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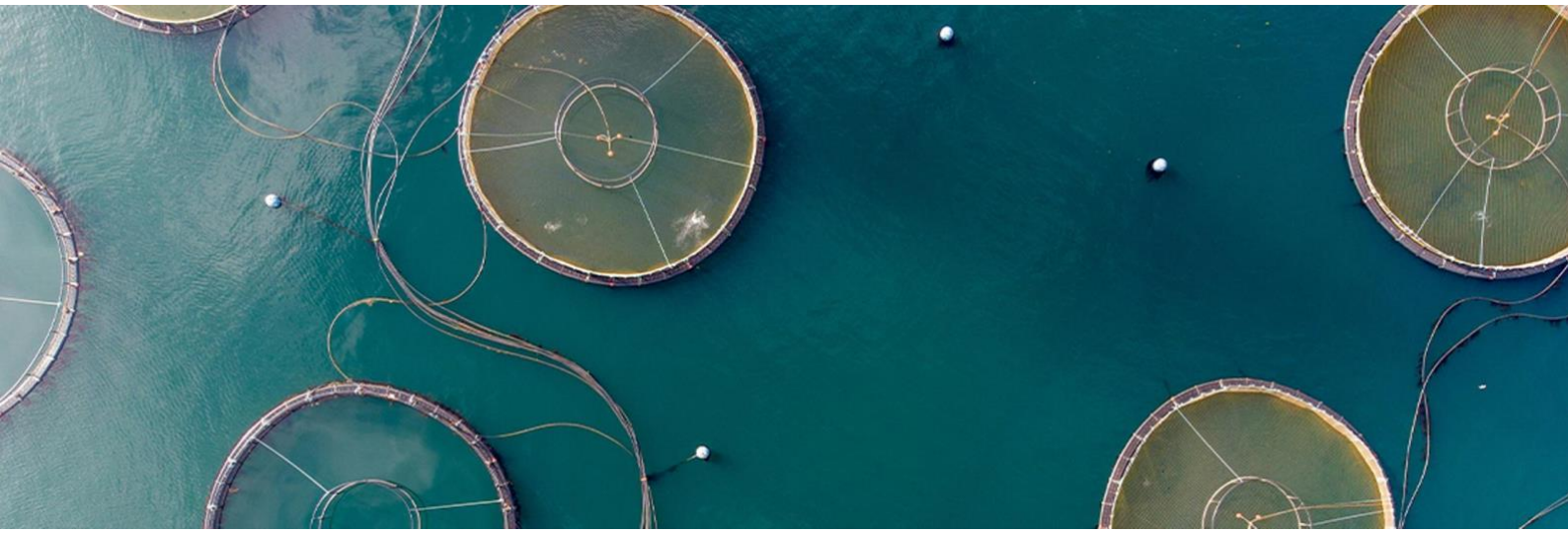

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D.3.2.2 - Action Plan for the transition to an Inclusive and Circular Economy in the aquaculture sector

Ria Formosa, Portugal

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Abbreviations

AMAL	Algarve Intermunicipal Community
AMIC	Culatra Island Residents' Association
AMN	National Maritime Authority – MARITIME POLICE
APA	Portuguese Environment Agency
ASAE	Food and Economic Safety Authority
BdE	Entrepreneur's Desk (Business Portal)
B-Mar	Electronic Sea Platform
C-AZA	Allocated Zones for Circular Aquaculture
CCDR	Regional Coordination and Development Commission
CCVAlg	Algarve Life Science Centre
CIMA-UAlg	Centre for Marine and Environmental Research, University of Algarve
DGAV	Directorate-General for Food and Veterinary Affairs
DGRM	Directorate-General for Natural Resources, Safety and Maritime Services
ENM	National Ocean Strategy
FC	Cohesion Fund
FEAMPA	European Maritime, Fisheries and Aquaculture Fund
FEADER	European Agricultural Fund for Rural Development
FEEI	European Structural and Investment Funds
FSE+	European Social Fund Plus
FTECE	Fund for Technology and Circular Economy
GALAC	Local Support Office for Circular Aquaculture
GNO	Olhão Naval Group
ICNF	Institute for Nature Conservation and Forests
IGT	Territorial Management Instruments
IMTA	Integrated Multi-Trophic Aquaculture
IPMA	Portuguese Institute for the Sea and Atmosphere
ITAC_RF	Transition Index for Circular Aquaculture in Ria Formosa
LiRRIEs	Living Ecosystems for Responsible Research and Innovation
LPN	League for Nature Protection
NGO	Non-Governmental Organization
pAqAT	Plan for Aquaculture in Transitional Waters
PEPNRF	Special Programme for the Ria Formosa Natural Park
POPNRF	Ria Formosa Natural Park Management Plan
PGRH	River Basin Management Plan
PRR	Recovery and Resilience Plan
RAS	Recirculating Aquaculture Systems
RTA	Algarve Tourism Region
SNIRH	National Water Resources Information System
SWOT	Strengths, Weaknesses, Opportunities and Threats
TAA	Aquaculture Activity License
UAlg	University of Algarve
VIVMAR	Associations of Shellfish Farmers and Harvesters of Ria Formosa

1. Executive Summary

At the global level, aquaculture plays a central role in food security and economic development, having surpassed capture fisheries in 2022 as the main source of aquatic animals [1]. In Portugal, the sector is primarily based on the production of bivalves and fish in brackish and marine waters, operating under extensive, semi-intensive and intensive systems [2], with the first characterized by low levels of intervention, although not entirely free from human management. Despite its potential, the sector faces structural challenges, notably the constrains imposed by territorial management instruments (IGT), which limit its development and its positioning in European and international markets.

In this context, the present Action Plan aims to promote the sustainable development of aquaculture in the Ria Formosa through the adoption of good environmental and operational practices, namely adequate water renewal, the use of appropriate stocking densities and the implementation of suitable feeding protocols, with the goal of ensuring more efficient resource use. As a lagoon system of high ecological value, the Ria Formosa presents significant restrictions on economic activities. However, the evolution of aquaculture has increasingly demonstrated its potential positive contribution to ecosystems, particularly through multitrophic and regenerative approaches. Whitin this framework, the Ria Formosa offers favourable conditions for the implementation and consolidation of solutions based on circular economy principles, reconciling sector development with ecosystem preservation.

Based on contributions from Living Ecosystems for Responsible Research and Innovation (LiRRIEs), the Plan integrates scientific knowledge, stakeholder participation, and public policy coordination, promoting more efficient, sustainable, and socially responsible practices.

The AZA4ICE Action Plan has the following main objectives:

- √ governance and the coherence of public policies by promoting coordination among authorities, the scientific community, and the productive sector;
- √ Encourage the development of aquaculture based on improved environmental performance of production systems, through the adoption of multitrophic and regenerative approaches, the valorisation of by-products, and greater efficiency in resource use;
- √ Promote inclusion and social innovation by encouraging stakeholder participation, skills development, and equitable access to opportunities.

The Plan defines priority actions, monitoring indicators, and implementation mechanisms, ensuring effective execution oriented toward continuous improvement. The knowledge generated by the LiRRIEs, including needs assessment, legal framework analysis, capacity building, and identification of best practices, will contribute to its consolidation. By promoting innovation,

cooperation, and responsible resource management, the AZA4ICE Action Plan aims to foster a more sustainable, resilient aquaculture aligned with circular economy principles, in coherence with regional, national, and European policies. Its structure and implementation flow are summarized in Figure 1.

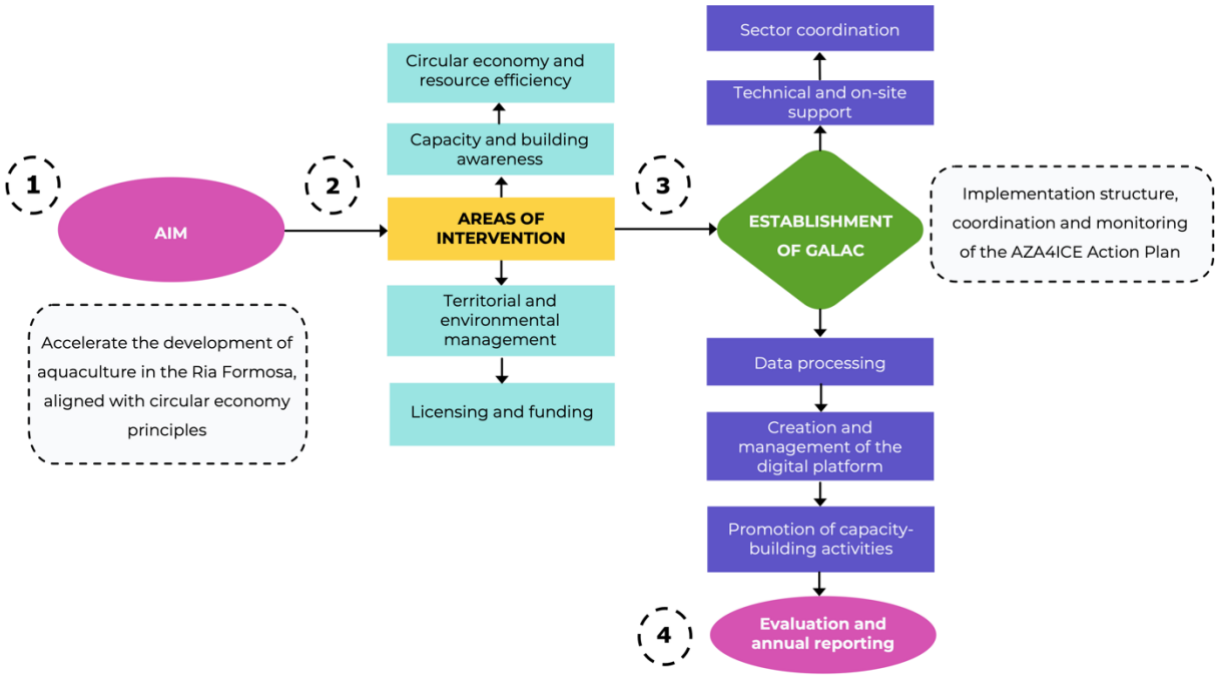

Figure 1 – Structure and implementation flow of the AZA4ICE Action Plan, including its objectives, areas of intervention and main operational actions.

2. Introduction

2.1. Scope and Objectives

This Action Plan, developed within the scope of the AZA4ICE project, provides a strategic framework to promote the development of the aquaculture sector in the Ria Formosa, based on circular and inclusive economy approaches. It aims to strengthen collaboration among multiple stakeholders and ensure that the proposed solutions are replicable, transferable, and aligned with regional and European Union sustainability objectives.

2.2. Context

National policies for the ocean and aquaculture in Portugal are guided by two key strategic instruments that define the pathway toward sustainable blue growth. The National Ocean Strategy (ENM) 2021–2030 establishes the national maritime policy, based on ten strategic objectives, including tackling climate change and pollution, restoring ecosystems, promoting employment, and developing a circular and sustainable blue economy [3].

In alignment, the Strategic Plan for Portuguese Aquaculture 2021–2030 [4] sets out a specific roadmap for the development of the aquaculture sector, promoting the sustainable use of natural resources, diversification of production, and the adoption of systems with lower environmental impact. These include solutions capable of delivering ecosystem services, such as Integrated Multi-Trophic Aquaculture (IMTA) and Recirculating Aquaculture Systems (RAS). Together, these instruments support the transition toward a more circular and sustainable model, based on nutrient recovery and reuse, energy efficiency, pollution prevention, and the promotion of innovation.

Despite this favourable framework, the development of aquaculture in Portugal continues to face structural limitations, reflected in a high dependence on imports. This situation mirrors the broader European Union trend, which in 2023 imported around 83% of the fishery and aquaculture products it consumes [5], highlighting the need for expansion and innovation in the sector. Key constraints include the complexity of administrative procedures and the restrictions associated with IGT, particularly relevant in areas suitable for aquaculture, often located in estuaries and lagoon system.

In this context, strengthening dialogue among stakeholders and improving public perception of the sector, often associated with negative impacts on ecosystems, are crucial. It is essential to promote an evidence-based approach that recognizes the potential of sustainable aquaculture to provide ecosystem services and contribute to environmental regeneration.

The Ria Formosa is a representative example of the challenges and opportunities associated with the sustainable development of aquaculture. This lagoon system, covering approximately 88 km^2 and extending about 55 km along the Algarve coast, is influenced by tidal regimes and characterized by a network of channels, salt marshes, mudflats, and sandy barrier islands that separate it from the Atlantic Ocean. Classified as a Natural Park, integrated into the Natura 2000 network, and recognized under the Ramsar Convention, it holds high ecological value and significant environmental sensitivity [6]. In this context, the Portuguese Environment Agency (APA), as the National Water Authority, has been developing, within the framework of the River Basin Management Plan (PGRH), an approach aligned with the principles of sustainable and circular aquaculture. This approach

promotes the use of inactive artificial areas for aquaculture development, while simultaneously enhancing the environmental quality of these areas. This concept was consolidated in the 3rd cycle PGRH, based on studies carried out by APA/ARH Algarve [7]. Following this, the Institute for Nature Conservation and Forests (ICNF) promoted the establishment of a working group known as ALREMAR, functionally led by S2AQUACoLAB and involving entities with relevant expertise, with the aim of deepening and systematizing existing knowledge. This work enabled not only the identification of aquatic areas with potential for aquaculture but also the delimitation of land-based aquaculture zones, particularly in areas adjacent to wetlands and under port jurisdiction. These areas total 645 hectares, representing approximately 33% of the artificialized areas of the Ria Formosa [7].

Currently, aquaculture, particularly bivalve production, is one of the main economic activities in the Ria Formosa, alongside coastal tourism, fisheries, and other recreational and urban uses across the municipalities of Loulé, Faro, Olhão, Tavira, and Vila Real de Santo António. Its unique ecological and socio-economic context positions this lagoon system as a living laboratory for the implementation, testing, and scaling of circular aquaculture solutions, where balancing productivity and ecosystem preservation is not only a challenge but also an opportunity to demonstrate the convergence between economic development and environmental sustainability.

3. Roles and Responsibilities of Key Actors

The development of this Action Plan resulted from a collaborative process based on the participatory approach of the AZA4ICE project, implemented through the LiRRIEs in the Ria Formosa. This process involved stakeholders representing the quintuple helix model (public authorities, academia, industry, civil society, and the environmental sector). The contributions of these actors made it possible to align the Action Plan with local realities, grounding it in scientific evidence and guiding it toward the implementation of an aquaculture model based on circular economy principles in the Ria Formosa.

a) Public Authorities

Representatives from central government bodies (DGRM – Directorate-General for Natural Resources, Safety and Maritime Services; ICNF – Institute for Nature Conservation and Forests; AMN – National Maritime Authority – MARITIME POLICE; GNR – National Republican Guard and IPMA – Portuguese Institute for the Sea and Atmosphere), regional entities (CCDR Algarve – Algarve Regional Coordination and Development Commission; and APA-ARH Algarve – Portuguese Environment Agency – Algarve River Basin District Administration), and local entities (AMAL – Algarve Intermunicipal Community and the municipalities of Olhão, Loulé, and Vila Real de Santo António) contributed information on regulatory frameworks and

territorial development priorities. This participation ensured alignment of the Action Plan with regional policies and environmental management objectives for the Ria Formosa.

As the Portuguese entity responsible for the AZA4ICE project, IPMA coordinated the development of the Action Plan, fostering stakeholder engagement, guiding the participatory process, and providing scientific expertise in sustainable aquaculture.

b) Academia

Representatives from the University of Algarve (UAlg), the Marine and Environmental Research Centre (CIMA-UAlg), and other educational institutions such as the Algarve Life Science Centre (CCVAlg) contributed to the development of educational and research approaches aimed at integrating circular aquaculture principles into learning processes, promoting ocean and environmental literacy among students and the wider community. Their contributions were key to strengthening the educational and scientific dimension of the Action Plan.

c) Industry

Local aquaculture producers, trade unions, cooperatives, and associations—including Edulis – Comércio de Peixe e Marisco, Lda., the Association of Shellfish Farmers and Harvesters of Ria Formosa (VIVMAR), Cooperativa Formosa, and the Southern Fisheries Workers' Union, as well as other actors in the value chain, notably Mercados de Olhão, E.M., contributed practical knowledge and identified challenges and opportunities related to circular production. Entities such as the Algarve Tourism Region (RTA) and the Olhão Naval Group (GNO) provided relevant perspectives for the tourism and cultural valorisation of the Ria Formosa. These contributions ensured the feasibility and alignment of the Action Plan's recommendations with the realities of the aquaculture and tourism sectors.

d) Civil Society and Environment

Environmental associations such as Sciaena, Almargem, and the League for Nature Protection (LPN), as well as representatives of the local community, including the Culatra Island Residents' Association (AMIC), participated in the LiRRIEs, contributing perspectives on environmental conservation, public awareness, and the evolution of social perceptions of aquaculture activities in the Ria Formosa. Their input was essential to ensuring the integration of social and environmental dimensions into the Action Plan.

4. Regional Need, Challenges and Opportunities

The aquaculture sector in the Ria Formosa has favourable conditions for adopting circular economy models, supported by technical knowledge, well-established production systems, and ongoing sustainability initiatives, such as the reuse of bivalve shells and the use of solar-powered vessels. Although challenges remain, particularly in stimulating markets for by-products, strengthening specialized

training, addressing implementation costs, overcoming resistance to change, dealing with spatial constraints, and the lack of supportive policies, these simultaneously represent opportunities for value creation and innovation.

Advancing the circular economy in the Ria Formosa could benefit from stronger coordination among local entities, the implementation of capacity-building programs, and the broader adoption of renewable technologies. Strengthening governance, improving access to funding, and fostering effective collaboration among stakeholders are key to driving innovation and promoting more efficient resource use. At the same time, the creation of targeted incentives and better alignment of public policies represent concrete opportunities to enhance profitability, simplify administrative processes, and strengthen market connections. In this context, the definition of a coordinated, multi-level strategy emerges as a crucial step toward consolidating the long-term sustainability, resilience, and competitiveness of the aquaculture sector in the Ria Formosa.

Table 1 – SWOT analysis of the circular economy in the aquaculture sector in the Ria Formosa Lagoon.

STRENGTHS	WEAKNESSES
• Established aquaculture sector supported by strong scientific and technical foundations; • In-depth knowledge of species life cycles and production systems; • Active initiatives for recycling by-products (e.g. bivalve shells, cultivation bags); • Adoption of renewable and low impact technologies (e.g. solar-powered vessels, shell crushing); • Involvement of local Non-Governmental Organizations (NGOs) in promoting sustainable and circular practices.	• Limited market demand for aquaculture by-products; • Gaps in capacity building, training and environmental awareness across the value chain; • High implementation and operational costs of circular practices; • Resistance to behavioural and cultural change; • Limited space for aquaculture operations, storage and waste management; • Lack of financial incentives and a supportive regulatory framework; • Restrictions on licensed areas for aquaculture.
OPPORTUNITIES	**THREATS**
• Creation of local coordination structures for by-product valorisation; • Implementation of renewable and low-impact technologies to reduce costs; • Development of knowledge-sharing platforms and targeted training; • Availability of an inventory of inactive artificialized areas; • Strengthening intersectoral collaboration and governance; • Increased access to funding, innovation support and research partnerships; • Enhancement of ecosystem services and biodiversity.	• Low short-term profitability and weak demand for circular products; • Spatial constraints for aquaculture and waste management; • Complex administrative and licensing procedures; • Weak intersectoral coordination and limited governance; • Resistance to innovation and limited recognition of long-term benefits.

5. Current legal/ regulatory/ licensing framework

The regulatory framework for aquaculture in Portugal is robust and multifaceted, reflecting efforts to reconcile the sector's sustainable development with environmental protection and administrative efficiency. The legal basis is established by Decree-Law No. 40/2017 of April 4, in its current version.

In the Ria Formosa, as a transitional water body, the coordination of licensing processes is ensured by the DGRM. A significant innovation was the creation of the Single Maritime Desk (Balcão Eletrónico do Mar, B-Mar) in 2019, a digital platform that enhances process transparency, simplifies administrative procedures, and promotes collaborative decision-making. The licensing process culminates in the issuance of the Aquaculture Activity Title (TAA), which serves as the single permit for the activity and incorporates the authorizations required for the installation and operation of aquaculture units, without prejudice to the application of specific environmental regimes when legally required. The duration of the evaluation process depends on the location of the unit and the type of license selected (Table 2).

Table 2 - Licensing conditions for aquaculture establishments in public and private domains in Portugal.

TYPE OF LICENSE	DURATION	RENEWAL	MAIN CONDITIONS
Public Domain			
Blue Licence	25-50 years*	Once	• Predefined government areas; • Public disclosure on DGRM website, port authority and municipalities.
General Licensing	10-25 years	Once	• Proposal submitted through B-Mar for the Activity License (TAA) • Coordinating authority consults all relevant public entities; • Publication of notices in local municipalities and the Entrepreneur's Desk (BdE); • If wastewater is discharged into the public domain, the maximum validity is 10 years.
PRIVATE DOMAIN			
Prior notification	10-25 years	Renewable**	• Simplified notification process by the applicant.
Authorization	10-25 years	Renewable**	• Standard authorization procedure.

* According to the conditions of the public notice; ** Subject to maintaining the conditions of the *TAA*.

Although the sector is highly regulated due to its environmental and public health implications, the legal framework also demonstrates flexibility, allowing for species diversification and adaptation to technological innovations. The implementation of the Plan for Aquaculture in Transitional Waters (PAqAT) in 2022 is an example of this approach, promoting alignment between aquaculture activities, spatial

planning, and ecological preservation. In this context, IMTA and RAS production systems stand out as sustainable models aligned with circular economy principles. In Portugal, their implementation falls within the existing legal framework for aquaculture, with no identified need for additional specific legislation. Furthermore, projects with these characteristics may benefit from higher funding rates under the Mar2030 program, encouraging the adoption of more sustainable and innovative solutions in the sector.

6. Status of aquaculture business

In Portugal, aquaculture is predominantly practiced in marine and transitional waters, which accounted for 98.5% of total production in 2023 [2]. Extensive systems represented 58.5% of national production, followed by intensive systems (31.5%) and semi-intensive systems (10%). Production structures are mainly composed of farms for bivalve mollusc production (88.9%), floating structures (2.4%), and tanks used for fish production (8.1%). The Ria Formosa continues to establish itself as the main aquaculture hub in the Algarve and as one of the leading centres for national bivalve production. In 2022, regional production accounted for 57% of total national aquaculture output and more than 90% of bivalve production in Portugal [8].

The adoption of circular production systems, such as Integrated Multi-Trophic Aquaculture (IMTA) and Recirculating Aquaculture Systems (RAS), is still in a consolidation phase in Portugal, with limited data available at the national level. Nevertheless, innovative initiatives have emerged that demonstrate the potential of these models. Notably, SEAentia (https://www.seaentia.pt/about-us/), a Portuguese start-up dedicated to the production of meagre (*Argyrosomus regius*) using RAS technology, standing out as an example of technologically advanced aquaculture focused on resource efficiency.

Regarding IMTA systems, their large-scale economic viability remains generally less established compared to RAS systems. However, this model may prove more viable when integrated into larger aquaculture units as a complementary system. In such cases, it primarily serves an ecosystem service function, contributing to the mitigation of environmental impacts, the valorisation of effluents, and the overall sustainability of operations, rather than acting as a direct source of production and revenue. In Portugal, many IMTA-related initiatives still have a predominantly scientific nature, being mainly linked to research and development activities rather than commercial exploitation, with the IPMA playing a key role in this domain. These projects generally focus on polyculture systems integrating three trophic levels, combining macroalgae, bivalve molluscs, and fish species such as meagre (*Argyrosomus regius*), white seabream (*Diplodus sargus*), and flathead grey mullet (*Mugil cephalus*) [9]. Also noteworthy is ALGAplus (https://www.algaplus.pt), based in Ílhavo, which is dedicated to the production and commercialization of marine

macroalgae for the food, cosmetic, scientific, and biotechnology sectors. Operating within an IMTA system, the company uses nutrients derived from semi-intensive aquaculture of seabass and seabream, promoting effluent valorisation, reducing environmental impact, and demonstrating the practical application of circular economy principles.

7. Vision

The development of aquaculture based on circular economy principles is increasingly recognized as a key pathway to ensuring the sector's long-term sustainability. This approach is reflected in the Strategic Plan for Portuguese Aquaculture 2021–2030, which promotes the efficient use of aquatic resources, diversification of protein sources, and the adoption of low-carbon production systems [4]. Despite this strategic direction, the development of the sector and the transition toward more circular and sustainable practices continue to be constrained by technical, environmental, and economic challenges.

An analysis carried out on nine aquaculture companies in the Ria Formosa, using a tool developed under the BLUEfasma project (*http://bluefasma.upatras.gr/pt_PT/authentication/login*), indicates that local operators show a strong orientation toward green economy and sustainability practices. All assessed participants were classified at the same level of circularity, standing out positively among the territories involved in the AZA4ICE project within the Euro-MED region, which includes eight regions across Bulgaria, Spain, Portugal, France, Italy, Croatia, Greece, and Montenegro, involving 65 stakeholders from the aquaculture value chain. In addition, operators expressed interest in investing in new circular economy measures. However, particularly among small-scale producers, challenges remain regarding the adoption of more investment-intensive environmental solutions. This situation highlights the need for targeted training, financial incentives, and stronger institutional support, especially in areas such as waste valorisation and by-product commercialization.

In the Ria Formosa, there are already promising examples of circular aquaculture practices, namely the reuse and valorisation of bivalve shells, which contribute to waste reduction and value creation within local production systems [10]. Building on these initiatives, the Ria Formosa has strong potential to consolidate a circular and sustainable aquaculture model that is environmentally responsible, economically viable, and socially beneficial. In this context, the future of the sector in this territory is grounded in the principles of circular economy and sustainability, structured around six interconnected pillars that support a resilient, innovative, and efficient production model (Figure 2).

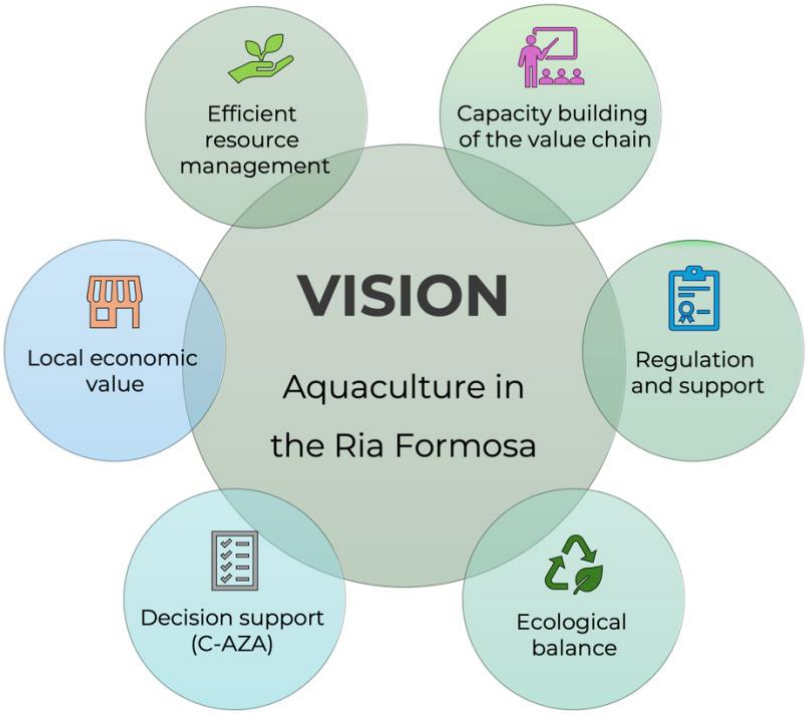

Figure 2 - Strategic vision for the development of aquaculture in the Ria Formosa Lagoon, framed within the principles of circular economy and sustainability. C-AZA – Allocated Zones for Circular Aquaculture.

Efficient resource management focuses on optimizing production processes, promoting waste reduction, reuse, and the valorisation of by-products. Local economic value prioritizes regional products and encourages production for local consumption, strengthening economic resilience and regional development. Ecological balance ensures that aquaculture develops within the limits of the Ria Formosa, promoting the adoption of systems such as IMTA, which contribute to more balanced environments, diversification of native species, and the maintenance of the ecosystem's regenerative capacity.

Value chain capacity building focuses on enhancing the skills of stakeholders and facilitating knowledge transfer, promoting the adoption of innovative practices and continuous improvement throughout the entire production chain.

Regulation and institutional support ensure a solid framework, supported by instruments that encourage sustainable practices and innovation, in coordination with other economic activities in the Ria Formosa. The Allocated Zones for Circular Aquaculture (C-AZA) methodology, developed within the AZA4ICE project, serves as a decision-support tool, guiding the selection of species and production systems that maximize circularity while minimizing environmental impact.

Together, these pillars support a circular, sustainable, and economically viable aquaculture model, tailored to the ecological and socio-economic context of the Ria Formosa.

8. Potential of the C-AZA results

The AZA4ICE project developed a technical-participatory methodology to identify and delineate the Allocated Zones for Circular Aquaculture (C-AZA), based on environmental, spatial, socio-economic, biological, and legal criteria. This approach integrates scientific analysis, land-use compatibility, and circular economy principles, and can serve as a decision-support tool for selecting species and production systems that promote more sustainable and resource-efficient aquaculture.

In the Ria Formosa, aquaculture coexists with other economic activities, particularly tourism. Production under extensive systems, carried out in ponds, is the most prevalent. For this reason, the methodology was applied to assess the suitability of the area for other production systems, namely semi-intensive systems in earthen ponds and intensive systems using recirculating aquaculture systems. The application of the methodology indicated that:

- Most of the native species analysed showed suitable conditions for aquaculture in the Ria Formosa, demonstrating the ecosystem's capacity to support a relevant diversity of species;
- Several species showed potential for integration into multitrophic systems, although factors such as market value, social acceptance, and production performance may influence their viability;
- The multitrophic models assessed, both in earthen ponds and in RAS, proved suitable for the Ria Formosa, with the potential to increase circularity through measures such as the use of recycled materials and greater reliance on solar energy.

Considering that the Ria Formosa is divided into five water bodies with distinct characteristics, collecting environmental data for each would allow for a more precise assessment of their potential for aquaculture development in this region. In this context, the C-AZA methodology may serve as a decision-support tool for evaluating the potential of circular models in different locations, while also showing potential for application and adaptation to other regions.

9. Proposed Actions

9.1. Key Actions and Interventions

The development of aquaculture in Portugal requires strengthened cooperation, capacity building, and intersectoral communication among the different stakeholders in the value chain. In the context of the Ria Formosa, the working group identified priority actions (Table 3), organized into complementary areas of

intervention that address specific technical, economic, environmental, and administrative challenges of the territory.

Table 3 - Priority actions for the development of aquaculture in the Ria Formosa identified within the AZA4ICE project.

AREA OF INTERVENTION	KEY ACTIONS
Capacity building and awareness	• Capacity-building of value chain stakeholders in circular economy principles; • Environmental education and awareness targeting children and adults not directly linked to the sector.
Environmental Management	• Continuous monitoring of environmental parameters • Selective dredging to improve water circulation and sediment management; • Proper management of obsolete or damaged equipment.
Circular economy	• Valorisation of co-products and by-products; • Promotion of intersectoral synergies; • Transition of production systems toward circular models, where feasible.
Territorial management	• Reuse and rehabilitation of artificial and abandoned areas; • Creation of collective infrastructure and shared support zones; • Update of the Plan for Aquaculture in Transitional Waters (pAqAT); • Approval of the Special Programme for the Ria Formosa Natural Park (PEPNRF).
Sustainability	• Definition of good practice guidelines; • Establishment of production limits based on ecosystem carrying capacity.
Licensing	• Licensing processes based on scientific evidence and sustainability criteria; • Adaptation of the legal framework to facilitate resource sharing.
Financing	• Funding mechanisms and incentives to support the adoption of sustainable and circular practices.

The proposed measures include strengthening the capacity of aquaculture sector stakeholders, with the aim of clarifying the concept of circular economy and developing skills through the sharing of practical success examples, preferably at the local level. In parallel, promoting environmental education and awareness initiatives targeting different audiences plays a strategic role in achieving sustainable development.

Environmental management of production areas is another key pillar, aiming to increase production efficiency through continuous monitoring of environmental parameters, selective dredging of production channels to improve water circulation and sediment management, and preventing the accumulation of obsolete or damaged production equipment within the ecosystem. The definition of sustainability guidelines based on the ecosystem's carrying capacity is also essential, enabling the assessment of cumulative pressures associated with different uses of the lagoon. In addition, the development of intersectoral synergies

is encouraged for the valorisation of co-products, namely through the reuse of bivalve shells or the use of sludge for agricultural purposes.

In terms of territorial management, particular emphasis is placed on the need to approve the Special Programme for the Ria Formosa Natural Park (PEPNRF), which will update the current framework defined by the Ria Formosa Natural Park Management Plan (POPNRF), approved by Council of Ministers Resolution No. 78/2009 of September 2. Furthermore, the reuse and renaturalisation of currently inactive artificial areas, such as former salt pans and abandoned fish farms, is proposed, as these present potential for aquaculture development, as identified by the ALREMAR working group. These findings highlight priority areas for intervention in territorial rehabilitation and valorisation. In this context, updating the PAqAT is a key strategic measure.

The creation of land-based support areas for aquaculture is also essential, particularly spaces for storing materials used in bivalve production (bags, floats, racks, among others) and sites for shell deposition. In fish production, this also includes storage areas for feed, nets, buoys, and other equipment. When designed as shared infrastructure, these facilities optimize the use of space and resources, while ensuring efficient storage, management, and handling of co-products, by-products, materials, and production surpluses (e.g., bivalve shells, non-commercial biomass, organic sludge, and algae associated with cultivation), as well as end-of-life equipment management.

Finally, funding mechanisms and economic incentives are needed to support the adoption of innovative and low environmental impact practices. In this context, it is important to review the evaluation criteria of funding programs, particularly Mar2030, to prioritize more sustainable and circular solutions rather than focusing exclusively on lower costs.

The application of planning and licensing tools based on scientific evidence, such as the C-AZA methodology, enables the alignment of aquaculture development with environmental protection. At the same time, the sharing of logistical resources among producers (e.g., joint transportation of production) contributes to improving operational efficiency and reducing environmental impact. However, the current legal framework does not yet clearly address these collaborative solutions, which may be subject to oversight by competent authorities, notably the Maritime Police, within the scope of the Maritime Public Domain.

Taken together, these actions establish a favourable framework for the development of aquaculture based on circular economy principles, ensuring its environmental sustainability and economic viability in the Ria Formosa.

9.2. Responsible Actors

Aquaculture in Portugal involves multiple public entities with responsibilities in

environmental management, licensing, spatial planning, food safety, and sector sustainability. The main institutions include the DGRM, APA, ICNF, IPMA, DGAV and CCDRs.

In the context of the Ria Formosa, the transition toward circular aquaculture requires strengthened coordination among these entities, as well as greater integration with scientific institutions, non-governmental organizations (NGOs), science education and outreach bodies, municipalities, cooperatives, associations, and R&D and industry companies. Within this framework, the creation of a Local Support Office for Circular Aquaculture (GALAC) could play a central role in facilitating coordination among stakeholders and supporting the implementation of the Action Plan (Figure 3). It is recommended that these functions be integrated into existing municipal structures in the Ria Formosa, ensuring proximity and local support for stakeholders. Clarifying responsibilities and strengthening intersectoral communication are therefore essential for the effective implementation of the proposed Action Plan.

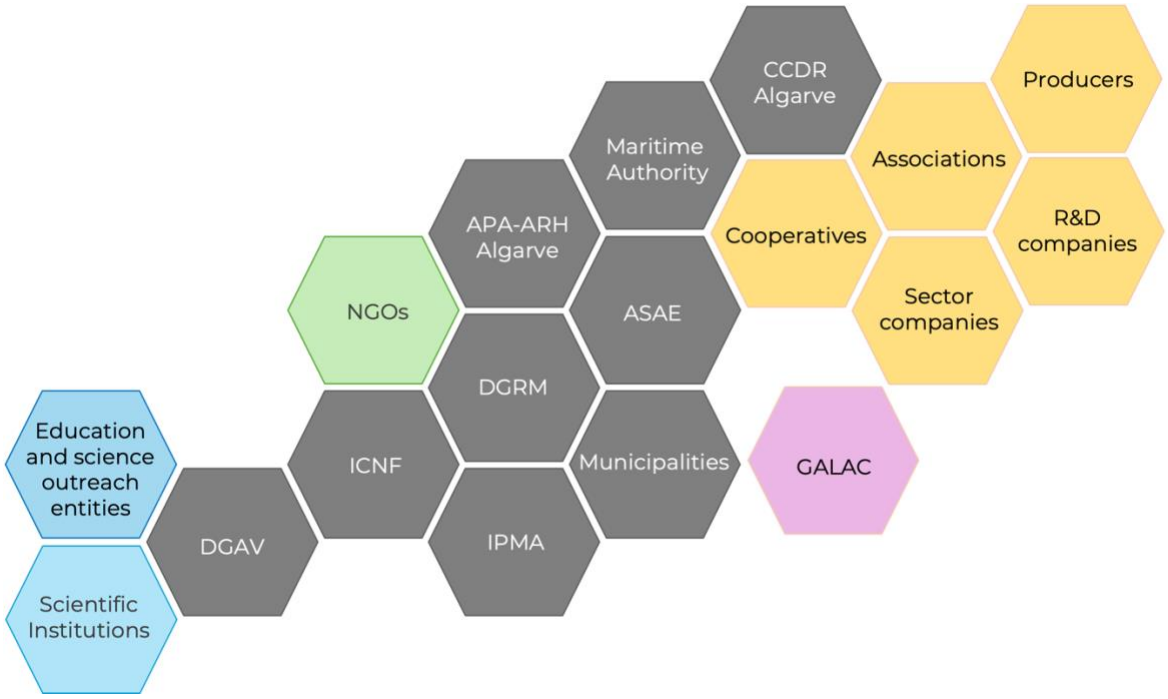

Figure 3 - Entities involved in the transition toward circular aquaculture in the Ria Formosa. DGAV - Directorate-General for Food and Veterinary Affairs; ICNF – Institute for Nature Conservation and Forests; IPMA – Portuguese Institute for the Sea and Atmosphere; NGOs – Non-Governmental Organizations; DGRM – Directorate-General for Natural Resources, Safety and Maritime Services; APA-ARH Algarve – Portuguese Environment Agency; ASAE – Food and Economic Safety Authority; GALAC – Local Support Office for Circular Aquaculture; CCDR – Regional Coordination and Development Commission; R&D – Research and Development.

9.3. Timeline

The development of aquaculture in the Ria Formosa, based on circular economy principles, can be implemented in phases through a progressive model that integrates structural, operational, capacity-building, and consolidation actions, organized according to implementation priority. This approach enables gradual and adaptive development, distinguishing between short-, medium-, and long-term interventions (Figure 4).

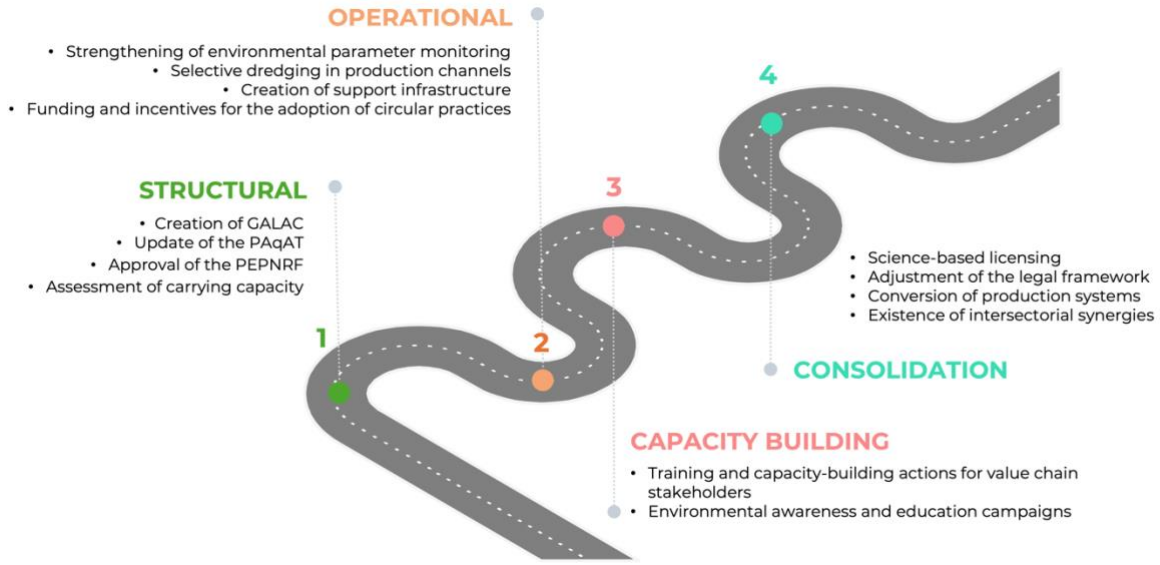

Figure 4 - Timeline for the development of aquaculture in the Ria Formosa, based on circular economy principles, proposed within the AZA4ICE project. The diagram presents the development phases and the priority of actions, distinguishing between short-term (immediate priority) and medium- to long-term interventions. GALAC – Local Support Office for Circular Aquaculture; pAqAT – Plan for Aquaculture in Transitional Waters; PEPNRF – Special Programme for the Ria Formosa Natural Park.

In the short term, the structural phase focuses on establishing institutional and planning foundations, including the creation of GALAC as a technical support structure, the update of the pAqAT, and the approval of the PEPNRF. The preparation of the latter was determined by Order No. 2069/2025 of February 13, as a key spatial planning instrument for the development of the aquaculture sector in the Ria Formosa. The use of inactive artificial areas identified by *ALREMAR* in the Ria Formosa, both for the provision of ecosystem services and for aquaculture development, is considered essential and urgent for improving the environmental conditions of the areas in which they are located. In this context, it is important to recognize, within the development of aquaculture based on circular economy principles, its potential positive contribution to ecosystems, which should be reflected in updates to IGT. In parallel, an assessment of the carrying capacity of the Ria Formosa should be conducted to ensure that aquaculture development is grounded in scientific evidence and respects the system's environmental limits.

In the medium term, the operational and capacity-building phase focuses on implementing on-the-ground measures and strengthening stakeholders' competencies. This includes reinforcing continuous monitoring of environmental parameters, ensuring regular oversight of activities across different water bodies, independently of isolated projects, and integrating data into modelling and forecasting platforms, such as the one developed under the CONNECT+ project (https://connect.lnec.pt). It also includes selective dredging of production channels, where technically justified, and the development of shared infrastructure for the storage, management, and valorisation of materials, equipment, and by-products.

At the same time, funding mechanisms should be implemented to incentivize the adoption of circular practices, with evaluation criteria that prioritize sustainable solutions beyond cost considerations. Despite a 16.2% increase in vocational training in the fisheries and aquaculture sectors, processing industry, and maritime activities in 2024 [2], there remains a need to strengthen technical and environmental capacity in the sector, given the growing demands and challenges associated with sustainability. In this context, the development of specialized training actions and environmental awareness and education initiatives is proposed, aimed at promoting best practices, enhancing environmental literacy, and engaging stakeholders across the value chain, highlighting local examples of economic success. Additionally, the creation of a dedicated digital platform for circular aquaculture is recommended, with a user-friendly design to facilitate knowledge sharing, promote collaboration among researchers, policymakers, and aquaculture operators, and centralize information on available government support.

In the long term, the consolidation phase aims to ensure the sustainability of the proposed model through the implementation of science-based licensing processes, the adaptation of the legal framework, and the conversion of production systems toward models that balance production with environmental enhancement. Furthermore, coordination with other economic sectors should be promoted, fostering synergies that support the development of circular value chains.

9.4. Financial aspects and Funding resources

The transition to a circular economy in the aquaculture sector requires the coordinated mobilization of public and private financing, including European and national funds, as well as direct investment from banks, venture capital, companies, and other actors in the value chain. At the European level, key direct management programs include Interreg, Horizon Europe, LIFE, and Digital Europe, which operate under autonomous application procedures and complement the European Structural and Investment Funds (FEEI). These include the European Regional Development Fund (FEDER), the European Social Fund Plus (FSE+), the Cohesion Fund (FC), the European Maritime, Fisheries and Aquaculture Fund (FEAMPA), and

the European Agricultural Fund for Rural Development (FEADER).

In Portugal, the FEEI are implemented through Portugal 2030, the national Partnership Agreement that defines development priorities up to 2030, approved by Council of Ministers Resolution No. 98/2020 of November 13. In the areas of the sea, fisheries, and aquaculture, MAR 2030 is the program responsible for implementing the FEAMPA. In parallel, there are complementary national financial instruments, such as the Recovery and Resilience Plan (PRR), the Environmental Fund, and the Fund for Technology and Circular Economy (FTECE). Although not formally part of Portugal 2030, these instruments are aligned with its strategic objectives, supporting the green, digital, and circular transitions. The PRR, in this context, is temporary in nature, with implementation scheduled until 2026 (Figure 5).

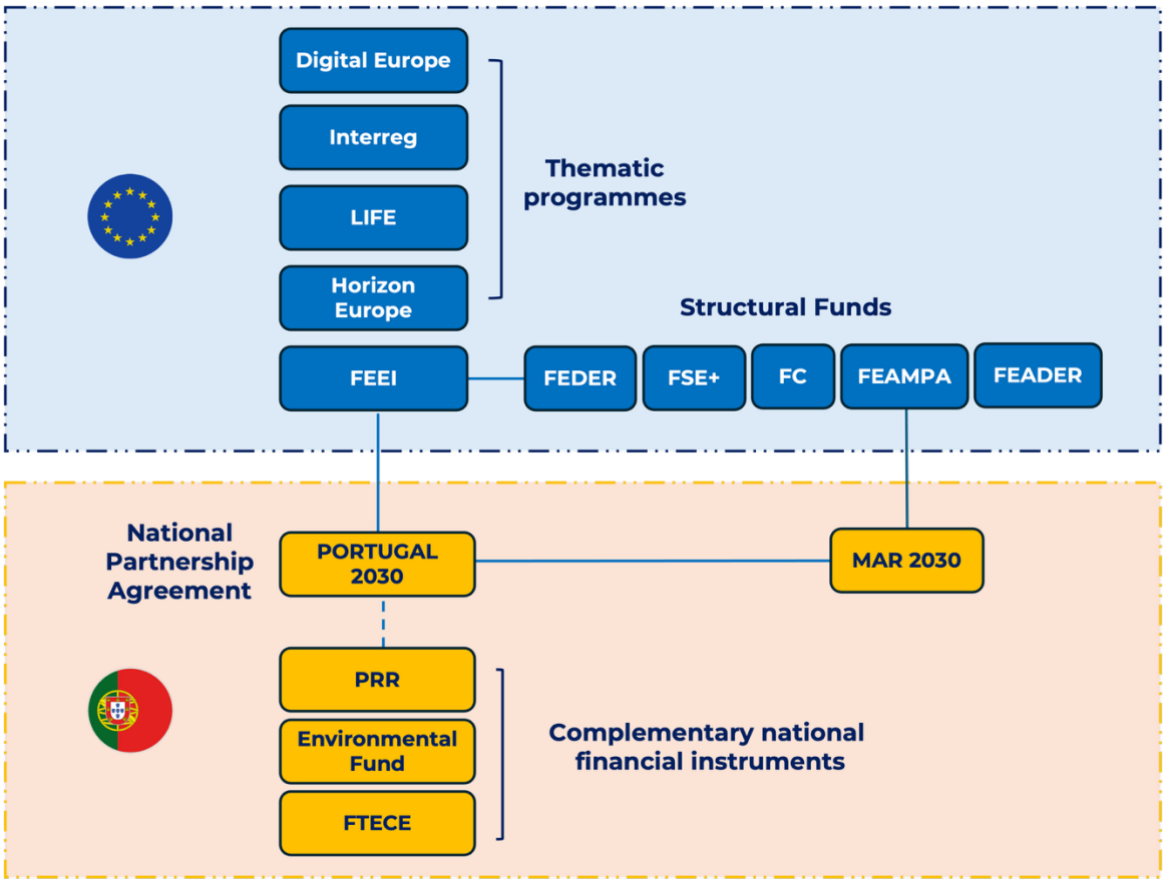

Figure 5 - Structure of European and national public funding for aquaculture. – European Structural and Investment Funds; FEEI – European Structural and Investment Funds; FSE+ – European Social Fund Plus; FC – Cohesion Fund; FEAMPA – European Maritime, Fisheries and Aquaculture Fund; FEADER – European Agricultural Fund for Rural Development; PRR – Recovery and Resilience Plan; FTECE – Fund for Technology and Circular Economy.

Although relevant support mechanisms already exist, there is still scoped to improve access to funding, particularly for small-scale producers, through better dissemination of available instruments and simplification of application processes. At the same time, the evaluation criteria of funding programs, especially MAR 2030,

should be reviewed to prioritize more sustainable and circular solutions, rather than predominantly favouring lower-cost options. The development of national and regional incentives specifically targeted at circular aquaculture approaches could accelerate the adoption of more sustainable production models.

Currently, many producers in the Ria Formosa operate under economically viable business models and do not perceive immediate benefits from changing their practices, particularly when such changes involve higher investment, effort, and operational complexity. In this context, it is essential to promote incentives across the entire value chain, from production to processing, marketing, and consumption, that support the creation of added value. These should include certification mechanisms, product valorisation strategies, and the development of collective or sustainability-based brands, translating into tangible economic benefits that offset the additional effort and make the adoption of this aquaculture model more attractive and financially viable.

10. Monitoring and Evaluation

10.1. Success Indicators

To support the development of aquaculture based on circular economy principles, it is essential to define clear, measurable, and comparable performance indicators over time. These indicators enable the monitoring of circular practice adoption, the assessment of environmental, economic, and social impacts, and support decision-making, as well as the adjustment of implemented measures. Table 4 presents the set of indicators proposed for monitoring a circular aquaculture approach in the Ria Formosa within the framework of the AZA4ICE project. The indicators are organized by dimension of analysis, including their respective weight, data collection frequency, and suggested data sources.

Table 4 - Monitoring indicators for aquaculture based on circular economy principles in the Ria Formosa, proposed within the AZA4ICE project.

DIMENSION (WEIGHT)	INDICATOR	FREQUENCY	PROPOSED DATA SOURCES
Circular Economy (**25%**)	Number of aquaculture units with circular practices	Annual	• Producers • Associations • Cooperatives • DGRM
	Number of products with traceability systems	Annual	• Producers • Cooperatives • Associations • Sector companies
	Number of new circular economic activities	Annual	• Producers • Associations • Cooperatives

Environmental Management (**20%**)	Number of new species in production areas	Annual	• ICNF • NGOs • IPMA
	Number of species produced per trophic level	Annual	• DGRM
	Productivity of carpet shell clam (*Ruditapes decussatus*) (ton/ha)	Annual	• Producers • Associations • Cooperatives • DGRM
	Number of water quality data records collected	Annual	• APA • Scientific institutions
	% of units by production system type (extensive, semi-intensive, intensive)	Annual	• DGRM
Energy Efficiency (**15%**)	Number of aquaculture units using renewable energy	Annual	• DGRM
Spatial Planning (**10%**)	Number if interventions in aquaculture infrastructure (rehabilitation, adaptation or conversion)	Annual	• Municipalities
	Recovered artificialized areas (ha)	Annual	• Municipalities • Associations • DGRM
Licensing (**10%**)	Number of licensed aquaculture units using IMTA and/or RAS systems	Annual	• DGRM
Financing (**15%**)	Amount of funding approved for circular aquaculture projects (€)	Annual	• Scientific institutions • R&D companies • CCDR Algarve
Capacity Building and Awareness (**5%**)	Number of training and awareness actions on circular economy	Annual	• Education and science outreach entities • Scientific institutions

DGRM – Directorate-General for Natural Resources, Safety and Maritime Services; IPMA – Portuguese Institute for the Sea and the Atmosphere, I.P.; APA – Portuguese Environment Agency; ICNF – Institute for Nature Conservation and Forests; NGOs – Non-Governmental Organizations; CCDR – Regional Coordination and Development Commission; R&D – Research and Development.

The collection of information associated with these indicators may be progressively integrated into aquaculture licensing processes and surveys, particularly regarding production systems, the use of renewable energy, species produced, and the adoption of circular practices. This integration will enable DGRM to ensure systematic monitoring of production units and the level of adoption of circular models.

Circular economy indicators allow the assessment of the level of adoption of circular practices in production units (e.g., use of recyclable materials), in products, and in associated economic activities. They also include initiatives for the valorisation of aquaculture by-products, regardless of their formal link to production units, reflecting the expansion of circular value chains in sectors such as construction, agriculture, and the pharmaceutical industry. The traceability of

aquaculture products derived from circular practices is based on batch identification and the recording of information throughout the value chain, including origin, production system, and practices adopted. This process should be ensured by producers, associations, and cooperatives, guaranteeing the validation and continuity of information up to the commercialization stage. Examples of products include:

- Gilthead seabream produced in RAS systems, partially powered by renewable energy;
- Mussels produced in offshore suspended structures;
- Oysters cultivated on tables using recycled bags.

The environmental management dimension includes both direct and indirect indicators of the ecological status of production areas. Species diversity and the trophic structure of production systems help assess ecological balance, while the productivity of carpet shell clams (*Ruditapes decussatus*) (ton/ha) can serve as an indirect indicator of environmental health and the regenerative capacity of the Ria Formosa. Monitoring is complemented by the volume of data collected on water quality, reflecting the effort and consistency of observation systems. This data collection may be primarily ensured by the APA through the National Water Resources Information System (SNIRH - https://snirh.apambiente.pt/) and complemented by systems operated by scientific institutions such as CCMAR, CIMA-UAlg, and S2AQUAcoLAB (Collaborative Laboratory for Sustainable and Smart Aquaculture) within research projects.

The spatial planning dimension can be monitored through the number of interventions in aquaculture infrastructure, including rehabilitation, adaptation, or conversion of production systems. These interventions may include the upgrading of ponds or tanks, the adaptation of salt pans for aquaculture production, the implementation of RAS or IMTA systems, as well as improvements to energy infrastructure.

Energy efficiency can be assessed through the adoption of renewable energy sources in production units, reflecting reduced dependence on fossil fuels and enhanced energy sustainability within the sector. The licensing dimension allows monitoring of the formal adoption of IMTA and RAS systems within the legal framework of aquaculture activity. Financing can be evaluated based on the amount of investment (€) approved for aquaculture projects based on circular economy principles, reflecting access to support instruments and the level of financial mobilization for sector development.

Finally, capacity building and awareness are monitored through the number of training and outreach actions carried out, reflecting the strengthening of skills and the level of engagement of different stakeholders in adopting more sustainable practices.

10.2. Follow-up and Adjustment

The development of aquaculture in Portugal requires a continuous process of monitoring, evaluation, and adjustment, focused on results and aligned with the needs of producers and the value chain. For this purpose, the AZA4ICE Plan defines the main monitoring and enforcement actions associated with the established dimensions and indicators, as presented in Table 5.

Table 5 - Monitoring and enforcement actions for the development of aquaculture based on circular economy principles in the Ria Formosa within the AZA4ICE project.

DIMENSION	ACTION	MONITORING	ENFORCEMENT
External pressure	Identification of external vessels and abandoned materials	• Local maritime authorities	• Local maritime authorities
Environmental management	Operation of environmental monitoring sensors	• APA • Scientific research entities	• APA • Scientific research entities
Circular economy	Monitoring the traceability of circular products along the value chain	• Cooperatives • Associations • Depuration facilities • Markets	• DGAV • ASAE • IPMA
Governance	Data processing and annual monitoring report	• GALAC	• GALAC

APA – Portuguese Environment Agency; DGAV – Directorate-General for Food and Veterinary Affairs; ASAE – Food and Economic Safety Authority; IPMA – Portuguese Institute for the Sea and the Atmosphere; GALAC – Local Support Office for Circular Aquaculture.

In terms of external pressure, local maritime authorities are responsible for monitoring and enforcing the presence and circulation of vessels and motorized vehicles not associated with aquaculture activities, within their competencies related to surveillance, safety, and maritime spatial management. This monitoring also includes identifying abandoned equipment or materials that may interfere with activities or compromise the ecological condition of production areas.

Environmental management is proposed to be ensured by the APA through the operation and maintenance of environmental monitoring sensors integrated into the SNIRH network. This system may be complemented by equipment installed by research entities within scientific projects, ensuring the continuous collection of data necessary to assess the ecological status of aquaculture areas.

Within the circular economy dimension, the traceability of aquaculture products may be operationally monitored by cooperatives and producer associations, purification plants, and markets, ensuring the continuity of information along the value chain. Legal enforcement of product traceability and food safety falls under DGAV and IPMA, particularly through the National Bivalve Monitoring System (SNMB), while ASAE ensures compliance with labelling rules and commercial practices at the consumer level.

Finally, the governance dimension is proposed to be ensured by GALAC, responsible for collecting and consolidating information from relevant entities and preparing the annual evaluation report. This report should assess progress achieved, identify potential deviations, and provide recommendations for adjusting measures and defining priorities for the following period. This integrated monitoring system strengthens the effectiveness of implemented measures and supports decision-making. GALAC may operate in coordination with existing local structures, such as Fisheries Local Action Groups (GAL/GALP) or municipal offices linked to the maritime sector. Its main functions include:

- Data processing and preparation of the annual monitoring report;
- Technical and on-site support to producers in adopting circular aquaculture practices;
- Creation and management of a digital support platform dedicated to aquaculture development in the Ria Formosa, facilitating knowledge sharing and dissemination of funding opportunities;
- Promotion of capacity-building activities in collaboration with researchers and policymakers;
- Promotion of intersectoral coordination.

The weights assigned to the different dimensions (Table 4) reflect their relative importance in aquaculture development and were validated with stakeholders in the Ria Formosa during the 4th LiRRIE meeting. Circular economy carries the greatest weight, as it directly reflects changes in production practices and value creation. Environmental management, energy efficiency, and licensing have intermediate weights, while spatial planning, financing, capacity building, and governance play a structural supporting role.

To assess the progress of circular aquaculture development in the Ria Formosa, the calculation of the Transition Index for Circular Aquaculture in the Ria Formosa (ITAC_RF) is proposed, based on the positive variation of defined indicators compared to the previous year. The index takes a value of zero when no progress is observed and values above zero when there is improvement. The score for each indicator is calculated based on the percentage change between the evaluation year (t) and the baseline year:

$$Indicator\ score = \frac{Value\ in\ year\ t - Value\ in\ baseline\ year}{Value\ in\ baseline\ year} \times 100$$

In cases where the baseline value is zero, the score is not calculated as a percentage change. Instead, a value of zero is assigned when no progress occurs, and 100 when the indicator becomes positive, reflecting the start of the transition.

The ITAC_RF results from the weighted aggregation of indicator scores, according to the weights assigned to each dimension:

$$ITAC\_RF = \sum(Indicator\ score \times Weight)$$

The index is normalized on a scale from 0 to 100, allowing a concise assessment of the level of implementation of actions and the evolution of indicators over time. In this way, the ITAC_RF serves as a tool to support annual monitoring, identify deviations, and adjust the measures defined in the Plan.

Figure 6 - Transition Index for Circular Aquaculture in the Ria Formosa (ITAC_RF), proposed within the AZA4ICE project.

Figure 6 presents the index classification scale on a continuous bar from 0 to 100, allowing interpretation of the level of progress in the transition. This graphical representation facilitates understanding of the transition status, monitoring of annual progress, and support for decision-making.

11. Conclusion

11.1. Summary and Next Steps

This plan, developed within the framework of the AZA4ICE project, sets out guidelines for the development of aquaculture in the Ria Formosa toward models based on good practices and circular economy principles that are sustainable and resilient. The definition of indicators, monitoring actions, and a monitoring system enables the assessment of the implementation of measures, the tracking of progress, and supports decision-making. In this context, the ITAC_RF serves as a tool to support monitoring and the adjustment of planned actions.

The next steps focus on operationalizing the proposed actions, strengthening coordination among entities, integrating information into licensing processes, enhancing the traceability of products derived from circular aquaculture practices, and building capacity among producers and other stakeholders in the value chain. The annual preparation of a monitoring report, coordinated by GALAC, will make it possible to track results and adjust priorities. The implementation of this plan will contribute to promoting the development of aquaculture in the Ria Formosa through a circular approach, strengthening the sustainability of the activity, the protection of ecosystems, and its integration into the territory, and may serve as a reference for other production areas in Portugal.

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Glossary

Blue Economy
A set of economic activities associated with oceans, seas, and coastal areas that use marine resources in a sustainable way. It includes sectors such as aquaculture, fisheries, biotechnology, shipping and shipbuilding, renewable energy, and coastal tourism, promoting a balance between economic development, environmental protection, and responsible use of marine resources.

Circular Economy
A production and consumption model that seeks to keep resources in use for as long as possible by promoting reduction, reuse, repair, recycling, and the valorisation of materials and by-products. In contrast to the traditional linear model ("take, make, dispose"), it aims to minimize waste generation, reduce pollution, and increase resource-use efficiency.

Ecosystem Services
The direct and indirect benefits that people obtain from ecosystems, natural systems composed of living organisms, physical environmental elements, and the interactions between them. In the context of aquaculture, these include natural processes such as water quality regulation, nutrient recycling, biodiversity maintenance, and food production.

Artificialized and Non-natural Areas
Areas whose natural morphology has been altered by hydromorphological pressures resulting from human intervention, particularly along the margins of aquatic systems influenced by tidal dynamics.

IMTA (Integrated Multi-Trophic Aquaculture)
An aquaculture production system that combines species from different trophic levels (fish, bivalves, algae), promoting biological complementarity among them. By allowing the by-products of one species to be used by another, IMTA increases production efficiency, reduces waste accumulation, and contributes to improved environmental quality.

RAS (Recirculating Aquaculture System)
An intensive aquaculture production system using tanks, in which water is continuously recirculated through filtration and treatment processes, allowing its reuse within the system. It reduces water consumption, isolates the cultured stock, and minimizes discharges into the environment, ensuring highly controlled production conditions. These systems can be further optimized through energy efficiency solutions and the use of renewable energy sources, particularly solar energy.

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