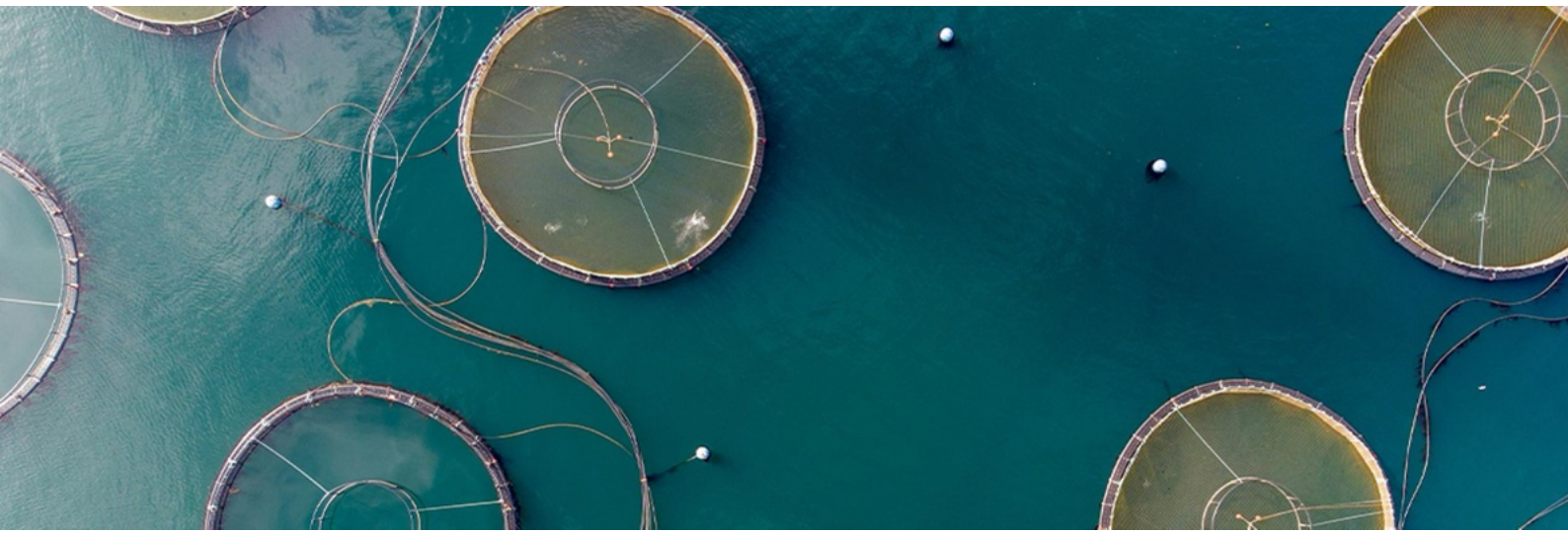

Action plan for Transitioning to Circular Aquaculture

https://aza4ice.interreg-euro-med.eu

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Executive Summary

This Action Plan outlines a strategic framework to facilitate the transition toward circular and eco-intensive aquaculture in Andalusia region (Spain), positioning the sector as a significant contributor to both the Andalusian Blue Economy Strategy (EA2) and regional objectives in sustainable aquaculture. Developed in accordance with European Circular Bioeconomy principles, the Plan proposes an integrated methodology that encompasses environmental protection, economic diversification, technological advancement, and social cohesion within coastal and protected areas.

The Action Plan examines regional needs, challenges, and opportunities related to circular aquaculture and particular in the Bay of Cádiz. Moreover, it assesses the regional regulatory information and reviews the status of the sector's adoption of circular practices. Consequently, it presents a strategy organized around five interconnected pillars designed to support the shift toward circular, resilient, and ecosystem-based production models, enhance the economic viability and competitiveness of aquaculture enterprises, promote targeted innovation and knowledge transfer, establish a proper policy framework and financing conditions and strengthen stakeholder engagement, governance, and market development.

By integrating regulatory points, advanced technology, business incentives, and participatory governance, this Action Plan extends beyond theoretical sustainability to provide actionable pathways for sectoral advancement and more competitive. It positions Andalusia as a leader in circular aquaculture, exemplifying how nature-based solutions and circular systems can restore ecosystems, generate new revenue streams, improve resilience and competitiveness in coastal economies, and ensure sustainable food security and social acceptance.

Introduction

The Action Plan for Circular Aquaculture constitutes a **region-specific roadmap** designed to promote and accelerate the transition of the aquaculture sector towards more inclusive, resilient, and circular production practices. Developed within the framework of the AZA4ICE project, this Action Plan aims **to identify concrete and targeted actions that facilitate this transition** adapted to the socio-economic, environmental, and regulatory context of Andalusian region.

This Action Plan centres on the **pilot site in the Bay of Cádiz** mainly characterized by coastal land-based aquaculture. Insights from LiRRIEs co-creation events and stakeholder engagement informed realistic needs and capabilities. While specifically tailored to the Bay of Cádiz, the methodology and several actions are also applicable to other Mediterranean and Atlantic aquaculture systems, including floating cages. The versatility of the methodology developed for assessment of the potential Circular Allocated Zones for Aquaculture (C-AZAs) ensures adaptability to other productive models identifying targeted actions if specific conditions are properly adjusted.

The Plan addresses the full aquaculture value chain, including production systems, waste and by-product management, logistics, governance, business models, and stakeholder engagement. It promotes the adoption of innovative circular production models such as Integrated Multitrophic Aquaculture (IMTA), Recirculating Aquaculture Systems (RAS), marine aquaponics, biofloc (BFT) and hybrid systems that enhance nutrient upcycling, biomass production and companies competitivity.

In addition, the Action Plan considers the legal, spatial planning, and licensing frameworks required to mainstream circular aquaculture practices within existing regulatory structures. It aims to facilitate policy alignment, innovation and institutional coordination to enable the long-term deployment of circular production models.

This Action Plan is aligned with relevant EU strategies and policy frameworks, including the European Green Deal, Blue Economy Strategy, Farm to Fork Strategy, **EU Strategic Guidelines for Smart and Sustainable Aquaculture (2021)**[1] and **Strategic Framework for a Competitive and Sustainable EU Bioeconomy (2025)**[2]. While tailored to regional needs, its structure and methodology ensure high transferability potential across the wider Euro-Mediterranean region.

[1] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:236:FIN*

[2] *https://environment.ec.europa.eu/document/download/dbf8d2ba-9332-4f7a-b336-f356fa4b7236_en?filename=COM_2025_960_1_EN_ACT_part1_v10_0.pdf*

Context

The Andalusian aquaculture sector has a long tradition with two clearly differentiated types of production zones from an environmental perspective, which determine the farming systems: **land-based aquaculture zones in the South Atlantic areas** (**Figure 1**) and **sea-based marine aquaculture zones in the Mediterranean Sea**. In both areas, production models remain largely linear, with high dependence on external inputs, limited valorisation of side streams, and increasing regulatory and environmental constraints.

***Figure 1**: Species and production models in Andalusian aquaculture (Credits: Manuel Manchado).*

In terms of number of establishments, land-based aquaculture is the most important in Andalusia. According to the latest available statistical data, this sector comprises 91 establishments, representing 89% of the authorisations for marine aquaculture in the region. However, between 2010 and 2024, the number of authorised land-based facilities has decreased by 41%. Most of this sector operates within a highly sensitive socio-ecological system characterized by protected coastal wetlands, estuarine environments, and strong interactions with tourism, fisheries, and conservation activities. While the sector is facing important challenges associated with environmental regulations, climate change, production costs, and social acceptance, the circular aquaculture and the blue economy policies open a new window of opportunity to boost aquaculture in important zones in Cádiz and Huelva.

The AZA4ICE project provides a strategic framework to address these challenges through the application of C-AZAs. Pilot actions in Andalusia demonstrate the feasibility of IMTA, RAS, and waste valorisation systems. This Action Plan is developed through the innovation ecosystems LiRRIEs, ensuring multi-actor participation of the following objectives:

1) **Operationalise Circular Aquaculture in C-AZAs.** Design and scale circular production models will be promoted within identified C-AZA pilot areas optimising spatial planning and resource allocation to maximize environmental and economic performance.
2) **Promote Innovative Production Systems.** Technological and implementation advances in IMTA, RAS, aquaponics, and hybrid systems guiding diversification in low-trophic organisms (macroalgae, halophytes, bivalves) will be supported to strengthen ecosystem services and market opportunities. Promote industrial symbiosis and business-to-business collaboration to consolidate production models.
3) **Enhance Resource Efficiency and Waste Valorisation.** Circular practices such as sludge recovery, by-product valorisation, nutrients upcycling, more efficient feeding and genetic selection and eco-design will be fostered.
4) **Strengthen Governance and Regulatory Integration** Alignment between circular aquaculture practices and licensing, spatial planning, and environmental regulations will be encouraged. Provide policy recommendations to support regulatory adaptation for circular production models.
5) **Foster Social Inclusiveness and Stakeholder Engagement**. Multi-actor participation of quadruple helix promoting knowledge transfer, and capacity building within the sector will be ensured.

3. Roles and Responsibilities of Actors

Main roles and actors in the Action Plan will be:

- **Regional Authorities:**

This includes the Directorate for Fisheries Aquaculture and Blue Economy of the Regional Ministry of Agriculture, Fisheries, Water and Rural Development (CAPDR) and the environmental authorities of the Junta of Andalusia, including the Natural Parks Administration and the Regional Ministry of Sustainability and Environment. Their main responsibilities include policy integration, licensing and permitting, spatial planning, regulatory oversight, and environmental protection.

- **National authorities**

This includes the department with competences of Public Maritime-Terrestrial Domain

from the Spanish Ministry for Ecological Transition and the Demographic Challenge.

- **IFAPA (Andalusian Institute for Agricultural and Fisheries Research and Training)**

IFAPA will contribute to the technical coordination, monitoring, and capacity-building activities. IFAPA will also support technology transfer and training programs aimed at facilitating the transition towards circular aquaculture practices

- **Administrative Agencies of Junta of Andalucia.**

AGAPA and AMAYA will support as advisor in allocated maritime planning

- **Aquaculture sector:**

This group includes producers, associations, service providers, and value-chain actors. They will be the primary agents responsible for implementing the transition to circular practices, piloting innovative production models

- **Universities and Research Centres**

These institutions will deliver technical support and applied research and develop innovative solutions for a better performance of aquaculture systems.

- **Civil Society**

Civil society organizations and local communities will contribute to foster social acceptance and shared responsibility for sustainable aquaculture development.

4. Regional Needs, Challenges and Opportunities (input from LiRRIE)

This section presents the main needs, challenges, and opportunities identified through the LiRRIE stakeholder engagement process conducted in the Andalusian region. These insights serve as key guiding elements for the Action Plan, ensuring that it responds to local conditions and supports solutions that are both feasible and meaningful for the sector in this area.

With respect to the **challenges**, they were grouped into five categories: a) Environment; b) economic viability; c) technological and knowledge gaps; d) policy and regulatory gaps and e) stakeholder engagement and coordination (**Figure 3**). These challenges reflect the key structural and contextual issues affecting aquaculture development in the Bay of Cádiz pilot site, as outlined below.

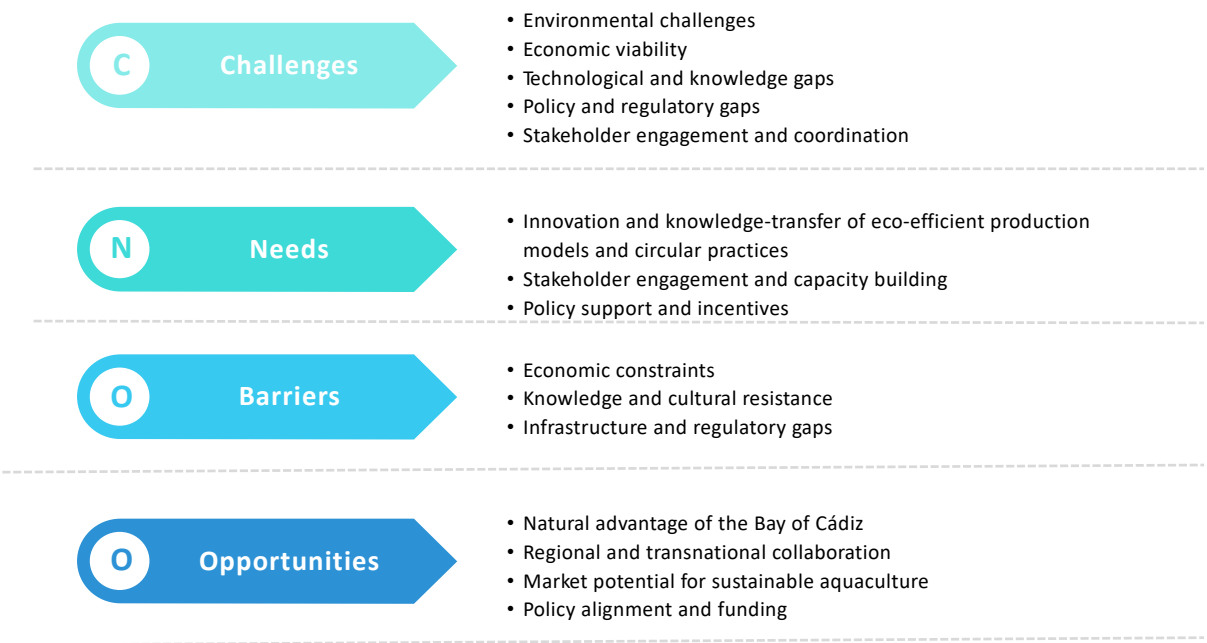

Figure 2. *Main challenges, needs, barriers and opportunities in the pilot site Bay of Cádiz*

a) Environmental challenges

Environmental constraints encompass a wide range of factors that directly influence the sustainability and performance of aquaculture activities in the Bay of Cádiz:

- **Eutrophication risks and nutrient discharges**. This is a major challenge for producers since all aquaculture facilities must fulfil water quality regulations controlling the levels of organic and inorganic particles in wastewater. These regulatory frameworks are particularly strict, requiring continuous monitoring and compliance with high environmental quality standards, increasing operational complexity and costs. Currently, most productive models follow a lineal approach.
- **Pollutant associated risks** especially the presence of heavy metals in the water resulting from anthropogenic and other blue-economy activities. This issue is of particular concern for organisms with bioaccumulation capacity, such as algae and molluscs, as well as for aquaculture sludge. This is of special relevance when circular strategies aim to valorise these materials as fertilisers, feed or food services.
- **Climate change impacts**, including rising seawater temperatures and the increasing frequency of extreme weather events. Seasonal temperature shifts are becoming more frequent, altering reproductive cycles, while rapid thermal fluctuations increase the occurrence of thermal stress episodes and uncontrol mortalities. Together, these changes represent an emerging challenge that requires adaptive strategies.
- **Salinity fluctuations.** The strong tidal dynamics typical of the Bay of Cádiz create significant variability in salinity and water quality. These fluctuations are further intensified during episodes of heavy rainfall, conditioning the range of species suitable

to be cultivated and generating stressful conditions for cultivated organisms and increasing the risk of production losses.

- **Balancing aquaculture growth with the preservation of sensitive coastal ecosystems**. This area is protected under natura Network 2000 and it hosts high biodiversity values. Therefore, there exists several restrictions to any action that disturb birds or modify environmental conditions toward aquaculture. There exists a particular classification of productive areas according to the degree of protection and requirements imposing limitations to the type of activity and actions.
- **Underutilisation of traditional marsh ponds ("esteros").** Many esteros are not exploited leading to a reduction of extensive and semi-extensive aquaculture, the degradation of wetland ecosystems, and the erosion of cultural and historical heritage linked to traditional aquaculture practices.

b) Economic viability

Economic viability challenges are the result of structural and operational constraints that limit long-term sustainability of aquaculture activities in the Bay of Cádiz such as:

- **Uncontrolled access and theft.** Difficulties in preventing unauthorized access to production areas and theft during production cycles. The Natural Park is surrounded by big urban areas and access is easy requiring rapid responses. As consequence, significant investments in security are usually required.
- **Inefficient production models.** Many existing traditional aquaculture systems show limited economic performance due to suboptimal feed efficiency, high input costs, and efficiency in water management. In most traditional systems is not easy to monitor or deliver feeds effectively. Moreover, survival is not easy to control producing overfeeding frequently. Moreover, the water quality fluctuations are high modifying growth rates with high pumping costs when tides are not possible.
- **Predation losses.** Significant production losses are caused by bird predation, particularly in extensive and semi-extensive systems, where control measures are often limited or costly. In the Natural park approximately 30% of the total annual extensive aquaculture production (114.4 kg/ha) is lost by ingestion by birds (Yufera & Arias 2010).
- **Transition costs.** The shift toward eco-efficient production systems and the adoption of circular aquaculture practices require substantial upfront investments, posing a major financial burden for operators.
- **Funding barriers.** Small and medium-sized enterprises (SMEs) and small-scale producers face significant barriers in accessing financing, investment instruments, and tailored support schemes to modernize their operations
- **Spatial planning constraints and competition for space**. Aquaculture activities must coexist with other blue economy sectors, including tourism, maritime transport, sports and recreational uses and compliance with military and security restrictions,

which further limit available space and increase operational complexity.

c) Technological and knowledge gaps

- **Insufficient integration of circular aquaculture systems.** Despite the proven potential of circular production approaches already recognized in regional regulatory frameworks and the conditions to implement them in the territory, implementation **IMTA**, **RAS**, marine **aquaponics**, BFT or hybrid systems remains limited at the local level. Although one company moved toward IMRAS system, most production models continue to rely on linear approaches with low levels of effective nutrient recovery, valorization and circular practices.
- **Limited access to advanced technologies and tools.** Many producers face difficulties in accessing and adopting modern technologies, including real-time water quality sensors, aquafeeds 3.0, automated feeding systems, genetic breeding programs, decision-support tools, performance monitoring platforms and biomass management. In addition, the limited integration of improvement and selective breeding programs constrains the optimization of growth, resilience, and feed efficiency.

d) Policy and regulatory gaps

Policy and regulatory constraints remain a significant barrier to the development of circular and eco-intensive aquaculture systems:

- **Lack of clear regulatory frameworks to promote circular and eco-intensive aquaculture systems.** Existing regulations are primarily designed for conventional aquaculture models and do not sufficiently recognise or facilitate the implementation of circular and eco-intensive approaches. In Andalusia, aquaculture legislation formally recognizes IMTA as a productive system, and the currently decree regulating the activity is currently being on revision to be amended to incorporate circular practices, clearly distinguishing them from linear intensive practices that are far removed from eco-intensive models. The absence of clear definitions and classification criteria for circular practices creates regulatory uncertainty.
- **Insufficient incentives for adopting sustainable practices.** There is a lack of targeted incentives, circularity indicators, support schemes, and regulatory flexibility to encourage producers to invest in sustainable and circular practices.
- **Fragmentation of competences and regulatory complexity.** Aquaculture activities are governed by multiple regulatory bodies with overlapping responsibilities, leading to complex, time-consuming authorisation processes and uncertainty for operators.

e) Stakeholder engagement and coordination

- **Difficulty in aligning diverse stakeholder interests.** Policymakers, researchers, producers, industry representatives, and local communities often operate with

differing priorities in advancing toward circularity and timelines. Perception is completely different. Producers typically prioritise energy stability and feed cost reduction, policymakers emphasise emissions, nutrient discharge, and licensing risk, while citizens value transparency, origin, and ecological responsibility. These differentiated priorities must be mediated through inclusive governance, stakeholder co-creation, and knowledge exchange protocols (Aitken *et al.* 2025).

- **Limited awareness and participation of small and medium enterprises (SMEs) in innovative circular aquaculture practices.** SMEs frequently have limited knowledge of circular aquaculture opportunities, technologies, and support mechanisms, which restricts their involvement in innovative practices.
- **Lack of coordination among stakeholders**. Weak linkages between producers, public authorities, research institutions, and advisory services hinder knowledge exchange, co-creation, and the effective transfer of innovation into practice.

These challenges are represented in the **Figure 3**.

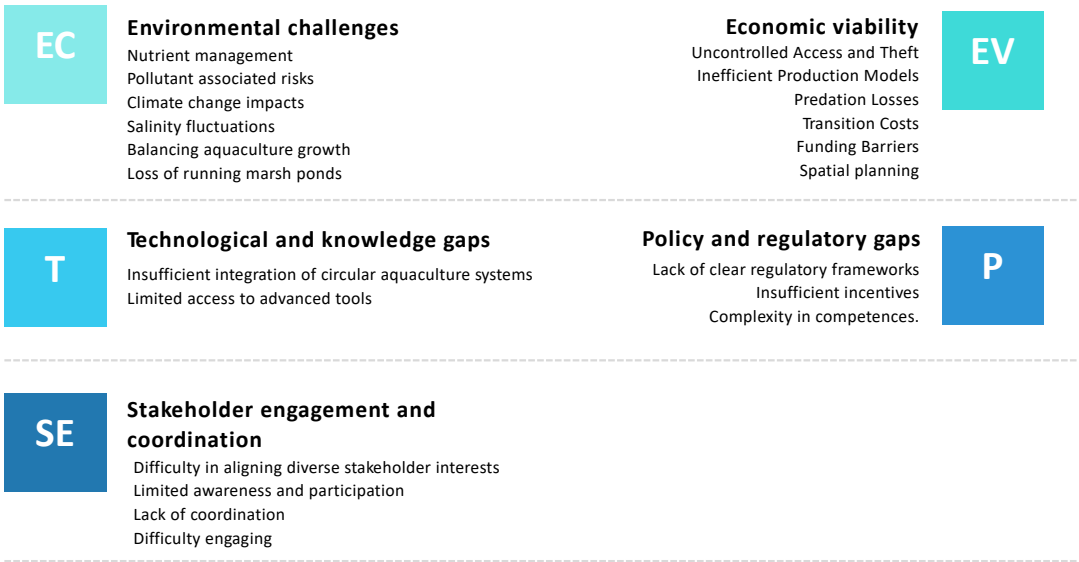

Figure 3. *Challenges identified in the pilot site Bay of Cádiz*

With respect to the **needs**, the transition toward circular aquaculture requires a coordinated set of technological, social, and policy-oriented actions that jointly address structural bottlenecks in production systems, governance, and value chains. **Figure 4** synthesizes the key **needs** that shown below:

a) Reinforcement of Innovation and knowledge-transfer of eco-efficient production models and circular practices

- **Adoption and transition toward circular IMTA, RAS, BFT, aquaponics and hybrid systems.** Throughout *pilot demonstration sites and case studies*, the current linear models should make easier the transition toward IMTA, hybrid systems IMRAS, BFT

and aquaponics solutions. Different combinations of fed species (fish, shrimp) and extractive organisms should be carefully assessed in each model for scalability and adaptability

- **Development and reinforcement of low-trophic species production capacity.** Priority should be given to establishing *robust, scalable farming technologies and dedicated facilities and breeding program* including genetic selection for the production and reliable supply of high-value, low-trophic aquaculture species adapted to local ecological conditions. *Species selection should prioritize those oriented toward direct human consumption* with strong consumer acceptance. Moreover, it is essential to strengthen capacities for *biomass production as a commodity* for downstream, high value-added applications in the food, cosmeceutical, nutraceutical, and aquafeed industries.
- **EcoInnovation in advanced circular aquaculture models.** New materials, resources, and *optimized workflows* should be integrated into aquaponics, IMTA, BFT, and RAS, in synergy with salt-marsh restoration practices and other nature-based solutions.
- **Technology development for by-product processing and valorization.** Design and validate *advanced technologies for the in situ processing and upscaling* of aquaculture by-products (algal or halophyte biomass) and residues (sludge, fish-by-products, shells). *In situ* technology validated to mechanize collection and cost-effective preservation methods should make cost-effective downstream valorization pathways including functional foods and feeds, biofuels and energy production, bioplastics and bio-polymers, fertilizers and biostimulants for agriculture, and integrated sludge management within circular bioeconomy frameworks.
- **Genetic and microbial innovation.** Genetic and microbiome-based innovation is essential to strengthen the resilience, health, and productivity of both fed and extractive species within circular aquaculture systems. This requires the expansion of *selective breeding and domestication programs*, the application of functional and quantitative genomics, and the strategic management of microbial consortia. In parallel, advancing in the biotechnological use of *bacteria-promoting growth bacteria*, host–microbiome interaction studies are required to support improved robustness, disease resistance, and resource-use efficiency, enabling stable performance under eco-intensive and environmentally variable conditions characteristic of circular aquaculture models.

b) Stakeholder engagement and capacity building

- **Capacity building and training for local producers.** Design and deliver tailored training programs that combine technical, economic, and environmental aspects of circular aquaculture.
- **Co-development of solutions through participatory platforms.** Actively engage

producers, public agencies, research institutions, and SMEs in co-developing practical and context-specific solutions using existing participatory platforms.

- **Strengthening multi-actor collaboration in aquaculture zones.** Leverage established participatory frameworks to facilitate continuous dialogue and co-design among multiple actors within aquaculture zones.

c) Policy support and incentives

- **Alignment and adaptation of regulatory frameworks.** Review and harmonize existing regulations to remove barriers and create enabling conditions for circular aquaculture, including the reuse of by-products, nutrient recycling, integrated systems, and innovative feed and energy solutions.
- **Financial incentives and economic support mechanisms.** Develop targeted financial instruments such as grants, subsidies, tax incentives, and access to green finance to support small and medium producers in transitioning toward eco-intensive and circular systems.
- **Definition and operationalization of Aquaculture Zones of Activity (AZAs).** Support the definition and implementation of AZAs as spatial and governance tools to identify regional needs, optimize resource use, and coordinate circular aquaculture activities.

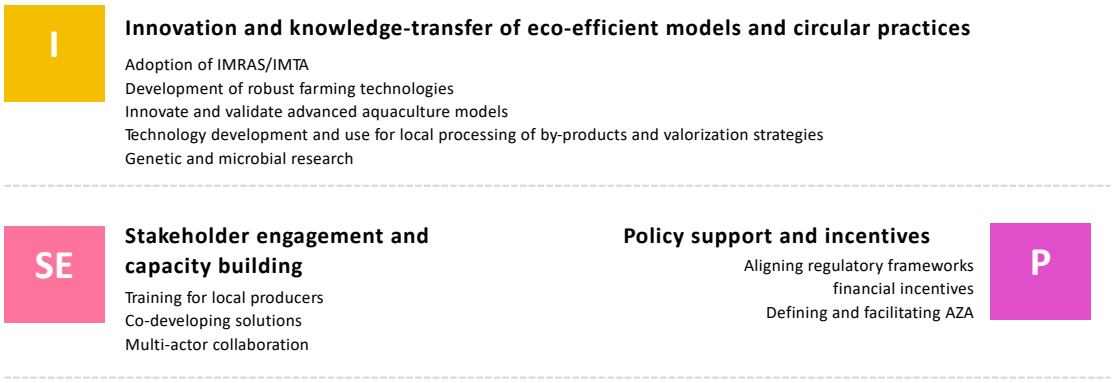

Figure 4. *Needs identified in the pilot site Bay of Cádiz*

With respect to the **barriers**, there are three main categories that currently hinder the transition toward circular aquaculture systems: economic constraints, infrastructure and regulatory gaps, and limitations in knowledge transfer and cultural acceptance. **Figure 5** synthesizes the most relevant obstacles that must be addressed as indicated below:

a) Economic Constraints

- **Limited access to dedicated funding and financial instruments.** SMEs often face difficulties in accessing public or private funding to transitioning existing facilities toward circular, eco-intensive systems. Investment schemes are frequently not tailored to the specific needs and risk profiles of integrated systems such as IMTA,

RAS, or aquaponics.

- **Perceived high costs and risks associated with implementing circular aquaculture models.** Circular aquaculture models are often perceived as capital-intensive and technologically complex, leading to concerns regarding return on investment, operational reliability, and market uncertainty.
- **Insufficient visibility of validated business models.** Despite the existence of successful pilot projects, there is a lack of widely disseminated, well-documented business cases demonstrating the economic viability of circular aquaculture.

b) Infrastructure and regulatory gaps

- **Outdated aquaculture infrastructure not adapted for multitrophic integration.** Many existing aquaculture facilities in the Bay of Cádiz were originally designed for monoculture production systems and some of them must face with the spatial design, water management capacity, and modular design needed to effectively integrate extractive species, biological filters, or nature-based solutions. Regulatory alignment is essential to enable facility transformation while ensuring environmental protection, operational feasibility, and legal certainty for producers.
- **Regulatory uncertainty and lack of specific guidelines** for implementing eco-intensive systems in the Bay of Cádiz. The absence of clear, harmonized regulatory frameworks, circularity indicators and technical guidelines for eco-intensive and circular aquaculture systems are necessary to increase confidence of producers and public authorities.
- **Limited integration of circularity into spatial planning.** Current coastal and aquaculture spatial planning instruments do not sufficiently incorporate circularity principles, limiting opportunities for co-location, resource sharing, and synergies with salt-marsh restoration, wastewater valorization, or other nature-based solutions.

c) Knowledge and Cultural Resistance

- **Resistance linked to cultural heritage and traditional practices.** Long-established aquaculture practices are deeply rooted in local identity and professional experience. These methods are often perceived as more reliable and less risky, leading to scepticism toward innovative production models and technological change.
- **Limited awareness and understanding of circular aquaculture benefits.** Without targeted education, demonstration activities, and communication efforts, many stakeholders remain unaware of the environmental, economic, and social benefits of circular systems.
- **Lack of efficient mechanism for knowledge transfer.** Ineffective communication channels and insufficient training programs hinder the practical application of research findings and best practices. Strengthening robust knowledge-exchange mechanisms, including hands-on training, demonstration sites, living labs, and multi-

actor collaborative networks, is essential to accelerate the transition toward sustainable, resilient, and circular aquaculture systems.

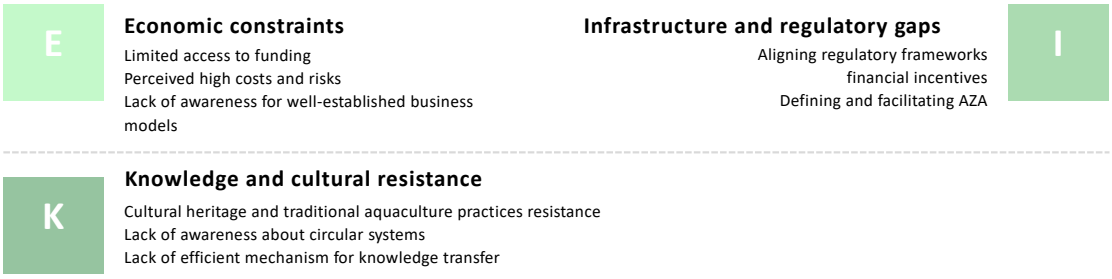

Figure 5. *Barriers identified in the pilot site Bay of Cádiz*

In spite of the needs and barriers identified, circular aquaculture presents several exciting **opportunities** (**Figure 7**) that can redefine the sustainability and productivity of the industry.

a) Natural advantage of the Bay of Cádiz

- **Unique wetlands for land IMTA-IMRAS, aquaponics and circular practices**. The Bay of Cádiz hosts extensive tidal wetlands, salt marshes, and semi-natural aquaculture areas that provide exceptional conditions for the implementation of land-based IMTA–IMRAS systems, aquaponics, and other circular practices. These ecosystems naturally support the integration of several species such as algae, halophytes, polychaetes, and shellfish, facilitating several approaches to biomass production for a commodity-approach of high-added value products and ecosystem-based production.
- **High biodiversity and availability of low-trophic species.** The area is characterized by rich biodiversity and the presence of numerous native low-trophic species with aquaculture potential. These biological resources can be sustainably exploited for food, feed, biofiltration, and bioproduct development, reinforcing the ecological and economic viability of circular aquaculture models.

b) Regional and transnational collaboration

- **Positioning Cádiz as an aquaculture innovation hub.** The Bay of Cádiz has the potential to become a regional and transnational reference hub for circular aquaculture innovation, providing validated methodologies, technical guidelines, and scalable solutions adaptable to other coastal and inland regions.
- **Strong research and knowledge networks.** Partnerships with local universities, research centres, and international institutions enable the testing, optimization, and validation of circular aquaculture systems under real operational conditions. These collaborations strengthen technology transfer, accelerate innovation uptake, and

enhance regional capacity building.

c) Market potential for Sustainable aquaculture

- **Growing market acceptance and consumer demand.** There exists growing consumer demand for sustainably produced seafood and niche products like algal and halophyte biomass.
- **New market for new value-added products**. Circular aquaculture makes feasible the valorisation of by-products and waste streams, supporting the development of high-value products such as functional feeds, nutraceuticals, bioactive compounds, and bio-based materials.
- **Synergies with other blue economy sectors**. Circular aquaculture can be effectively integrated with coastal tourism, environmental education, and blue biotechnology. Activities such as aquaculture tours, demonstration sites, educational programs, and local seafood tasting experiences enhance public engagement, while biomass and metabolites derived from aquaculture systems offer new resources for blue biotechnology and pharmaceutical applications.

d) Policy alignment and Funding opportunities

- **Strong alignment with EU and regional policy frameworks.** Circular aquaculture directly supports key European and regional strategies, including the European Green Deal, the Blue Economy Strategy, and bioeconomy and climate adaptation policies, reinforcing its strategic relevance for public investment.
- **Access to EU and national funding instruments for Innovation**. Circular aquaculture is eligible for multiple funding opportunities at EU and national levels (e.g. Horizon Europe, EMFAF, Interreg, and regional innovation programs), facilitating pilot projects, infrastructure upgrades, and the scaling-up of validated solutions.

Figure 6. *Opportunities identified in the pilot site Bay of Cádiz*

5. Current legal/regulatory/licensing framework

5.1 Lessons Learned for Stakeholders

Within the project AZA4ICE, a cross-analysis of regulatory frameworks throughout the eight countries participating in this project was carried and seven proposals to improve the governance for circular aquaculture were identified:

1) Harmonization of regulatory frameworks. Diverse legal and institutional frameworks throughout different countries and regions act as barriers to efficient licensing and compliance. A better alignment of national regulations with broader EU directives is important. In addition, collaborative efforts to develop shared standards and guidelines can enhance cross-border cooperation and improve the overall regulatory environment is required

Main European strategic plans related to circular aquaculture are aligned directly to the European Green Deal, Farm-to-Fork Strategy and Blue Economy Strategies. The European Commission's communication **COM/2021/240**[3] outlines the **Blue Economy Strategy**, a key policy initiative aimed at fostering sustainable use of marine and aquatic resources in line with the **European Green Deal** and broader EU goals for a climate-neutral economy by 2050. In the context of *circular aquaculture*, this strategy emphasizes the importance of supporting the transition to circular economy models within blue economy sectors, aiming to reduce waste and optimize resource use. **A key priority is preventing nutrient loss into the sea and implementing innovative recycling methods for marine litter, all while promoting sustainable aquaculture practices such as IMTA.**

This blue economy strategy is complemented with the **COM/2021/236**[4] **Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture for the Period 2021 to 2030**. This strategic plan addresses different challenges and opportunities of the EU aquaculture sector and four main objectives: (1) building resilience and competitiveness; (2) participating in the green transition; (3) ensuring social acceptance and consumer information; and (4) increasing knowledge and innovation. This strategy promotes diversification and an the added-value of productions to enhance sector resilience and competitiveness, focusing not only on farming emerging species, particularly non-fed and low-trophic species with a lower environmental footprint, but also on innovative production methods such as polyculture in pond aquaculture and IMTA. Additionally, promoting EU sustainable **aquaculture as a model of local production connected to short food supply chains** plays a key role in diversifying and

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0240
[4] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0236

adding value to EU aquaculture production.

In addition, circular models play a key role to guide in green transition. Some priority actions are:

- Applying a circular economy approach, including the reuse and valorization of waste streams to enhance resource efficiency.
- Promoting the development of environmentally friendly aquaculture systems, such as IMTA, IMRAS, and diversification into lower-trophic species, combining production of fish, molluscs, other invertebrates, and photosynthetic organisms.
- Highlighting and supporting aquaculture practices that provide ecosystem services, such as those conducted in ponds, wetlands, and brackish water systems.

This Strategic Guidelines also identifies access to *space and water* as key stakeholders contributing to building resilience and competitiveness for the aquaculture sector, especially through coordinated planning based on the designation of areas.

2) Importance of decentralized and streamlined governance Decentralized governance models, as observed in Greece, Spain and France, provide opportunities for localized solutions but often result in fragmentation and inefficiencies. Conversely, centralized systems, such as those in Croatia and Montenegro, offer consistency but lack the flexibility to address region-specific needs. A balanced approach that combines the strengths of both models can help stakeholders design governance structures that are efficient, adaptable and conducive to innovation. Digital platforms have demonstrated the potential for technology to reduce bureaucratic delays and increase transparency in aquaculture licensing processes.

3) Overcoming barriers to innovation. Legal and administrative challenges remain a significant hindrance to adopting innovative circular aquaculture systems. Outdated environmental regulations and complex licensing requirements often impede the implementation of eco-friendly techniques. Stakeholders need to apply for regulatory updates that explicitly address these systems, providing clarity and incentives for their implementation.

4) Integrating sustainability and circular economy principles. Stakeholders need to emphasize policies that promote resource efficiency, avoid nutrient loss and the use of renewable inputs in aquaculture operations. Supporting **pilot projects** and **best practices** are key drivers for scaling up sustainable aquaculture systems.

5) Addressing financial and market barriers. Financial constraints and market competition pose significant challenges, particularly for small-scale operators. High compliance costs and limited access to funding often restrict opportunities for growth and innovation. Stakeholders should work to identify and promote funding mechanisms, including subsidies and EU co-financing programs, that support sustainable aquaculture

practices.

6) Enhancing stakeholder collaboration. The complexity of aquaculture governance underscores the need for robust collaboration among stakeholders. Effective communication and coordination between regulatory authorities, industry operators and research institutions are essential for overcoming institutional conflicts and aligning objectives. Initiatives such as stakeholder workshops and participatory governance models can facilitate knowledge sharing and build trust among diverse groups. Moreover, integrating public consultation processes can help to align aquaculture projects with community needs and values.

5.2 Regulatory framework in the Andalusian region

As indicated above, the regulatory framework that governs the marine aquaculture is complex since it is an agri-food industry that mostly performs its activity in zones within the Public Maritime-Terrestrial Domain. There are numerous regulations that govern the establishment, authorization, placement, and management of public domain concessions, as well as the adherence to environmental, health, and commercialization standards. In addition, there are specific regulations to warrant animal welfare and health during the transport and movement of animals, the introduction of non-native organisms for aquaculture purposes, and shellfish harvesting. These regulations play a crucial role in guiding the licensing and regulatory processes for aquaculture operations. Moreover, launching aquaculture ventures may require additional requirements, such as acquiring supplementary permits or licenses, and ensuring alignment with territorial planning frameworks.

According with the subject, regulations can be classified into six groups, although they are not entirely exclusive: 1) Activity authorizations; 2) Activity location; 3) Environmental protection; 4) Animal health; 5) Commercialization; 6) Hygiene and sanitary commitments. Although an exhaustive review of all these regulations is out of the objective of this document, we will focus on the main aspects related to circular aquaculture.

Firstly, we should highlight the **Contribution of Spain to the Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture 2021-2030**[5]. This strategy serves as a roadmap for fostering sustainability, innovation, and economic growth in the aquaculture industry while addressing key environmental and social challenges. The strategy emphasizes collaboration among Spain's regional and national authorities, stakeholders, and the scientific community. This strategy highlight the relevance of: a) *Circular economy and innovation* and incorporate waste reuse, resource optimization, and

[5] https://www.mapa.gob.es/es/pesca/temas/acuicultura/plan-estrategico/estrategia-2021-2030/default.aspx

systems including IMTA and RAS to reduce environmental impacts; b) *Diversification* to expand the range of cultivated species, including low-trophic species; c) *Ecosystem services* to promote aquaculture practices that provide ecological benefits, such as nutrient cycling and habitat conservation; d) *Technology and knowledge transfer* to facilitate collaboration between the industry, academia, and policymakers to ensure the effective application of innovative solutions.

The **New Marine Aquaculture Strategy in Andalusia 2021-2030**[6] is a comprehensive framework aimed at advancing sustainable, competitive, and innovative aquaculture in the Andalusian region. Its primary focus is to integrate environmental, economic, and social dimensions to ensure the long-term growth and resilience of the aquaculture sector. This strategy is fully aligned with the Spanish Strategy to support environmental sustainability, competitiveness and innovation, circular economy and blue growth. This strategy encourages aquaculture practices with minimal impact on marine ecosystems, promotes the efficient use of natural resources and the adoption of circular economy principles including IMTA and low-trophic species. Moreover, it drives R&D efforts to cover main innovative fields in genetics, nutrition, health and technology to develop eco-intensive systems such as RAS and IMTA for environmental integration, management, and the development of specific solutions. It should be stated that, in the mid-term review, the transition towards circular models will be a cross-cutting objective to drive the aquaculture sector forward.

Within the most important regulations, we should highlight the **Decree (58/2017 April 18th)**, regulating marine aquaculture in Andalusia. This decree includes specific definitions in **Annex III** concerning trophic relationships and types of aquaculture systems and defined as: monoculture, polyculture and **multitrophic culture or IMTA.** All of them follow the same authorization process.

Licensing procedures in Andalusia are very well-defined but complex[7] acting on these principles:

1. All establishment should operate in accordance with the approved project, species authorized and the conditions outlined in the authorization resolution (Article 51, law 1/2002).
2. All facilities must maintain the Public Maritime-Terrestrial Domain (Article 51, law 1/2002).
3. Aquaculture projects must align with the technical criteria established by the Regional Ministry in Agriculture and Fisheries

[6] https://www.juntadeandalucia.es/sites/default/files/inline-files/2023/03/Estrategia_Acuicultura_2021_2030_0.pdf
[7] *https://www.juntadeandalucia.es/servicios/sede/tramites/procedimientos/detalle/116.html*

4. Implement corrective measures to minimize environmental impact and preserve historical heritage.
5. Ensure that water discharge fulfil water quality standards (Article 51, Ley 1/2002).

Procedure is well-defined[8] and structured in three main steps: a) **Initiation** in which the required documentation is submitted to start the process. b) **Processing** in which the relevant national and regional authorities review the request and make any required assessments; c) **Completion** with the final approval or rejection of the project with any necessary permits or additional requirements specified. Overall, a maximum period of 6 months is established from the date of the application's registration to the issuance of the Resolution. If this period expires without receiving the Resolution, the request may be considered as denied. For marine farming authorizations on private land, this period is reduced to 3 months

It is necessary for the applicants to request registration in the General Register of Livestock Exploitations (REGA), in compliance with Article 4 of Royal Decree 1614/2008 October 3th, regarding the zoosanitary requirements for aquaculture animals and products, as well as the prevention and control of certain aquatic animal diseases. This must be done at the same Territorial Delegation of the province where the project is to be carried out. The applicant must indicate this on the standardized joint application form (Annex I of Decree 58/2017, April 18th, regulating marine aquaculture in Andalusia).

5.3 Proposed Common Solutions in AZA4ICE

The lessons outlined above provide a roadmap for stakeholders to address the challenges and opportunities within the aquaculture sector. Main proposed solutions are:

a) A unified approach to licensing across participating countries is important to reduce delays and increase transparency. Countries should adopt digital tools to consolidate applications, streamline approvals through different administration and provide real-time updates to applicants. Harmonizing licensing criteria across the region, including clear definitions and indicators for innovative systems IMTA- RAS, can further simplify the process and foster collaboration.

b) Alignment of national and regional regulations with EU directives in Blue economy, Sustainable aquaculture and Bioeconomy. Standardizing key aspects like environmental impact assessments and operational monitoring can help to reduce jurisdictional conflicts and facilitate regional and transregional investments.

[8] *https://www.juntadeandalucia.es/organismos/agriculturapescaaguaydesarrollorural/areas/pesca-acuicultura/acuicultura/paginas/procedimiento-autorizacion-cultivos-marinos.html*
https://www.juntadeandalucia.es/export/drupaljda/procedimiento_autorizacion_cultivos_marinos.pdf

c) Investments in research and capacity-building programs are essential for regulators and operators to stay informed about innovative technologies and best practices. Establishing regional research hubs and knowledge sharing platforms can enable stakeholders to address technical challenges and adopt advanced aquaculture more effectively.

d) Financial support mechanisms, including subsidies and tax incentives, should be designed to encourage sustainable aquaculture practices. Participating countries can leverage EU funding programs to support small scale operators and projects that demonstrate innovative and environmentally friendly methods. Enhanced financial accessibility will enable broader participation in the sector.

e) Building partnerships between public institutions and private operators can drive innovation and reduce administrative bottlenecks. Collaborative frameworks can also foster transparency and accountability while ensuring that aquaculture projects align with both national goals and local community interests.

f) Countries should adopt policies that emphasize the **integration of circular economy principles into aquaculture operations**. Encouraging the use of renewable inputs, recycling waste, and developing closed-loop systems can enhance resource efficiency and align the sector with global sustainability objectives.

g) Proactive engagement with stakeholders, including local communities, industry players, and environmental groups, is critical for building trust and addressing resistance to aquaculture projects. Structured consultation processes and participatory decision-making models can ensure that regulatory reforms are inclusive and reflective of diverse perspectives.

6. Current status of aquaculture businesses (input from D2.2.1 - Bluefasma self-assessment tool)

In project AZA4ICE, the Circular Economy (CE) readiness and willingness of aquaculture actors was analysed using the BLUEfasma self-assessment tool. In this analysis, different companies including producers, retailers, service providers, suppliers and sectoral organizations were investigated (**Figure 7**). Overall, readiness levels across the beneficiaries remain **moderate**, with **most positioned in the "eco-thinking / green economy" stage** (indices between 1.6 and 2.4). Only two companies, stood out as an advanced adopter (>2.5 readiness, Silver Medal), demonstrating tangible steps toward systemic circular integration. In contrast, **the majority remain in early phases of circularity adoption**, with progress primarily reflected in awareness and pilot initiatives rather than full-scale implementation.

By comparison, willingness to invest in CE practices is considerably higher across all beneficiaries, ranging from 3.0 to 4.9. This indicates strong **motivation and openness to adopt circular strategies despite current limitations in readiness**. All express ambitions to improve through targeted investments. The assessment highlights a **clear gap between present readiness and future ambition**. Most organizations have not yet consolidated circular practices but express commitment to evolve. Priority areas for action include **renewable energy integration, sustainable packaging, waste valorization, local supply chain circularity, and cross-sector collaborations.** With proper support, several Bronze Medal companies could rapidly progress toward Silver and beyond.

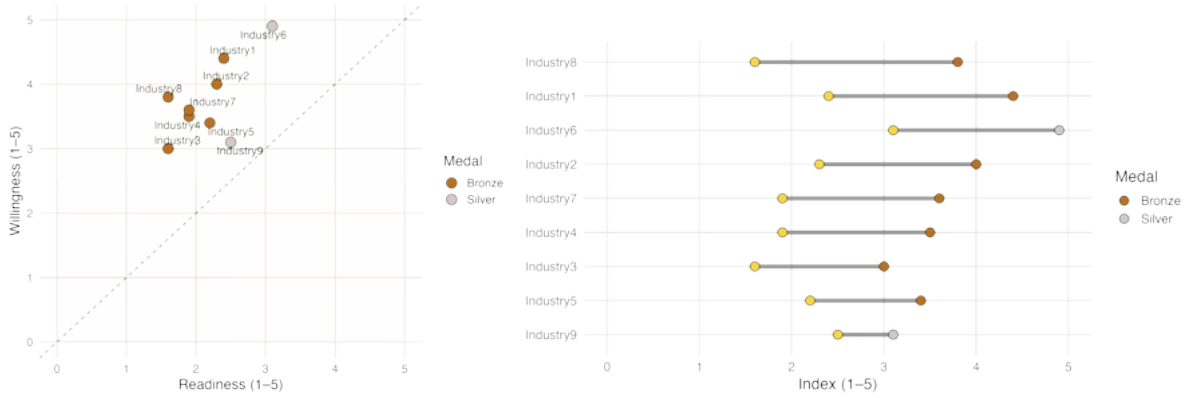

Figure 7. Circular economy readiness versus willingness to invest among aquaculture-related companies. *Each point represents one company, positioned according to its readiness index (x-axis) and willingness to invest score (y-axis). The background colour zones reflect levels of adoption and commitment: red (very low), orange (low), yellow (eco-thinking), and green (advanced/leader). The diagonal line indicates alignment between readiness and willingness. Companies located above the line show higher willingness than readiness, suggesting strong potential for accelerated circular transition.*

The analysis of 65 SMEs across the Euro-MED area reveals a significant disparity between intent and action regarding the Circular Economy.

a) Generalized Circular Economy Readiness Index (CERI)

- The average CERI of 1.9 firmly places the sector in the 'Eco-Thinking/Green Economy' stage, indicating that while companies have moved past the purely linear "take-make-waste" model, **their primary focus is on basic eco-efficiency** (e.g., resource management) rather than deep, strategic CE integration.
- The readiness score is uniform across all eight participating territories, underscoring that the aquaculture sector, by its nature, remains a predominantly traditional domain that has been **slow to adopt the disruptive technological and operational changes** required for CE.

- 43.1% of surveyed SMEs entirely neglect sustainability and CE in their formal business planning, confirming that for a large portion of the community, **circularity is not a strategic priority.**

b) Generalized Willingness to Invest in Circular Economy (WICE)

- The average WICE score of 3.5 is highly encouraging, indicating that industry stakeholders are financially receptive and actively positioned to allocate capital towards systemic change. This score suggests that the financial inertia often associated with sustainability transitions is not the primary roadblock.
- The dominant motivations for adopting CE are 50.8% practical resource management and 36.9% ethical/environmental values. This suggests that messaging and policy should focus on the immediate operational benefits (e.g., cost savings from resource efficiency) alongside environmental mandates.

c) Main Areas of Linear Practice

- *Waste Valorization Failure:* There is a major gap in treating by-products as resources. A combined 84.0% of companies either discard fish/shellfish waste directly (56.0%) or send it for external organic treatment. Furthermore, nearly 60% of companies do not recover products' waste at all.
- *Packaging and Storage:* Reliance on single-use packaging remains high (50%), and nearly half of companies (46.2%) perceive item recovery for reuse as infeasible, indicating a lack of formal, systematized recovery strategies.
- *Vessel Inefficiency:* 88% of vessels rely on traditional, high-consumption fuels, highlighting a substantial need for investment and incentives to modernize fleets.
- *Commercialization Gap:* Of the small number of companies that do recover waste and produce by-products, over 90% either don't commercialize them or only sell locally on a small scale, demonstrating a significant missed opportunity in developing profitable, non- local circular business models.

Lessons Learned

The study provides critical lessons for policymakers and the industry to bridge the gap between high willingness and low readiness.

1. A high willingness to invest (3.5) does *not automatically translate* into high readiness (1.9). The transition to circularity requires more than capital; it needs *strategic knowledge, technical capacity, and systemic infrastructure*.

2. A primary bottleneck is the *treatment of biomass/processing waste and packaging waste* considered as disposal problems rather than resource opportunities. Interventions must focus on technologies that facilitate upscaling (e.g., transforming fish scales into collagen) and developing market linkages for by-products.

3. Given that 43.1% of SMEs lack a formal CE plan, policy should shift from broad awareness *to incentivizing and co-funding the integration of CE into core business*

strategies. This includes support for deep-level integration and innovation (27.7% currently).

4. The high WISE score should be leveraged by policymakers to create targeted financial mechanisms (e.g., specialized loans, grants) that specifically fund the move away from linear practices.

5. The low commercialization of recovered by-products (over 90% of producers sell locally/not at all) indicates a critical need for business development support. This includes training on non-local market access, supply chain collaboration, and the creation of shared valorization facilities that can process waste volumes from multiple SMEs efficiently.

7. Vision for circular aquaculture in the Bay of Cádiz

The Bay of Cádiz is an excellent territory to become a global leader in circular aquaculture, drawing upon its exceptional natural resources, long experience in traditional aquaculture in ponds, large biodiversity, and rich cultural traditions to promote sustainable and eco-efficient practices. This vision adopts an integrated approach that combines production, innovation, collaborative partnerships, and active community participation to tackle challenges and unlock the region's potential in the blue economy.

Our vision is "***To transform the Bay of Cádiz into a hub for innovative, circular, and eco-intensive aquaculture, harmonizing ecological sustainability with economic growth***". By addressing environmental, economic, and social challenges, this action plan aims to progressive transition the aquaculture in the bay of Cádiz region toward a model of resilience, efficiency, and circularity while maintaining high standards of social acceptance and cultural heritage.

The core pillars of the vision are:

1. Promote the transition and adoption of eco-intensive and sustainable eco-friendly systems and scaling of low-trophic biomass production

The Bay's future should be based in integrating cutting-edge technologies and practices to create a successful circular aquaculture model. While the Bay of Cádiz has traditionally linked to aquaculture, we need to increase the competitivity and profitability of this activity while maintaining the core of this traditional features to support sustainability and environmental services. Hence, it is a priority to design site-specific, eco-intensive systems tailored to the Bay's unique tidal wetlands and biodiversity. These systems will incorporate circular principles to avoid nutrient loss, improve recycling and water quality, and minimize waste streams.

This approach is based on two complementary strategic pathways: (i) the generation of suitable biomass as a valuable resource within a biorefinery and bio-valorisation

framework, and (ii) the production of high-quality, sustainable aquaculture products closely linked to other blue sectors.

Two ecosystem-based models of circular aquaculture can be identified: **regenerative aquaculture** defined as *a farming approach that uses aquatic ecosystem conservation as the* entry *point to regenerate and contribute to provisioning, regulating, and supporting ecosystem services* (including fed species) and **restorative aquaculture** *or extractive aquaculture (combining extractive species such as algae and shellfish) that generate net positive environmental outcomes.* This latter particularly interesting in areas of high environmental protection. While these terms are sometimes used interchangeably, incorporating extractive species in IMTA is considered regenerative if it aims to improve the environment; however, if done solely to reduce finfish farming waste without producing net positive effects, it does not qualify as restorative aquaculture (Alleway *et al.* 2021).

Some **potential initiatives** will be:

- **Assessing of pilot site** suitability for circular practices
- **Spreading knowledge** about circular production models and create reference models to be replicated
- **Promotion of species diversification**, including halophytes, algae, shellfish, and low-trophic fish close to the market
- **Promote biomass production**, conservation and preservation as a high-quality commodity in the core of blue symbiotic ecosystems
- **Promote valorization of aquaculture biomass** and by-products into aquafeeds 3.0, fertilisers, and bioplastics to reduce waste.
- **Supporting advanced monitoring systems** for water quality and species performance.
- Supporting **genetic and microbial research** to enhance resilience and productivity.

2. Support economic resilience and enhance market potential

Circular aquaculture opens significant market opportunities. The growing consumer demand for sustainably produced seafood and niche products, such as algae and halophyte biomass and bioactive compounds, offers economic incentives for producers. Synergies with other blue economy sectors, such as coastal tourism, can further diversify incomes through aquaculture tours, educational programs, and seafood tastings. These activities can also promote new resources for blue biotechnology, fostering a competitive edge for Cádiz in global markets.

A key element will be supporting scalable, profitable, and sustainable aquaculture practices that drive economic growth. By tapping into the market potential of circular

aquaculture, traditional markets will be consolidated while new niches based on biomass and by-products for side stream applications promoting new jobs and diversifying incomes.

Some **initiatives** include:

- **Technical assistance for companies transitioning** to circular systems.
- **Technical assistance for biomass production**, collection and preservation and selection of best candidate species.
- **Identifying good practices and niche markets** for sustainably farmed seafood, aquafeeds 3.0, bioactive compounds, and nutraceuticals.

3. Incentive applied knowledge and collaboration

The Bay of Cádiz is positioned as an innovation hub for circular aquaculture, supported by partnerships with IFAPA, technological center, local universities, research institutes, and industry stakeholders. By creating methodologies and scalable solutions, the region can drive advancements that are transferable across the Mediterranean and beyond.
By fostering participatory platforms, LiRRIE will enhance collaboration and ensure that solutions are inclusive and tailored to regional needs.

Some **actions** are:

- **Establishment of multi-actor collaboration** events to align interests and co-develop solutions.
- Develop **action plans focused on circular aquaculture practices** and innovative technologies.
- **Support of knowledge-sharing networks** to disseminate best practices and research findings.

4. Policy advocacy

Aligned with EU sustainability policies, Cádiz should capitalize on funding opportunities to support the transition to circular aquaculture. Simplifying regulatory frameworks, offering financial incentives, and fostering transnational collaboration will accelerate the adoption of eco-intensive systems.
By aligning local policies with EU sustainability goals, the initiative will make feasible a beneficial environment for innovation and investment including:

- **Advocacy for simplified and harmonized regulatory** frameworks.
- **Introduction of financial incentives**, such as subsidies and tax benefits, to support eco-intensive systems.
- **Positioning the Bay of Cádiz as a model region** for sustainable aquaculture within European policy circles.

8. Potential of the C-AZA results

C-AZA approach represents a strategic opportunity to transform traditional aquaculture activity into a territorial, integrated, and circular production model. By combining spatial planning, environmental performance, species suitability and circular economy principles, C-AZA provides a replicable framework with high added value for policy, industry, and society.

Main outputs of C-AZA methodology across the eight pilot sites were:

- **C-AZA results demonstrated the feasibility of aligning aquaculture production with environmental protection objectives**. The integration of multitrophic systems, nutrient recovery pathways, and nature-based solutions shows that aquaculture can shift from a source of pressure to a provider of ecosystem services, including water quality improvement, nutrient retention, and habitat support. This strengthens regulatory compliance and supports evidence-based decision-making by public authorities.
- **C-AZA outcomes highlight the economic and innovation potential** of circular aquaculture at territorial scale. By enabling the valorisation of side streams (e.g. sludge, biofilters, algae, halophytes) and fostering linkages with biorefineries, feed production, agriculture, and other blue sectors, C-AZA creates new value chains and market opportunities. This diversification reduces dependency on single production outputs and enhances the resilience and competitiveness of aquaculture enterprises.
- **C-AZA results reinforce governance and stakeholder coo**rdination. The multi-actor, quadruple-helix approach underpinning C-AZA facilitates dialogue between public authorities, producers, researchers, and civil society, improving social acceptance and trust. Clear spatial planning, shared indicators, and transparent monitoring tools support coordinated management and reduce conflicts with other coastal uses.
- **C-AZA provides a scalable and transferable model**. The methodologies, indicators, and lessons learned can be adapted to other coastal and inland aquaculture areas, supporting regional, national, and European policy objectives related to the Blue Economy, circularity, and climate adaptation. As such, C-AZA results offer a solid foundation for upscaling circular aquaculture practices and positioning the territory as a reference hub for sustainable aquaculture innovation.

9. Proposed Actions

This Action Plan proposes a set of actions (**Figure 8**) that simultaneously address the main environmental, economic, technological, regulatory, and governance challenges, while actively recognising the unique natural, scientific, market, and policy opportunities of aquaculture in the Bay of Cádiz. This action plan is framed not only as a theoretical roadmap, but as a transformative development pathway to support transition toward new and competitive production models

9.1 Actions and Interventions

Proposed action has been structured in five pillars that support complement actions on the activity and position circular aquaculture as a key driver of the Andalusian Blue Economy Strategy (EA2) by combining environmental protection, economic diversification, innovation, and social cohesion in Natura network 2000 coastal areas.

Figure 8. *Pillars and actions in the action plan to support transition to circular aquaculture.*

Pillar 1. Facilitate the transition toward circular, resilient and ecosystem-compatible aquaculture

Objective: Safeguard environmental integrity while enhancing productivity and resilience

Actions:

a) **Identify and assess potential circular production models in the area.** Explicitly assess the feasibility and operation of restorative and regenerative circular models compatible in the zone ensuring biodiversity conservation, habitat restoration, and minimal disturbance while support local communities and economies Support the ecological recovery of underutilised esteros by circular aquaculture.

b) **Develop and establish pilot and demonstration of circular aquaculture systems adapted to local conditions.** Support and establish pilot-scale circular aquaculture units in selected esteros and existing facilities to demonstrate how to avoid nutrient loss, waste valorisation (sludge, by-products), energy efficiency, and low-impact production under real operating conditions. Support models of circular nutrient management systems through IMTA, marine aquaponics, BFT, RAS and hybrid configurations making different combinations of compatible species.

c) **Reinforce digitalisation and environmental monitoring.** Promote real-time water quality sensors (nutrients, oxygen, temperature, salinity, turbidity), decision-support tools, and digital reporting systems aligned with C-AZA indicators to improve compliance, transparency, and adaptive management.

d) **Develop contaminant monitoring and risk assessment protocols** (e.g. heavy metals, emerging pollutants) to ensure the safe circular valorisation of sludge, algae, halophytes, and other by-products.

e) **Implement climate-resilient and model-specific production strategies,** including selective breeding for environmental fluctuation tolerance, adaptive production calendars, species diversification, shading solutions, and improved water management.

Main leverage points of this pillar 1 are:

- Shift the paradigm of linear models. Adopt **nutrient recovery to prevent loss instead of discharge** supports regulatory compliance and ecosystem services. This high-leverage approach reduces pollution, supports regulations, generates biomass and revenue, restores ecosystems, and increases public support.
- **Low-trophic biomass yield** increases performance and outputs per hectare
- **Restoration** unlocks protected areas for productive use

Pillar 2. Economically viable and competitive circular production models

Objective: Improve profitability, reduce operational risks, and strengthen competitiveness of aquaculture enterprises.

Actions:

a) **Design modular technologies and pilot-scale demonstrators** that make feasible progressive transition reducing upfront investment risks.

b) **Upgrade traditional production models with technological tool, digitalization and mechanization including precision feeding systems, biomass estimation tools water quality control and in situ collection and preservation** to improve feed efficiency, survival, and growth performance.

c) Strengthen biosecurity and operational protection through smart surveillance, access control technologies, and coordinated rapid-response mechanisms adapted to public-domain and Natural Park contexts.

d) **Develop bird predation mitigation strategies**, including nature-based measures such as adapted nets and noise measurements or adaptive pond design.

e) **Improve access to tailored financial instruments** (grants, co-financing, guarantees, blended finance) specifically **designed** for SMEs and companies for uptake transitioning measures. KPIs should be clearly identified to monitor effectively the measures adopted.

f) **Strengthen integration of circular aquaculture into maritime and coastal spatial planning** to reduce conflicts with tourism, transport, cultural heritage, security uses, and other blue economy activities.

Main leverage points of this pillar 2 are:

- **Improve feed efficiency** which is the fastest cost-reduction driver
- **Developing effective modular systems** to decrease entry barriers for companies
- **Implementing risk-sharing** strategies to encourage more private investment

Pillar 3. Innovation, technology uptake, and knowledge transfer

Objective: Accelerate the adoption and scaling of circular aquaculture through applied innovation and capacity building.

Actions:

a) **Develop locally adapted technical guidelines, operational protocols, and best-practice manuals** to bridge the gap between research and commercial implementation.

b) **R&D of low trophic farming and logistics focusing on upscaling biomass** not only as a food or source of high-add value product but also as a valuable commodity

c) **Optimize and validate advanced technologies**, including real-time monitoring, automated feeding, decision-support systems, aquafeeds 3.0 optimization, and biomass management tools.

d) Integrate **genetic improvement and selective breeding programmes** targeting robustness, feed efficiency, and environmental tolerance.

e) **Create digital knowledge platforms, advisory services, and troubleshooting support** to enable continuous learning and innovation uptake by producers.

f) **Innovate on biomass farming, including collection techniques, automatization, in situ processing, logistics and preservation opening feasible downstream applications** (functional feeds, nutraceuticals, bioactive compounds, halophyte-based foods, bio-based materials).

g) Create an innovative ecosystem for transformation of side streams into **high–added-value products** following a downstream and scalable **biorefinery approach** (from biomass to final product) for functional feed ingredients, biofertilizers, biostimulants, biopolymers, energy, and nutraceutical compounds, represents a critical source of additional revenue and risk diversification.

h) **Capacity building and knowledge transfer.** Implement targeted training programmes for producers, regulators, and technicians focused on circular practices, licensing in protected areas, and operational management of IMTA/IMRAS systems.

i) **Support mentoring programs and new entrepreneurship** to move into circular business

Main leverage points of this pillar 3 are:

- Improve feed efficiency which is the fastest cost-reduction driver
- Developing effective modular systems to decrease entry barriers for companies
- Implementing risk-sharing strategies to encourage more private investment
- Scale production of low-trophic biomass (macroalgae, halophytes, invertebrates)

Pillar 4. Enabling Policy, Regulatory Frameworks, and Financing

Objective: Create a supportive regulatory and financial environment for circular and eco-intensive aquaculture.

Actions:

a) **Clarify and formalise legal definitions and classifications** for circular and eco-intensive aquaculture systems, including hybrid configurations, within Andalusian and national legislation. Produce guidance documents and regulatory roadmaps to reduce legal uncertainty for innovative systems.

b) **Simplify and streamline licensing procedures** through harmonised criteria, standardised documentation, and digital permitting platforms.

c) **Introduce regulatory flexibility and innovation clauses** for pilot and demonstration projects to enable controlled testing of novel systems.

d) **Establish incentive schemes** linked to measurable circularity and environmental performance indicators.

e) **Facilitate coordinated access** to EU, national, and regional funding instruments (Horizon Europe, EMFAF/FEMPA, Interreg Euro-MED, Andalusian programmes).

f) **Design blended-finance and co-investment** schemes to reduce financial risk and accelerate scaling.

Main leverage points of this pillar 4 are:

- ***Inclusion of circularity criteria*** *and eco-intensive systems in regulations and strategic plans*
- ***Safe testing*** *environment for novel systems*
- ***Strategic bundling*** *of funding instruments*

Pillar 5. Stakeholder Engagement, Governance, and Market Development

Objective: Strengthen social acceptance, coordination, and value creation across the aquaculture value chain.

Actions:

a) **Operationalise LiRRIE-based participatory governance structures** to ensure continuous dialogue among producers, policymakers, researchers, and civil society.

b) **Support the Andalusian aquaculture committee** as structured co-creation and mediation processes to reconcile divergent priorities related to productivity, environmental protection, and societal expectations.

c) **Enhance SME engagement** through targeted outreach, tailored training, simplified funding access, and direct participation in pilot systems.

d) **Strengthen science–policy–industry interfaces** through advisory boards, technical working groups, and regular knowledge-exchange forums.

e) **Support market differentiation of circular aquaculture products** via certification, traceability, and sustainability communication.

f) **Encourage business symbiosis** with blue biotechnology**,** agri-food, fertiliser, cosmetic, tourism, and education sectors.

g) **Develop communication, visibility, and storytelling tools** to increase public awareness and trust.

Main leverage points of this pillar 5 are:

- Making stakeholder **dialogue permanent** and decision-oriented
- **Accelerate translation** of evidence into policy & practice
- **Expanding value chains** beyond aquaculture by connecting blue sectors and stakeholders

9.2 Responsible Actors

- **Public authorities** (national, regional, and local): regulatory reform, licensing, funding allocation
- **Research and knowledge institutions:** innovation support, capacity building, monitoring
- **Aquaculture producers and SMEs**: implementation and validation of circular practices
- **EU and regional programmes**: funding, coordination, policy alignment
- **Civil society and local communities: social acceptance**, territorial integration

9.3 Timeline

The timeline is structured into three progressive phases:

Initial phase (1–2 years)

During this initial phase, the focus will be on building strong foundations. Key actions include mapping of potential circular models in the zone for regenerative and restorative aquaculture, revision of existing regulatory landscape and identifying gaps, engaging stakeholders through participatory co-design processes, and launching pilot and demonstration initiatives. At the same time, support innovative actions and initial capacity-building and training activities will be rolled out to strengthen skills and awareness across the sector.

Key points:

- Create map of potential circular models
- Regulatory mapping and gap analysis
- Stakeholder engagement and co-design processes
- Launch of pilot and demonstration actions
- Canalize targeted innovation actions
- Initial capacity-building and training activities

Intermediate phase (3–5 years)

This phase will concentrate on consolidation and expansion. Regulatory frameworks will be adjusted and harmonised where needed, while successful pilot systems will be scaled up. Circular practices will gradually be embedded into mainstream aquaculture production, supported by the implementation of digital tools and monitoring platforms to improve decision-making and performance tracking.

Key points:

- Regulatory adjustments and harmonisation
- Scaling up of successful pilot systems
- Integration of circular practices into mainstream production
- Implementation of digital tools and monitoring platforms

Long term (beyond 5 years)

In the long run, circular aquaculture will be consolidated as a standard practice across the sector. It will be fully integrated into spatial planning and broader bioeconomy strategies. This phase will also include comprehensive assessments of long-term environmental and socio-economic impacts to ensure sustained benefits and continuous

improvement.

Key points:

- Consolidation of circular aquaculture as a standard practice
- Full integration into spatial planning and bioeconomy strategies
- Long-term environmental and socio-economic impact assessment
- The timeline should include milestones and review points to allow adaptive management and corrective actions.

9.4 Financial aspects and Funding resources

This section outlines the financial requirements and identifies potential funding sources needed to implement the proposed actions effectively. It should address both investment costs and operational sustainability.

Financial Aspects and Funding Resources

1. Public Funding Instruments

Public funding will play a catalytic role, particularly in the early phases of system design, piloting, and validation. Key sources include:

- **European Union programmes**[9], such as Horizon Europe (R&I, demonstration and upscaling of circular aquaculture models), EMFAF/FEMPA (investments in sustainable aquaculture, innovation, and environmental services), Interreg (territorial cooperation and C-AZA implementation), and LIFE (nature-based solutions, biodiversity, and ecosystem restoration linked to aquaculture).
- **National and regional funding schemes**, supporting infrastructure development, technology adoption, digitalisation, and environmental monitoring, aligned with regional blue economy and bioeconomy strategies.
- **Public support for capacity building**, including training, technical assistance, and knowledge transfer to SMEs, cooperatives, and local stakeholders.

These funds will primarily support infrastructure adaptation, pilot-scale facilities, environmental monitoring systems, and applied research, reducing entry barriers for circular aquaculture operators.

2. Private Investment and Co-financing

Private investment is essential to ensure the commercial sustainability of circular aquaculture systems. Co-financing mechanisms will be promoted through:

[9] *https://aquaculture.ec.europa.eu/system/files/2024-03/AAM_WP4_EU%20Funding%20Opportunities_Background%20Paper.pdf*

- **Public–private partnerships (PPPs)** for the deployment of eco-intensive IMTA/IMRAS facilities, biorefinery units, and valorisation chains.
- **Industry co-investment,** particularly from aquaculture producers, feed companies, technology providers, and blue bioeconomy enterprises interested in secondary biomass streams (e.g. algae, halophytes, biofilters).
- **Risk-sharing instruments**, where public funds de-risk initial investments, enabling private actors to engage in innovative but capital-intensive solutions.

This mixed approach will support the transition from pilot projects to commercial-scale operations.

3. Innovative Financial Mechanisms

To reinforce financial sustainability, the Action Plan will explore innovative mechanisms, including:

- **Green and blue finance instruments**, such as green loans, sustainability-linked loans, or blue bonds, tied to measurable environmental performance indicators (nutrient recovery, emission reduction, ecosystem services).
- **Revenue diversification models,** based on the valorisation of side streams (biofertilisers, functional ingredients, bioproducts), reducing dependency on primary fish production alone.

10. Monitoring and Evaluation

10.1 Progress Indicators

The M&E system will be aligned with circular economy principles, environmental regulations, and regional Blue Economy strategies, ensuring transparency, accountability, and continuous improvement. Progress and success will be assessed through a set of quantitative and qualitative indicators, structured across environmental, technical, economic, and governance dimensions, including:

1) Environmental performance indicators

Indicator	**KPI**	**Measurement Method**	**Frequency**	**Responsible**
Nutrient efficiency	Nutrient recovery (NUE (%)	Water sampling & lab analysis	annually	Operators
Biomass efficiency	% biomass yield per hectare	Mass balance calculations	Bi-annual	Technical team
Water quality	DO (mg/L),	In-situ sensors	Continuous	Operators

improvement	turbidity (NTU)	+ manual validation	+ bi-annual review	
Ecosystem services	Area restored (ha), biodiversity index	Field surveys & remote sensing	Annual	Research partners
Sludge safety	Contaminant levels vs thresholds	Laboratory analysis	Annual	Accredited labs

2. Technical and operational indicators

Indicator	**KPI**	**Measurement Method**	**Frequency**	**Responsible**
Adoption of circular practices	*operators implementing*	Number of authorizations	Annual	Governance body
Demo cases	Number of pilot cases	number cases identified	Annual	*Project coordination*
Biomass efficiency	% biomass yield per hectare (*kg/ha/year fed & extractive species*	*Harvest records*	Annual	Operators
Feeding efficiency	*FCR*	*Survey*	Annual	Operators
Digital integration	*farms using sensors/automation*	*Survey*	Annual	Operators

3. Economic and circularity

Indicator	**KPI**	**Measurement Method**	**Frequency**	**Responsible**
Production efficiency in circularity	Cost per kg produced	Financial records	Annual	Operators
Revenue diversification	% income from secondary biomass	Financial reports	Annual	Operators
Investment uptake	€ leveraged from private and public sources	Financial tracking	Annual	Project manager

4. Social and governance

Indicator	**KPI**	**Measurement Method**	**Frequency**	**Responsible**
Stakeholder participation	*Nº participants in events*	Financial records	Annual	
Training outcomes	*Nº trained persons/ satisfaction score*	*Training reports*	Annual	*Coordination project*
Public perception score	*Nº of surveys*	*Surveys*	*Bi-annual*	*Proyecto*
Regulatory alignment	*Nº farms compliant with C-AZA*	*Permit reviews*	Annual	*Governance body*

10.2 Follow-up and Adjustment

These indicators will be periodically reviewed and refined to reflect evolving priorities and lessons learned. Monitoring results will feed into a continuous follow-up and adaptive management process. Regular technical reviews and stakeholder consultations will be organised to assess performance, identify bottlenecks, and propose corrective actions. Where necessary, operational protocols, system designs, or implementation timelines will be adjusted to enhance efficiency, reduce risks, and maximise impact. This iterative approach will ensure flexibility and responsiveness to environmental, economic, and regulatory changes.

11 Conclusion

This Action Plan should be a roadmap to accelerate the transition towards circular and eco-intensive aquaculture in Andalusia. By structuring specific actions and priorities across five complementary pillars, it integrates environmental protection, economic competitiveness, technological innovation, enabling governance, and stakeholder engagement into a coherent strategy aligned with the Andalusian Blue Economy (EA2).

Through pilot demonstrations, regulatory facilitation, targeted financing, and strong knowledge transfer mechanisms, the Plan moves beyond theory to practical implementation, to facilitate the producers to adopt circular models that reduce environmental pressures while creating new value streams. Its adaptive monitoring framework ensures continuous learning, transparency, and evidence-based decision-making, allowing policies and practices to evolve with emerging challenges and opportunities.