FEDERATION OF EUROPEAN AQUACULTURE PRODUCERS

FACTS ABOUT FINFISH AQUACULTURE

Sustainability and Environmental Impacts of Aquaculture

Understanding the Local and Global Sustainability of Fish Farming.

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European aquaculture is at a critical turning point, balancing economic viability, environmental responsibility, and social well-being. While policy frameworks, technological innovations, and ecosystem-based approaches are driving sustainability, challenges like global competition and high production costs persist.

To address these challenges, the document **Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture** for the period 2021 to 2030, outlines the European Commission's approach to fostering a sustainable, resilient, and competitive aquaculture sector. The document defines the sustainable development of aquaculture by aligning it with the objectives of the European Green Deal and the Farm to Fork Strategy. It highlights the potential of farmed aquatic food as a low-carbon protein source and emphasizes the role of aquaculture in job creation, economic development, and environmental sustainability. The strategy aims to make EU aquaculture more competitive, resilient, and environmentally friendly while reducing dependency on aquatic food imports.

The EU's aquaculture strategy strongly aligns with FAO's SDG framework, particularly in promoting sustainable food production, environmental responsibility, and economic resilience. The guidelines provide a blueprint for ensuring that aquaculture contributes positively to global sustainability goals while meeting EU-specific needs for food security and economic development.

The Food and Agriculture Organization of the United Nations (FAO) **defines sustainability** as meeting present needs without compromising the ability of future generations to meet theirs. Achieving this requires balancing **economic, social, and environmental** factors to support long-term sustainable development.

These three pillars of sustainability—economic, environmental, and social—are fully integrated into the **Aquaculture Performance Indicators (API)** methodology (Garlock et al., 2024), ensuring a balanced and comprehensive assessment of sustainability in aquaculture systems. Each pillar is represented by a set of quantifiable indicators that measure the sector's long-term viability from multiple perspectives. APIs are a standardized set of metrics designed to assess the sustainability of aquaculture systems. They provide a holistic evaluation by measuring economic, environmental, and social aspects of fish farming operations.

The most recent API based evaluation of the European aquaculture sector (Nielsen et al., 2025) shows that Europe outperforms the global aquaculture sector in all three sustainability dimensions. The results suggest that the commitment of European countries to policies and regulations has been successful in establishing a sustainable aquaculture sector. However, the relatively weak growth performance compared to the rest of the world indicates that this has come at a cost. Nevertheless, the sector still has considerable growth capacity, as it shows a relatively fast potential growth rate.

While API is the most recent method to assess aquaculture sustainability including all three pillars on local and global levels, from a practical perspective, like planning and licensing a fish farm, the local environmental impacts of aquaculture are the most relevant to measure. Nowadays the **ecosystem approach to aquaculture (EAA)** is widely used in planning and management of aquaculture activities and this approach is also integrated in the **Environmental Impact**

Assessments (EIA) and monitoring of fish farms. (FAO, 2009). The EIA is a process by which environmental and production information is gathered and assessed for the environmental impacts of a fish farm (both positive and negative). First, baseline studies check various parameters like water quality and biodiversity. Carrying capacity models are also applied to estimate how much farming the site and the ecosystem can handle (Ross et al., 2013). EIA also predicts potential impacts, suggests ways to reduce harm (like waste management and responsible stocking), and includes social and economic concerns. Once a farm has the necessary licences and has been established there are a number of ongoing monitoring procedures that ensure the farm is operating in compliance with the terms of the licence and regulatory standards. By following these principles, aquaculture remains productive without damaging nature. These processes are strictly regulated on EU, national and regional levels and require several environmental indicator data from fish farmers.

As sustainability standards are getting increasingly important on the markets and from a regulatory perspective, there is a growing interest in measuring the global environmental impacts of fish farming. While EIA focuses on site-specific effects, **Life Cycle Assessment (LCA)** evaluates the entire life cycle of aquaculture—from feed production and farming to processing, transportation, and waste disposal (Henriksson et al., 2013). This approach provides a comprehensive picture of the sectors' sustainability and environmental impacts. These impacts are broad, global in scope, and accumulate over time. LCA methodology evaluates environmental impacts across various categories, such as greenhouse gas emissions, water use, energy consumption, and eutrophication, providing a holistic understanding of a product's or system's overall environmental burden. The studies applying this method show, that aquaculture is a relatively resource-efficient type of animal food production with lower environmental impact than most livestock production (Gephart et al., 2021).

The LCA methodology is standardised by ISO 140405 and ISO 140446 which describe principles, application, phases of an LCA study, requirements, critical review, and reporting.

In the Impact Assessment (Life Cycle Impact Assessment - LCIA) the most relevant environmental impacts must be selected and the emissions are calculated for each selected impact category. In marine and freshwater fish farming some of the relevant impact categories are for example:

- Global warming potential (GWP): GWP expresses the impact of each Green House Gas - GHG (CO_2, CH_4, N_2O) in terms of the equivalent amount of CO_2 (called CO_2-equivalents or CO_2e) over a specific time frame (commonly 100 years).
- Eutrophication potential (marine and freshwater): Evaluate nutrient runoff (nitrogen and phosphorus) and its impact on aquatic ecosystems.
- Land use: Transformation and use of land for agriculture, roads, housing, mining or other purposes. The impact can include loss of species, organic matter, soil, filtration capacity, and permeability
- Acidification potential: Assess the effects of nitrogen and sulphur emissions leading to acid rain.
- Water use and consumption: Analyse freshwater use efficiency and consumption rates in aquaculture systems.
- Ecotoxicity, freshwater: It is measured in the Comparative Toxic Unit for ecosystems (CTUe) to quantify the impact of toxic substances on freshwater ecosystems.

Life Cycle Assessment (LCA) studies on different fish farming technologies show that aquaculture's global environmental impact is largely linked to feed production. One reason farmed fish have a lower environmental footprint than other livestock is their efficient feed use. They require only 0.95 to 2.4 kg of feed to produce 1 kg of fish, resulting in a low Feed Conversion Ratio (FCR) and reduced resource consumption.

The environmental impact of aquaculture is also improving thanks to ongoing research, development, and innovation. For example, producing 1 kg of farmed Atlantic salmon at the farm gate emitted 3.8 kg CO_2e in 2021, down from 4.2 kg CO_2e in 2017 (Ziegler et al., 2024).

As with other animal production sectors, greenhouse gas (GHG) emissions from aquaculture depend heavily on processing and transportation. The carbon footprint of 1 kg of salmon varies based on its destination. If transported by truck to Paris, it emits 5 kg CO_2e, while air freight to Tokyo increases emissions to 17 kg CO_2e. Continuous advancements in feed, farming techniques, and logistics are key to further reducing aquaculture's environmental impact (Johansen et al., 2022).

Over the last two decades, the European Commission has been driving a process of implementation of **life cycle thinking in European product policies**. In particular, the Communication COM/2003/302 on the Integrated Product Policy established the framework conditions for the continuous environmental improvement of all products throughout the production, use and disposal phases of their life cycle. **The Product Environmental Footprint (PEF)** is a standardized methodology developed by the European Union to evaluate and communicate the environmental impacts of products throughout their life cycle. It uses a life cycle assessment (LCA) approach, guided by consistent rules (PEF Category Rules or PEFCRs) to ensure comparability and reliability across product types. The PEF also assesses multiple environmental impact categories, such as global warming potential, resource depletion, water use, and pollution, providing a holistic view of a product's environmental performance. Its main goal is to promote sustainability by enabling businesses and consumers to make informed choices, supporting policies like the European Green Deal, and fostering a circular economy.

Recently there is a Product Environmental Footprint Category Rule (PEFCR) being developed for aquaculture products within the Marine Fish PEFCR initiative (www.marinefishpefcr.eu). This initiative aims to establish rules for assessing the environmental performance of unprocessed marine fish products, which include both wild-caught and farmed fish.

A careful analysis during the interpretation of all LCA based methodology is essential for understanding the full environmental footprint of aquaculture activities. While certain systems, such as pond fish farming, may have higher freshwater and land use compared to other technologies, these factors should be evaluated in context. For example fish ponds are not just production sites; they also function as valuable wetlands that support biodiversity, carbon sequestration, and water purification. The water within these systems also provides healthy microclimate, groundwater recharge and nutrient cycling.

Integrating these **ecosystem services** (Potschin and Haines-Young, 2016) into LCA evaluations is crucial for a more accurate and holistic assessment of aquaculture's environmental impact. Traditional LCA methods often focus on resource use and emissions but may overlook the positive contributions of aquaculture systems to the surrounding environment. Recognizing these benefits helps balance trade-offs and supports the development of more sustainable aquaculture practices that enhance both food production and ecosystem health (Taelman et al., 2024).

Aquaculture, particularly extensive and integrated freshwater and marine systems, provides a multitude of ecosystem services that are essential for both environmental sustainability and human well-being. These services can be categorized into provisioning, regulating, cultural, and supporting services, each contributing to the multifunctionality of aquaculture systems. **Provisioning services** primarily encompass the production of fish and other aquatic organisms, which are vital for food security and economic livelihoods. This service is crucial as aquaculture continues to grow as a significant source of protein for the global population. **Regulating services** in aquaculture include the maintenance of water quality, nutrient cycling, and habitat provision for various species. **Cultural services** are also highlighted, which encompass recreational opportunities, educational experiences, and the preservation of cultural heritage associated with aquaculture practices (Willot et al., 2019).

All these tools and frameworks are essential for assessing the sustainability and resilience of European aquaculture because they offer complementary insights. Together, these tools can help farmers and regulators to develop aquaculture in a way that is environmentally sound, economically viable, and socially responsible.

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