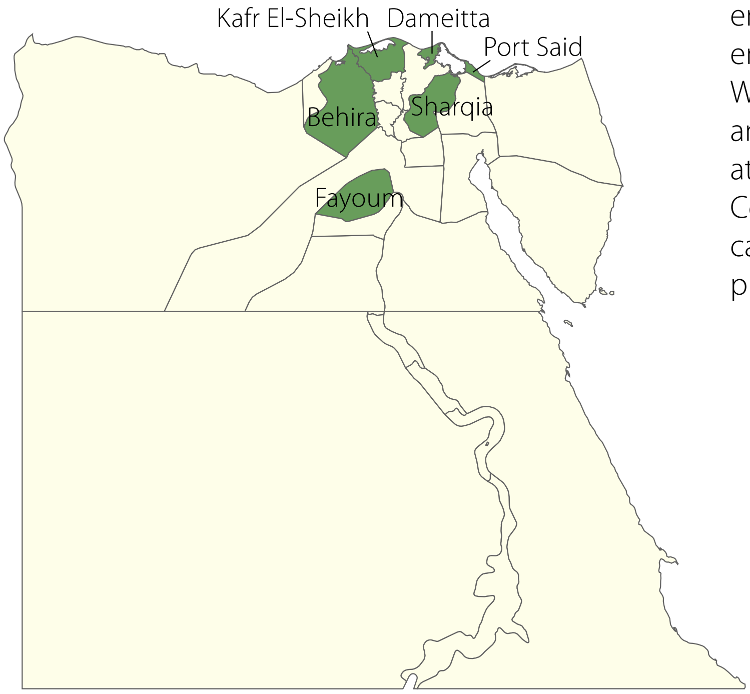


Figure 2. Map of target governorates, where the study was focused.

Of the 239 aquaculture establishments visited, 186 were semi-intensive polyculture (tilapia and mullet) farms, 25 were semi-intensive monoculture tilapia farms, 15 were hatcheries and 13 were marine polyculture farms. The selection of farms and data collection was executed by local consultants and enumerators between January 8 and February 17. Data was collected through on-site interviews and entered using KoboToolbox (https://www.kobotoolbox.org/). After data entry and cleaning, SPSS software was used for data analysis.

Eight focus group discussions were held, interviewing a total of 51 farmers in Sharkia, Port Said, Damietta, Kafr el Sheikh and Fayoum. These explored the costs of existing energy sources and attitudes toward replacing these with renewable energy as well as the support being provided by the project.

Data was gathered from other value chain actors including feed companies, companies providing renewable energy systems, renewable energy experts, NGOs and networks related to aquaculture and finance institutions supporting aquaculture-related businesses. The consultancy team met seven feed businesses (including traders and feed producers), eight renewable energy system providers, two renewable energy experts, two NGOs (the Network for Women Fish Trading Processing in Egypt and the Association for Agricultural Investors at Al Moghra Oasis, Marsa Matrouh) and the Commercial International Bank (CIB) and also carried out on-line research on a range of potential providers of services and finance for the sector.

4. Results

4.1. Fish farms

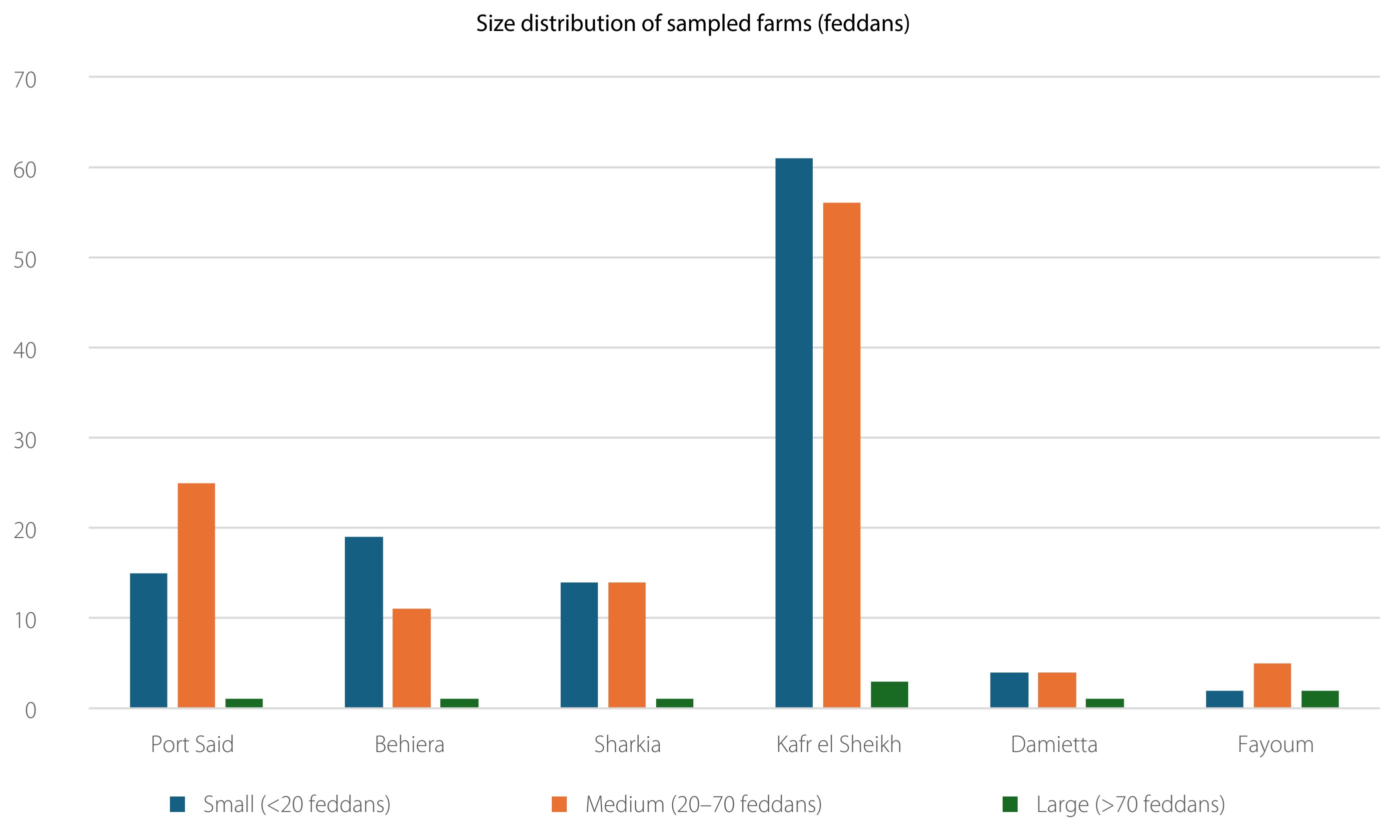
The fish farms were classified into size ranges as shown in Figure 2, which shows the number of fish farms interviewed in each governorate and their size range.

Most of the surveyed fish farms fall within the size categories of small and medium used in this survey. The size distribution is determined primarily by the leasing policy in each aquaculture zone and the type of activity being pursued by the farm, such as grow-out, hatchery or marine fish farm. All the fish farms in Damietta were marine farms, while the only other marine farms in the survey were in the Kafr el Sheikh governorate and hatcheries are usually smaller than grow-out farms.

Among the 239 respondents, 77 percent were adults (36 years and older), while 23 percent were young men (aged 21 to 35 years).

More than 90 percent of the fish farms used water from irrigation drainage canals, while 8.4 percent used water from lakes or rivers. One farm used seawater.

Most farms (60.7 percent) operated without access to grid electricity (off-grid), while 39.3 percent had access to grid electricity (on-grid) (Figure 3). Of these, only 17.9 percent relied on grid electricity as their primary energy source, whereas 82.1 percent of the sampled farmers used diesel as the main energy source for their farms.



Note: 20 feddans = 8.4 ha, 70 feddans = 29.4 ha

Figure 3. Size range of surveyed farms by governorate (number of farms).

Diesel-powered pumps were used as the main way to move water in 75 percent of farms while electrical pumping was used in 25 percent of farms (Figure 4). Aerators powered by main electricity were used in 8 percent of farms while five percent of farms used aerators supplied with power from a diesel generator (Figure 5).

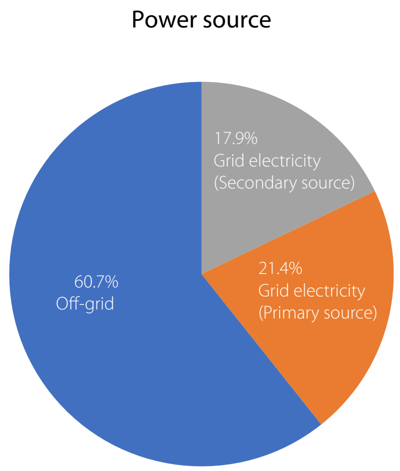


Figure 4. Power source distribution.

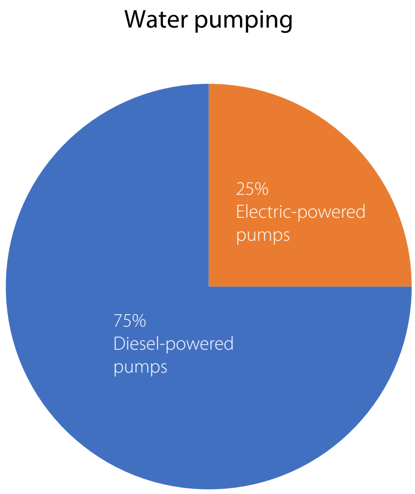


Figure 5. Water pumping distribution, by power source.

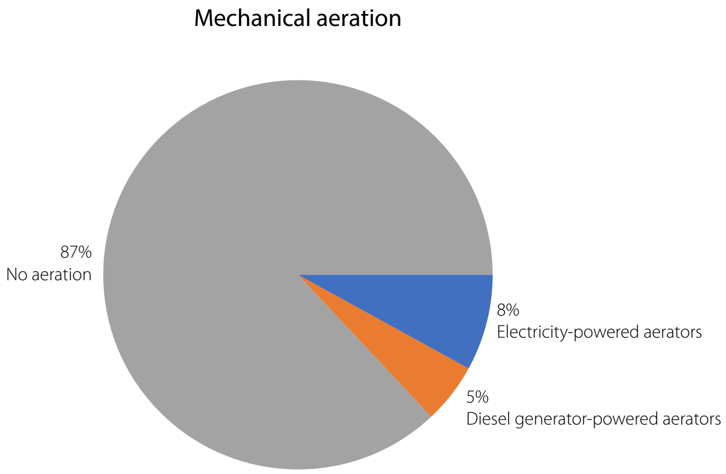


Figure 6. Mechanical aeration distribution, by power source.

More than half of the samples (50 percent) said they changed the water in the farm daily, 30.2 percent said they changed the water every 2 to 3 days, 19.8 percent changed the water weekly. Most farms (87.4 percent) used gravity drainage to discharge water from their ponds while the remainder used pumps.

The terminology, "renewable energy" was known to 58 percent of farmers. Potential benefits were listed as reducing fuel consumption, reducing water exchange rates, reducing chemical usage and other benefits such as aeration, lighting and reducing the energy cost. On further discussion only 16 farms had actually used renewable energy, and this was mostly for lighting (Figure 7).

Figure 7. Solar PV panels installed at a fish farm for energy supply and lighting.

None of the farmers said they had problems with financing. Only five farms said they had obtained loans for fish farm operations over the period 2011 to 2022.

Eight focus group discussions were held with farmers from Port Said, Sharkia, Kafr el Sheikh (three groups), Behaira, Damietta and Fayoum. Most of the farmers (26) owned their land rather than renting it (25). The average landholding ranged from 0.8 ha to 250 ha. Among the farmers, 42 used diesels as their energy source, while 25 used electricity, with 18 of them using a combination of both diesel and electricity. Only one of the farmers, in Port Said was using a solar powered system (Box 2). The farmers said they understood the importance of renewable energy and the accepted sources were solar power and wind energy. The cost of electricity or diesel typically represents 3 percent to 7 percent of total farm expenses, and the farmers hoped this could be reduced by using renewable energy.

Box 2. Farmer experience of installing a solar energy system.

One of the focus group farmers had set up an on-grid solar energy system on a farm size of 60 ha around 2 years ago. The system cost USD 25,000 without batteries and is connected to the electricity grid. This reduced his energy costs by 20–25 percent.

However, the focus group farmers perceived that the installation costs would be high and unpredictable because key components are imported. They all said they would like an off-grid solution with batteries to provide 24-hour power but recognized that this would be expensive and entail regular replacement of batteries. Most acknowledged that an on-grid system without batteries and export of surplus electricity to the grid would be more efficient. However, there were concerns that some coastal areas may have insufficient sunlight for this to be worthwhile. As many of the farmers rent their land, they will need a portable solution that can be easily moved or expanded if they change their location. Some farmers said they only use solar to provide lighting for accomomdations rather than the fish farm.

The farmers expressed concern about a lack of trusted companies supplying renewable energy systems, which could mean poor after-sales service and maintenance, exacerbated by the fact that providers are not based near the fish farming zones. It was felt that solar energy would be too expensive for small farms (less than 20 ha). There was very limited information on other renewable options, such as biogas, wind and green hydrogen, and more technical support is needed for farmers to make choices appropriate to their needs.

The farmers said group-based financing approaches are unlikely to work. Their farms are scattered and the costs of installing renewable energy systems should be subsidized, with farmers paying 25 percent of the capital costs upfront and the remainder spread over a 1- to 2-year period.

4.2. Fish feed businesses

Feed producers use electricity from the national grid as their main energy source, and generators are used as standby for electricity power cuts. One of the feed companies explored the use of solar energy in 2014, but the system was too expensive. The horsepower of machinery in feed mills is significantly higher compared to other businesses within the aquaculture value chain. Consequently, using renewable energy in the fish feed sector requires a substantial investment for installation. An alternative approach is to focus on specific machinery within feed mills that have lower horsepower demands, enabling the use of renewable energy in the short term.

4.3. Renewable energy companies

Online meetings were held with six solar energy providers, one of which also provides biogas and green hydrogen systems. All have previous experience in working with agriculture farms, particularly for solar pumping in the new agriculture areas providing systems with and without batteries. All have factories in Egypt and build frames locally while importing the main components such as panels, inverters and batteries. They are licensed by the National Authority for Electricity and Renewable Energy.

They lack information on the needs of aquaculture farmers, which would help them develop suitable technical and financial solutions for the sector. However, two of the companies said they had provided solar systems for fish farms.

Box 3. Feed-in Tariff.

Under the Egypt Renewable Energy Law (Decree No 203/2014), there is a feed-in-tariff (FIT) support system under which private sector investors are allowed to build, own and operate renewable energy power stations and sell generated electricity to the Egyptian Electricity Transmission Company (EETC) or to other licensed distribution companies through power purchase agreements. The FIT system is open only for solar PV and wind technologies at present. Independent power production through a third-party access scheme allows independent power producers to enter bilateral electricity purchase contracts with eligible consumers and sell them produced electricity directly. However, the EETC is allowed to charge and collect grid access fees for grid usage.

Only one of the renewable energy companies (Triple M) provides biogas-based systems. These use feedstocks including residues from crop production, waste food and animal manures to produce methane through a process called anaerobic digestion. The produced gas can be burned directly for cooking or heat as well as converted to electrical energy through a combined heat and power plant. Biogas is considered to be a renewable energy system, as it replaces fossil fuel-based energy. Development of biogas can be carried out a range of scales from household to industrial. Although there has been widespread uptake at either the household or large-scale level in many countries, uptake has been slow in Egypt.[12]

Triple M also offers a prototype green hydrogen system offering the capability to use surplus renewable energy to generate hydrogen that can be stored and used when required as a substitute for fossil fuels. This could be particularly useful for hatcheries that have high fuel demand for water heating early in the season. However, this technology has not yet been implemented in Egypt and requires further research. The field application of such a system has not yet been tested in Egypt.

4.4. Finance institutions

CIB provides a range of credit facilities, including around nine products for the agriculture sector and value chain processes from input supply to processing. Annual interest rates are between seven and 10 percent and the loan size can be up to USD 250,000 with loan terms of 5 years. CIB works directly with the Ministry of Environmental Affairs to provide green finance products (25 percent grant, 75 percent loan) and is ready to collaborate to provide green finance to aquaculture farms.

The National Bank of Egypt has provided finance products for aquaculture since 2022 with a loan covering 85 percent of working capital and a 5-year loan period. The maximum loan is greater for farms that have updated financial statements. The Agriculture Bank of Egypt provides long- and short-term loans for aquaculture businesses of up to 75 percent of total costs. It also provides small loans to female-headed households and women's groups. The Bank of Alexandria also has finance products for aquaculture farms, with loans for individual farmers and larger loans for businesses and cooperatives.

Microfinance is provided by Tamweely, which has 230 branches across Egypt. This includes funding for micro-enterprises, very small enterprises and tools for artisans and craftsmen. The Credit Guarantee Company Egypt helps businesses access financing through de-risking the investment. It promotes orderly debt settlement while helping finance institutions sustain lending and support investment. Leasing and factoring have been facilitated in Egypt after a relevant law was passed in 2018. Two companies have been identified that could provide this service for financing of renewable energy projects.

4.5. NGOs

The Association for Agriculture Investors at Al Moghra Oasis in Marsa Matrouh was established in 2020 and has implemented a range of agriculture, aquaculture and fish processing initiatives in an area supplied with solar power. The brackish water from the oasis will be used to grow marine fish species while other key crops include jojoba and olives. The NGO is a member of the Agri-Misr Platform, which will help farmers access finance from the Agriculture Bank of Egypt.

The Network for Women Fish Trading and Processing is an African network established in 2000 that has had new initiatives in Egypt since 2020. Its aim is to improve the socioeconomic status and economically empower women in fishery agribusinesses by providing access to finance and entrepreneurship. The women need to have a formal business structure with secure premises, including an effective cooling system for storing fishery products (Figure 8). The network can help them develop sustainable and low-cost renewable energy solutions as well as provide training and improving market access.

Figure 8. Women fish vendors selling fresh fish.

5. Discussion

5.1. Fish farms

The case for increased use of renewable energy in aquaculture is clear, as it has the potential to provide power to fish farming areas that are not connected to the national electricity grid as well as reduce energy costs in farms connected to the grid. Using currently available technology, a solar-powered system combined with batteries, has the potential to provide a reliable, 24-hour power supply to operate pumps, aerators, automatic feeders, alarm systems, chill stores, ice-machines, on-farm transportation, lighting and water heating. Meanwhile other technologies, such as wind turbines, biogas or green hydrogen, may have applications in Egyptian aquaculture but have yet to be tested.

The results of the farm surveys illustrate that the majority of fish farms operate with very basic technology because they do not have secure power supplies. This is primarily the result of the tenure system for farmers renting land in the main aquaculture zones. Most farms in these zones operate on short leases and a condition of their lease is that they should not build permanent structures. As a result, there has only been minimal investment in infrastructure such as roads, electricity distribution systems and buildings since the establishment of aquaculture zones in the 1980s and 1990s. Diesel-powered pumps were favored as they could be lifted and moved, if necessary, while subsidies made this by far the cheapest option. At harvest, wholesalers come to the farm and take the fish to their facilities for distribution, so no on-farm chilled storage is needed. Feed is supplied by feed companies on credit terms with additional credit offered by the wholesaler, who recovers the credit for both the feed company and his business at the end of the season when the fish are sold.

Most of these farms have been able to produce fish with only minimal levels of seasonal or capital investment for several decades now, operating as informal businesses without a need to access banking services for their day-to-day needs. However, this is a serious barrier to investment in new technology, such as renewable energy systems, as they have no collateral or formal accounts that can be used to facilitate financial support. Not all fish farmers rent their land, and some farms operate on longer lease periods. These more bankable farms would be more likely to invest in renewable energy systems than the "short lease" fish farms, who will find it difficult to raise finance for capital projects.

Alternatively, finance for renewable energy infrastructure could be raised through a group-based approach and many renewable energy investments, such as anaerobic digesters (biogas), would suit being implemented at a large scale rather than individual farm level. This will require functioning associations or producer organizations. There is a national producers organization and governorate-level fish farming associations with variable track records in terms of providing services for their members. The Fayoum Fish Farming Association has been relatively successful, perhaps because of its leadership but also because its formation facilitated access to a new area of land for aquaculture development. This could be a promising approach in "new land" mixed agriculture/aquaculture zones.

Alternatively, investment support for new technology could be channeled through the feed companies who already have financial relationships with the fish farms and provide technical services, as part of their support and marketing efforts. There are several major companies involved in the sector, many of which are subsidiaries of international businesses that would like to see technological progress on Egyptian fish farms to increase the size of their market. The feed companies could act as aggregators to attract grant support from international donors for large-scale upgrading at the farm level.

The operating systems used by Egyptian fish farmers have not changed much in the past 20 years, mainly because there has been so little capital investment in infrastructure. Fish farmers need good access roads, access to the national electricity grid and improved water quality in order to increase their efficiency and ensure a sustainable future for the sector. Access to the electrical grid would help them to move toward increased use of renewable energy as the country increasingly invests in large-scale renewable energy systems. Increased operation of water-efficient aquaculture systems such as in-pond raceways would allow more fish to be produced without increasing the pond area and with greatly reduced water requirements. However, it also needs significant capital investment, secure land tenure and access to a reliable power supply for aeration.

Solar panels need a significant amount of space. However, there is very little land space within the aquaculture zones, as most of the area is occupied with ponds or internal access roads while the entire space within the aquaculture zone and sometimes also the margins of the zone has also been developed. It might be worth exploring the potential to use floating solar panels that could be installed within ponds or at the margins of ponds. This could mitigate summer water temperatures through shading while cooling the solar panels, improving their efficiency.

Diesel-powered pumps are relatively powerful, pumping large quantities of water in a short time. Electrical pumps using solar energy are likely to be less powerful, meaning that farmers would need to modify their water management accordingly.

5.2. Renewable energy companies

The renewable energy companies in Egypt can offer a range of technologies for aquaculture, although the main one is generation of solar power, with or without a battery system. They need to consider the specific circumstances of fish farmers and other value chain actors such as hatcheries and retailers.

For fish farms with short lease periods, the technology needs to be portable so that it can be moved, if necessary to another location. It should be capable of integration with existing systems and the electricity grid, if available. Although biogas systems may have some applications, they need regular supplies of raw materials and careful management in order to work. This might be more suitable for agriculture farms generating large quantities of plant biomass or animal manure than fish farms where material such as pond mud is only occasionally available. However, since most aquaculture farms in Egypt are located in rural areas of the Nile Delta and near northern lakes, many fish farmers also raise livestock nearby. This presents a significant opportunity to use animal manure for biogas (methane) production. Retailers or fish processors may be able to operate small-scale biogas systems. The development of green hydrogen systems seems unlikely at present.

The development of appropriate financing mechanisms will be critical. Most fish farmers have little incentive or capability to invest in their farms. They face rising operating costs for diesel, while those who are connected to the grid face higher costs for electricity. Renewable energy offers the potential for reduced operating costs but entails significant capital investment. Renewable energy companies need to focus primarily on larger farms that are either owned or operated on long-term leases. Alternatively, they need to consider a group-based approach involving producers' organizations or perhaps feed companies as intermediaries between financing institutions and fish farmers.

6. Conclusions

6.1. Renewable energy interventions targeting Egyptian fish farms

- Several types of renewable energy systems need to be tested covering different stages of the fish farm value chain in the main aquaculture areas of Kafr El Sheikh, Sharkia, Behera, Port Said, Damietta and Fayoum. These are likely to be adopted first by larger farmers and those who own their farms rather than farmers who rent small areas of land or have short leases.
- Renewable solutions should focus on the water pumping and aeration systems of the farms. The oxygen level is usually the factor controlling the density of fish in pond-based systems and it tends to fluctuate with the lowest levels at night and early morning. This can be remedied by operating paddle wheel aerators, but that means farms need to have renewable energy at times when there is little or no energy production by solar panels.
- Renewable energy firms in Egypt have not yet developed specific products for aquaculture. Their most widely applied systems are in the agriculture sector, particularly for water pumping, so prototype testing needs to be evaluated by a counselling committee of experts.
- The most suitable places to test biogas systems are at aquaculture farms in the Kafr El-Sheikh Sharkia and Behiera governorates, in terms of resources and culture of the people.
- Once the larger farmers have started to adopt renewable energy systems, peer-to-peer awareness sessions could help adoption by aquaculture farmers with smaller land areas.
- Floating solar panels should be tested as a potential renewable energy technology, as they do not reduce the limited amount of land available on most fish farms. It could also be a potential strategy for marine aquaculture farms in Port Said and Damietta.
- Group-based operation of solar systems, wind turbines or anaerobic digesters could provide renewable energy for several farms or co-located businesses, particularly in areas where there is no access to the national grid. These could be established and/or operated by renewable energy companies or farmers groups serving a cluster of users through a micro-grid in return for agreed-upon supply contracts and consumption fees.
- A special roundtable should be organized to discuss financing for renewable energy interventions in the aquaculture sector involving a wide range of stakeholders. The aim would be to develop a framework with defined roles and responsibilities for key actors to explore interest and opportunities for green finance products in the aquaculture sector.

6.2. Renewable energy interventions targeting women and social inclusion

- Women fish traders and processors face problems with transporting fish. This could be alleviated by testing the use of a small mobile solar vending with chest cooler/freezer unit to alleviate transportation constraints and provide chilled storage for fish retailers.
- Biogas systems and solar panels could be added to designated fish retailing spaces for groups of retailers. Fish sellers and processors generate significant quantities of fish waste that could provide material for biogas digesters and gas could be used for cooking and grilling fish.

6.3. Recommended renewable innovations

Stakeholder interviews, partners and experts recommended the following innovation to be tested under the CeREA project.

	Renewable energy solution module	Target beneficiaries	Target governorates	Remark
1	On-grid and off-grid solar water pumping	Farmers	All	
2	On-grid solar-powered aerator paddle wheels	Farmers	All	
3	Biogas energy system and a hybrid biogas and solar energy system	Farmers	Kafr El Sheikh, Behaira and Sharkia	Need for enough sources of agri/animal waste
4	Solar ice-making machine or a solar ice-crushing machine	Farmers, women retailers and wholesalers	All	Ice block and crushed ice machine maker and storage
5	Solar automatic feeders	Farmers	All	
6	Mobile Solar vending with chest cooler/freezer	Women retailer	All	Transportation and cooling unit
7	Biogas thermal energy unit for fish cooking/grilling	Women sellers in fish product processing	Kafr El Sheikh, Beheira, Damietta and Sharkia	Need for enough sources of agri-waste
8	Wind energy for aeration (paddles) and lifting water	Farmers	Port Said, Damietta and Behaira	Paddles will need up to 1.5 hours of power in semi-intensive farms *Source resident supplier*
9	Green hydrogen small system	Farmers	All	Still under study
10	Hydroelectric systems	Farmers	Fayoum	Micro-hydro setups in streams, generating electricity for individual farms or small communities

Table 1. Ranked list of the 10 most promising renewable energy innovations proposed for testing.

Notes

[1] https://climatepromise.undp.org/what-we-do/where-we-work/egypt. June, 2023.

[2] https://www.energymining.sa.gov.au/consumers/energy-grid-and-supply/our-electricity-supply-and-market

[3] https://www.undp.org/arab-states/press-releases/ministry-tourism-and-antiquities-represented-sca-imc-and-undp-egypt-inaugurate-solar-power-stations-world-heritage-sites. 18 January, 2024.

[4] https://english.ahram.org.eg/NewsContent/50/1208/399742/AlAhram-Weekly/Features/Egypt-Generating-solar-energy-at-home.aspx. 30 January, 2021.

[5] https://www.worldbank.org/en/results/2020/08/12/clean-energy-scaling-up-wind-power-in-egypt. 12 August, 2020.

[6] https://www.energy.gov/energysaver/installing-and-maintaining-small-wind-electric-system

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[8] https://energy-utilities.com/egypt-builds-wind-power-momentum-with-news119356.html. 8 November, 2022.

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[10] https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane. 2020.

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About WorldFish

WorldFish is a leading international research organization working to transform aquatic food systems to reduce hunger, malnutrition and poverty. It collaborates with international, regional and national partners to co-develop and deliver scientific innovations, evidence for policy, and knowledge to enable equitable and inclusive impact for millions who depend on fish for their livelihoods. As a member of CGIAR, WorldFish contributes to building a food- and nutrition-secure future and restoring natural resources. Headquartered in Penang, Malaysia, with country offices across Africa, Asia and the Pacific, WorldFish strives to create resilient and inclusive food systems for shared prosperity.

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