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Implementing the Strategic Guidelines on EU Aquaculture
Energy transition in the EU aquaculture sector

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LIST OF ACRONYMS

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AAC	Aquaculture Advisory Council
AI	Artificial intelligence
API	Associazione Piscicoltori Italiani
APROMAR	Asociación Empresarial de Acuicultura de España
CO_2-eq	CO_2 equivalent
EATiP	European Aquaculture Technology and Innovation Platform
ERSEO	Énergies Renouvelables au Service des Exploitations Ostréicoles
ETP	Energy Transition Partnership for EU Fisheries and Aquaculture
EU	European Union
EUMOFA	European Market Observatory for Fisheries and Aquaculture Products
FEFAC	European Feed Manufacturers' Federation
FM	Fish meal
FO	Fish oil
GHG	Greenhouse gas
GW	Gigawatt
HVO	Hydrotreated vegetable oil
IPCC	Intergovernmental Panel on Climate Change
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale
LNG	Liquefied natural gas
OPEX	Operating expenses
PV	Photovoltaic
RAS	Recirculating aquaculture systems
ROV	Remotely operated vessel
STECF	Scientific, Technical and Economic Committee for Fisheries
TRL	Technology readiness levels
TSSPs	Thematic smart specialisation partnerships
USV	Unmanned service vehicle

1. INTRODUCTION

The Strategic Guidelines for a more sustainable and competitive EU aquaculture for 2021-2030 were adopted by the Commission in 2021 (1) and stress the need for EU aquaculture to contribute to the European Green Deal's objectives (2). The Green Deal aims for the EU to reach climate neutrality by 2050, including a 'clean energy transition'. The guidelines state that 'Energy consumption and carbon emissions from production, transport and processing must be reduced as much as possible.' They recommend promoting the use of renewable energy sources and greater energy efficiency.

In 2023, the Commission adopted a Communication on the energy transition in EU fisheries and aquaculture (3) (the 'Energy Transition Initiative'). This Communication identifies actions that seek to speed up the transition, while ensuring the sustainability and competitiveness of the two sectors. The Communication also aims to increase resource and energy efficiency in the short and medium term through changes to vessels, equipment and operations management. Additionally, the Commission launched the Energy Transition Partnership for EU Fisheries and Aquaculture (ETP) to facilitate stakeholder cooperation and support developing a roadmap for the sector's transition to climate neutrality by 2050.

An important document that frames the energy transition in fisheries and aquaculture is the 'Techno-economic analysis for the energy transition of the EU fisheries and aquaculture sector' (4). This analyses these sectors' current energy use and assesses the viability of decarbonisation technologies. The study identified three main solutions to be implemented across the sector:

1. energy management and audits, which could reduce energy usage by 2-10%;
2. precision fish farming, which could reduce the feed conversion ratio and optimise oxygen, potentially leading to notable decreases in greenhouse gas (GHG) emissions;
3. novel feed formulations, which could reduce the carbon footprint of aquaculture feeds.

To promote simplified access to information on funding and better identify which funds can be used to support the energy transition, the Commission prepared a guide (5) on financing opportunities for the green energy transition of fisheries and aquaculture (November 2023). It is targeted at businesses, public administrations and other stakeholders and has been designed to swiftly identify and assess EU funding sources that can support the energy transition.

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(1) COM/2023/100 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023DC0100.

(2) Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, and the Committee of the Regions: The European Green Deal (COM/2019/640 final), EUR-Lex - 52019DC0640_EN EUR-Lex (europa.eu)

(3) COM/2023/100 on the Energy Transition of the EU Fisheries and Aquaculture sector, The Energy Transition partnership (ETP) (assets-cdn.io).

(4) https://maritime-forum.ec.europa.eu/study-techno-economic-analysis-energy-transition-eu-fisheries-and-aquaculture-sector_en

(5) European Commission, Directorate-General for Maritime Affairs and Fisheries, Guide on financing the green energy transition of fisheries and aquaculture – Supporting the energy transition in fisheries and aquaculture through EU funding opportunities under the 2021-2027 multiannual financial framework, NextGenerationEU and beyond, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2771/377801.

This staff working document covers energy efficiency and the use of renewable sources of energy to reduce the carbon footprint in primary aquaculture production.

While the Commission acknowledges that the carbon footprint of aquaculture is affected by transportation activities, such as transporting resources required for production (equipment, services, medicines, feed, fingerlings) and transporting fish for processing and entry into the distribution chain, these aspects are not covered in this document. Similarly, feed production and sourcing of feed ingredients, a major contributor to the carbon footprint of fed aquaculture production, are also not covered in this document.

Annex 1 describes the methodology used to prepare this document. In addition to EU Member States, this document's development has also drawn on practices and tools from the United Kingdom (UK) and Norway due to their proximity to the EU and the importance of their aquaculture production, research and innovation.

Annex 2 lists the EU-funded projects referred to in the document.

Given the rapid pace of innovation and technological development in the aquaculture sector, the information provided in this staff working document will be updated in the future to reflect progress in this area. The Commission will publish these updates on the EU Aquaculture Assistance Mechanism website (6).

It is important to note that the hyperlinks in this document were valid at the time of its publication. These hyperlinks may be updated in the future and made available on the EU Aquaculture Assistance Mechanism website.

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(6) http://aquaculture.ec.europa.eu

2. OVERVIEW OF ENERGY USE AND POSSIBLE ACTIONS FOR THE DECARBONISATION OF THE AQUACULTURE SECTOR

This section provides an overview of the main energy use in different aquaculture production systems and technologies and possible actions to decarbonise the sector. The diversity in aquaculture production systems and technologies throughout the EU poses a challenge in the implementation of the energy transition. Solutions developed for one system may provide challenges for others. In addition, older aquaculture facilities may not be optimised for energy efficiency in terms of their design and insulation so may require upgrading.

Aquaculture installations require a steady supply of electricity. The energy production from renewables needs to be balanced with the use of generators when there is no energy production. Storage solutions, including batteries, need to be developed that are suitable for aquaculture purposes – either on-site or within support facilities, such as ports.

Aquaculture operations currently use and/or test the following renewable energy sources.

- **Wind energy** – with production from wind turbines of different sizes and generation capacity for use in production facilities on land and at sea.

- **Solar energy** – with photovoltaic (PV) panels attached to the roofs of production facilities (land-based or at-sea sites on feed barges or other floating structures) or as free-standing rotating devices that track and follow the sun’s path to optimise solar capture using a relatively reduced surface area.

- **Wave energy** – devices (e.g. point absorbers (7), oscillating water columns (8)) can be placed on the seabed, within the water column, on the water surface or attached to structures such as piers. They present an opportunity to use the energetic wave conditions to power marine aquaculture.

- **Tidal energy** – use of turbines to convert tidal currents into electricity or tidal impoundment (e.g. a barrage or lagoon) that uses the height difference of rising and falling tides. Both technologies have potential for coastal and intertidal aquaculture operations for bivalves and seaweed cultivation.

- **Geothermal energy** – derived from the natural heat of the Earth, it can be used for input water in land-based intensive production systems requiring higher water temperatures or for heating production facilities during cold months.

- **Biogas energy** – produced from organic matter, it may be used in production facilities and for fuelling support vehicles and vessels.

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(7) A point absorber is a wave energy converter that captures energy from ocean waves. It typically consists of a floating or submerged device that moves up and down with the waves. This movement generates energy, which can then be converted into electricity (Guo et al., 2022).

(8) An oscillating water column is a hollow structure on the seabed, partly underwater. Waves enter it, causing the water inside to move up and down. This movement pushes and pulls the air above the water, making it flow through a turbine. The turbine then generates electricity (Cuadra et al., 2016).

- **Hydroelectric energy** – produced by harnessing the power of water in motion, it is particularly well-suited for flow-through systems (ponds and raceways).

Energy efficiency can also be achieved during the production phase. With energy audits on operations, efficiency may be achieved through changes to heating and lighting systems to reduce the overall power used. An improved understanding and a real-time assessment of the growth, behaviour and welfare of fish in production systems can also help to better manage operations and inputs to optimise their efficiency.

2.1. Marine production systems

For simplicity, marine production systems have been divided into: (i) net pen systems (finfish); and (ii) intertidal and suspended systems (molluscs and algae).

2.1.1. Net pen systems

Floating net pen systems, in units of several net pens moored together and anchored to the sea floor, are used to produce cold- and warm-water fish species. The net pen units are supplied by feed barges and rely on specialised boats for service and operations. In addition, air-blown automatic feeding systems are used to better manage and distribute feed according to the fish behaviour, as observed through underwater cameras.

Industry data from Norway (9) estimates that energy consumption in cold-water net pen culture may be 1.1-1.5% of production costs. According to industry sources, comparable figures for the Mediterranean are 1.6-2.2%.

A recent study of the Norwegian salmon farming sector by Ziegler et al. (2024) shows that the five most important emission reduction measures, based only on existing technology were: 1) slightly improved feed efficiency; 2) increased utilisation of side streams occurring in secondary processing after export, 3) preference for sea freight to market over road and air; 4) higher energy efficiency and cleaner energy sources; and 5) changes to feed composition. Collectively, they have the potential to reduce greenhouse gas emissions by 60%.

Net pen farm units are implementing renewable energy solutions for facilities and equipment. These solutions, include those described above for marine aquaculture, on and under fixed and moored structures at sea, such as control centres, feeding barges and storage areas. Their technical and economic feasibility requires a site-specific analysis, including on the availability of the power sources and on the risk of failure due to power outages and adverse weather conditions.

Bearing in mind the scope of this document, decarbonisation in net pen aquaculture production can be achieved through the two main energy components: 1) energy used for facilities and equipment; and 2) energy used for supply vessels.

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(9) 2023 PwC Seafood Sustainability Barometer, p. 18. https://www.pwc.no/no/publikasjoner/2023-rapport-sjoematbarometeret.pdf.

In terms of equipment, the power needed for automation systems, such as sensors and remote-operated vehicles, can also be powered by renewable sources or at least such sources for charging batteries.

Regarding energy use for supply vessels, many energy supply and energy efficiency developments coming from the maritime and fisheries sectors are also being applied in new generation or retrofitted aquaculture support vessels. The report ‘Possibilities and examples for the energy transition of fishing and aquaculture sectors’ (EC, 2023) provides several examples.

As marine net pen culture moves further offshore, this can potentially increase energy consumption (for transport, remote control, data connectivity, etc.). However, there is also greater potential to use technology to produce energy from the higher energy of water currents (and potentially wind) at such locations.

2.1.2. Intertidal and suspended systems

European mollusc production uses intertidal structures to keep them off the seafloor with racks, trays, bags and stakes or, in deeper waters, bags (socks) attached to longlines and indicated on the surface by buoys. Longline production is also the principal technology used for macro-algae production. Mollusc production accounts for more than 50% of aquaculture activity in the EU, with varying energy costs; the Energy Transition Initiative reports that energy costs for blue mussel aquaculture range from 3% of total costs in operations using mussel rafts to 14% of total costs in operations using mussel longlines.

‘Human power’ has traditionally supplied the ‘energy’ needed for traditional intertidal mollusc farming (bag turning, cleaning, defouling), while materials are transported by tractors and small boats. But with more automation in the sector, especially with the energy needed for harvesting, cleaning and depuration, the proportion of energy in total production costs is non-negligible.

Suspended, longline systems require servicing and maintenance from specific vessels equipped with machinery for seeding, grading and harvesting. There are examples of fully electric vessels or hybrid vessels that can service farms located further offshore.

2.2. Land-based production systems

This section on land-based production systems covers flow-through systems (ponds and raceways), recirculating aquaculture systems (RAS) and hatcheries for juvenile production. The energy demand for each of these systems is described below.

2.2.1. Ponds

Fishponds are flow-through human-made constructions that maintain significant artificial wetland habitats in EU (more than 300 000 ha). When managed sustainably, they create a specific ‘fishpond ecosystem’ that closely resembles natural wetland habitats. Although it is an artificial system, its nutrient cycling processes are identical to natural semi-static wetlands.

Fishpond production is typically managed through polyculture, where the common carp is produced in combination with other fish species (e.g. silver carp, grass carp, European catfish, pikeperch and pike) of the same age class. Pond production in the EU is mostly an extensive or semi-intensive farming technology that uses natural food sources (mainly zooplankton) often complemented with cereals.

Fuel costs are estimated to account for 15% of the total operating costs, with electricity at 6% according to the conclusions of the expert consultation workshop organised to prepare this document (see Annex 1).

2.2.2. Raceways

Raceways are flow-through systems that take water from rivers and wells and are associated with the traditional culture of rainbow trout in many European countries. These systems also support the culture of other species, such as other trout species and sturgeon.

The main energy costs are for pumping the relatively large quantity of water required for these systems. Energy costs for rainbow trout culture in raceways could be up to 8% of total production costs.

Roofing structures are used to provide shade and reduce fluctuations in the water temperature. These structures provide a convenient support for solar panels and wind turbines can also be installed where appropriate.

2.2.3. Recirculating aquaculture systems (RAS)

RAS are designed to be water-efficient and highly productive. Typical RAS are indoor and recirculate almost all the incoming water and act as an almost completely closed circuit. However, all systems that have been adapted to use less water and to treat used water are effectively ‘recirculation’ or ‘partial recirculation’ systems. Due to their ‘closed system’ nature, RAS avoid adverse environmental impacts, but they are energy-intensive, using energy for all operation components (pumping, aeration, temperature control, filtration, solids treatment, etc.). In addition, the removal, transportation and treatment of sludge can also be energy-intensive processes.

It is very difficult to have an estimate of the energy costs as a proportion of total production costs as much depends on the use of the system (juvenile production or market-size production) and the species concerned. Although Badiola (RasTech Magazine) (10) generally considers a figure of 5 kWh/kg of fish a reasonable estimate, energy use and efficiency vary considerably.

Some energy-saving measures relate to operating expenses, while others are linked to original capital investment in infrastructure.

Possible actions to decarbonise RAS include the on-site production of energy (solar panels on the roofs of buildings and wind turbines where possible). However, energy-use reduction and efficiency depend on the initial design of the system (tank size, shape, piping, etc. to reduce pumping costs) and the equipment used (highly efficient pumps, LED lighting, etc.). Another key factor is the building itself. A highly insulated and energy-efficient building could ideally reduce the need to heat or cool water, resulting in a clear reduction in energy and costs. Furthermore, the design and the inclination of the roof can be optimised for the installation of solar panels.

Therefore, some energy-saving measures relate to operating expenses, while others are linked to original capital investment in infrastructure.

2.2.4. Hatcheries

Hatcheries are RAS, so they can also be energy intensive. The energy demands of the broodstock unit are moderately high due to water supply, lighting and controlled room and water temperatures. The live feed unit (algae, rotifers and Artemia) constantly uses extensive equipment to ensure controlled rearing conditions, resulting in increased energy demand. In the hatchery itself, water temperature is the most important variable to be controlled as water might need heating or cooling. Therefore, energy demand is mainly associated with the water supply, controlled water temperature and quality, room temperature and lighting. Energy transition measures for hatcheries are therefore the same for RAS.

Locating a hatchery close to farms producing the same species could bring benefits. These benefits include economies of scale, breeding programmes for that species and lower energy use due to shorter transport distances from the hatchery to the farm.

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(10) RasTech Magazine. Spring 2024. Pages 10-11
https://cdn.coverstand.com/60230/813545/03dd8ec24cb60094c2d1a69fe5eccbe522eff0d7.2.pdf.

3. GOOD PRACTICES

This section contains eight good practices, each described in its own factsheet (see Table 1). Good practices for energy efficiency and carbon-footprint reduction (or decarbonisation) were selected from the EU, as well as Norway and the UK due to their geographical proximity to the EU and their significant aquaculture sectors. The factsheets describe the technology or good practice, highlighting both positive aspects (benefits/impacts) and challenges, and the countries behind the good practice.

Additionally, the examples differentiate between research/pilots and industry/commercial applications.

Table 1: Topics addressed in this document and good practices selected

Topics	Good practice	Countries
Energy efficiency and the decarbonisation of aquaculture facilities (renewable resources and equipment)	Renewable energy solutions to power farms' operations	Belgium, Cyprus, Denmark, Estonia, France, Italy, Portugal, Spain, the Netherlands, UK, Germany, Italy, Lithuania and Norway
	Using digitalisation to optimise aquaculture production processes in land-based facilities	Norway, Hungary, Italy, Spain and UK
Energy efficiency and the decarbonisation of aquaculture vessels and remote operations	Aquaculture vessels with electric and hybrid engines and alternative energy sources	Ireland, Italy, Norway, France, Germany and UK
	Solar power battery-based equipment for unmanned or remote operations	Italy
Mass and energy transfer schemes in land-based facilities (waste streams and heat)	Symbiosis and synergies with other sectors	Belgium, Germany, the Netherlands, France, Hungary, Lithuania and Sweden
Training	Learning programmes for aquaculture operators	France, Greece, Ireland, Italy, Latvia, Slovenia, Portugal and Spain
Measures to support the energy transition	Measures taken by producer organisations to accelerate the energy transition	Italy, Poland, Romania and Spain
	Public authority initiatives to facilitate the energy transition	Czechia and Italy

Factsheet 1. Renewable energy solutions to power farms' operations

Description

Wave, tidal, solar and offshore wind energy show great potential as renewable energy sources for aquaculture as described in Section 2. This factsheet gives more details on these energy sources and to which type of production system they may apply.

Marine aquaculture ([11])

- Wave energy, with a global estimated resource of 2 000 GW, is generated by capturing the energy from ocean waves using wave energy converters.
- Tidal energy has a global estimated resource of around 120 GW. This technology converts kinetic energy from tidal currents into electricity or uses tidal impoundment technologies (e.g. barrage or lagoon) to capture the potential energy in the height difference of rising and falling tides.
- Floating or intertidal structures have a particularly great potential to use energy from waves, water currents and tidal movements.

Land-based aquaculture

- Geothermal energy ([12]) is heat generated within the Earth's crust as a result of the planet's formation and the radioactive decay of materials. It can satisfy around 25% of heating and cooling consumption in Europe.
- Hydroelectric energy or hydropower comes from flowing water that powers a turbine. It is one of the oldest sources of renewable energy, having been used already in pre-industrial times, for instance, in watermills. Hydroelectric energy can be produced at small and large scale.

All systems

- Solar energy stands out as the most abundant renewable energy source.
- Wind energy ([13])is obtained from kinetic energy from the winds in the ocean and on land. Offshore wind energy benefits from the more consistent winds in the ocean. Turbines can be fixed to the seafloor or floating. By the end of 2023, the worldwide capacity of offshore wind capacity was 75 GW. However, there are also smaller-scale micro-wind turbines for smaller-scale marine and land-based aquaculture electricity requirements.

([11]) Offshore aquaculture is a market for ocean renewable energy, Energy Agency Ocean Energy Systems: https://www.ocean-energy-systems.org/publications/oes-documents/market-policy-/document/offshore-aquaculture-a-market-for-ocean-renewable-energy./.

([12]) Geothermal energy in the EU https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/754566/EPRS_BRI%282023%29754566_EN.pdf

([13]) Global Offshore Wind Report 2024 - Global Wind Energy Council (gwec.net)

Benefits/impacts

- Wave energy production is a viable technology for powering feed operations in marine farms effectively.
- Tidal energy can provide an energy source that is constant and predictable in marine farms.
- PV panels are an efficient and mature technology. They can be used for land-based aquaculture and hatcheries, with the potential to reduce GHG by 5-14% and 43%, respectively ([14]). Small panels are also used, for example, to power feeding systems or monitoring systems on farms' net pens.
- Offshore wind energy is a sustainable option for providing renewable energy. Aquaculture located close to these wind farms can use some of this energy. Small, dedicated wind turbines could also power individual farms.
- Geothermal energy for RAS and hatcheries is well-established and has low running costs.
- Hydroelectric mini-stations can produce energy at a low cost for freshwater flow-through systems using the natural flow of water with no environmental impact on the river.

Implementation challenges

- Installing wave and tidal technologies for energy production involves high costs and investments, which can be a financial challenge, especially for small companies.
- Solar and wave energy sources are variable and unpredictable.
- Positioning PV panels may require specific site considerations or adjustments to building designs (except for mini panels as mentioned above).
- Although there are European research projects and some pilot projects exploring wave and tidal energy to power aquaculture sites, with promising developments expected in the years to come, there are no commercial-scale devices available yet in which aquaculture producers could invest.
- Offshore wind energy supply might exceed the needs of aquaculture sites but could provide indirect benefits by delivering clean energy through the grid.
- Geothermal energy is not always available due to geographic constraints, and its initial investment cost is high (e.g. drilling).
- Large-scale hydroelectric production can disrupt the natural course of rivers, potentially affecting wildlife.
- In general, authorities do not allow solar panels and windmills to be installed in Natura 2000 areas.
- For mollusc depuration, comparative studies and energy budgets are needed to assess the costs and benefits of traditional methods against heated water depuration as a sanitary measure (to counter potential threats of disease, such as norovirus).

([14])Techno-economic analysis for the energy transition of the EU fisheries and aquaculture sector - Publications Office of the EU

Examples	
Studies and research projects	
Belgium, Denmark, Germany and the Netherlands	The Horizon 2020 research project ULTFARMS (15) plans to develop six pilots to locate low trophic aquaculture in offshore wind farms. These pilots will cover mussel, oyster and seaweed aquaculture and will apply novel technical processes to face harsh offshore conditions and low-salinity environments.
Germany	The FINO3 Platform (16), run by a company and situated 80 km offshore in the North Sea, offers a good setting for testing and showcasing an aquaculture business that is economically feasible. The sustainable farming of seaweed and mussels is combined in the German North Sea experiment. At this location, FUE is currently conducting multi-use research trials as a part of the Horizon 2020 project UNITED. The pilot's goal is to design the operational framework for all system components, including seaweed and mussel cultivation, and their possible combined farming at the edge of an existing wind park. Techniques for sowing and strain development for more profitable seaweed species will be investigated for offshore production. In addition, the pilot will experiment the possibility of using locally produced renewable energy and investigate interactions between target culture species and the offshore environment in order to develop environmental protection strategies.
Cyprus	Under the Blue Deal Interreg MED project (17), a Cypriot net pen aquaculture company, which runs two European seabass and seabream grow-out farms, is currently assessing the performance of **wave energy devices** with battery packs to power their feeding platforms.
Denmark, Estonia and Germany	The EU research project OLAMUR (18) put in place three case studies. Two of them involve aquaculture facilities co-located with offshore wind farms where low trophic aquaculture will

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(15) ULTFARMS project: https://ultfarms.eu/pilots/

(16)https://www.fino3.de/en/

(17)Bluedealmed Interreg project: https://bluedealmed.eu/colab/challenges/integration-of-marine-renewable-energy-source-s-at-levantina-fish-feeding-platforms

(18) OLAMUR project: https://olamur.eu/case_studies/

	be carried out to produce seaweed and bivalves in the North Sea and the Baltic Sea. The third case study is a pilot study, also in the Baltic Sea (in Estonia), where an existing fish farm will be expanded to include low trophic aquaculture.
France	*Énergies Renouvelables au Service des Exploitations Ostréicoles* (ERSEO) (19) is a project that aims to provide renewable energy for oyster farms. A **tidal turbine** was tested for this purpose in an estuarine environment. The project also experimented with an electric oyster barge with a **coupled photovoltaic water current turbine** in the estuary.
Italy	The Blue Growth Farm (20), a Horizon 2020 research project, tested wind-turbine prototypes. One of these was moored in the Mediterranean Sea off the coast of Calabria. This prototype enables the researcher to determine the wind turbine's performance. The results show that the prototype can be scaled up to power a commercial aquaculture operation.
	Small freshwater aquaculture companies installed **hydroelectrical micro stations** in aquaculture sites that produce green energy and power farms.
Portugal	A research paper (21) has reviewed five **wave energy devices** to evaluate the feasibility in using them in two potential aquaculture sites located several kilometres from the coastline. The case studies consider the culture of not only seabass and seabream but also oyster and seaweed.
Spain	The EU research project AQUAWIND (22) successfully tested a floating wind platform named W2Power in the Canary Islands. This pilot combines aquaculture and **offshore wind energy** production. The trial included a customised aquaculture net pen, a remote feeding system and floating wind technology. Monitoring the environment is also part of the pilot.

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(19) Farnet 2021, Making oyster farming energy self-sufficient: https://webgate.ec.europa.eu/fpfis/cms/farnet2/on-the-ground/good-practice/projects/making-oyster-farming-energy-self-sufficient_en.html

(20) THE BLUE GROWTH FARM project: https://thebluegrowthfarm.eu/

(21) Wave energy conversion energizing offshore aquaculture: Prospects along the Portuguese coastline: https://www.sciencedirect.com/science/article/pii/S0960148123000095

(22) AQUAWIND project: https://aquawind.eu/

UK (Scotland and Wales)	**Energy wave systems** have been tested in Atlantic salmon net pens and seaweed aquaculture. The results were positive, and further research and projects are in development (23).
Portugal	Ilha da Culatra, in Ria Formosa, is where 41% of Portugal’s aquaculture takes place. As part of the ‘Culatra 2030 – Sustainable Energy Community’ initiative, the Culatra harbour aims to install: (i) a photovoltaic plant of 64 kWp; (ii) a 32KwH energy storage unit; (iii) a pilot solar-powered vessel for use by all shellfish growers in the community; and (iv) a charging station to sustainably support aquaculture and tourism. It also aims to support the development of a local micro-grid concept that enables the effective management of available energy resources at peak hours and the intelligent use of energy (24).
Lithuania	TETRAS (25) is an Interreg Baltic research project that tests the techno-economic viability of using **geothermal resources** (heat, water and minerals) for white shrimp production in brackish-saltwater RAS.
Implementation at industry level	
Germany	The use of **photovoltaic panels** can significantly reduce CO_2 emissions from rainbow trout production in a farm in which approximately 40% of raceways for grow-out are roofed to provide shading. Roofs are used for a photovoltaic system that provides a renewable energy source for farming operations (26).
Italy	The use of **photovoltaic panels to partially power an oxygen generator** at a trout farm can reduce emissions by up to 50% (14).
Norway	Two companies, an aquaculture equipment producer and a renewable energy solutions provider, are going to integrate their technologies to **supply farmers with net pens with solar panels on the top**. Combined with a battery and waterborne

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(23)https://www.ocean-energy-systems.org/publications/oes-documents/market-policy-/document/offshore-aquaculture-a-market-for-ocean-renewable-energy./

(24) https://webgate.ec.europa.eu/fpfis/cms/farnet2/on-the-ground/good-practice/short-stories/decarbonising-economic-activities-culatra-island_en.html and http://www.culatra2030.pt/Agenda-de-Transicao.pdf

(25) Technology transfer for thriving recirculating aquaculture systems in the Baltic Sea region (TETRAS project): https://interreg-baltic.eu/project-pilots/pilot-2-geothermal-resources-and-ras/

(26) Life-cycle assessment of rainbow trout farming in the temperate climate zone based on the typical farm concept: https://www.sciencedirect.com/science/article/pii/S0959652622044249

	feeding, the new solution is expected to reduce the running time of diesel generators on a typical farm by 90% (27).
	A producer installed **8 000 m^2 of solar panels** on the roof of one of its RAS plants. This saves approximately 1.2 gigawatts of electricity each year (around the annual consumption of 79 households). Both energy production and consumption are monitored in real time by the plant's managers (28).
Spain	A company specialised in amberjack grow-out has built a facility with the roof adapted to accommodate **solar panels**. The installation prevents the emission of 19 000 kg of CO_2 into the atmosphere every year (29).

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(27) Akva signs green energy partnership: https://www.hatcheryfm.com/products/suppliers-news/akva-signs-green-energy-partnership/

(28) Solar power to reduce fish farming energy footprint: https://www.hatcheryfm.com/news/latest-news/solar-power-to-reduce-fish-farmings-energy-footprint/

(29) RAS facilities with roof designed for energy efficiency: https://www.blennius.es/

Factsheet 2. Digitalisation to optimise aquaculture production processes in land-based facilities

Description

Energy is the second-largest cost after feed for producers running land-based systems. This factsheet provides examples of how digital tools, such as dynamic modelling, decision support systems and artificial intelligence (AI), can reduce energy consumption.

Although the examples are of digital tools used in RAS facilities, the solutions can also apply to flow-through systems (ponds and raceways).

- Removing CO_2 from the water: this highly demanding energy process (15-20% of the total energy consumption). The process involves degasses units where the water is exposed to air. The air captures the CO_2 from the water, and the gas is then expelled by air-moving devices (e.g. fans that create a continuous flow of air).
- Recirculating water: this energy-consuming activity is crucial to pump the water back to the tanks after it has been filtered.
- Cooling and heating water: these are also energy-consuming activities and depend on several factors, for instance, the species, the seasonality, latitude and the production-cycle phase (reproduction, hatching, larvae development, live feed production).

Benefits/impacts

- Unlocking the potential of precision fish farming, digital tools save both energy and optimise feed use and water quality.

Implementation challenges

- Software and hardware solutions (e.g. sensors and cameras connected to the internet) could be expensive for small companies since they require the development or purchase of digital tools and the skills to manage them.

Examples

Studies and research projects

Norway	In a research paper (30), a chemical process simulator was tested. The trial was conducted on a laboratory scale. The simulator was used to replicate the operating conditions of RAS for Atlantic salmon farming, generating a mathematical model of the typical chemical processes in this kind of facility. The model facilitates an analysis of the energy consumption and identifies ways to reduce it through adjusted water flows. Energy demand is reduced by 8% when the recirculating water flow is adjusted according to the feedback from the simulator.

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(30) Linear modelling of the mass balance and energy demand for a recirculating aquaculture system: https://www.sciencedirect.com/science/article/pii/S0144860923000171

	A computer model has been developed to manage the system that circulates the air to remove the CO_2. The results show that this model saves energy. **A digital toolbox for Atlantic salmon RAS managers will be developed following further practical validation** (31)**.**
Hungary	In fishponds, **smart buoys** equipped with real-time water quality monitoring systems were tested to support continuous data collection and analysis. This technology ensures that oxygen deficiency, which can lead to fish mortality, is detected days in advance across all layers of the water column. Furthermore, the system has the potential to monitor the nutrient supply of a pond, facilitating precision and resource-saving management.
UK and Italy	The '**Just add water**' project (32) is based on Atlantic salmon fish grown in RAS. These fish can have a 'muddy' taste caused by a build-up of certain bacteria in the water that are absorbed by the fish. Currently, removing these bacteria from the fish requires 12 days of depuration treatment. This is costly in terms of equipment and energy requirements and adversely affects fish welfare. The Universities of Trento and Bologna and the Innovation Hub of Trentino (HIT) with funding from the EIT Food, will develop a technology to eradicate those bacteria. This will reduce the energy consumption and improve fish welfare and fish weight. This technology is based on a filtration unit used with Unitn Sys PO water treatment. The solution can be extended to other aquaculture species. The project is in an advanced state of readiness, with planning consents and licences granted, but the testing and implementation phases have not started yet.
Implementation at industry level	
Spain	A **turbot hatchery** is testing a new system (TRL 8-9) using **AI.** Aiming to improve the energy efficiency of the hatchery unit, the system monitors different parameters in the plant. As a result, the system determines the optimal conditions and manages the equipment accordingly. It also identifies periods of peak energy consumption when heating or cooling the water according to the production stages. The company also produces energy locally through solar panels. (33)

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(31) Cutting energy use in a growing RAS industry: https://www.hatcheryfm.com/news/latest-news/cutting-energy-use-in-a-growing-ras-industry/

(32) https://www.eitfood.eu/projects/just-add-water

(33) Nueva Pescanova Group to test new energy management system in turbot hatchery:https://www.hatcheryfm.com/news/latest-news/nueva-pescanova-group-to-test-new-energy-management-system-in-turbot-hatchery/

Factsheet 3. Vehicles and aquaculture vessels with hybrid and alternative energy-powered engines

Description

Electric and hybrid engines are the most feasible alternative to switch aquaculture vehicles and vessels from fossil fuels.

As reported in the document 'Possibilities and examples for energy transition of fishing and aquaculture sectors' (34), the maritime sector is witnessing several initiatives aiming to develop alternative fuels to replace diesel, with potential use for the aquaculture industry.

- Biogas produced from organic waste (manure, food and crop waste/coproducts) is a circular approach to waste management (35).
- Alternatives to diesel, such as ammonia, methanol, methane and liquefied natural gas (LNG) are being explored and could contribute to decarbonising vessels.
- Studies highlight biodiesel's suitability for marine engines, emphasising its environmentally friendly, renewable, non-toxic and biodegradable nature. It is derived from aquatic sources, such as kelp harvesting, fish processing waste and farmed algae. Blending these biodiesels with conventional marine fuels can mitigate air pollution while complying with International Maritime Organisation (IMO) regulations. However, several obstacles hinder progress, including fuel stability and higher production costs.

Not every solution presented here for electric and hybrid engines may be suitable for all aquaculture companies and production systems. However, these solutions can serve to inspire tailor-made solutions to develop specific applications for both fed and non-fed marine aquaculture.

Benefits/impacts

- Reducing aquaculture GHGs, which harm the environment.
- Reducing noises and fumes during aquaculture operations, which harm both fish and workers.
- Unlocking the industry's shift away from fossil fuels.

Implementation challenges

- The commercial availability of diesel engine alternatives is still limited. Furthermore, using these alternatives, particularly methanol and ammonia, can pose risks to both seafarers and the environment.
- Several obstacles hinder progress in using biodiesels, including fuel stability and higher production costs.

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(34) Possibilities and examples for energy transition of fishing and aquaculture sectors: https://aquaculture.ec.europa.eu/knowledge-base/good-practices-and-experiences/possibilities-and-examples-energy-transition-fishing

(35) Biomethane: https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane_en

Off-road vehicles used in inland aquaculture are often very specialised for certain tasks (feed delivery, harvesting, juvenile transportation, etc.) and purchasing hybrid and electric vehicles or retrofitting vehicles with new engines has cost implications.

Examples	
Studies and research projects	
Italy	The HORUS project (36) is developing **battery-based vessels for bivalve production**. The project is supported by the World Wildlife Fund and a producer organisation. These fully electric vessels use batteries that can be charged both at the dock and at sea.
Norway	A company aims to set in motion a rapid **technology shift for all vessel types in the industry.** It plans to develop and demonstrate new zero-emission engineering solutions, provide services for retrofitting and maintaining zero-emission vessels and propose a comprehensive solution for the flexible supply of electricity and green hydrogen as a maritime fuel (37).
Implementation at industry level	
France	A Breton oyster farmer is using a **barge powered by two electric motors and has two batteries charged via solar panels and two small wind turbines** (38)**.** The barge has been designed to be upgraded with a hydrogen kit. (Construction cost is EUR 250 000).
Ireland	There is considerable interest in using hydrotreated vegetable oil (HVO) as a diesel replacement in aquaculture vessels and vehicles. The main advantage is that no engine modifications are required. However, there is a limited supply for industry consumers as the oil is used to fuel public transport vehicles.
Norway	In 2017, **fully electric workboats** started to be used in aquaculture with no engine noise, no diesel fumes and zero emissions. They are 13.9 m long and 7.6 m wide, running on a battery. The estimated annual savings are substantial – an 80% reduction in maintenance costs, 33 700 litres of diesel saved per year and a 90-tonne reduction in CO_2 emissions. The company is also developing **energy storage systems** for vessels only running on battery power during low-power tasks. For higher power operations, the vessel can switch to a diesel-electric mode. This switch charges the energy storage system utilising generators, making it ready for all-electric use later. Through this

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(36) Project *HORUS*: http://www.binav.it/progetto_horus_category.php

(37) Corvus Energy: https://corvusenergy.com/about/contact-us/

(38) The François Cadoret boat: https://lemarin.ouest-france.fr/peche/lancement-dune-barge-electrique-pour-les-ostreiculteurs-bretons-419e9982-7c8a-4bdb-afdd-43de10659816

	energy optimisation, the fuel savings on a vessel could be about 25% and reduce emissions by 25-40%.
	A cod aquaculture company acquired an **electrically powered service vessel (feed barge)**, which has been in use since April 2022. The barge and the equipment supplying the energy will enable savings of around 160 000 litres of diesel per year (420 tonnes in CO_2 emissions). **The energy to power the barge is clean hydroelectric power.** The switch from diesel generators has also helped fish welfare by reducing environmental noise (36).
UK (Scotland)	The largest fish farming vessel in Scottish aquaculture (87 m) works with a **hybrid diesel-electric engine.** The system reduces fuel consumption and emissions, generating less noise (33).
Germany	The North Salmon Service is working together with an international provider of technology and services for the maritime and marine industries to develop an **emission-free well-boat** to reduce aquaculture's carbon footprint. The 6-month preliminary project has been launched and will build a vessel designed with the most advanced equipment to reduce fuel consumption. The vessel will be propelled by a dual-fuel engine using ammonia as fuel (39).

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(39) https://weareaquaculture.com/news/aquaculture/new-emission-free-wellboat-technology-for-aquaculture-is-under-development

Factsheet 4. Solar power battery-based equipment for unmanned or remote operations

Description

Battery-based remotely operated vessels (ROVs) and unmanned service vehicles (USVs) are recommended for marine aquaculture, especially when batteries are rechargeable by solar energy.

ROVs and USVs can be tailored to a company’s needs for offshore facilities. These can be used to:

- inspect submerged structures;
- carry out maintenance tasks (e.g. net cleaning and defouling).

Benefits/impacts

- Contributes to decarbonisation by disconnecting from the grid and moving away from diesel-based engines and energy generators.

Implementation challenges

- Limited availability of this technology on the market.

Examples

Implementation at industry level

Italy	An integrative platform ROV and USV, completely powered by renewable energy system with **batteries that can be recharged through photovoltaic panels,** was created to provide surface and subsea operations. These devices have full-electric propulsion and power supply systems (40).

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(40) ETICA IP: https://www.youtube.com/watch?v=vcADeo9NgfI

Factsheet 5. Symbiosis and synergies with other sectors

Description

The concept of creating synergies between different sectors is a cross-cutting issue usually based on two facts:

- a product or by-product from a certain activity is the primary input for another;
- the companies involved are located in close proximity to each other.

The process of industries collaborating to share surplus resources has been around for several decades. Symbiosis centres are based on ‘loops’ where two or more companies engage in a reciprocal relationship, providing each other with products and by-products. For the energy transition, developing synergies and symbiosis in aquaculture is important since:

- waste streams (e.g. by-products from processing plants, sludge from land-based aquaculture facilities) can be used to produce valuable products (feed for aquaculture and fertilisers for agriculture);
- waste heat generated from an anchor industry can be transferred to an adjacent facility where it can be used as a resource for agriculture, aquaculture or other innovative applications, such as biochar, biofuel and lye production.

Benefits/impacts

- Reducing GHG emissions.
- Reducing transport requirements by shortening the distance between the source of raw materials and factories.
- Using waste heat reduces the cost of production processes that require heating.

Implementation challenges

- Turning a synergetic or symbiotic model into a viable business involves designing and building new facilities, financing and managing assets and scaling operations.
- Planning the space or location of the different activities for which synergies can be created.
- Defining a strong contractual framework setting out the relationships and transactions between the different companies involved.
- Using sludge as fertiliser faces some regulatory obstacles.

Examples

Studies and research projects

Belgium, Germany and the Netherlands	The EU research project UNITED (41) provides evidence on the viability of ocean multi-use through the development of demonstration pilots in the European marine environment

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(41) UNITED project: https://maritime-spatial-planning.ec.europa.eu/case-studies/offshore-wind-flat-oyster-aquaculture-restoration-seaweed-cultivation

	(TRL 5-7). The pilots combine molluscs and seaweed production with wind and solar energy production.
Implementation at industry level	
France	In the 1980s, a former oil well in Le Teich, Nouvelle Aquitaine, was converted into a geothermal hot water producer with a temperature of 73 °C. Today, it is the source of 3 000 m^3 of hot water for a fish farm's ponds. The production of local caviar avoids using the equivalent of 5 000 tonnes of CO_2 of geothermal energy (42).
Belgium	The Graas2Algae project (43) involved a horticulturist and dairy farmer in the Flanders, Belgium, producing microalgae. The first uses excess heat and CO_2 from tomato production to grow Spirulina, and the second uses energy from the bio-digestion of manure from the dairy farm to produce chlorella. Initial funding came from Flemish Department of Agriculture and Fisheries.
Hungary	In combined intensive and extensive aquaculture systems, intensive RAS for catfish farming use the geothermal water's consistent temperature to create optimal conditions for fish growth. In some cases, the nutrient-rich effluent from these systems is effectively used and treated in extensive and semi-intensive fishponds, where it boosts overall productivity by improving primary production and compensating for evaporation (Multi-annual National Aquaculture Strategic Plan of Hungary (44). Another approach to the multiple use of geothermal water is when its primary use is to heat greenhouses for large-scale vegetable production, and the cooled water, which is still above 30 °C, is subsequently used in intensive catfish farming. This creates a synergistic system that maximises resource efficiency (45).
Sweden	The largest fuel company in the country redirects waste heat from the oil refinery to a red seaweed production unit in

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(42) Exploratory environmental assessment of large-scale cultivation of seaweed used to reduce enteric methane emissions: https://www.sciencedirect.com/science/article/pii/S2352550921003535

(43) https://nutricycle.vlaanderen/onderzoek/grass2algae/

(44) Hungary Multi-annual National Strategic Plan for the development of sustainable Aquaculture for the period 2021 to 2030: https://aquaculture.ec.europa.eu/system/files/2023-03/AAM_MNSP_HUNGARY_0.pdf

(45) http://www.geofish.hu

	Lysekil. These algae can be used to produce feed additives. (46)
	In Härnösand, freshwater aquaculture is joined with pulp production by a scalable technology that can be combined with any pulp or paper mill. A RAS fish farm uses the oxygen and the heat left over from hydrogen production. The **oxygen** is used in fish farming and the oxygenation of the effluents. The **heat** is used to maintain optimal temperatures for fish farming. **This results in a 20% increase in fish farming efficiency without any environmental impact.** In addition, the paper pulp factory does not need to purchase fertilisers for the bioremediation of its effluent as it can use the nutrients from the fish farm (47).

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(46) WA3RM: www.wa3rm.com/

(47) BIGAKWA: https://www.bigakwa.com/

Factsheet 6. Learning programmes and other services for aquaculture operators

Description

As the need to decarbonise the aquaculture sector grows, so does the need for training on the energy transition.

- For aquaculture run in net pens, the new maritime technologies being developed to reduce a vessel's environmental footprint requires a trained crew. This is crucial to navigate safely with alternative equipment and fuels, protecting both the crew and the environment.
- In land-based facilities, both aquaculture managers and technicians need to be prepared to optimise energy-intensive operations (e.g. water recirculation, lighting, heating and cooling systems) and other cross-cutting issues (e.g. thermal insulation) that are important to ensure the facility is managed efficiently.
- Organising online training facilitates the engagement of people from remote areas.

Benefits/impacts

- Skills development.
- Facilitating the exchange of good practices among professionals.

Implementation challenges

- Although training activities for implementing new technologies on ships can be adapted to aquaculture vessels, they are mostly tailored to transport or fishing.

Examples

Ireland, Italy, Latvia, Slovenia and Spain	The EU Erasmus+ EWEAS (48) project developed a learning platform and guide to help producers reduce water and energy consumption in aquaculture facilities through improved management practices and environmentally safe and cost-effective solutions.
Ireland	Although targeted at seafood processors, the 'Green Seafood Business Programme' (49) is open to all businesses in the seafood industry and conducts audits and assessments to optimise energy use and efficiency.
EU project with eight countries involved	The 'Next Blue Generation' project (50) provides a portal for career information and massive open online courses (MOOCS) for teachers.

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(48) Energy and water efficiency in the aquaculture sector (EWEAS Project): https://eweasproject.eu/index.html

(49) Green Seafood Business Programme: https://bim.ie/seafood-processing/sustainability-and-certification/green-seafood-business-programme/

(50) Next Blue Generation: https://nextbluegeneration.eu/results/

France, Greece, Ireland, Italy and Spain	OPTIMA (Good Practices in Molluscs Aquaculture) (51) is a project funded by the Erasmus+ programme. This project aims to raise the level of qualifications and skills of aquaculture professionals and mentors in the sector, with a focus on shellfish farming. This project is centred around an innovative training model developed as e-learning and led by mentors who can guide students remotely using the platform created by the project.
France, Greece, Italy, Portugal, Spain and Türkiye	AQUATECHinn 4.0 (52) is an EU project developing a digital learning platform for aquaculture professionals and students. It started in June 2023 and will run for 3 years.

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(51) OPTIMA Good Practices in Molluscs Aquaculture: https://optima-erasmusproject.eu/

(52) AQUATECHinn 4.0: https://www.aquatechinn.com/

Factsheet 7. Measures taken by producer organisations to accelerate the energy transition

Description

Aquaculture Producers Organisations (POs) pursue the improvement of energy management in the sector, given its importance on costs and impact on environmental performance. They can help farmers understand technologies and adopt good practices to save energy or switch to renewable resources. European producer organisations can take part in the following activities.

- Teaming up with research and technology centres that promote actions aiming to:
    - provide useful information to producers unfamiliar with energy efficiency on how to maximise the energy efficiency of aquaculture facilities;
    - helping producers in identifying operations that fall short in terms of energy efficiency or climate neutrality and assess when and how these issues can be tackled through the adoption of new technology.
- Collecting data from farmers about the fuel they use and their energy consumption to have an overview of energy use and the carbon footprint of their processes.
- Carrying out sustainability reports and setting objectives for energy-saving and decarbonisation measures.

Benefits/impacts

- Helping producers adopt measures to make their facilities more energy efficient, thereby reducing energy costs.
- Providing useful information for assessing the energy use and carbon footprint of primary aquaculture production.
- Promoting collaboration and sharing information and good practices among members. This is especially beneficial for small and medium-size companies that do not have the means or technical/scientific staff to follow developments in the industry.

Implementation challenges

To support producers in adopting practices to make their facilities more energy efficient, producer organisations or associations need to have sufficient resources to, for example, follow up innovation and technological developments, give training and facilitate access to investment.

Examples

Implementation at industry level

EU (Multiple countries)	A project is currently being run between three 'mirror platforms' of the European Aquaculture Technology and Innovation Platform (EATiP) (53) in France, Spain and Norway. These platforms are industry-driven multi-stakeholder aquaculture clusters, supporting the implementation of strategic research and innovation activities at a regional/national level. This project aims to address several core

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(53) https://eatip.eu/

	aquaculture thematic priorities related to efficient energy use, efficient water use, resource-efficient aquaculture feeds, better use of side streams as part of circular production systems and more targeted and skilled human capacity.
Italy	The Italian fish farmers association (API) has produced a document that includes **analytical elements and calculation tools** to determine how to carry out energy-consuming activities more efficiently. This includes lighting, heating, cooling systems and the production of compressed air. The document also provides tools to enable producers to make decisions on the use of electric motors, pumps and thermal insulation (54).
	A producer organisation involved in bivalve production has set up a freezer powered by solar panels funded by the European Maritime, Fisheries and Aquaculture Fund (EMFAF). The panels have been made available to members at preferential rates.
Poland	For many years, the Polish Trout Breeders Association has provided support and training to its members. Information and best practices on the energy transition are also part of its support programme (55).
Romania	Producers share environmental data on aquaculture in the Production Plan Report. They provide the authorities with data for the energy, fuel and water use for a tonne of sold product and for a tonne of production. These data are provided to the Scientific, Technical and Economic Committee for Fisheries (STECF).
Spain	In the first Sustainability Report 2020 (APROMAR – Asociación Empresarial de Acuicultura de España), the Spanish aquaculture sector made a series of commitments for improvements (56). The sector proposed a series of actions and objectives directly related to the sustainable aquaculture activities. A 10-year deadline was set to achieve the proposed goals by 2030. In the second report (2022), the energy-saving measures were evaluated. **Aquaculture farms have achieved a level of compliance of the objectives of 25% between 2020 and 2022.**

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(54) Guida per la valutazione e il miglioramento dell’efficienza energetica degli impianti di acquacoltura: https://www.acquacoltura.org/wp-content/uploads/2023/03/Q31-Energia.pdf

(55) Stowarzyszenie Producentów Ryb Łososiowatych: https://sprl.pl/aktualnosci/

(56) Memoria de Sostenibilidad de Acuicultura de España (2023) MEMORIA DE SOSTENIBILIDAD 2023 de Acuicultura de España_WEB (acuiculturadeespana.es)

Factsheet 8. Public authority initiatives to facilitate the energy transition

Description

According to their multiannual national strategic plans for aquaculture (MNSPA) (57), Member States support the sector as follows.

- **Investing** in solutions to improve energy efficiency and **getting involved with projects and research** initiatives that introduce innovative methods and practices that reduce dependence on fossil fuels (e.g. Austria, Czechia, Italy, Lithuania, Germany, Poland and Sweden).
- **Diversifying energy sources**, including through the use of renewable energy sources (e.g. Belgium, Cyprus, Greece, Lithuania, Italy, Malta, Poland, Portugal and Sweden).
- Considering factors that can contribute to the decarbonisation of the sector **through spatial planning**, including the identification of allocated zones for aquaculture.

Examples

Czechia	The programme 'Technologies and Applications for Competitiveness', in conjunction with its National Programme for Inland Fisheries, provides support, in particular, in the field of energy savings. The programme enables producers to implement investment projects that aim to reduce the energy intensity of buildings.
Italy	Under the EMFF 2014-2020, funds have supported investments in aquaculture dedicated to energy efficiency, leading to a reduced impact from the use of hydrocarbons as an energy source (28 projects, for a contribution amounting to EUR 5 million across 11 regional administrations). Furthermore, the energy transition has been given even greater attention in the Italian 2021-2027 MNSPA, which is directly linked to the EMFAF Program. As a result, a greater number of EMFAF-funded projects are expected in this programming period to support investments improving the energy efficiency of aquaculture facilities.
	In line with recommendations from the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), the selection of allocated zones for aquaculture took into account the distance between aquaculture areas and land-based infrastructure supporting aquaculture operations and the distance to access transportation infrastructure.

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(57) AAM website country profiles MSNP for Aquaculture: https://aquaculture.ec.europa.eu/country-information

4. REGULATORY AND SECTORAL CHALLENGES

As described in this document, there are promising approaches to the aquaculture sector’s energy transition. Some are already in use and others remain at the testing and pilot phase. To accelerate the energy transition, knowledge, technology and regulation challenges need to be considered and addressed.

(1) Mapping GHG emissions to set a baseline for improvement and efficiency measures

There is a scarcity of data on GHG emissions from aquaculture activities in peer-reviewed publications, not only for many species but also production technologies. In addition, there are no clear standards or approved indicators for professional audits. A sound baseline of GHG emissions is therefore needed to set realistic targets and monitor progress in decarbonising the sector. Life cycle assessments, in particular environmental footprint methodologies (including product environmental footprints), could be used to estimate GHG emissions from the main aquaculture production technologies based on primary data collected in national studies and compiled in EU Member States.

In the context of the Energy Transition Initiative, the Commission launched a study on ‘Greenhouse gas emission reduction targets, costs, and strategies for EU fisheries and aquaculture’. The study will provide evidence-based recommendations on GHG emissions reduction targets and actionable pathways for the EU fisheries and aquaculture sector, with possible milestones set for 2030, 2040 and 2050. These pathways should primarily focus on direct emissions, with complementary scenarios including indirect emissions. The study will support the work on the roadmap for the sector’s energy transition by informing stakeholders in a clear and targeted way about the state of emissions, developments and conclusions of the most recent scientific data on decarbonisation.

(2) Limited commercial availability of certain technologies

Some energy transition solutions arising from research and pilot projects still need economic validation, upscaling and commercialisation. There is also limited commercial availability of other technologies already on the market. Therefore, further support and investment for scaling up solutions is required to enable aquaculture producers to adopt them.

(3) Cost and investment as an obstacle for uptake by small companies

Even when available at sufficient scale on the market, some solutions are expensive and require a large investment. This can be a serious obstacle for adoption by small companies, which make up the large majority of aquaculture producers in the EU. In addition, older aquaculture facilities may not be optimised for energy efficiency in terms of their design and insulation and therefore often require upgrading.

(4) Required skills in managing energy transition solutions

Energy transition and optimisation is not just a question of adopting technology but also of providing support and training on its optimal use. Most solutions available require a minimum level of skills that traditional small-scale aquaculture producers might lack. Digital solutions require even more specialised skills. Having properly trained staff is therefore crucial to manage energy transition technologies.

(5) Regulatory obstacles to installing renewable energy production

The installation of solar panels and windmills on aquaculture buildings or production structures is subject to building permission approval from local authorities and needs to comply with environmental legislation. Requests are often rejected due to the landscape and heritage status of ‘traditional’ or ‘historic’ buildings.

Authorities do not generally allow solar panel and windmill installations in Natura 2000 areas. The use of floating solar panels in ponds and lakes can reduce energy costs and provide shelter protection for young fish from predators. Its positive and negative impacts need to be documented to support regulations on using such solar panels.

Socio-economic and technical data can support policy and regulations on the ‘visual impacts on the environment’ of energy transition infrastructure, such as panels, masts, windmills and batteries in coastal and inland production locations. Member States can work on aligning policies and objectives for the aquaculture sector’s energy transition with landscape and environmental regulations and involve the necessary expertise, including that of aquaculture professionals, in planning the use of such space.

(6) Early planning of the energy transition

To enable energy transition solutions, they should be factored into aquaculture planning and decision-making processes. Besides the energy used in aquaculture installations themselves or the vehicles and equipment that are used for production supply and services, it is essential to consider the transport of goods (inputs and product outputs) and their associated costs and emissions. These factors should be assessed in the planning and decision-making processes to avoid additional value-chain effects and emissions. The proximity and availability of renewable energy sources could also be a criterion when planning new aquaculture projects.

For industrial symbiosis, early planning is particularly important since it involves connecting different types of industries.

(7) Ensuring land-support/port services for electricity and energy storage

Aquaculture facilities require a steady supply of electricity. The energy produced from renewable sources needs to be balanced with the use of generators when there is insufficient production from renewables. Storage solutions, including batteries, need to be developed that are suitable for aquaculture purposes – either on-site or within support facilities, such as ports.

Some ports are starting to be equipped with new infrastructure to support the use of electric and hybrid support vessels. However, the deployment of suitable electricity networks (especially in isolated coastal areas) remains minimal. Changes to existing networks are expensive and sometimes technically challenging.

(8) Cooperation between different actors

Producer organisations and associations have a role to play in the energy transition. They serve as intermediaries, data collectors, facilitators for SMEs to access funding, training providers and communicators to authorities and governments to share success stories and accelerate the transition. However, in many cases the relationship between producers, scientific institutes and regulatory authorities in collecting and using farm data (e.g. Life cycle assessment studies) needs to be clarified, especially where data sharing may be considered a barrier for individual operators.

ANNEX 1: METHODOLOGY

This document has been prepared on the basis of the following:

- the 'Techno-economic analysis for the energy transition of the EU fisheries and aquaculture sector' (De Vet et al., 2024);
- the document 'Possibilities and examples for energy transition of fishing and aquaculture' (EC, 2023) as updated in February 2024;
- the work of the EU Aquaculture Assistance Mechanism to provide guidance on the energy transition by identifying specific measures and aspects of the topic and producing factsheets of good practices that include examples from different EU and non-EU countries.

To provide relevant and updated information on the energy transition, a literature review/desk study was carried out. In addition, recommendations from stakeholders, including the Aquaculture Advisory Council (AAC), and outputs of EU projects funded under Horizon 2020 with direct relevance to the topic were analysed.

The result of this work was presented and discussed at an experts' workshop organised by the European Commission in Brussels in June 2024. Before the workshop, the document was circulated to participants to enable an informed discussion to take place. After the workshop, detailed contributions from Member States, representatives of the aquaculture sector and several experts were taken into consideration to update the factsheets on the basis of the discussions and contributions received.

ANNEX 2: EU-FUNDED PROJECTS

ULTFARMS - Horizon 2020 project

The Blue Deal - Interreg MED project

OLAMUR - EU Mission Ocean Lighthouse Project
The Blue Growth Farm - Horizon 2020 research project

AQUAWIND- European Maritime, Fisheries and Aquaculture Fund (EMFAF) project

UNITED - European Maritime, Fisheries and Aquaculture Fund (EMFAF) project

TETRAS - Interreg Baltic research project

EWEAS - EU Erasmus+ project

Next Blue Generation - European Maritime, Fisheries and Aquaculture Fund (EMFAF) project
OPTIMA - EU Erasmus+ project

AQUATECHinn 4.0 - ERASMUS2027 Programme project

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