Circutech

WP2: Roadmap for Transitioning European Aquaculture toward a more Sustainable and Circular Model

A1. Fieldwork activities (M1-M3)

R.2.1. Summary report of the Fieldwork

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Circular Competence Training for Aquaculture Waste Management using VR and AR Tools

Project N. 2024-1-ES01-KA220-VET-000249427

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1. Introduction

1.1. Purpose of the Report

This report presents the findings from fieldwork conducted to assess waste management practices and the degree of circular economy (CE) integration in the European aquaculture sector. It offers detailed insights into operational realities on the ground, identifies key barriers and gaps, and proposes recommendations to enhance sustainability and circularity in aquaculture production systems.

1.2. Scope and Objectives

The study focuses on small to medium-sized aquaculture enterprises operating in three key European aquaculture-producing countries: Spain, Italy, and Portugal. These countries represent diverse geographical, environmental, and production contexts, offering a broad perspective on sectoral practices and challenges.

The main objectives of the report are to:

- Analyse current waste generation and management practices across farms;
- Evaluate the level of implementation of CE-related measures;
- Identify legal, economic, environmental, and social barriers to CE adoption;
- Map existing knowledge gaps and training needs;
- Highlight successful practices and scalable solutions.

1.3. Methodological Approach

Fieldwork activities were based on a combination of desktop research, structured surveys, and direct field visits to aquaculture farms.

1.3.1. Survey Design

A common questionnaire was designed to ensure consistency across the three countries. It was structured into four main sections:

1. General company profile
2. Production and species characteristics
3. Waste management and circular economy practices

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4. Training, challenges, and future perspectives

The survey included both quantitative and qualitative questions, allowing for the collection of comparable data while also capturing unique contextual insights from each company.

1.3.2. Participant Profile

Participants included technical staff, farm managers, and sustainability officers from a wide range of aquaculture systems, including inland freshwater, coastal marine, and offshore production. The majority of surveyed entities are small or medium-sized enterprises (SMEs), although some larger companies were also included for comparative analysis.

1.3.3. Countries and Companies Involved

The fieldwork covered aquaculture producers in Spain, Italy, and Portugal, with a total of [insert number] companies participating in the study. These companies were selected to represent a diversity of production methods (e.g., intensive, extensive, integrated multitrophic systems), species (e.g., seabream, trout, oysters, clams, turbot), and regional characteristics (e.g., inland, coastal, island-based operations).

1.3.4. Data Collection and Limitations

Data were collected through:

- Desktop research to review background information, regulatory context, and existing CE initiatives;
- Structured questionnaires filled out by aquaculture companies;
- On-site field visits in all three countries for deeper engagement and qualitative validation.

While the sample offers a broad and representative overview of the sector, the report acknowledges some limitations, including the voluntary nature of participation, regional disparities in data availability, and the inherent diversity of aquaculture systems across Europe. Nonetheless, the findings provide a solid basis for policy recommendations and future work.

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SECTION 1 - A.1.1 DESKTOP RESEARCH

1. Introduction

This documentary research study is part of WP2: Roadmap for Transitioning European Aquaculture toward a more Sustainable and Circular Model, which aims to lay the fundamental foundations for the development of a roadmap that will serve as a strategic transformation plan to support the transition towards a more circular and sustainable aquaculture industry.

To achieve this, the work begins with the development of Activity **A1: Fieldwork Activities,** which includes conducting documentary research by country to collect data and analyze the current state of waste management practices in European aquaculture, including compliance with European and national laws on waste management in the sea and ports. The goal is to **gather valuable information on the needs and challenges faced by aquaculture farms.**

2. Definition of Scope and Objectives

- **General Objective:** Identify trends, barriers, and best practices in the implementation of circular economy in European aquaculture.
- **Key Areas:**
  - Technological, current regulations (EU, national) and policy trends.
  - Economic, social, regulatory, research and technical barriers
  - Best practices on sustainable management.

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3. Portugal

3.1. Methodology

To carry out this research, Perplexity.ai was used as a literature search tool. Also, an extensive literature review was conducted using various primary sources, and the databases consulted were Google Scholar, Scopus, Web of Science, and PubMed. These sources were selected due to their broad coverage and reputation in publishing relevant research in the field of circularity.

The search formula used was as follows, including the descriptors and keywords specified:

- "Circular economy" AND "aquaculture" AND "Portugal."
- "Barriers" AND "circular economy" AND "fisheries." AND “Portugal”
- "Best practices" AND "sustainable aquaculture" AND “Portugal”.

To ensure the timeliness and relevance of the information, a 10-year time range was applied. Inclusion and exclusion criteria, as specified in Table 1, were applied to select the most relevant studies:

Table 1. Inclusion and Exclusion Criteria

CRITERIA	INCLUSION	EXCLUSION
Type of studies	Scientific publications, government reports, and reports from international organizations (FAO, EFARO, etc.), and recent practical case studies from Europe.	Narrative reviews with no significant empirical basis.
Publication date	References from the last 10 years (2015-2025).	Studies prior to 2015 (more than 10 years old).
Context.	European studies.	Studies outside the European context.
Accessibility	Studies/articles available in full text and accessible through recognized scientific databases.	Texts that are not available in full or accessible through subscriptions.
Language	Studies/articles in English or the language of the partner's country.	Studies/articles in other languages.

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Table 2. List of Sources (max. 15 sources)

Nº	Databases	Author	Title	Link
1	EEA	European Environment Agency (2024)	ETC Circular economy and resource use: Circular economy country profile 2024 – Portugal.	https://www.eionet.europa.eu/etcs/etc-ce
2	EIONET	European Environment Agency (2025)	ETC Circular economy and resource use: Circular economy country profile – Report 2022/5 Portugal.	https://www.eionet.europa.eu/etcs/etc-ce
3	PECH	Basurko, O. C., Aranda, M., Caballero, A. (2023)	Workshop on the European Green Deal – Challenges and opportunities for EU fisheries and aquaculture – Part I: Decarbonisation & circular economy aspects for fisheries.	https://www.europarl.europa.eu/thinktank/en/document/IPOL_STU(2023)747294
4	B2E	Lima, S.	Status of marine co-products in Portugal: overview, opportunities, and challenges.	https://b2e.pt/status-of-marine-co-products-in-portugal-overview-opportunities-and-challenges/
5	iFishIENCI	Balsells, S, Bardócz, T., Chary, K., Alias, D. C., Enyedi, E., Hávardsson, B., Kane, F., Kause, A., Kleinegris, D., Lengyel, P., Mihalffy, S., O'Brien, D., Ravagnan, E., Rodríguez, L., Sanchez, I., Shrestha, M., Dankel, D. J., (2021)	Policy Recommendations for a More Circular Aquaculture.	https://ifishienci.eu/wp-content/uploads/2022/03/IfishcIENCi_Policydoc_Jan-2022Final.pdf
6	GOPARITY	GoParity	Sustainable Aquaculture II: Acquisition of an oxygenation system for a sustainable aquaculture in Algarve.	https://goparity.com/project/sustainable-aquaculture-ii-119

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7	RECYCLING	Magalhães, F.C., Bellei, P., Flores-Colen, I. & Marques da Costa, E. (2024).	Blue Circular Economy—Reuse and Valorization of Bivalve Shells: The Case of Algarve, Portugal. Recycling, 9(2), 27.	http://hdl.handle.net/10451/63868
8	B2E	B2E	Portugal wants to generate new value chains with fish waste.	https://b2e.pt/portugal-wants-to-generate-new-value-chains-with-fish-waste/
9	WEAREAQUACULTURE	WEAREAQUACULTURE (2024)	Portugal's offshore aquaculture revolution: Mariculture Systems Portugal	https://weareaquaculture.com/featured/portugals-offshore-aquaculture-revolution-mariculture-systems-portugal
10	CIIMAR	Vasconcelos, V., Moreira-Silva, J., Moreira, S. (2019)	Portugal Blue Bioeconomy Roadmap - BLUEandGREEN. CIIMAR, Matosinhos, 68	https://www2.ciimar.up.pt/pdfs/resources/roadmap_digital_hGBit_.pdf
11	SSRN	Almeida, M., Corticeiro, S., Oliveira, B. R. F., Laranjeiro, D., Lillebø, A., Vieira, H. (2024)	The Needs and Challenges of the Blue Economy sector in Portugal: bridging national and European strategies with the perceptions of the Stakeholders.	https://ssrn.com/abstract=4897705
12	Recycling	Magalhães, F. C., Bellei, P., Flores-Colen, I., Marques da Costa, E. (2024)	Blue Circular Economy—Reuse and Valorization of Bivalve Shells: The Case of Algarve, Portugal, Recycling, 9(2), 27	https://doi.org/10.3390/recycling9020027
13	Environmental Management	Klein, N., Deutz, P., Ramos, T. (2022)	A survey of Circular Economy initiatives in Portuguese central public sector organisations: National outlook for implementation, Journal of Environmental Management, 314	https://doi.org/10.1016/j.jenvman.2022.114982
14	Sustainability	Carreira, R. J., Ferreira, J. V., Ramos, A. L. (2024)	Mapping Circular Economy in Portuguese SMEs, Sustainability, 16(16), 7009	https://doi.org/10.3390/su16167009

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3.2. Results

Section 1: Technological, current regulations (EU, national) and policy trends in Portugal.

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

Portugal is actively incorporating circular economy principles into its aquaculture sector through various technological and policy initiatives.

1. **Technological trends:**
   - Algae and Microalgae Production: The aquaculture sector is focusing on producing algae and microalgae compounds that can be used as agricultural supplements, replacing chemical fertilizers [1].
   - Circular Aquaculture Models: There is a push towards developing circular aquaculture systems that minimize waste and maximize resource efficiency [1].
   - Biodegradable Materials: The industry is promoting the use of fishing equipment containing biodegradable materials with greater ecological neutrality [1].
2. **Policy trends:**
   - Strategic Plan for Aquaculture 2021-2023: This plan outlines ten strategic objectives, including combating climate change and promoting circular economy practices in the aquaculture sector [1].
   - National Action Plan for Marine Litter 2024-2026 (PALM2026): This upcoming plan includes measures to prevent plastic loss from aquaculture activities and promote circular economy mechanisms for end-of-life fishing gear [1].
   - Circular Economy Integration: The Portuguese government is actively working to mainstream circular strategies across all economic sectors, including aquaculture, through the upcoming PAEC 2030 (Action Plan for Circular Economy) [1].
   - Collaborative Governance: There is a focus on involving multiple stakeholders, including industry associations and research institutions, in the development and implementation of circular economy policies for aquaculture [1].
   - Bioeconomy Initiatives: The Recovery and Resilience Plan includes integrated projects related to sustainable bioeconomy, which are closely linked to circular economy practices in aquaculture [1].

These trends demonstrate Portugal's commitment to transitioning its aquaculture sector towards more sustainable and circular practices, aligning with broader national and European Union goals for environmental protection and resource efficiency.

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Section 2: Economic, social, regulatory, research and technical barriers in Portugal.

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

Portuguese aquaculture faces several barriers in implementing circular economy practices.

1. Economic Barriers:

- Lack of funds for investing in low-carbon practices and equipment, especially challenging for small-scale operators [3].
- Difficulty in scaling up added-value uses due to insufficient quantities of some co-products [4].
- High costs associated with changing processes and implementing new technologies [4].

2. Social and Human Barriers:

- Resistance to change within organizations, as it requires employee training and new processes [4].
- Traditional nature of the fishing sector, which can hamper proactivity towards innovations [3].

3. Regulatory Barriers:

- Regulations often act as obstacles rather than facilitators for innovations. [3].
- Current legislation does not allow all options for circular feed production, mainly due to safety reasons [5].
- Administrative burden associated with applying for funding [3].

4. Technical Barriers:

- Lack of accurate information about quantities and composition of co-products from seafood processing industries [4].
- Challenges in recycling fishing gear due to mixed materials (polymers and metals) [3].
- Limited knowledge transfer between industry and academia, hindering innovation [4].
- Insufficient port infrastructure to supply alternative energy for fishing vessels [3].

5. Other Challenges:

- Lack of organized markets for co-products, especially for biotechnological applications [4].
- Limited awareness and willingness to collaborate among fishers, port managers, and waste managers [3].
- Insufficient communication about available technologies and their benefits [3].

Addressing these barriers will be crucial for Portugal to fully embrace circular economy practices in its aquaculture sector and move towards more sustainable and efficient operations.

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Section 3: *Best practices on sustainable management in Portugal.*

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

Portugal has been making significant strides in developing a circular economy model for its aquaculture sector, demonstrating several best practices and successful strategies.

1. Sustainable Aquaculture Projects:

NaturaFish, located in the Algarve region, exemplifies a sustainable aquaculture model. This seabass and seabream farm is harmoniously integrated into nature, representing a sustainable alternative to wild fishing and high-density offshore cage aquaculture [6]. Key features include:

- 19 hectares of total area with 19 tanks
- Capacity to produce 500 tons of fish per year
- Located in a Natura 2000 conservation area
- Utilizes natural water renovation through tidal exchange
- Focuses on animal wellbeing and positive environmental impact

2. Waste Valorization and Reuse:

The Blue Circular Economy concept is being applied to bivalve shell waste in the Algarve [7]. This approach aims to:

- Reintegrate waste into the production cycle
- Minimize environmental disposal
- Reduce unrestrained extraction of raw materials
- Transform residues into new products

3. Marine Coproducts Utilization:

The Roadmap4MarineCoproducts project, led by B2E – Blue Bioeconomy CoLAB, focuses on maximizing the value of fish by-products [8]. This initiative:

- Learns from Norwegian and Icelandic best practices
- Identifies circular economy business ideas
- Aims to create new value chains from fish waste
- Explores uses in food, textiles, carpentry, and other industries

4. Offshore Aquaculture Innovation:

Mariculture Systems Portugal is developing large-scale offshore platforms designed for scalability and sustainability [9]. Their CORALIS fish farming platform aims to:

- Produce up to 8,000 tonnes of fish per year
- Minimize environmental impact
- Meet rising global demand for seafood sustainably

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5. Policy and Strategic Incentives:

Portugal has implemented several policies and strategies to support circular economy in aquaculture:

- The National Strategy for the Sea 2021-2030 promotes circular aquaculture and business models based on CE logic [2].
- The National Strategy for Tourism 2027 includes stimulating the circular economy in tourism, which can indirectly benefit sustainable aquaculture [2].
- The National Action Plan for Marine Litter 2024-2026 includes measures to prevent plastic waste from aquaculture through circular economy mechanisms [1].

These initiatives demonstrate Portugal's commitment to developing a viable and sustainable circular economy model for its aquaculture sector, focusing on waste reduction, resource efficiency, and environmental protection.

3.3. Conclusions and recommendations

Section 1: Propose a roadmap for advancing circular economy in Portuguese aquaculture.

Based on Portugal's current initiatives and future goals for a circular for circular economy in aquaculture, here's a proposed roadmap for advancing this sector.

1. Research and Innovation:

Establish a Blue Bioeconomy hub portal to centralize information about stakeholders, expertise, products, and services in the aquaculture sector [10].

2. Policy and Regulation:

Develop action plans for transitioning to an Inclusive and Circular Economy in the aquaculture sector and revise training programs for young scientists in blue biobased courses to include circular economy principles [10, 11].

- Industry Collaboration: Establish cross-border cooperative alliances to foster collaboration between different regions and stakeholders, and encourage partnerships between research institutions and industry players [11].
- Waste Valorization: Promote the reuse and valorization of aquaculture by-products, such as bivalve shells [12].

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3. Funding and Support:

- Create specific bank support credit lines for the blue sector [10].
- Utilize funding programs like MAR 2020, Fundo Azul, and European funding mechanisms to support circular economy initiatives in aquaculture [4].

4. Education and Awareness:

Organize workshops and training sessions to educate stakeholders about the potential of circular economy in aquaculture and the valorization of marine co-products [4, 11].

Section 2: Identify research gaps and areas for future study.

1. There is a need for a thorough evaluation of the current state of circular economy practices in Portuguese aquaculture [11, 13]. Future studies should focus on assessing the extent of implementation across different aquaculture operations and identifying barriers to adoption.
2. Research is needed to develop and test innovative circular business models specifically tailored to the Portuguese aquaculture sector [2, 11]. This could include exploring new approaches to resource efficiency, waste reduction, and value creation from by-products.
3. There is potential for further research into technologies that can enhance circularity in aquaculture, such as improved waste collection and treatment systems for open-cage aquaculture [5, 11, 13], advanced biorefineries for processing aquaculture by-products [4], or novel feed formulations using circular ingredients [5].
4. Future studies should examine the effectiveness of current policies in promoting circular economy practices in Portuguese aquaculture and propose improvements [14]. This could include analyzing regulatory barriers and incentives for circular initiatives.
5. Research is needed to understand consumer attitudes towards circular aquaculture products and develop strategies to increase awareness and demand [11, 13, 14].
6. Studies should quantify the economic benefits and challenges of transitioning to more circular practices in Portuguese aquaculture [2, 4].
7. Exploring synergies between aquaculture and other industries (e.g., agriculture, energy) could reveal new opportunities for circular economy applications [1].
8. Research on how to effectively scale up and replicate successful circular economy projects across the Portuguese aquaculture sector is needed [4].

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4. Italy

4.1. Methodology

To carry out this research, an extensive literature review was conducted using various academic sources. The databases consulted were Scopus, Web of Science, PubMed, ScienceDirect, MDPI, Springer Link and Google scholar. These sources were selected due to their broad coverage and reputation in publishing relevant research in the field of circularity.

The search formula used was as follows, including the descriptors and keywords specified:

- "Circular economy" AND "aquaculture" AND "Europe."
- "Barriers" AND "circular economy" AND "fisheries."
- "Best practices" AND "sustainable aquaculture," sustainability, and aquaculture.

To ensure the timeliness and relevance of the information, a 10-year time range was applied. Inclusion and exclusion criteria, as specified in Table 1, were applied to select the most relevant studies:

Table 1. Inclusion and Exclusion Criteria

CRITERIA	INCLUSION	EXCLUSION
Type of studies	Scientific publications, government reports, and reports from international organizations (FAO, EFARO, etc.), and recent practical case studies from Europe.	Narrative reviews with no significant empirical basis.
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Table 2. List of Sources (max. 15 sources)

Nº	Databases	Author	Title	Link
1	Google scholar	Peceño, B., Bakit, J., Cortes, N., Alonso-Fariñas, B., Bonilla, E., & Leiva, C. (2022). Assessing Durability Properties and Economic Potential of Shellfish Aquaculture Waste in the Construction Industry: A Circular Economy Perspective. Sustainability, 14(14)	Assessing Durability Properties and Economic Potential of Shellfish Aquaculture Waste in the Construction Industry: A Circular Economy Perspective	https://www.mdpi.com/2071-1050/14/14/8383
2	Google scholar	Zhan J, Lu J, Wang D. Review of shell waste reutilization to promote sustainable shellfish aquaculture. Rev Aquac. 2022;14:477–488.	Review of shell waste reutilization to promote sustainable shellfish aquaculture	https://doi.org/10.1111/raq.12610
3	Google scholar	Topić Popović, N., Lorencin, V., Strunjak-Perović, I., & Čož-Rakovac, R. (2023). Shell Waste Management and Utilization: Mitigating Organic Pollution and Enhancing Sustainability. Applied Sciences, 13(1), 623.	Shell Waste Management and Utilization: Mitigating Organic Pollution and Enhancing Sustainability	https://doi.org/10.3390/app13010623
4	Scopus	Ana Rotter, Antonia Giannakourou, Jesús E. Argente García, Grazia Marina Quero, Charlène Auregan, George Triantaphyllidis, Amalia Venetsanopoulou, Roberta De Carolis, Chrysa Efstratiou, Marina Aboal, María Ángeles Esteban Abad,	Identification of Marine Biotechnology Value Chains with High Potential in the Northern Mediterranean Region	https://doi.org/10.3390/md21070416 https://www.mdpi.com/journal/marinedrugs

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		Ernesta Grigalionyte-Bembič, Yannis Kotzamanis, Mate Kovač 10, Maja Ljubi´c Cmelar ˇ, Gian Marco Luna, Cristóbal Aguilera, Francisco Gabriel Acién Fernández, Juan Luis Gómez Pinchetti, Sonia Manzo, Iva Milašin ˇci´c, Antun Nadarmija, Luisa Parrella, Massimiliano Pinat, Efstratios Roussos, Colin Ruel,Elisabetta Salvatori, Francisco Javier Sánchez Vázquez, María Semitiel García,Antonio F. Skarmeta Gómez, Jan Ulčar 1 and Cristian Chiavetta		
5	Scopus	Poliana Bellei, Isabel Torres, Runar Solstad, and Inês Flores-Colen	Potential Use of Oyster Shell Waste in the Composition of Construction Composites: A Review	https://doi.org/10.3390/buildings13061546
6	Scopus	M. Fraga-Corral, P. Ronza, P. Garcia-Oliveira, A.G. Pereira, A.P. Losada, M.A. Prieto,M.I. Quiroga, J. Simal-Gandara	Aquaculture as a circular bio-economy model with Galicia as a study case: How to transform waste into revalorized by-products	https://doi.org/10.1016/j.tifs.2021.11.026
7	Scopus	W. Malcorps, R. W. Newton, M. Sprangue, B. D. Glencross and D. C. Little	Nutritional characterisation of European Aquaculture Processing By-Products to facilitate Strategic Utilisation	www.frontiersin.org
8	ScienceDirect	W.S. Lakra, K.K. Krishnani	Chapter 19 - Circular bioeconomy for stress-resilient fisheries and aquaculture	https://doi.org/10.1016/B978-0-323-89855-3.00010-8
9	ScienceDirect	Jingsi Zhang, Çağrı Akyol, Erik Meers	Nutrient recovery and recycling from fishery waste and by-products	https://doi.org/10.1016/j.jenvman.2023.119266

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10	ScienceDirect	M. Masi, F. Adinolfi, E.S. Marrocco, Y. Vecchio	A circular transition model for the European aquaculture sector	https://doi.org/10.1016/j.aquaculture.2024.741819
11	ScienceDirect	Julien R. Stevens , Richard W. Newton, Michael Tlusty, David C. Little	The rise of aquaculture by-products: Increasing food production, value, and sustainability through strategic utilisation	https://doi.org/10.1016/j.marpol.2017.12.027
12	MDPI	Daniela Coppola, Chiara Lauritano, Fortunato Palma Esposito, Gennaro Riccio, Carmen Rizzo and Donatella de Pascale	Fish Waste: From Problem to Valuable Resource	https://doi.org/10.3390/md19020116
13	PubMed	Fadila Al Khawli, Francisco J. Martí-Quijal, Emilia Ferrer, María-José Ruiz, Houda Berrada, Mohsen Gavahian, Francisco J. Barba , Beatriz de la Fuente	Aquaculture and its by-products as a source of nutrients and bioactive compounds	https://doi.org/10.1016/bs.afnr.2020.01.001
14	Springer Link	Abdurahman Hafez Mohammed Kashem, Probir Das, Alaa H. Hawari, Sanjeet Mehariya, Mahmoud Ibrahim Thaher, Shoyeb Khan, Mohamamed Abduquadir & Hareb Al-Jabri	Aquaculture from inland fish cultivation to wastewater treatment: a review	https://link.springer.com/article/10.1007/s11157-023-09672-1#citeas
15	ScienceDirect	Akeem Babatunde Dauda, Abdullateef Ajadi, Adenike Susan Tola-Fabunmi, Ayoola Olusegun Akinwole	Waste production in aquaculture: Sources, components and managements in different culture systems	https://doi.org/10.1016/j.aaf.2018.10.002

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4.2. Results

Section 1: Technological, current regulations (EU, national) and policy trends in Country.

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

Aquaculture in the European Union (EU) operates within a complex regulatory framework designed to ensure environmental sustainability, resource management, food safety, and industry competitiveness. At the EU level, the Common Fisheries Policy (CFP) establishes guidelines for managing aquatic resources, including aquaculture, but each country adapts EU policies to its specific context.

In Italy, current policy trends focus on adopting innovative technologies to enhance sustainability and operational efficiency. However, the implementation of Recirculating Aquaculture Systems (RAS), and Integrated Multi-Trophic Aquaculture (IMTA), which enhance nutrient recycling by integrating different species, are still low widespread. As it is, even the use of Information and Communication Technologies (ICT) is not improved yet, even if it could rapidly enhance water management, optimizing feeding routines,increasing energy-efficiency and quality of productions. These advancements are fundamental to reducing environmental impacts and improving resource utilization by minimizing waste. Nowadays, iit is a minor reality, not yet well implemented especially in the smallest realities.

A key financial instrument supporting innovation in the sector is the European Maritime, Fisheries and Aquaculture Fund (EMFAF), which funds projects that promote sustainable practices and improve industry efficiency. Moreover, Italy participates in cross-border initiatives, such as Interreg projects with Croatia, which develop digital solutions to improve aquaculture conditions for fish and shellfish farming. These collaborations aim to improve overall farm management through real-time data collection and automation, thanks to modern monitoring systems.

In conclusion, while Italy is attempting progress in integrating advanced technologies and participating in EU-led initiatives, addressing financial and bureaucratic barriers remains essential. Despite efforts to promote sustainable aquaculture and circular economy, significant challenges remain. Simplifying the regulatory framework, standardizing circular economy models for easier adoption on farms, and ensuring equitable access to EU funds—especially for small-scale fishers and shellfish farmers—will foster innovation at all levels. These measures will accelerate the transition to a more sustainable and competitive aquaculture sector; the synergy between innovation and policy will be crucial in ensuring a more resilient and resource-efficient industry.

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Section 2: Economic, social, regulatory, research and technical barriers in Country.

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

Aquaculture is a rapidly growing sector that plays a crucial role in global food security, sustainable seafood production, and economic development. However, its expansion in the European Union (EU) and undoubtedly in Italy faces several economic, social, regulatory, research, and technical barriers that hinder its full potential. Addressing these challenges is essential for ensuring a more resilient, sustainable, and competitive aquaculture industry.

1. Economic Barriers

One of the primary challenges in aquaculture development is the high initial investment and operational costs. Setting up and maintaining aquaculture farms requires significant capital expenditure on infrastructure, water management systems, and feed production. Additionally, fluctuations in feed prices, energy costs, and labor expenses contribute to financial uncertainty for producers. Standardizing affordable circular economy models for easier adoption by farmers is a key challenge. Besides, the access to funding and credit remains an important theme, particularly for small and medium-sized enterprises (SMEs), which often struggle to secure investments due to perceived risks in the sector.

2. Social Barriers

Public perception and social acceptance of aquaculture can significantly impact its growth. Concerns about environmental impacts, such as water pollution, habitat degradation, and interactions with wild fish and shellfish populations, often lead to opposition from local communities and environmental groups, often caused by lack of awareness. Additionally, competition for coastal and inland water resources can create conflicts even with other sectors, including fisheries, tourism, and urban development. Increasing consumer perception and providing transparent information about sustainable practices in aquaculture are crucial for improving its social acceptance. Moreover, promoting the importance of aquaculture, particularly through specialized training courses, will not only increase workforce availability—especially among youth—but also facilitate the adoption of innovative circular model approaches more effectively.

3. Regulatory Barriers

The regulatory framework governing aquaculture in the EU is complex and varies between member states. In Italy, bureaucratic hurdles, lengthy licensing procedures, and inconsistent implementation of regulations slow down innovation for new entrants and limit sectoral growth. Compliance with environmental and safety standards is essential, but navigating the multiple layers of EU and national legislation can be challenging. Simplifying administrative and legislative processes and establishing clear, harmonized guidelines among all EU countries could help streamline the regulatory landscape and encourage sustainable expansion.

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4. Research Barriers

Despite significant advancements in aquaculture activities, research gaps persist in areas such as disease management, feed alternatives, and sustainable production techniques. The development of innovative solutions requires continued investment in research and development (R&D), yet funding limitations often slow down progress. Additionally, better collaboration between academia, industry, and policymakers is needed to translate research findings into practical applications. Bridging the gap between scientific innovation and commercial viability is crucial for enhancing the efficiency and sustainability of aquaculture.

5. Technical Barriers

Technological advancements attempt to improve productivity in aquaculture, but technical challenges still remain. Water quality control, efficient feed utilization and, more in general, waste and by-products management require constant innovation. For instance, the regular adoption of recirculating aquaculture systems (RAS) and integrated multi-trophic aquaculture (IMTA) could help to improve sustainability, but these technologies require specialized knowledge and significant investment within farms and existing facilities. Additionally, climate change poses new challenges, such as rising water temperatures and extreme weather events, which affect farm operations and production stability. Investing in resilient infrastructure and adaptive management strategies is essential for mitigating these risks. Key challenges are also related to the high costs of technologies, besides digitization and automation, which are still not common, particularly in small-scale farms.

Conclusion

Aquaculture in the EU, and specifically in Italy, holds great potential for contributing to economic growth, enhancing circular waste management and environmental sustainability. However, overcoming economic, social, regulatory, research, and technical barriers are crucial for its long-term success. A coordinated approach involving policymakers, stakeholders, researchers, and local communities is necessary to create a more supportive environment for aquaculture development. By addressing these challenges, the sector can continue to evolve, ensuring a sustainable and competitive future for all European aquaculture.

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Section 3: Best practices on sustainable management in Country.

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

Best practices designed for sustainable aquaculture focus on efficiency, minimize waste and by-products, and support biodiversity, all while maintaining industry competitiveness and upholding social responsibility. Considering this landscape an ecosystem-based approach is crucial: involves selecting sites that minimize ecological disruption, monitoring water quality, and integrating aquaculture within the natural environment. A significant related strategy could be the Integrated Multi-Trophic Aquaculture (IMTA), where species at different trophic levels, such as fish, shellfish, and seaweed, are farmed together to reduce waste and enhance resource efficiency. An additional example is the Recirculating Aquaculture System (RAS), which could significantly contribute to reducing water consumption while enhancing sustainability and efficiency in aquaculture practices.

Organic aquaculture follows strict regulations that promote high animal welfare standards, the use of sustainable feed, and reduced reliance on synthetic chemicals. Similarly, certification and eco-labeling schemes like the Aquaculture Stewardship Council (ASC) and Friend of the Sea (FOS) help consumers identify sustainably produced seafood, encouraging responsible practices within the industry. An additional example could be the implementation of quality labels, allowing consumers to easily identify products sourced from sustainable aquaculture farms. Collective sustainability labels (such as “acquacoltura sostenibile”) highlight not only the quality of the products but also the farming techniques, which are designed to be as sustainable as possible

Improving energy efficiency is another key factor. Renewable energy sources such as solar and wind, along with energy-efficient farming techniques, can reduce the carbon footprint of aquaculture operations. Sustainable feed practices, including alternative protein sources such as insect meal or plant-based feeds, also contribute to reducing reliance on wild fish stocks and minimizing environmental impact.

Social acceptance and community engagement are vital for the industry's success. involvement, and adherence to high environmental standards, including improvement by tailored training courses focused on circular economy, waste and by products management, will facilitate the fostering of the sectors. Enhancing knowledge among both consumers and producers on crucial topics, such as waste minimization, will contribute to the long-term sustainability and resilience of the sector, from both an economic and social perspective. Compliance with EU and national regulations ensures responsible practices while providing financial incentives and support for sustainable initiatives.

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4.3. Conclusions and recommendations

Section 1: Propose a roadmap for advancing circular economy in (Country) aquaculture.

The transition towards a circular economy approach in aquaculture requires a structured roadmap that integrates sustainability principles, regulatory frameworks, technological advancements, quality labels and social acceptance. In Italy, the key strategies should focus on enhancing resource efficiency, reducing environmental impact, and improving long-term sector resilience.

A crucial step is the optimization of waste and by-product management. Implementing Recirculating Aquaculture Systems (RAS) and Integrated Multi-Trophic Aquaculture (IMTA) could minimize resource consumption and maximize nutrient recycling. Additionally, sustainable feed alternatives, and the powerful reuse of by-products, transforming waste into new opportunities, should be actively promoted. A key challenge is even reducing the dependency on wild fish stocks.

Technological innovations, such as real-time monitoring systems and precision aquaculture tools, can even improve waste and resource management, optimize production costs, enhance operational efficiency, and significantly reduce waste..

Regulatory and policy support is essential to ensure that circular economy principles are embedded in Italy's national aquaculture strategies. Streamlining administrative procedures besides direct stakeholder engagement plays a crucial role in fostering the adoption of circular economy models.

A roadmap for Italy should focus on a multi-stakeholder approach, integrating innovative technologies, regulatory incentives, and sustainable production methods to create a resilient and resource-efficient aquaculture sector aligned with EU sustainability goals.

Research and innovation play a critical role in advancing sustainable aquaculture. Investments in new technologies and techniques and improved farming systems help optimize production while minimizing negative impacts. Collaboration between research institutions, farmers and waste industries, besides policymakers, is essential for bridging knowledge gaps and facilitating the transition and the whole adoption of sustainable solutions.

By implementing these best practices, the aquaculture sector in the EU and Italy can enhance its sustainability, reduce its environmental footprint, and ensure long-term both environmental and economic viability.

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Section 2: Identify research gaps and areas for future study.

Despite advancements in aquaculture sustainability, several gaps remain that must be addressed to optimize circular economy practices in Italy's aquaculture sector. Based on several studies, key areas for future study include waste management efficiency, alternative feed sources, offshore aquaculture sustainability, and policy implementation challenges.

One significant research gap concerns the long-term environmental impact of aquaculture waste and by-products. While Integrated Multi-Trophic Aquaculture (IMTA) and Recirculating Aquaculture Systems (RAS) have demonstrated potential, further research is needed to assess their scalability, economic feasibility, and ecological benefits in Italy's specific marine and freshwater environments.

Another critical area is the development of alternative and sustainable feed sources. The reliance on fishmeal and fish oil remains a sustainability bottleneck, requiring further investigation into insect-based proteins, algae, and microbial alternatives. Research should focus on optimizing feed formulations to balance cost, nutritional value, and environmental impact.

The sustainability of offshore aquaculture in Italian waters, which will play a significant role in promoting a sustainable approach, also requires deeper investigation. As offshore farming expands, more studies are needed to assess the effects of climate change, water quality dynamics, and interactions with marine ecosystems. Advanced real-time monitoring technologies and precision aquaculture tools must be further refined to ensure the resilience and efficiency of offshore operations.

On the regulatory front, there is a need to evaluate the effectiveness of existing policies and identify barriers that hinder the adoption of circular economy practices. Research should explore how bureaucratic simplifications, financial incentives, and regulatory harmonization at the EU and national levels could accelerate sustainable innovation in aquaculture.

To sum up, future steps should adopt a multidisciplinary approach, integrating marine biology, engineering, economics, social and policy analysis to develop comprehensive strategies for sustainable aquaculture in Italy, and in all EU countries. Addressing these research gaps will be essential for advancing a resilient, resource-efficient, and circular aquaculture sector aligned with European sustainability objectives.

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5. Spain

5.1. Methodology

To carry out this research, an extensive literature review was conducted using various academic articles. The databases consulted were Scopus, Web of Science and Google Scholar.

These sources were selected due to their broad coverage and reputation in publishing relevant research in the field of circularity.

The search formula used was as follows, including the descriptors and keywords specified:

- "Circular economy" AND "aquaculture" AND "Europe."
- "Barriers" AND "circular economy" AND "fisheries."
- "Best practices" AND "sustainable aquaculture," sustainability, and aquaculture.
- “Spain”.

To ensure the timeliness and relevance of the information, a 10-year time range was applied. Inclusion and exclusion criteria, as specified in Table 1, were applied to select the most relevant studies:

Table 1. Inclusion and Exclusion Criteria

CRITERIA	INCLUSION	EXCLUSION
Type of studies	Scientific publications, government reports, and reports from international organizations (FAO, EFARO, etc.), and recent practical case studies from Europe.	Narrative reviews with no significant empirical basis.
Publication date	References from the last 10 years (2015-2025).	Studies prior to 2015 (more than 10 years old).
Context.	European studies.	Studies outside the European context.
Accessibility	Studies/articles available in full text and accessible through recognized scientific databases.	Texts that are not available in full or accessible through subscriptions.
Language	Studies/articles in English or the language of the partner's country.	Studies/articles in other languages.

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Table 2. List of Sources (max. 15 sources)

Nº	Databases	Author	Title	Link
1	MDPI	Masi, M. G., Adinolfi, F., Vecchio, Y., Agnusdei, G. P., & Coluccia, B. (2024).	Toward the Circular Economy in the Aquaculture Sector: Bibliometric, Network and Content Analyses. Sustainability, 16(13), 5405.	https://doi.org/10.3390/su16135405
2		Fraga-Corral, M., Ronza, P., Garcia-Oliveira, P., Pereira, A. G., Pereira, A. G., Losada, A. P., Prieto, M. A., Prieto, M. A., Quiroga, M. I., & Simal-Gandara, J. (2021).	Aquaculture as a circular bio-economy model with galicia as a study case: How to transform waste into revalorized by-products. Trends in Food Science and Technology	https://doi.org/10.1016/J.TIFS.2021.11.026
3		Chary, K., van Riel, A., Muscat, A., Wilfart, A., Harchaoui, S., Verdegem, M., Filgueira, R., Troell, M., Henriksson, P. J. G., de Boer, I. J. M., & Wiegertjes, G. F. (2023).	Transforming sustainable aquaculture by applying circularity principles. Reviews in Aquaculture.	https://doi.org/10.1111/raq.12860
4		Verreth, J. A. J., Roy, K., & Turchini, G. M. (2023).	Circular bio-economy in aquaculture. Reviews in Aquaculture, 15(3), 944–946.	https://doi.org/10.1111/raq.12812
5		Pandit, A. V., Dittrich, N., Strand, A. V., Lozach, L., Hernández, M. L. H., Reitan, K. I., & Müller, D. B. (2023).	Circular economy for aquatic food systems: insights from a multiscale phosphorus flow analysis in Norway. Frontiers in Sustainable Food Systems.	https://doi.org/10.3389/fsufs.2023.1248984
6		Checa, D., Macey, B. M., Bolton, J. J., Brink-Hull, M., O'Donohoe, P., Cardozo, A., ... & Sánchez, I. (2024).	Circularity Assessment in Aquaculture: The Case of Integrated Multi-Trophic Aquaculture (IMTA) Systems. Fishes, 9(5), 165.	https://doi.org/10.3390/fishes9050165

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7		Campanati, C., Willer, D., Schubert, J., & Aldridge, D. (2021).	Sustainable Intensification of Aquaculture through Nutrient Recycling and Circular Economies: More Fish, Less Waste, Blue Growth. Reviews in Fisheries Science & Aquaculture, 30, 143 - 169.	https://doi.org/10.1080/23308249.2021.1897520.
8		Eroldoğan, O., Glencross, B., Novoveská, L., Gaudêncio, S., Rinkevich, B., Varese, G., De Fátima Carvalho, M., Taşdemir, D., Šafařík, I., Nielsen, S., Rebours, C., Lada, L., Robbens, J., Strode, E.,Haznedaroglu, B., Kotta, J., Evliyaoğlu, E., Oliveira, J., Girão, M., Vasquez, M., Čabarkapa, I., Rakita, S., Klun, K., & Rotter, A. (2022).	From the sea to aquafeed: A perspective overview. Reviews in Aquaculture	https://doi.org/10.1111/raq.12740.
9		Regueiro, L., Newton, R., Soula, M., Méndez, D., Kok, B., Little, D., Pastres, R., Johansen, J., & Ferreira, M. (2021).	Opportunities and limitations for the introduction of circular economy principles in EU aquaculture based on the regulatory framework. Journal of Industrial Ecology, 26, 2033 - 2044.	https://doi.org/10.1111/jiec.13188.
10		Ruiz-Salmón, I., Margallo, M., Laso, J., Villaneuva-Rey, P., Mariño, D., Quinteiro, P., Dias, A., Nunes, M., Marques, A., Feijóo, G., Moreira, M., Loubet, P., Sonnemann, G., Morse, A., Cooney, R., Clifford, E., Rowan, N., Méndez-Paz, D., Iglesias-Parga, X., Anglada, C., Martin, J., Irabien, Á., & Aldaco, R. (2020).	Addressing challenges and opportunities of the European seafood sector under a circular economy framework. Current Opinion in Environmental Science & Health	https://doi.org/10.1016/j.coesh.2020.01.004.

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11		Dovgal, O., & I., O. (2024).	Barriers to the development of the country's circular economy.	https://doi.org/10.31521/978-617-7149-78-0-51
12		Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018).	Barriers to the Circular Economy: Evidence From the European Union (EU). Ecological Economics	https://doi.org/10.1016/J.ECOLECON.2018.04.028.
13		Badiola, M., Albaum, B., Curtin, R., Gartzia, I., & Mendiola, D. (2017).	Land based on-growing of Atlantic cod (Gadus morhua) using Recirculating Aquaculture Systems; a case study from the Basque region (Northern Spain).	Aquaculture, 468, 428-441.
14		Fernández-González, R., Teixeira Pereira, Z. G., & Ricoy Casas, R. M. (2024).	Governance of the circular economy in the canned fish industry: A case study from Spain. Environmental Technology and Innovation, 34, 103618	https://doi.org/10.1016/j.eti.2024.103618
15		Cavallo, M., Frangoudes, K., Agúndez, J., & Raux, P. (2020).	Exploring Troubles, Attitudes, and Strategies Related to Integrated Aquaculture. A Case of the Andalusia Region (South of Spain). Journal of Marine Science and Engineering	https://doi.org/10.3390/jmse8090684.

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5.2. Results

Section 1: Technological, current regulations (EU, national) and policy trends in Country.

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

EU ANALYSIS

This report presents the findings and analysis from documentary research on current trends, barriers, and best practices for implementing the circular economy in the European aquaculture sector. Waste management practices, existing gaps, and legal, environmental, economic, and social challenges the sector faces are examined. The transition towards circularity aims to enhance sustainability by optimizing resource use and minimizing waste. However, several challenges hinder this shift, including regulatory gaps and the need for universally accepted assessment methods. The key aspects of this topic are outlined below.

a) Current Trends in the Circular Economy in Aquaculture

The aquaculture sector has made progress in adopting circular economy principles, with the following trends standing out:

- Implementation of waste minimization strategies through optimized input use. Emphasis is placed on reducing waste and improving resource recovery, aligning with the European Green Deal and sustainability goals (Masi et al., 2024).
- There is an increasing use of recycled and biodegradable materials in packaging and equipment. An example of this is integrated multitrophic aquaculture (IMTA), a model that promotes nutrient and waste recycling, enhancing environmental and economic outcomes (Fraga-Corral et al., 2021). Similarly, the study by Checa et al. (2024) focuses on IMTA systems and highlights nutrient management and resource use efficiency as key circularity attributes. However, it notes that the lack of harmonized definitions and standards is an obstacle to quantifying circular practices in aquaculture.
- Innovations in effluent treatment systems to reduce environmental impact.
- Integration of aquaculture by-products into other industries, promoting industrial symbiosis.

b) Barriers to Implementing the Circular Economy

Despite advancements, several barriers limiting the transition to a circular model have been identified:

- Regulatory: There is a lack of harmonization in waste management regulations across EU countries. Existing regulations often do not support innovative circular practices, creating a gap in effective implementation (Masi et al., 2024).
- Economic: High costs associated with adopting circular technologies.
- Technical: Infrastructure limitations for recycling and material reuse.

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- Social: There is a lack of awareness and training in circular economy practices. An example is the study by Verreth et al. (2023), which highlights that current trends in European aquaculture include circular production system design and biomass recycling. Barriers include insufficient presentations on system-based thinking and energy analysis. Best practices involve waste stream valorization and integrating circularity concepts into aquafeed, improving sustainability and resource efficiency.
- Research: Limited research on certain circularity principles, particularly in aquaculture, restricts the development of effective strategies (Chary et al., 2023).

c) Best Practices on sustainable management

Based on the research, the following best practices implemented in the sector are highlighted:

- Design of durable and recyclable products. Implementing practices that support nutrient recovery at various scales can significantly reduce waste (Chary et al., 2023). Similarly, the study by Pandit et al. (2023) highlights the growing dependence on agricultural feed, increased phosphorus emissions, and low phosphorus use efficiency in Norwegian aquaculture. In this study, best practices include phytase addition, integrated multi-trophic aquaculture, and sludge collection, while barriers include phosphorus accumulation and existing infrastructure challenges.
- Closed-loop water reuse systems to reduce water consumption.
- Intersectoral collaboration for utilizing by-products and waste.
- Use of renewable energy in aquaculture facilities.

SPANISH ANALYSIS

The circular economy in Spain's aquaculture sector is evolving through both technological advancements and policy developments. The main trends focus on enhancing sustainability by reducing waste, improving resource efficiency, and integrating circular principles into aquaculture practices.

a) Technological Trends

- Nutrient Recycling and Waste Reduction: Technologies such as biofilters, bioaccumulation, and multitrophic systems are being explored to recycle nutrients and reduce waste in aquaculture. These methods aim to improve by-product recovery and support sustainable intensification of aquaculture (Campanati et al., 2021).
- Alternative Aquafeed Ingredients: There is a growing trend towards using alternative, sustainable feed ingredients derived from marine organisms like microalgae, bacteria, and macroalgae. This shift aims to reduce reliance on terrestrial agroecosystems and promote circular use of resources in aquafeed manufacturing (Eroldogan et al., 2022).
- Energy Recovery: By-products from aquaculture are being considered for energy generation, which can support land-based recirculating aquaculture systems (RAS) and contribute to more sustainable production methods (Campanati et al., 2021).

b) Policy Trends

- Regulatory Frameworks: The EU's circular economy policies are pushing for high environmental protection standards in aquaculture. However, current regulations may

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limit the implementation of some circular solutions, necessitating adjustments to facilitate the adoption of circular practices (Regueiro et al., 2021).

- Sustainability and Collaboration: There is a push for improved collaboration among stakeholders to create efficient networks along the seafood and aquaculture supply chain. This involves adopting a "nexus thinking" approach to analyze interconnected systems and facilitate the transition to a circular economy (Ruiz-Salmón et al., 2020).
- Addressing Research Gaps: Identifying and addressing research gaps is crucial for advancing circular economy strategies in aquaculture. This includes developing universally accepted methods for assessing the environmental impacts of aquaculture systems (Masi et al., 2024).

***Section 2**: Economic, social, regulatory, research and technical barriers in Country.*

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

a) Economic Barriers

- Cost of Transition: The initial costs associated with adopting circular practices can be high, discouraging businesses from making the shift (Dovgal & O., 2024).

b) Social Barriers

- Cultural Resistance: There is a general lack of consumer interest and awareness about circular economy benefits, which can slow adoption (Kirchherr et al., 2018).

c) Regulatory Barriers

- Regulatory Frameworks: Current EU regulations may restrict the implementation of circular solutions in aquaculture, as they often do not align with circular economy principles (Masi et al., 2024).
- Policy Gaps: There is a need for more supportive policies and frameworks that facilitate circular economy practices, including international standards and government interventions (Masi et al., 2024).

d) Technical Barriers

- Technological Risks: The absence of universally accepted methods for assessing the impacts of aquaculture systems and the lack of technical skills are significant hurdles (Masi et al., 2024).
- Infrastructure Limitations: Inadequate infrastructure to support circular processes, such as waste recycling systems, poses a challenge (Dovgal & O., 2024).

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Section 3: Best practices on sustainable management in Country.

Use of flowcharts, concept maps, and graphs to illustrate findings (if it considers it necessary).

The aquaculture sector in Spain is increasingly adopting circular economy principles, demonstrating viable models through innovative practices and technologies. Key strategies include the implementation of Recirculating Aquaculture Systems (RAS), which significantly reduce water usage and environmental impact, and the integration of product valorization in the canned fish industry, enhancing resource efficiency and sustainability.

Recirculating Aquaculture Systems (RAS)

- RAS recirculate water, minimizing consumption by up to 99% compared to traditional methods. These systems isolate farmed fish from natural populations, reducing disease transmission and pollution risks. The integration of aquaponics allows for simultaneous vegetable production, creating a closed-loop system that maximizes resource use (Badiola et al., 2024).

Canned Fish Industry Innovations

- Spain's canned fish sector has evolved through a robust legal framework and increased collaboration, fostering circular economy practices. The establishment of research centers has driven innovation in product valorization, enhancing sustainability and economic viability (Fernández-González et al., 2024).

Integrated Aquaculture Development

- In Andalucia, efforts have been made to integrate aquaculture with other coastal activities. This includes addressing legislative and social challenges to improve acceptance and integration with existing economic activities, thereby enhancing the social acceptability of aquaculture (Cavallo et al., 2020).

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5.3. Conclusions and recommendations

Section 1: Propose a roadmap for advancing circular economy in (Country) aquaculture.

Spain's aquaculture sector is increasingly adopting circular economy principles through technological innovations like nutrient recycling and alternative feed ingredients, alongside policy efforts to enhance sustainability and collaboration. However, regulatory challenges and research gaps remain areas that need attention to fully realize the potential of circular aquaculture.

The implementation of a circular economy in Spanish aquaculture is hindered by financial, cultural, regulatory, and technical barriers. Addressing these challenges requires coordinated efforts across policy-making, market development, and technological innovation to create enabling conditions for sustainable practices.

The sector faces significant gaps in infrastructure, regulation, and financing. It is necessary to:

- Develop economic and fiscal incentives to promote the transition to circularity.
- Establish standardization mechanisms for practices and certifications at the European level.
- Strengthen research and development in recycling technologies applicable to aquaculture.
- Promote training and awareness programs on the circular economy.

The circular economy represents a key opportunity to enhance the sustainability of aquaculture in Europe. To advance its implementation, it is recommended to:

- Align national regulations with EU circularity objectives.
- Increase investment in reuse and recycling technologies.
- Encourage collaboration among sector stakeholders to share knowledge and experiences.
- Promote the adoption of business models based on circularity and resource efficiency.

Section 2: Identify research gaps and areas for future study.

Despite these advancements, challenges remain, such as regulatory voids and the need for universally accepted assessment methods for circularity in aquaculture (Masi et al., 2024). Addressing these issues is crucial for the continued success of Spain's aquaculture sector.

This report provides a comprehensive overview of the current state and challenges of the circular economy in European aquaculture, serving as a foundation for future implementation strategies.

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6. Europe

Answer to Question 1: What are the current main technological and policy trends in the circular economy applied to European aquaculture?

The EU aquaculture sector is increasingly embracing circular economy principles to align with the European Green Deal and the Farm to Fork Strategy (European Commission, 2022; IfishcIENCi, 2022; Europarl, 2023). These strategies highlight aquaculture's potential as a low-carbon protein source and its role in sustainable food systems (European Commission, 2022). The sector focuses on pollution reduction, climate change mitigation, and ecosystem preservation (EEA, 2021; European Commission, 2022).

Key Technological Trends:

- Waste-to-Resource: Repurposing aquaculture waste through reuse, recycling, and valorization (IfishcIENCi, 2022; StartUs Insights, 2021).
- Circular Feed Production: Enhancing circularity in feed production by valorizing aquaculture waste such as effluent and sludge (IfishcIENCi, 2022).
- Innovative Techniques: Developing controllable production systems and circular feed materials (Europarl, 2023).
- Integrated Multi-Trophic Aquaculture (IMTA) and Recirculating Aquaculture Systems (RAS): Implementing systems integrating fed and extractive species to recover nutrients (IfishcIENCi, 2022).
- Monitoring and Valorization: Tracking nutrient assimilation and waste bioremediation to improve feed formulations (IfishcIENCi, 2022).

Key Policy Trends:

- Strategic Guidelines by the European Commission promote sustainable and competitive aquaculture (European Commission, 2022).
- Funding via the European Maritime and Fisheries Fund (EMFAF) supports circular initiatives (European Commission, 2022; IfishcIENCi, 2022).
- Cross-sector collaboration encourages synergies between agriculture and aquaculture (IfishcIENCi, 2022).
- Streamlined regulations facilitate establishing circular aquaculture operations (IfishcIENCi, 2022).
- Development of circularity indicators to assess aquaculture performance (IfishcIENCi, 2022).
- Legislative reviews to enable circular solutions (IfishcIENCi, 2022).
- Integration of circularity in EU missions like "Restore our Ocean and Waters" (IfishcIENCi, 2022).

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Answer to Question 2: What Economic, social, regulatory, and technical barriers do companies and organizations face in implementing circular economy in European aquaculture?

Implementation faces economic, social, regulatory, and technical challenges (Europarl, 2023; UvaDoc, 2021):

- Economic Barriers: High investment costs and limited funds, especially for small-scale fishers, coupled with high recycling costs and low prices for virgin materials (Europarl, 2023; EEA, 2021).
- Social Barriers: Limited consumer awareness and preference for new products; traditional mindsets hinder innovation (EEA, 2021; Europarl, 2023).
- Regulatory Barriers: Complex laws, eligibility restrictions for funding, administrative burdens, and gaps in energy efficiency regulations (Europarl, 2023; IfishcIENCi, 2022).
- Technical Barriers: Need for port infrastructure upgrades, specialized expertise, lack of universal recycling technologies, and difficulty recycling mixed-material fishing gear (Europarl, 2023; UvaDoc, 2021).

Answer to Question 3: What best practices and successful strategies in Europe demonstrate the viability of an aquaculture model based on a circular economy?

Europe has several examples showcasing circular aquaculture viability (IfishcIENCi, 2022; SirkAQ, 2023):

- Digital Product Passports (DPP): The SirkAQ project created the first DPP for circular plastics in aquaculture, enabling traceability and reuse of fish farming materials (SirkAQ, 2023).
- Waste Valorization: Land-based RAS and (semi) closed sea farms recover nutrients for algae growth and support zero-waste approaches (European Commission, 2022).
- Circular Feed Management: Using circular ingredients and improving feed efficiency through stage-matched formulations and digestibility (European Commission, 2022).
- Integrated Multi-Trophic Aquaculture (IMTA): IMTA combines species to optimize nutrient cycling and bioremediation (European Commission, 2022).
- Policy and Funding Support: Simplified regulations and incentives via funds like EMFAF and EAFRD encourage circular projects (European Commission, 2022).

These strategies align with the European Green Deal and promote sustainable food systems and bioeconomy development (European Commission, 2022).

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SECTION 2 – A.1.2 SURVEYS

1. Introduction

This documentary research study is part of WP2: Roadmap for Transitioning European Aquaculture toward a more Sustainable and Circular Model, which aims to lay the fundamental foundations for the development of a roadmap that will serve as a strategic transformation plan to support the transition towards a more circular and sustainable aquaculture industry.

To achieve this, the work begins with the development of Activity **A1: Fieldwork Activities,** which includes surveys within aquaculture farms to gather data on existing waste management practices, including types of waste and byproducts generated, current level of knowledge and available training.

2. Objectives

- Obtain data on existing waste management practices, including the types of waste and by-products generated.
- The current level of knowledge and training available.
- The implementation of the circular economy in European aquaculture.

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3. Spain

3.1. Questionnaire on waste/by-product management, circularity, and sustainability in aquaculture(ESRS E5 based)

1. General Company Information

1.1. Company name:

Answer: The names of the participating entities are: Insuiña, Carpeix Pollença S.A.T., Universidad Politécnica de Madrid, AVRAMAR ESPAÑA ACUICULTURA SL, and FUTUNA BLUE ESPAÑA S.L.

1.2. Location of production facilities (country, region):

Answer: The surveyed entities are geographically diverse, including companies located in Galicia, Pollença (Mallorca), Alicante, and El Puerto de Santa María (Cádiz), as well as a university based in Madrid. This distribution provides a broad representation of different aquaculture contexts across Spain, encompassing both continental and marine environments.

1.3. Company size (small, medium, large according to EU criteria):

Answer: Of the five surveyed entities, three are small-sized companies and one is a medium-sized company. The remaining entity is a university that operates its own fish farm, contributing a valuable research and training perspective to the study.

1.4. Type of aquaculture practiced (marine, continental, mixed):

Answer: All five respondents represent different aquaculture systems practiced in Spain. Three of them operate in continental aquaculture. One company practices marine aquaculture with land-based facilities, while another operates in offshore marine aquaculture.

1.5. Cultivated species:

Answer: One of the surveyed entities focuses exclusively on the farming of turbot (Scophthalmus maximus). Another company works with various species that are raised but not actively cultivated, including royal carp, koi carp, tench, and carassius, which are more commonly associated with ornamental or extensive aquaculture systems. The university respondent farms a mix of salmonids,

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cyprinids, and exotic ornamental fish, reflecting a diverse continental aquaculture setup. The fourth company specializes in the cultivation of sea bass (Dicentrarchus labrax), sea bream (Sparus aurata), and meagre (Argyrosomus regius). Finally, one entity is dedicated to the production of Seriola sumerili.

1.6. Environmental certifications obtained (e.g., ASC, MSC, ISO 14001):

Answer: Only two of the surveyed entities reported holding environmental certifications. One company is certified with Global GAP, IFS, ISO 14001, and EMAS, demonstrating a strong commitment to quality, environmental management, and sustainability standards. The other holds ASC and ISO 14001 certifications, aligning with international benchmarks for responsible aquaculture and environmental performance.

2. Circular Economy Policies and Strategies

2.1. Does the company have a formal resource use and circular economy policy? (Yes/No)

Answer: Three of the surveyed entities indicated that they implement circular economy practices within their operations, such as resource efficiency, waste reduction, and reuse or recycling of materials. The remaining two entities reported that they do not currently apply circular economy strategies.

2.2. If yes, which of the following aspects does it cover? (Check all that apply)

Answer: According to the responses, this policy covers several key aspects: efficient use of resources and waste minimization are both addressed by 66.7% of respondents. Additionally, all respondents (100%) indicated that the policy includes recycling and reuse of materials. Other aspects such as the elimination of hazardous materials and the supply of sustainable materials are also covered, each mentioned by 33.3% of respondents.

2.3. Have quantifiable objectives related to the circular economy been established? (Yes/No)

Answer: Two of the surveyed entities indicated that they have established quantifiable targets related to the circular economy. The remaining two entities reported that they do not currently apply circular economy strategies.

2.4. If yes, specify the objectives:

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Answer: The only company that has responded, has set ambitious goals aimed at achieving a 100% reduction in waste generation and water consumption.

3. Types of Waste and By-products Generated

3.1. What are the main wastes generated in production? (Check all that apply and specify estimated quantities in tons/year)

Answer: The main wastes generated in production vary depending on the type of aquaculture operation. Among the shellfish companies, organic waste is a primary byproduct, with one company reporting that it mainly consists of oyster shells, while another estimates generating approximately 3–4 tons per year. Additionally, all shellfish companies generate plastic waste, primarily composed of polypropylene nets (tubular "socks"), floats, and polyethylene (PE) oyster containers. Only one company produces hazardous waste, which includes batteries, oils, contaminated containers, laboratory residues, and chemical products, amounting to an estimated 1.5 tons per year. Metal waste, such as anchors, chains, and structural materials, is also reported, with a total estimated generation of around 40 tons per year across operations. Regarding wastewater containing contaminants, no significant generation is reported by most companies, except for one that mentions the presence of organic matter and residues of domestic disinfectants, although no specific quantity is provided. In finfish farms, other types of waste are observed, such as feed bags, disposable clothing used in processing plants (gowns, gloves, caps, sleeves), and various packaging materials. In the case of extensive farming systems, waste generation associated with fish farming is considered negligible.

3.2. Are the organic wastes generated reused or recycled? (Yes/No) - If yes, how? (e.g., composting, feed for other animals, biodigesters)

Answer: When asked whether the generated organic waste is reused or recycled, only 20% of respondents (1 out of 5) indicated that they do reuse or recycle their organic waste. The remaining 80% (4 out of 5) reported that they do not reuse or recycle such waste. Among those who reuse or recycle, the primary methods mentioned include composting, improving soil structure, and using the waste as fertilizers. This highlights a significant opportunity for increased recycling and sustainable management of organic waste in the industry.

3.3. Does the company separate waste at source? (Yes/No)

Answer: Four out of five companies separate waste at source.

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3.4. What percentage of the waste generated is destined for recycling or reuse? (%)

Answer: One respondent indicated that approximately 40% of the waste is recycled or reused, while another reported that 100% of their waste is managed in this way. However, some respondents expressed uncertainty. Another response specifically mentioned that 100% of plastic and net waste is recycled or reused, but no other types of waste are handled in this manner. Finally, one respondent marked "N/A," indicating that they did not provide a specific percentage. This suggests a mixed approach to waste management, with some companies actively recycling significant portions of their waste, while others either lack clear data or do not prioritize recycling for all materials.

3.5. What are the main sources of generation of these wastes and by-products generated? (you may select several):

Answer: As for the sources of waste, respondents identified several key areas contributing to the generation of waste and by-products. The least significant source was "Processing Operations/Packaging," which was rated as "not Important" by four respondents. Feeding practices were also considered relevant, with two respondents rating them as "Moderately Important" and one as "Important." Infrastructure and equipment ranked as "Important" and "Slightly Important" according to two companies for each, while another reported it as "Not Important." Maintenance and repair activities were identified as a significant source of waste by one company, which rated it as "Very Important," and as "Moderately Important" by another. Water treatment processes were also considered to play a role, with two respondents classifying them as "Moderately Important."

3.6. Classify the waste and by-products generated based on the type of management:

Answer: When classifying the generated waste and by-products based on their management type, the data reveals distinct patterns in how these materials are handled. The largest portion of waste is described as being "Collected by authorized waste management entities," with four responses indicating this as the primary method of disposal. This suggests that a significant amount of waste is managed through regulated and official channels, ensuring proper handling and compliance with environmental standards.

A smaller portion of waste is classified as being "Disposed of by the producing company," with only one response indicating this practice. This implies that in some cases, companies manage the final disposal of their own waste, potentially through methods such as controlled burning or landfilling on-site.

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Another category involves waste being "Sent to recycling companies," with two responses noting this approach. This indicates that while not the most common method, some companies do engage in recycling practices, contributing to more sustainable resource use.

Lastly, the option "Reused as a secondary product" was selected by one respondent, suggesting that certain types of waste are repurposed into new products or used for other purposes. However, this practice appears to be less common among the surveyed companies.

Overall, the data shows that the majority of waste is managed through authorized collection services, while recycling, reuse, and self-disposal methods are less widespread. This highlights the need to promote more circular approaches, such as increasing recycling and finding valuable uses for by-products.

4. Waste Management and Circularity

4.1. What strategies does the company use to reduce waste? (Check all that apply)

Answer: The most commonly adopted strategy is "Material reuse in processes," with four respondents (80%) indicating that they utilize this approach. This suggests that companies are actively focusing on reusing materials within their operations as a primary method to minimize waste generation.
Another significant strategy is "Optimization of information usage" and "Programs for raising awareness and training staff," each adopted by three respondents (60%). These findings highlight the importance of leveraging data and educating employees about sustainable practices to drive waste reduction efforts.
Two respondents (40%) reported using "Innovation in packaging and packaging methods," indicating that some companies are exploring more efficient or environmentally friendly packaging solutions. However, only one respondent (20%) mentioned the use of "Biodegradable materials," suggesting that while some companies are exploring sustainable alternatives, this practice is not yet widely adopted.

Interestingly, "Material reuse in processes" stands out as the most frequently implemented strategy, reflecting a strong focus on operational efficiency and resource optimization. In contrast, the adoption of biodegradable materials remains limited, possibly due to cost, availability, or other challenges.

Overall, the data shows that companies prioritize strategies such as material reuse, optimizing information usage, and raising employee awareness, while innovation in packaging and the use of biodegradable materials present opportunities for further improvement in waste reduction efforts.

5. Use of Materials and Resources

5.1. What are the main inputs used in production? (Check all that apply and specify estimated quantities in tons/year)

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Answer: One of the key categories analyzed is plastics and synthetic materials, which are widely used across operations. Foam boxes are reported to be used in significant quantities, with one company indicating an annual consumption of 85 tons. Other plastic items commonly used include nets and feed sacks, although specific quantities are not always provided. It is also noted that at least one company does not use packaging materials, suggesting some variation in operational practices.

In terms of energy consumption, electricity is the primary energy source used. One company reports an annual electricity consumption of 13,000,000 kWh, while another indicates a combination of conventional electricity and solar (photovoltaic) energy. Another respondent notes an annual usage of 60,000 kWh and confirms the use of both electricity and solar power. Additionally, one company receives its electricity supply directly from a university's main grid, showing that energy sources may vary depending on infrastructure availability and sustainability initiatives.

When it comes to chemical products, the most commonly used substances are detergents and disinfectants. One company reports using approximately 350 tons per year of these products, mostly for cleaning and sanitation purposes. Another company specifies the use of authorized disinfectants only, indicating compliance with regulatory standards. A third respondent provides more detailed figures, stating the use of 189,000 liters of formaldehyde and 630 liters of disinfectants annually. However, there is also at least one company that does not use any chemical products, highlighting differences in operational approaches and possible alternative hygiene or maintenance methods.

Regarding freshwater usage, the data shows varied consumption levels. One company reports using around 20,000 m^3 per year, accounting for losses due to evaporation, agricultural irrigation, and minor leaks. Another company uses 600 m^3 per year, while a third mentions operating with an open water circuit. In contrast, one respondent indicates that seawater is not applicable in their farming system, while another reports using 175,200 m^3 of seawater per year (equivalent to 20 m^3 per hour), reflecting different production environments such as freshwater versus marine-based aquaculture.

Finally, feed inputs represent a major component of production, especially in finfish farming. Commercial feed is widely used, with one company reporting an annual consumption of 3,700 tons. Another mentions using 400 kilograms of feed per year, likely indicating a smaller-scale operation. A more detailed breakdown reveals that 2,560,000 tons of feed are used annually, composed of 65% fishmeal and 35% fish oil, although this figure seems unusually high and may reflect a typo or misinterpretation. Another company reports using 18 tons of feed per year, showing a wide range in feed requirements depending on the scale and species being farmed.

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6. Effluents and Water

6.1. How much water does the company use annually? (m^3/year)

Answer: The survey results indicate that the five companies exhibit significant variation in their annual water usage, with differences observed in both freshwater and seawater consumption.

One company reported using 20,000 m^3 per year, suggesting substantial freshwater consumption likely due to large-scale operations or intensive processes. Another company stated that they do not know their freshwater usage, indicating a lack of accurate measurement or record-keeping systems. A third company reported using 6,000 m^3 per year, reflecting moderate consumption, while a fourth company indicated much lower usage at 600 m^3 per year, which could be attributed to smaller-scale operations or more efficient water management practices.

One company reported using 175,200 m^3 per year of seawater. This significantly higher volume compared to freshwater usage suggests that this company operates in an industry heavily reliant on seawater, such as marine aquaculture, coastal processing, or other activities involving open-water systems.

The responses reveal notable variations in freshwater usage, ranging from 600 m^3/year to 20,000 m^3/year. This disparity could be due to differences in operational scale, production processes, or geographical factors (e.g., regions with limited access to freshwater). The high seawater dependency highlighted by one company underscores its importance in certain industries, particularly those related to marine environments. Additionally, the lack of data from one company regarding freshwater usage highlights the need for improved monitoring and reporting mechanisms to ensure accurate tracking of water consumption.

These findings emphasize the diverse water usage patterns among companies, depending on their specific industries and operational needs. While some companies demonstrate high levels of water consumption, others show more efficient use or rely primarily on alternative sources like seawater. These insights can inform targeted efforts to improve water efficiency and sustainability across different sectors.

In summary, the survey reveals significant differences in water usage among the five companies, with notable variations in both freshwater and seawater consumption.

6.2. Is water reused in production processes? (Yes/No)

Answer: Among all the shellfish companies, only one does not reuse water in production processes.

6.3. Has the company implemented effluent treatment systems? (Yes/No)

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Answer: Only one company answered that they do not implement effluent treatment systems.

7. Economic and Financial Impact

7.1. Has the company evaluated the costs associated with waste management and circularity? (Yes/No)

Answer: Only three companies have evaluated the costs associated with waste management and circularity, the other three did not.

7.2. Have economic incentives or subsidies been received for implementing circular practices? (Yes/No)

Answer: None of the companies has received incentives or subsidies for the implementation of circular practices.

8. Transparency and Reporting

8.1. Is there any public reporting on sustainability and waste management? (Yes/No)

Answer: Only two among the companies present a public report on sustainability and waste management, while the others do not.

8.2. Have key performance indicators (KPIs) been established for circularity and sustainability? (Yes/No)

Answer: Just one of the companies has established key performance indicators.

9. Final Comments

9.1. What are the main challenges the company faces in waste management and circularity?

Answer: The companies identified a range of challenges related to circularity and waste management, highlighting different operational realities and levels of progress in sustainability practices. One company does not publish its own environmental report but is part of Grupo Pescanova, which includes such

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information in its annual report, suggesting a reliance on the parent group's reporting systems rather than independent tracking of circular economy goals and waste performance. Another entity pointed out that the main challenge lies in understanding and applying current legislation, citing as an example the goal of eliminating expanded polystyrene (porex) boxes by 2030. This reflects the difficulty of keeping up with evolving regulations and implementing sustainable alternatives. A third company stated that it no longer faces major challenges, as it has been operating for over 40 years and has now closed due to retirement, indicating that many issues had already been addressed during its long activity period. In contrast, another company noted that "there is still almost everything left to do," revealing that it is at a very early stage in adopting circular practices and managing waste effectively. Finally, a fifth company highlighted three specific areas of challenge: improving water quality to ensure optimal conditions for fish health, using water more efficiently through recirculating aquaculture systems (RAS), and better managing the waste generated by farmed organisms to reduce environmental contamination.

9.2. What type of support (technical, financial, regulatory) is considered necessary to improve in these areas?

Answer: The responses show a shared recognition of the need for different types of support to advance in circularity and waste management. Several companies emphasized the importance of technical training as a key form of assistance, pointing to the need for updated knowledge and specialized skills to implement more sustainable solutions. Some companies indicated that support should be comprehensive, including technical, financial, and regulatory aspects, suggesting that a multi-dimensional approach is essential for making meaningful progress. Others specifically highlighted the importance of financial and regulatory support, recognizing that without economic incentives or clear legal frameworks, it can be difficult to invest in cleaner technologies or infrastructure for waste reduction and reuse. Technical assistance was also frequently mentioned, particularly in relation to process innovation and the adoption of new tools and systems. Overall, the companies expressed that a balanced combination of these forms of support is crucial to overcoming existing barriers and promoting an effective transition toward more circular and environmentally responsible production models.

10. Training and Education

10.1. Has your staff received specific training on circularity?

A. Efficient water management

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a) Reuse and recycling of water through aquaculture recirculating system (RAS), which allow for filtering and purifying water to reduce consumption and effluent discharge into the environment

Answer: Just one of the company's staff did not receive training on reuse and recycling of water. One of the companies which has received training says that they are references and they participate in the diffusion of knowledge in this area.

b) Capture and treatment of dissolved nutrients in water to prevent eutrophication of nearby ecosystem

Answer: Three of the companies' staff received training on capture and treatment of dissolved nutrients in water.

B. Utilization of organic waste/by-products

a) Transforming solid waste (feces, uneaten feed) into useful products, such as organic fertilizers for agriculture or raw materials for biogas

Answer: Two companies among the interviewed answered that their staff received training on the transformation of solid waste into useful products. One of them produces Intensive phyto and zooplankton (own system: "in situ")

b) Use of filter organisms, such as mussels or algae, to capture excess nutrients and improve water quality

Answer: Just one company's staff received training on the use of filter organisms.

C. Utilization of organic waste

a) Transforming solid waste (feces, uneaten feed) into useful products, such as organic fertilizers for agriculture or raw materials for biogas

Answer: Three companies answered the question saying that none of their staff received training on the transformation of solid waste into useful products.

b) Use of filter organisms, such as mussels or algae, to capture excess nutrients and improve water quality

Answer: Just one company's staff received training on the use of filter organisms.

D. Integrated multi-trophic aquaculture (IMTA)

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a) Combining species at different trophic levels (fish, crustaceans, mollusks, algae) to utilize by-products from one as resources for others. For example, algae absorb nutrients generated by fish, and in turn, can be used as food or input for other processes

Answer: Two farming staff receive training on the combination of species at different trophic levels, while three say that none of their staff received training about the subject. Moreover, one of the companies points out that they own their own system "Lagunado dinámico para la depuración de efluentes".

E. Feed optimization

a) Using feed formulated with sustainable ingredients, such as by-products from fishing, insect meal, or plant based proteins, instead of relying solely on fish meal and oils

Answer: Three companies answered that their staff received training on using feed with sustainable ingredients.

b) Minimizing feed conversion rates to reduce waste

Answer: All companies answered that all of their staff received training on minimizing feed conversion rates, making specific training on this point.

F. Renewable energy and energy efficiency

a) Implementing solar panels, wind turbines, or other renewable technologies to meet the farm's energy needs.

Answer: Four companies answered that their staff received training on the implementation of renewable technologies.

b) Optimizing pumping and heating/cooling processes to reduce energy consumption

Answer: Three farms answered that their staff received training on optimization of pumping processes to reduce energy consumption.

G. Co-product valorization

a) Extracting and valorizing high-value biomolecules (collagen, fatty acids, antioxidants) from fish and mollusks by products such as shell and byssus

Answer: None farming staff receive training on the extraction and valorization of high-value biomolecules.

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b) Generating additional products like functional foods, cosmetics, or supplements from farm by-products

Answer: Any staff employed by one among farms receive training on the generation of additional products. This statement shows that there is little knowledge on the subject.

H. Collaborative economy approach

a) Establishing synergies with agricultural, livestock, or industrial sectors to exchange waste or by-products that can be mutually used

Answer: Four companies answered that none of their staff received training on synergies with other sectors. One of the companies points out that thay apply their own technology of "lagunado dinamico" in agritourism and similar.

10.2. Has your staff received specific training on waste management and by-products Generated? (Yes/No)

a) Organic waste (e.g fish remains, algae, uneaten feed)

Answer: Four companies answered that their staff received training on waste management and by-products generated by organic waste.

b) Plastics (e.g. nets, buoys, packaging)

Answer: Two companies answered that their staff received training on waste management and by-products generated by plastic.

c) Metals (e.g structures, cages)

Answer: Two companies answered that their staff received training on waste management and by-products generated by metals.

d) Hazardous waste (e.g chemicals, pharmaceuticals)

Answer: One company answered that none of their staff received training on waste management and by-products generated by hazardous waste, while four stated that their staff received specific training about the topic.

e) Wastewater with contaminants

Answer: Three companies answered that their staff received training on waste management and by-products generated by wastewater with contaminants.

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10.3. Do you consider that further education and awareness-raising on these topics is necessary? And why?

Answer: All five entities consulted agreed that further education and awareness-raising on these topics is necessary. Their responses were unanimous, emphasizing its importance for the development of the aquaculture industry and reinforcing the need for continued efforts in this area.

The entities emphasized that education and awareness-raising are essential because current knowledge is limited and general awareness remains weak. Despite ongoing efforts, issues such as improper waste segregation persist. They agreed that education is no longer a matter of choice or corporate philosophy, but a pressing necessity. Enhancing training not only improves environmental management but also strengthens the aquaculture industry by promoting sustainability, social and ecological responsibility, and the adoption of innovative, more efficient practices.

10.4. What type of training would you consider most useful for your company?

Answer: The results are presented across six categories, with each bar representing how five different companies rated the importance of each training modality. The responses range from "Not Important" to "Very Important".

When analyzing the responses related to theoretical training, it is observed that most companies consider this type of training to be moderately important. Three companies classified it as such, one considered it important, and one marked it as not important at all. This suggests that while theoretical knowledge has some value, it is not seen as the most essential form of training for these businesses.

In contrast, practical training receives the highest overall level of positive evaluation. Three companies rated it as important, and two others considered it moderately important and very important. This indicates a clear preference for hands-on learning experiences that can be directly applied in daily operations, highlighting its relevance for skill development and problem-solving in real work environments.

Regarding in-person training, the majority of companies view it as important, with two respondents selecting this category. Two other companies rated it as very important and moderately important, showing that face-to-face instruction remains a valued method, especially for fostering interaction and engagement among participants.

When it comes to e-learning or online training, the perception is more varied but generally less favorable. Only one company rated it as important and another as slightly important, while other companies considered it not important at all. This low valuation could suggest that online formats are not seen as effective or suitable for the specific needs of these companies, possibly due to lack of interactivity or practical application.

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Training focused on water treatment also appears to be of limited interest to most respondents. One company found it important, another considered it moderately important, and the remaining three marked it as very important. This may indicate that water treatment topics are not a priority for many of the surveyed companies, perhaps because they either already have sufficient expertise or the subject does not align closely with their operational focus.

Finally, hybrid training, which combines in-person and online methods, was rated positively by all respondents. Two companies considered it important and three labeled it as not important, slightly important and very important. This shows a general openness to flexible training models that combine the benefits of direct interaction with the convenience of digital learning tools.

3.2. Results

The survey highlights several key findings regarding sustainability, circular economy practices, and training needs in small to medium-scale aquaculture enterprises. Among the five surveyed companies, three are small-sized, one is medium-sized, and one is a university-operated fish farm. The operations include continental, marine, and mixed systems, with species ranging from turbot and salmonids to sea bass, sea bream, meagre, and ornamental fish.

Only two companies hold environmental certifications such as Global GAP, ISO 14001, ASC, or EMAS, and only one publishes public sustainability reports or has established measurable KPIs for circularity and sustainability. Three companies implement some form of circular economy policy, focusing on resource efficiency, waste reduction, and reuse or recycling of materials, but only one has set quantifiable goals—aiming at a 100% reduction in waste generation and water consumption.

The main wastes generated include organic waste (such as oyster shells and fish remains), plastic waste (nets, floats, packaging), metal waste (anchors, cages), hazardous waste (batteries, chemicals), and wastewater. While some companies report high levels of waste recycling—especially for plastics—most rely on authorized waste management services. Organic waste is rarely reused or recycled, with only 20% of respondents engaging in composting or soil improvement.

Water usage varies widely, from 600 to 20,000 m^3/year for freshwater and up to 175,200 m^3/year for seawater. Most companies use recirculating aquaculture systems (RAS) or implement effluent treatment systems to improve water quality and reduce consumption. Four out of five companies separate waste at source, indicating basic waste management discipline.

Training needs differ by operation type and scale, but practical, hands-on training is consistently preferred over theoretical instruction. All companies have trained staff in minimizing feed conversion rates, while fewer have focused on sustainable feed ingredients, water treatment, or by-product valorization. Training

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on renewable energy and energy efficiency is more widespread, though co-product valorization and integrated multi-trophic aquaculture (IMTA) remain underdeveloped areas.

All five entities agree that further education and awareness-raising efforts are necessary. They emphasize that current knowledge is limited and awareness remains weak, despite existing initiatives. Technical training, especially related to process innovation and new technologies, is considered essential alongside financial incentives and clearer regulatory frameworks.

Financial and regulatory support are frequently cited as essential for advancing circular economy goals. None of the companies have received economic incentives for implementing sustainable practices, and bureaucratic barriers are seen as a major constraint, especially concerning recyclable materials.

In summary, while there is general awareness of sustainability challenges and opportunities, concrete actions remain fragmented. Shellfish companies show more structured approaches to waste management and circular practices, while finfish farms exhibit more informal but promising behaviors. Extensive aquaculture operations naturally align with low-waste principles. However, widespread adoption of best practices requires greater investment in training, improved access to funding, and supportive regulations that encourage innovation and compliance.

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4. Italy

4.1. Questionnaire on waste/by-product management, circularity, and sustainability in aquaculture (ESRS E5 based)

1. General Company Information

1.1. Company name:

1.2. Location of production facilities (country, region):

Answer: Two shellfish companies present their production facilities in Veneto (Italy), one in Emilia-Romagna (Italy), one in Emilia-Romagna and Marche (Italy) and one in Sardinia and Veneto (Italy). Finfish farms interviewed are in different regions: Friuli V.G., Lombardy, Tuscany and Veneto (Italy).

1.3. Company size (small, medium, large according to EU criteria):

Answer: All five shellfish companies are small size enterprises. Of the 4 finfish farms, two are small businesses, two are medium-sized.

1.4. Type of aquaculture practiced (marine, continental, mixed):

Answer: All five shellfish companies practice marine aquaculture. The four finfish farms represent a cross-section of the different types of Italian farming: two freshwater plants (with different species and different water supply sources), a mariculture company (with a land-based and an off-shore farm), a traditional extensive farm in brackish water.

1.5. Cultivated species:

Answer: One of the investigated shellfish companies cultivates only oysters (*Magallana gigas* and *Ostrea edulis*), another focuses solely on Mediterranean mussels (*Mytilus galloprovincialis*), while a third cultivates both *Mytilus galloprovincialis* and *Magallana gigas*. The remaining two companies farm both Mediterranean mussels (*Mytilus galloprovincialis*) and clams (*Ruditapes philippinarum*), though they provided responses only regarding mussels.

In fact, over the past two years, clam production has declined along the Adriatic coast due to the spread of the blue crab and extreme weather events, such as the May 2023 flood, which altered the ecological conditions of the waters. As a result, these two companies have shifted their primary focus to mussel farming. However, waste management practices remain largely the same for both types of farming. One

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of the freshwater finfish farms breeds rainbow trout and minor salmonids (brook trout and whitefish), the other several species of sturgeon (Acipenseridae); the other two companies farm sea bass and sea bream in different environments and with different technologies.

1.6. Environmental certifications obtained (e.g., ASC, MSC, ISO 14001):

Answer: Only two shellfish companies have environmental certifications, which are sustainable aquaculture and organic products from sustainable aquaculture.

As regards finfish farms: the two in fresh water do not have any certification, the mariculture company has the national certification of zootechnical sustainability (SQN): "sustainable aquaculture", the productions of the one in brackish water are certified "Organic".

2. Circular Economy Policies and Strategies

2.1. Does the company have a formal resource use and circular economy policy? (Yes/No)

2.2. If yes, which of the following aspects does it cover? (Check all that apply)

Answer: Four of the shellfish companies have formal resources use and a circular economy policy, which includes efficient use of resources, waste minimization, recycling and reuse of material and elimination of hazardous materials. Other investigated aspect (supply of sustainable inputs) is not covered. Two out of four of the finfish companies have formal resources use and a circular economy policy including efficient use of resources, waste minimization, use of sustainable resources and elimination of hazardous materials.

2.3. Have quantifiable objectives related to the circular economy been established? (Yes/No)

2.4. If yes, specify the objectives:

Answer: Only one of the survey-involved enterprises, a shellfish company, has established quantifiable objectives related to the circular economy, which are waste reduction target (80% per year) and material reuse target (80% per year).

3. Types of Waste and By-products Generated

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3.1. What are the main wastes generated in production? (Check all that apply and specify estimated quantities in tons/year)

Answer: Two of the shellfish companies stated that the main waste generated in production is organic waste; one reports that it mainly consists of oyster shells, while another says that 3-4 tons are generated per year. In addition, all the shellfish companies generate plastic waste, primarily consisting of polypropylene nets (tubular nets, also called 'socks'), floats, and polyethylene (PE) oyster containers.

Lastly, only one company produces hazardous waste, which consists of batteries. As for other types of waste, such as metals and wastewater containing contaminants, none of the companies generate them. The variety of waste generated in finfish farms varies greatly depending on the type of farm: feed bags/big bags; disposable clothing in processing plants (gowns, gloves, caps, sleeves); various packaging.

In the case of extensive farming, the waste production associated with fish farming is negligible.

3.2. Are the organic wastes generated reused or recycled? (Yes/No) - If yes, how? (e.g., composting, feed for other animals, biodigesters)

Answer: Even if all shellfish companies declare that organic waste is not reused or recycled, one company confirms that the organic waste is regenerated in the sea. All the intensive finfish farms allocate animal by-products (dead fish or processing trimmings) for reuse in accordance with current legislation.

3.3. Does the company separate waste at source? (Yes/No)

Answer: All shellfish companies separate waste at source. All the finfish farms separate waste at source.

3.4. What percentage of the waste generated is destined for recycling or reuse? (%)

Answer: A shellfish company answered 80%, another one answered 10%, one enterprise stated that a low percentage of the waste generated is destined for recycling or reuse, and another one stated that they don't know the precise percentage; lastly, one company did not answer. In the intensive fish farms the percentage of recycling or reuse is between 70% to 80%.

3.5. What are the main sources of generation of these wastes and by-products generated? (you may select several):

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Answer: As for the source of waste, two shellfish companies answered that feeding practices are not important. Considering processing operation/packaging, four companies answered, one that this source is moderately important and three that is very important. As for infrastructure and equipment, one company considered them not important, two considered them slightly important and another one moderately important. Only two companies answered on source from maintenance/repair activity and water treatment, considering them respectively slightly important and not important. The mail source for fin fish farming of waste is related to the use of feed.

3.6. Classify the waste and by-products generated based on the type of management:

Answer: While all five shellfish companies stated that waste and by-products generated are collected by authorized waste management entities, only one affirms that waste is also sent to recycling companies, while another affirms that it is also disposed of by the producer and reused as a secondary product. In the case of the intensive finfish farms waste and by-product generated are collected by authorised waste management entities, and sent to recycling companies, while only one affirm that is also disposed of by the producer.

4. Waste Management and Circularity

4.1. What strategies does the company use to reduce waste? (Check all that apply)

Answer: Regarding waste reduction strategies, four shellfish companies optimize input use and reuse materials in their processes, while only one focuses on innovation in packaging and wrapping, along with material reuse. Three companies implement employee awareness and training programs as part of their strategy. As for the use of biodegradable materials, none of the investigated companies adopt this approach.

The strategies used by the intensive fish farms are different and mixed; in the case of the extensive farm there is no answer as the production of waste is negligible.

5. Use of Materials and Resources

5.1. What are the main inputs used in production? (Check all that apply and specify estimated quantities in tons/year)

Answer: Regarding the main inputs in shellfish aquaculture, only one company stated that they cannot quantify the tons of seawater used during production. As for energy, four shellfish companies reported using electricity, diesel, and gasoline. Regarding plastic use, three companies stated that they primarily

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use tubular nets (also called 'socks') made of polypropylene, as well as buoys and ropes. Only one company specified that they use 4 tons of plastic. Feed, freshwater, chemicals and others are not used during the production. In the case of finfish farms there is a specific quantification of the inputs that vary significantly based on the different types of breeding and different production as can be seen in the excel file.

6. Effluents and Water

6.1. How much water does the company use annually? (m³/year)

Answer: Considering shellfish aquaculture, the only one who answered didn't know precisely how much water the company uses annually but a very low amount definitively. Generally, in shellfish farming the only type of water used is seawater, which at the end of processes flows back into the sea. In the case of finfish farms (intensive) there is a completely different use of freshwater that is completely returned to the environment.

6.2. Is water reused in production processes? (Yes/No)

Answer: Among all the shellfish companies, only one reuse water in production processes. Generally, in marine shellfish farming, during the processing steps seawater is taken from the sea and directly used. At the end of the process it flows back into the sea. In Finfish aquaculture there is one farm which reuses water.

6.3. Has the company implemented effluent treatment systems? (Yes/No)

Answer: Only two shellfish companies answered, saying that they do not implement effluent treatment systems. In this type of aquaculture, there is no need for an effluent treatment system, since no wastewater is generated during the processes. In all the three intensive fish farms there is an effluent treatment system.

7. Economic and Financial Impact

7.1. Has the company evaluated the costs associated with waste management and circularity? (Yes/No)

Answer: While two of the shellfish companies have evaluated the costs associated with waste management and circularity, the other three did not. Two finfish farms have evaluated the costs associated with waste management and circularity.

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7.2. Have economic incentives or subsidies been received for implementing circular practices? (Yes/No)

Answer: None of the shellfish and finfish companies has received incentives or subsidies for the implementation of circular practices.

8. Transparency and Reporting

8.1. Is there any public reporting on sustainability and waste management? (Yes/No)

Answer: Only one among the shellfish companies present a public report on sustainability and waste management, while the others and all the finfish farms do not.

8.2. Have key performance indicators (KPIs) been established for circularity and sustainability? (Yes/No)

Answer: None of the shellfish and finfish companies have established key performance indicators.

9. Final Comments

9.1. What are the main challenges the company faces in waste management and circularity?

Answer: All shellfish companies responded to this question, highlighting their interest in the topic.

The first company stated that, given the minimal environmental impact of their operations and the company's reduced activity, they have not yet set specific goals, relying only on common sense in daily energy and waste management.

Another company mentioned that their main challenges are achieving 100% reuse of nets used in mussel farming and finding a compostable biomaterial with similar strength characteristics to polypropylene.

One company identified waste reduction as their primary focus, while another stated that their main challenge is finding materials that enable true circularity.

The last company responded that their biggest challenge is simply staying in business, as bivalve farming is inherently sustainable. Only one of finfish farms identifies the main challenges: costs and regulatory framework.

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9.2. What type of support (technical, financial, regulatory) is considered necessary to improve in these areas?

Answer: The support considered necessary for shellfish companies are a balance set of them, but mostly technical and regulatory support. One company also stated that it would be better to de-bureaucratize management and transport procedures regarding recyclable material. Another highlights the financial support needed in the purchase of more sustainable technical materials.
For the finfish sector the principal supports are needed in the financial/economic area and especially in the harmonization and consistency of the legislation.

10. Training and Education

10.1. Has your staff received specific training on circularity?

A. Efficient water management

a) Reuse and recycling of water through aquaculture recirculating system (RAS), which allow for filtering and purifying water to reduce consumption and effluent discharge into the environment

Answer: None of the shellfish companies' staff received training on reuse and recycling of water, mainly because this concept is not applicable to mussel farming; it is more relevant to fish farming. In only one finfish farm was carried out.

b) Capture and treatment of dissolved nutrients in water to prevent eutrophication of nearby ecosystem

Answer: None of the shellfish companies' staff received training on capture and treatment of dissolved nutrients in water, mainly because this concept is not applicable to mussel farming; it is more relevant to fish farming. Two finfish farms were carried out. One of the shellfish companies pointed out that since they work in a vessel in open sea there is no need to use freshwater.

B. Utilization of organic waste/by-products

a) Transforming solid waste (feces, uneaten feed) into useful products, such as organic fertilizers for agriculture or raw materials for biogas

Answer: Three shellfish companies among the interviewed answered that none of their staff received training on the transformation of solid waste into useful products, while in two finfish farms specific training were carried out.

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b) Use of filter organisms, such as mussels or algae, to capture excess nutrients and improve water quality

Answer: Two shellfish companies' staff received training on the use of filter organisms, while other two say that none of their staff received training in relation to the subject, also because this concept is intrinsically present in bivalve farming. In two finfish farms specific training were carried out.
One of the shellfish companies pointed out that since they work in a vessel in open sea there is no need to use fertilizers in their opinion. In one finfish farm is under evaluation the possibility of applying a phytoremediation process with emerged plants.

C. Utilization of organic waste

a) Transforming solid waste (feces, uneaten feed) into useful products, such as organic fertilizers for agriculture or raw materials for biogas

Answer: Four shellfish companies answered at the question saying that none of their staff received training on the transformation of solid waste into useful products, while in two finfish farms specific training were carried out.

b) Use of filter organisms, such as mussels or algae, to capture excess nutrients and improve water quality

Answer: Two shellfish company's staff received training on the use of filter organisms, while two say that none of their staff received training in relation to the subject, also because this concept is intrinsically present in bivalve farming. In two finfish farms specific training were carried out. One of the shellfish companies pointed out that since they work in a vessel in open sea there is no production of solid waste. In one finfish farm is under evaluation the possibility of applying a phytoremediation process with emerged plants.

D. Integrated multi-trophic aquaculture (IMTA)

a) Combining species at different trophic levels (fish, crustaceans, mollusks, algae) to utilize by-products from one as resources for others. For example, algae absorb nutrients generated by fish, and in turn, can be used as food or input for other processes

Answer: One shellfish farming staff receive training on the combination of species at different trophic levels, while three say that none of their staff received training about the subject. Moreover, one of the shellfish companies points out that they consider it not applicable in shell farming, since this concept is

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intrinsically present in bivalve farming. The only species that could be combined are algae to help capture the carbon dioxide generated by bivalves. Finfish farms have no specific training on this point.

E. Feed optimization

a) Using feed formulated with sustainable ingredients, such as by-products from fishing, insect meal, or plant based proteins, instead of relying solely on fish meal and oils

Answer: Three shellfish companies answered that none of their staff received training on using feed with sustainable ingredients, also because in shellfish farming there is no need for feed since these organisms take nutrients filtering the water that surround them. All the finfish farms that feed fish (3) made specific training on this point.

b) Minimizing feed conversion rates to reduce waste

Answer: Three shellfish companies answered that none of their staff received training on minimizing feed conversion rates, also because in shellfish farming there is no need for feed since these organisms take nutrients filtering the water that surround them. One of the shellfish companies points out that is not applicable in shell farming. All the finfish farms that feed fish (3) made specific training on this point.

F. Renewable energy and energy efficiency

a) Implementing solar panels, wind turbines, or other renewable technologies to meet the farm's energy needs.

Answer: Three shellfish companies answered that none of their staff received training on the implementation of renewable technologies. Since all shellfish farming examined are in a marine environment, renewable technologies are not applicable in the offshore plant. They could be used for several processes on the vessel, but their use is irrelevant in this case. Two finfish farms answered that their staff received training on the implementation of renewable technologies.

b) Optimizing pumping and heating/cooling processes to reduce energy consumption

Answer: Three shellfish companies answered that none of their staff received training on the optimization of pumping processes. One point out that considers it not applicable in shell farming.

Three finfish farms answered that their staff received training on optimization of pumping processes to reduce energy consumption.

G. Co-product valorization

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a) Extracting and valorizing high-value biomolecules (collagen, fatty acids, antioxidants) from fish and mollusks by products such as shell and byssus

Answer: One shellfish farming staff receive training on the extraction and valorization of high-value biomolecules, while three say that none of their staff received training about the subject.
No one from finfish farms answers affirmatively to this question.

b) Generating additional products like functional foods, cosmetics, or supplements from farm by-products

Answer: Staff employed by one among shellfish farms receive training on the generation of additional products, while three companies say that none of their staff received training about the subject. One company points out that is not applicable in shell farming even if studies show that it is possible to extract high value biomolecules from shellfish by-products. This statement shows that there is little knowledge on the subject by the company. In one finfish farm specific training on this issue was given.

H. Collaborative economy approach

a) Establishing synergies with agricultural, livestock, or industrial sectors to exchange waste or by-products that can be mutually used

Answer: Three shellfish companies answered that none of their staff received training on synergies with other sectors, while two finfish companies answered affirmatively. One of the shellfish companies points out that is not applicable in shell farming.

10.2. Has your staff received specific training on waste management and by-products Generated? (Yes/No)

a) Organic waste (e.g fish remains, algae, uneaten feed)

Answer: Three shellfish companies answered that none of their staff received training on waste management and by-products generated by organic waste. Three finfish farms answered that their staff received training on waste management and by-products generated by organic waste.

b) Plastics (e.g. nets, buoys, packaging)

Answer: Two shellfish companies answered that none of their staff received training on waste management and by-products generated by plastic, while three say that their staff received specific training about the topic. All the finfish farms answered that their staff received training on plastics waste management.

c) Metals (e.g structures, cages)

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Answer: Two shellfish companies answered that none of their staff received training on waste management and by-products generated by metals, while one company stated that their staff received the training about the topic.

Three finfish farms answered that their staff received training on metals waste management.

d) Hazardous waste (e.g chemicals, pharmaceuticals)

Answer: One shellfish company answered that none of their staff received training on waste management and by-products generated by hazardous waste, while three stated that their staff received specific training about the topic.

Three finfish farms answered that their staff received training on hazardous waste management.

e) Wastewater with contaminants

Answer: Three shellfish companies answered that none of their staff received training on waste management and by-products generated by wastewater with contaminants. One of the shellfish companies pointed out that its staff performed training courses on plastic net management and recovery of material generated from engine maintenance.

Only two finfish farms answered that their staff received training on wastewater management.

10.3. Do you consider that further education and awareness-raising on these topics is necessary? And why?

Answer: All the shellfish companies agreed about the fact that it is not necessary further education about the topic except for one, that they consider the education about recycling necessary. One also pointed out that first there is the need to train the trainers on the pragmatic realities of traditional marine production, adding that their type of farming is so simple that it does not require any special training.

Three finfish farms consider that further education and awareness-raising on these topics is necessary, for continuous update and to adapt to climate emergencies.

10.4. What type of training would you consider most useful for your company?

Answer: For theoretical training, three shellfish companies consider it slightly important, moderately important, and important. For practical training, one company rated it as slightly important, another as very important, and the other two considered it important and moderately important. Regarding face-to-face training, one company rated it as slightly important, another as very important, while the other two considered it moderately important and important. For e-learning, two shellfish companies rated it as slightly important, and one rated it as important. Finally, for mixed training, two companies rated it as slightly important, while one rated it as moderately important. In general, the companies show different perceptions and approaches to the topic.

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Regarding the type of training finfish farms expressed quite uniformly on the importance of combining theoretical and practical training. One farm did not respond to point 10.4). One finfish farm did not give importance to the training modality, while one gave preference to face to face training and another farm gave a greater importance to the mixed modality.

4.2. Results

The questionnaire highlights several key challenges and perspectives regarding sustainability and the circular economy in small to medium-scale aquaculture enterprises. While two of the investigated shellfish companies have circular economy policies, only one has set measurable goals, and none hold environmental certifications. Transparency is also limited, as no company has established sustainability KPIs or publicly reports on waste management efforts. Additionally, financial and regulatory challenges hinder progress. No shellfish or finfish companies have received economic incentives for circular economy efforts, and bureaucracy is seen as a major obstacle (especially around recyclable materials). Another key issue is the lack of training in circularity and waste management, along with a lack of awareness of the importance of training paths within most investigated enterprises. Most companies consider their environmental impact minimal and see little need for specialized education, though they acknowledge that practical, hands-on training would be more useful than theoretical approaches. These companies operate with a practical, low-impact approach to aquaculture, but their sustainability efforts remain informal. While these shellfish companies appear to have environmental awareness, they feel quite marginal due to their small size and the challenges posed by financial constraints, bureaucratic hurdles, and limited external support.

In the case of finfish farms, a certain difference in training needs is noted, connected to the degree of intensification of the activity and the size of the company. There is greater sensitivity and greater need for training in companies that use feed and energy.

The traditional extensive fish farm is characterized by a form of natural "economic circularity" with reduced if not negligible production of waste.

Training on the use of by-products and recycling of waste materials is generally considered important by all finfish farms surveyed.

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5. Portugal

5.1. Questionnaire on waste/by-product management, circularity, and sustainability in aquaculture(ESRS E5 based).

1. General Company Information

1.1. Company name:

Answer: The surveyed companies are Oceano Fresco, Greenaqua Vagos, Quinta do Salmão, EXPORSADO, FigueiraFish, Seaculture, and Flatlantic.

1.2. Location of production facilities (country, region):

Answer: All companies are located in Portugal, with production sites spread across different regions including Vagos, Figueira da Foz, Nazaré, Algarve, and the North region. This geographic spread reflects a diverse representation of both inland and coastal aquaculture systems.

1.3. Company size:

Answer: Most surveyed companies are small enterprises, except for EXPORSADO (medium-sized), Flatlantic (SME), and Seaculture (large company).

2. Production Characteristics

2.1. Type of aquaculture practiced:

Answer: The companies represent various production systems including offshore marine aquaculture (Oceano Fresco, Seaculture), continental aquaculture (Greenaqua Vagos), inland freshwater (Quinta do Salmão), intertidal systems (EXPORSADO), integrated multitrophic aquaculture in ponds (FigueiraFish), and intensive marine aquaculture (Flatlantic).

2.2. Main species cultivated:

Answer: Species cultivated vary widely and include clams (Venerupis, Ruditapes) and oysters (Ostrea) by Oceano Fresco; seaweed (Ulva, Gracilaria) by Greenaqua Vagos; rainbow trout (Oncorhynchus mykiss) by Quinta do Salmão; oysters by EXPORSADO; gilthead seabream, European seabass, sole, and oysters by FigueiraFish; gilthead seabream and seabass by Seaculture; and turbot and sole by Flatlantic.

2.3. Certifications or quality labels:

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Answer: Certifications are not widely adopted across the companies. Oceano Fresco holds organic certification, Flatlantic holds a GLOBALG.A.P. certification, while the remaining companies currently do not have specific certifications or eco-labels.

3. Circular Economy (CE) Practices

3.1. Does the company have a Circular Economy (CE) policy?

Answer: Most companies report having implemented some form of CE policy. Only Greenaqua Vagos indicated not having a CE policy.

3.2. CE strategies implemented:

Answer: Reported CE strategies include material reuse and resource efficiency (Oceano Fresco), waste minimization and recycling (Greenaqua Vagos, Quinta do Salmão), use of biodegradable materials, staff training, and recycling (EXPORSADO), efficient use of resources and reduction of hazardous inputs (FigueiraFish), eco-design packaging and waste minimization (Seaculture), and staff training and waste valorization (Flatlantic).

3.3. Percentage of waste recycled or recovered:

Answer: Recycling rates vary by company:

- Oceano Fresco recycles 90% of its plastic.
- Greenaqua Vagos reports 75% waste recycling.
- Quinta do Salmão recycles 95% of waste.
- EXPORSADO recycles approximately 80%.
- FigueiraFish reports 100% recycling of plastic.
- Seaculture recycles 56% of waste.
- Flatlantic recycles 95% of its waste.

3.4. Are organic residues reused (e.g., sludge, shells, mortalities)?

Answer: Reuse of organic residues is limited. EXPORSADO reuses oyster shells as soil amendments, and Flatlantic valorizes organic waste for animal feed. Other companies (Oceano Fresco, Greenaqua Vagos, Quinta do Salmão, FigueiraFish, Seaculture) do not currently reuse organic residues.

3.5. Are CE-specific Key Performance Indicators (KPIs) in place?

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Answer: Only Seaculture and Flatlantic have implemented KPIs related to Circular Economy performance. The rest of the companies do not yet track CE through specific indicators.

3.6. Has staff received CE training?

Answer: Training has been provided in most companies, including Quinta do Salmão, EXPORSADO, FigueiraFish, Seaculture, and Flatlantic. Oceano Fresco and Greenaqua Vagos have not yet conducted CE-specific training.

3.7. Main challenges to adopting CE measures:

Answer: Challenges include lack of proper waste separation and need for technical support (Oceano Fresco), insufficient municipal infrastructure (Greenaqua Vagos), constraints in packaging and by-product reuse (Quinta do Salmão), lack of trained operators and coordination (EXPORSADO), gaps in knowledge and financing (FigueiraFish), absence of treatment facilities and incineration of by-products (Seaculture), and shortage of qualified operators for treating residues (Flatlantic).

5.2. Results

The questionnaire responses reveal a moderate but growing awareness of circular economy (CE) principles among Portuguese aquaculture companies. While most companies report having implemented some type of CE strategy, only two (Seaculture and Flatlantic) have adopted specific CE Key Performance Indicators (KPIs), and just a few hold certifications such as organic or GLOBALG.A.P. This suggests that while CE is present in discourse, formalization and standardization remain limited.

Training is another area with considerable variation. Most companies have provided CE-related training to staff, but some (e.g., Oceano Fresco, Greenaqua Vagos) have yet to introduce structured training programs. Moreover, while several firms have implemented concrete measures such as recycling (with rates ranging from 56% to 100%), the reuse of organic waste like sludge or shells is still largely undeveloped, with only two companies reporting such initiatives.

Key challenges identified include inadequate infrastructure for waste separation and treatment, lack of technical expertise, and insufficient municipal or institutional support. Smaller companies particularly highlight financial and operational barriers that limit their ability to implement advanced CE measures. Some companies express the need for more coordination, technical assistance, and training, especially regarding waste valorization and packaging innovation.

Overall, the findings suggest that CE practices are present but largely informal and unevenly applied. Larger and more technologically advanced companies show a greater commitment to CE through KPIs,

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certifications, and structured training. Meanwhile, small and medium enterprises often face logistical and economic hurdles, despite showing willingness to adopt more sustainable practices if adequate support and training pathways were available.

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6. Conclusion

The survey results from Spain, Italy, and Portugal show that small to medium aquaculture enterprises are increasingly aware of sustainability and circular economy (CE) principles, yet their efforts remain largely informal, inconsistent, and lacking in measurable frameworks. Across all three countries, only a few companies have formal CE policies, environmental certifications, or defined Key Performance Indicators (KPIs), and public reporting on sustainability is almost nonexistent.

Key challenges are shared across regions: lack of financial incentives, regulatory complexity, and limited training or technical support in circularity and waste management. While most enterprises practice basic waste separation and some degree of recycling, the reuse of organic waste and valorization of by-products remains limited, particularly among smaller firms.

The Portuguese case adds further insight, showing a moderate but growing engagement with CE. Several companies report high recycling rates and have adopted strategies such as waste minimization and material reuse. However, only two companies report using CE-specific KPIs, and only a minority hold sustainability certifications. Staff training is uneven, and reuse of organic residues (e.g., shells, sludge) is still rare.

Finfish farms across the three countries tend to express higher needs for structured training, especially those using feed and energy intensively. In contrast, extensive and traditional systems often rely on a form of natural circularity but lack formal sustainability practices.

Overall, the findings highlight a common need across Southern European aquaculture for improved access to funding, better coordination, simplified bureaucracy, and more tailored, practical training. These measures are essential to support innovation, scale up sustainable practices, and effectively integrate circular economy principles into everyday aquaculture operations.

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SECTION 3 – A.1.3 VISITS

1. Introduction

This documentary research study is part of WP2: Roadmap for Transitioning European Aquaculture toward a more Sustainable and Circular Model, which aims to lay the fundamental foundations for the development of a roadmap that will serve as a strategic transformation plan to support the transition towards a more circular and sustainable aquaculture industry.

To achieve this, the work begins with the development of Activity **A1: Fieldwork Activities**, which includes:

- The visit justification template
- The interview script to be carried out.

For task A1.3 field visits to aquaculture facilities, which aims to gather key information about the needs and practices of European aquaculture companies regarding waste management, the level of circularity implementation, and awareness of eco-design.

NOTE:

To justify the visit, the signed and stamped visit justification and a photograph with location,

Recommendation:

To take photographs with the company's permission to use them in training content. Also, take some photographs with the interviewed person to publish on social media and promote the project." surveys within aquaculture farms to gather data on existing waste management practices, including types of waste and byproducts generated, current level of knowledge and available trainings.

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2. Definition of scope and objectives

General Objective:

To understand, from the experience of professionals working in companies in the aquaculture sector:

- The existing waste management practices, including the types of waste and byproducts generated.
- The current level of knowledge and available trainings.
- The implementation of circular economy in European aquaculture."

3. Visit justification template

3.1. Spain

3.1.1. Avramar

1. General Company Information

- What is the name and location of the company?
  - We are AVRAMAR, located in Greece and Spain.
- What type of aquaculture do you practice (marine, continental, mixed)?
  - We specialize in marine aquaculture, mainly in open-sea farming across the Mediterranean.
- What are the main species you cultivate?
  - We farm sea bass, gilthead sea bream, corvina (stone bass), and Pagrus major.
- Does the company have environmental certifications (ASC, MSC, ISO 14001, etc.)?
  - Yes, we have ASC, GlobalG.A.P., BRC, and IFS certifications, and all our operations follow GFSI and GSSI recognized standards.

2. Circular Economy Strategies

- Does the company have a formal policy on resource use and circular economy?
  - Yes, we have a structured plan to reduce waste, minimize emissions, and optimize resource use.
- If yes, what aspects does it cover?
  - Our strategy focuses on recycling and composting 90% of waste, reducing energy consumption, using 81% renewable energy, and decreasing greenhouse gas emissions.
- Have you established quantifiable circular economy objectives?

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- Yes, our goals include a 14% reduction in Scope 1 and 2 GHG emissions (achieved in 2023) and maintaining a 90% waste recycling, composting, or reuse rate.

3. Waste and By-product Management

- What are the main types of waste generated in your production?
  - We produce organic waste such as fish remains and uneaten feed, as well as plastic waste from nets, ropes, and packaging materials.
- Do you separate waste at the source? What percentage of waste is recycled or reused?
  - Yes, we separate different waste streams, and approximately 90% of our waste is recycled, reused, or composted.
- How do you manage organic waste?
  - Fish remains and other organic by-products are processed and sent to specialized companies for reuse, including transformation into animal feed.
- Do you collaborate with other companies to reuse by-products?
  - Yes, we work with research institutions, universities, and industry partners to develop ways to reuse and upcycle by-products.

4. Use of Resources and Materials

- What are the main inputs used in production?
  - We use formulated fish feed, seawater, electricity, polyethylene nets, and packaging materials.
- Have you implemented strategies to reduce water and energy consumption?
  - Yes, we apply water-efficient systems in our hatcheries and processing plants and use precision aquaculture technologies to optimize operations.
- Do you use renewable energy in your operations?
  - Yes, 81% of our energy comes from renewable sources.

5. Economic and Financial Impact

- Have you evaluated the costs associated with waste management and circularity?
  - Yes, we evaluate these costs as part of our overall sustainability performance, although specific figures are not disclosed in the report.
- Have you received incentives or subsidies for implementing circular practices?
  - Yes, we participate in several co-funded EU and innovation projects supporting our circular economy and sustainability efforts.

6. Transparency and Reporting

- Do you publish reports on sustainability and waste management?
  - Yes, we publish an annual sustainability report aligned with GRI Standards.

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- Have you defined key performance indicators (KPIs) for circularity and sustainability?
  - Yes, we track KPIs including waste reduction, renewable energy use, greenhouse gas emissions, fish health and welfare, and training hours.

7. Training and Education

- Does your staff receive training in circular economy and waste management?
  - Yes, we offer ongoing training programs on health, safety, sustainability, ethics, compliance, and environmental best practices.
- What type of training do you consider most useful for your company?
  - We prefer a combination of hands-on training and digital learning (e.g., AVRAMAR Academy) to build both technical and soft skills.
- Do you think further awareness and education on these topics is necessary? Why?
  - Yes, because raising awareness helps embed sustainability into daily operations and supports a culture of responsibility and continuous improvement.

8. Challenges and Future Plans

- What are the main challenges your company faces in transitioning to a more circular and sustainable model?
  - The main challenges include the cost of sustainable technologies and the limited availability of suppliers offering eco-friendly or recycled materials.
- What type of support (technical, financial, regulatory) do you consider necessary to improve circularity in your company?
  - We need greater access to tax incentives, technical assistance, and regulatory support tailored to aquaculture sustainability.
- Do you have any future plans or strategies to improve sustainability in your production?
  - Yes, we are developing integrated multi-trophic aquaculture (IMTA) systems and implementing electrical stunning systems to improve fish welfare and reduce environmental impact.

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3.1.2. Valaqua

1. General Company Information

- What is the name and location of the company?
  - We are Valaqua, headquartered in the Valencia region, Spain.
- What type of aquaculture do you practice (marine, continental, mixed)?
  - We specialize in marine aquaculture, primarily focusing on open-sea farming.
- What are the main species you cultivate?
  - Our main cultivated species are European sea bass (Dicentrarchus labrax) and gilthead sea bream (Sparus aurata).
- Does the company have environmental certifications (ASC, MSC, ISO 14001, etc.)?
  - Yes, we hold the ASC (Aquaculture Stewardship Council) certification for responsible farming practices, and we are working towards obtaining ISO 14001 certification to further strengthen our environmental management system.

2. Circular Economy Strategies

- Does the company have a formal policy on resource use and circular economy?
  - Yes, Valaqua has a formal sustainability and circular economy policy designed to optimize resource use and minimize waste.
- If yes, what aspects does it cover?
  - Our strategy emphasizes reducing feed waste through precision feeding techniques, recycling plastic materials used in cages and packaging, and implementing water quality optimization practices to minimize environmental impact.
- Have you established quantifiable circular economy objectives?
  - Yes, our current objectives include reducing plastic consumption by 30% by 2026 and decreasing feed waste by 12% annually.

3. Waste and By-product Management

- What are the main types of waste generated in your production?
  - The primary waste types are organic waste such as mortalities and uneaten feed, as well as plastic waste from nets, buoys, and other farm equipment.
- Do you separate waste at the source? What percentage of waste is recycled or reused?
  - Yes, we separate waste at the source, particularly distinguishing organic from plastic waste. Approximately 70% of our waste is recycled or reused.
- How do you manage organic waste?
  - Organic waste is collected and sent to specialized companies that process it into fish meal and organic fertilizers.

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- Do you collaborate with other companies to reuse by-products?
  - Indeed, we collaborate with local agricultural firms that use residual biomass and organic by-products to produce biofertilizers, closing the loop between aquaculture and agriculture.

4. Use of Resources and Materials

- What are the main inputs used in production?
  - Our main inputs include formulated fish feed, seawater, electricity for pumping and monitoring systems, and high-density polyethylene (HDPE) nets and cages.
- Have you implemented strategies to reduce water and energy consumption?
  - Yes, we have optimized water flow management in our cages to maintain water quality with minimal energy use and have implemented energy-efficient technologies in our operational processes.
- Do you use renewable energy in your operations?
  - Currently, we are installing solar panels aimed at covering about 20% of our electricity consumption in the next two years.

5. Economic and Financial Impact

- Have you evaluated the costs associated with waste management and circularity?
  - Yes, waste management accounts for roughly 8-10% of our operational expenses, primarily due to recycling processes and specialized disposal of organic waste.
- Have you received incentives or subsidies for implementing circular practices?
  - We have successfully obtained European regional development funds aimed at supporting energy efficiency and environmental sustainability initiatives.

6. Transparency and Reporting

- Do you publish reports on sustainability and waste management?
  - Yes, Valaqua publishes an annual sustainability report detailing progress in environmental metrics, including waste reduction and resource efficiency.
- Have you defined key performance indicators (KPIs) for circularity and sustainability?
  - We monitor KPIs such as feed conversion ratio improvements, percentage of recycled materials used, and reductions in plastic waste generation

7. Training and Education

- Does your staff receive training in circular economy and waste management?
  - Yes, we organize quarterly training sessions combining practical workshops and online courses focused on environmental best practices and circular economy principles.
- What type of training do you consider most useful for your company?

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- A blended approach works best — hands-on training enhances operational awareness, while e-learning offers flexibility.

- Do you think further awareness and education on these topics is necessary? Why?
  - Absolutely. Continuous education ensures that all employees, especially new hires, understand their role in minimizing environmental impact.

8. Challenges and Future Plans

- What are the main challenges your company faces in transitioning to a more circular and sustainable model?
  - The major challenges include the initial investment costs for sustainable technologies and the limited availability of recycled materials that meet aquaculture standards.

- What type of support (technical, financial, regulatory) do you consider necessary to improve circularity in your company?
  - Greater financial incentives, such as tax breaks, and access to expert technical guidance would greatly support our transition. Additionally, clearer and more supportive regulatory frameworks would facilitate innovation.

- Do you have any future plans or strategies to improve sustainability in your production?
  - Yes, we are actively researching integrated multi-trophic aquaculture (IMTA) approaches and exploring partnerships to incorporate renewable energy sources to further reduce our environmental footprint.

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3.2. Italy

3.2.1. Foschi

1. General Company Information

- What is the name and location of the company?
  - Answer: company name is Foschi Massimiliano, located in Cesenatico (FC), Italy.
- What type of aquaculture do you practice (marine, continental, mixed)?
  - Answer: we are specialized in marine aquaculture
- What are the main species you cultivate?
  - Answer: the only species cultivated is mediterranean mussel (Mytilus galloprovincialis)
- Does the company have environmental certifications (ASC, MSC, ISO 14001,etc.)?
  - Answer: no, the company doesn't have any environmental certification

2. Circular Economy Strategies

- Does the company have a formal policy on resource use and circular economy?
  - Answer: no, the company does not have a formal policy.
- If yes, what aspects does it cover?
- Have you established quantifiable circular economy objectives?
  - Answer: no, any objective has been established.

3. Waste and By-product Management

- What are the main types of waste generated in your production?
  - Answer: main type of waste generated are tubular nets (called "socks") in polypropylene used in mussel farming.
- Do you separate waste at the source? What percentage of waste is recycled or reused?
  - Answer: yes, also because is mainly only one type of waste.
- How do you manage organic waste?
  - Answer: the company does not produce organic waste.
- Do you collaborate with other companies to reuse by-products?
  - Answer: no, the company does not collaborate with other companies.

4. Use of Resources and Materials

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- What are the main inputs used in production?
  - Answer: main inputs are fuel for vessel and polypropylene socks.
- Have you implemented strategies to reduce water and energy consumption?
  - Answer: no, the company does not implemented strategies. In addition, during mussel farming operation fresh water is never used.
- Do you use renewable energy in your operations?
  - Answer: no renewable energy is used during operations.

5. Economic and Financial Impact

- Have you evaluated the costs associated with waste management and circularity?
  - Answer: no, the company never evaluated these costs.
- Have you received incentives or subsidies for implementing circular practices?
  - Answer: no, also because no circular practices has been applied.

6. Transparency and Reporting

- Do you publish reports on sustainability and waste management?
  - Answer: no, the company does not publish report on sustainability and waste management.
- Have you defined key performance indicators (KPIs) for circularity and sustainability?
  - Answer: no KPIs has been defined by the company.

7. Training and Education

- Does your staff receive training in circular economy and waste management?
  - Answer: no, they do not.
- What type of training do you consider most useful for your company?
  - Answer: theoretical and practical training are considered the most useful
- Do you think further awareness and education on these topics is necessary? Why?
  - Answer: Yes, because seems that there is a lack of awareness about these topics, mainly because mussel farming is already considered sustainable. Being more aware about the topic could push farmers to act more for circularity.

8. Challenges and Future Plans

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- What are the main challenges your company faces in transitioning to a more circular and sustainable model?
  - Answer: biggest challenge is find new sustainable and green material that present the same mechanical and physical performances of the one used nowadays (e.g. polypropylene socks).
- What type of support (technical, financial, regulatory) do you consider necessary to improve circularity in your company?
  - Answer: is necessary to have a technical and financial support, in this way better and greener material and machinery could be purchased thanks to incentives.
- Do you have any future plans or strategies to improve sustainability in your production?
  - Answer: no at the moment.

3.2.2. Giaveri

1. General Company Information

- What is the name and location of the company?
  - Giaveri Rodolfo - Caviar Giaveri - Via Villanova, 10 San Bartolomeo 31030 Breda di Piave (TV) - ITALY
- What type of aquaculture do you practice (marine, continental, mixed)?
  - Fresh water fish farm (sturgeon and in the past eel) and processing plant for caviar production
- What are the main species you cultivate?
  - We farm 11 different species of sturgeon (Acipenseridae) included autochthonous species as Huso huso and Acipenser naccari.
- Does the company have environmental certifications (ASC, MSC, ISO 14001, etc.)?
  - Yes we have IFS Food certification and we are getting Friend of the Sea certified.

2. Circular Economy Strategies

- Does the company have a formal policy on resource use and circular economy?
  - Yes, we have a plan to reduce waste.
- If yes, what aspects does it cover?
  - Our strategy focuses on reducing waste, recycling plastic materials and and valorisation of by-products (in particular processing waste and parts of fish not intended for direct human consumption).

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- Have you established quantifiable circular economy objectives?
  - We are aiming for 100% separate waste collection (and we are almost there) for the complete recycling of plastic material and metal containers

3. Waste and By-product Management

- What are the main types of waste generated in your production?
  - The main waste from the farm are empty plastic feed bags, and by-products such as the few dead fish. From processing we have: animal by-products (entrails, inedible parts,...) and processing waste, used metal containers,polystyrene packaging or other plastic material.
- Do you separate waste at the source? What percentage of waste is recycled or reused?
  - For solid waste (plastic, paper packaging, metal) we do separate collection
- How do you manage organic waste?
  - Fish waste not intended for human consumption are sent to companies that turn them into fish meal for animal feed. Fish manure is used as a fertilizer
- Do you collaborate with other companies to reuse by-products?
  - We have a formal and coordinated collaboration with the company (FARPRO.) that transforms animal by-products into fishmeal for feed. Other non-edible parts of female sturgeons (e.g. ovary remains and eggs not suitable for caviar production) are valorised in the cosmetic and/or pharmaceutical industry.

4. Use of Resources and Materials

- What are the main inputs used in production?
  - We use formulated fish feed, fresh water, electricity, and plastic/metal packaging.
- Have you implemented strategies to reduce water and energy consumption?
  - Yes, in the hatchery we reuse 30/40% of water.
- Do you use renewable energy in your operations?
  - Not yet, but we are installing solar panels to cover >50% of our energy needs.

5. Economic and Financial Impact

- Have you evaluated the costs associated with waste management and circularity?
  - We estimate that waste management accounts for 5% of our operational costs.
- Have you received incentives or subsidies for implementing circular practices?
  - No

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6. Transparency and Reporting

- Do you publish reports on sustainability and waste management?
  - Yes, we publish an annual report on our sustainability progress.
- Have you defined key performance indicators (KPIs) for circularity and sustainability?
  - Yes, for example, achieving 100% separate waste collection with different destinations, recycling/using waste materials.

7. Training and Education

- Does your staff receive training in circular economy and waste management?
  - Yes, we have periodic training sessions on environmental best practices.
- What type of training do you consider most useful for your company?
  - We prefer a combination of training with face-to-face lessons and e-learning for flexibility
- Do you think further awareness and education on these topics is necessary? Why?
  - Yes to improve company environmetal and economic sustainability

8. Challenges and Future Plans

- What are the main challenges your company faces in transitioning to a more circular and sustainable model?
  - One of the main challenges is the temporary storage (and also conservation in the case of animal by-products) of waste materials, especially in terms of space and management costs.
- What type of support (technical, financial, regulatory) do you consider necessary to improve circularity in your company?
  - We need in equal parts technical, financial support and a clear regulatory framework.
- Do you have any future plans or strategies to improve sustainability in your production?
  - Electricity production with the installation of photovoltaic panels in line with accumulators, greater use of biodegradable or smaller volume packaging.

3.2.3 Vendrame

1. General Company Information

- What is the name and location of the company?
  - Soc. Agr. F.lli Vendame Via Cartera, 16/1 Codroipo
- What type of aquaculture do you practice (marine, continental, mixed)?

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- Fresh water aquaculture inland and other agricultural activities (e.g. sowing of maize, other cereals or oilseeds)

- What are the main species you cultivate?
  - Rainbow trout
- Does the company have environmental certifications (ASC, MSC, ISO 14001, etc.)?
  - Not for now

2. Circular Economy Strategies

- Does the company have a formal policy on resource use and circular economy?
  - Yes, we have a plan to reduce waste and optimize water use
- If yes, what aspects does it cover?
  - Our strategy focuses on water reuse, reduce the use and recycle plastic materials.
- Have you established quantifiable circular economy objectives?
  - We have not set specific parameters.

3. Waste and By-product Management

- What are the main types of waste generated in your production?
  - We produce in our farming activity mainly animal by-products (dead fish) and plastic waste from feed bags.
- Do you separate waste at the source? What percentage of waste is recycled or reused?
  - Dead fish are collected one or two times/day and temporarily stored in a specific refrigerated container until collected by an authorized company. Empty plastic bags are kept separately until collected by a specialized company together with other plastic waste deriving from agricultural activity.
- How do you manage organic waste? See above
- Do you collaborate with other companies to reuse by-products?
  - Only authorized companies for by-products treatment (production of energy from biomass)

4. Use of Resources and Materials

- What are the main inputs used in production?

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- We use formulated fish feed, fresh water, electricity, diesel for tractors and other company vehicles.

- Have you implemented strategies to reduce water and energy consumption?
  - Yes, we partially recirculate the water in the hatchery with a water reuse in this sector of 25%

- Do you use renewable energy in your operations?
  - Yes, we have solar panels (with coupled battery system) that cover 100% of our electricity requirement.

5. Economic and Financial Impact

- Have you evaluated the costs associated with waste management and circularity?
  - No, we haven't quantified it precisely.

- Have you received incentives or subsidies for implementing circular practices?
  - Yes, we received a European grant to install the photovoltaic system and the batteries

6. Transparency and Reporting

- Do you publish reports on sustainability and waste management?
  - No

- Have you defined key performance indicators (KPIs) for circularity and sustainability?
  - Yes, by using a silo feed storage system we have reduced the production of plastic waste (empty bags) by 95%.

7. Training and Education

- Does your staff receive training in circular economy and waste management?
  - Yes, we attended some seminars organized by the producers' associations (API)

- What type of training do you consider most useful for your company?
  - Mainly e-learning for convenience and ease of attendance.

- Do you think further awareness and education on these topics is necessary? Why?
  - To optimize farm environmental sustainability.

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8. Challenges and Future Plans

- What are the main challenges your company faces in transitioning to a more circular and sustainable model?
  - The biggest challenge is the cost of water recirculation technologies
- What type of support (technical, financial, regulatory) do you consider necessary to improve circularity in your company?
  - We need more tax incentives and access to specialized technical support
- Do you have any future plans or strategies to improve sustainability in your production?
  - Our main goal is to increase the % of water recirculation and not only in the hatchery but also in order to better respond to climate change (in particular to long periods of drought)

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3.3. Portugal

3.3.1. Marvellous wave

1. General Company Information

- What is the name and location of the company?
  - We are Marvellous Wave SA, located in Setúbal, Portugal.
- What type of aquaculture do you practice (marine, continental, mixed)?
  - We specialize in mixed aquaculture.
- What are the main species you cultivate?
  - We farm Crassostrea spp. and Ostrea edulis.
- Does the company have environmental certifications (ASC, MSC, ISO 14001, etc.)?
  - No.

2. Circular Economy Strategies

- Does the company have a formal policy on resource use and circular economy?
  - No.
- Have you established quantifiable circular economy objectives?
  - No.

3. Waste and By-product Management

- What are the main types of waste generated in your production?
  - We produce organic waste, as well as metals and plastic waste from packaging.
- Do you separate waste at the source? What percentage of waste is recycled or reused?
  - Yes, we separate plastic and glass waste. Approximately 35% of our waste is recycled.
- How do you manage organic waste?
  - Animal by-products are mainly collected by authorized waste management entities, and the shells are reused as a secondary product.
- Do you collaborate with other companies to reuse by-products?
  - No.

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4. Use of Resources and Materials

- What are the main inputs used in production?
  - We use freshwater, seawater, and electricity.
- Have you implemented strategies to reduce water and energy consumption?
  - Yes, we use recirculating aquaculture systems to reduce water consumption.
- Do you use renewable energy in your operations?
  - No.

5. Economic and Financial Impact

- Have you evaluated the costs associated with waste management and circularity?
  - Yes.
- Have you received incentives or subsidies for implementing circular practices?
  - No.

6. Transparency and Reporting

- Do you publish reports on sustainability and waste management?
  - No.
- Have you defined key performance indicators (KPIs) for circularity and sustainability?
  - No.

7. Training and Education

- Does your staff receive training in circular economy and waste management?
  - Yes, we offer training sessions on environmental best practices, water reuse and recycling, capture and treatment of nutrients dissolved in water to prevent eutrophication of surrounding ecosystems, use of filter-feeding organisms, integrated multitrophic aquaculture, and renewable energy and energy efficiency.
- What type of training do you consider most useful for your company?
  - We prefer a combination of hands-on training and e-learning for flexibility.
- Do you think further awareness and education on these topics is necessary? Why?
  - Yes, because sustainability is one of the most important pillars of our company and the industry. We depend on the ecosystems we are in and their fragile balance. Additionally,

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we take into account the financial and brand image impact that these topics have.

8. Challenges and Future Plans

- What are the main challenges your company faces in transitioning to a more circular and sustainable model?
  - The big challenge is to gather critical volume that justifies processing.
- What type of support (technical, financial, regulatory) do you consider necessary to improve circularity in your company?
  - We need more tax incentives.
- Do you have any future plans or strategies to improve sustainability in your production?
  - The main efforts are in the development of our company's unique and innovative production systems, which range from recirculation to minimizing negative impacts, and maximizing potential positive impacts such as improving water quality, nutrient balance and biodiversity through the creation of artificial reefs and production and feeding areas. In addition to these current efforts, we intend to launch a project to use by-products for the production of feed and/or fertilizers.

3.3.2. Exporsado

1. General Company Information

- What is the name and location of the company?
  - We are Exporsado, located in Setúbal, Portugal.
- What type of aquaculture do you practice (marine, continental, mixed)?
  - We specialize in offshore aquaculture.
- What are the main species you cultivate?
  - We farm Crassostrea spp.
- Does the company have environmental certifications (ASC, MSC, ISO 14001, etc.)?
  - No.

2. Circular Economy Strategies

- Does the company have a formal policy on resource use and circular economy?
  - No.

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- Have you established quantifiable circular economy objectives?
  - No.

3. Waste and By-product Management

- What are the main types of waste generated in your production?
  - We produce organic waste, as well as plastic waste from bags for oyster production.
- Do you separate waste at the source? What percentage of waste is recycled or reused?
  - Yes, we separate organic and plastic waste. Approximately 10% of our waste is recycled.
- How do you manage organic waste?
  - Oyster shells are crushed and used for soil consolidation.
- Do you collaborate with other companies to reuse by-products?
  - No.

4. Use of Resources and Materials

- What are the main inputs used in production?
  - We use intertidal water and electricity.
- Have you implemented strategies to reduce water and energy consumption?
  - Yes, we reuse materials during the production processes, use biodegradable materials, and raise awareness among our employees about sustainable practices.
- Do you use renewable energy in your operations?
  - No.

5. Economic and Financial Impact

- Have you evaluated the costs associated with waste management and circularity?
  - No.
- Have you received incentives or subsidies for implementing circular practices?
  - No.

6. Transparency and Reporting

- Do you publish reports on sustainability and waste management?

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- No.

- Have you defined key performance indicators (KPIs) for circularity and sustainability?
  - No.

7. Training and Education

- Does your staff receive training in circular economy and waste management?
  - Yes, we offer training sessions on the usage of filter-feeding organisms.

- What type of training do you consider most useful for your company?
  - We prefer a combination of hands-on training and e-learning.

- Do you think further awareness and education on these topics is necessary? Why?
  - Yes, because good environmental and circularity practices are fundamental to maintaining the ecosystem, which is the basis of oyster production. Beyond that, the balance of the entire planet also depends on this type of practice.

8. Challenges and Future Plans

- What are the main challenges your company faces in transitioning to a more circular and sustainable model?
  - The big challenge is dealing with the large quantities of oyster shell.

- What type of support (technical, financial, regulatory) do you consider necessary to improve circularity in your company?
  - We essentially need technical support.

- Do you have any future plans or strategies to improve sustainability in your production?
  - We are currently looking to increase the reuse of materials and the use of biodegradable materials. In addition, we are looking for a solution for the sustainable disposal and use of oyster shells.

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