

# A circular transition model for the European aquaculture sector

M. Masi, F. Adinolfi, E.S. Marrocco, Y. Vecchio\*

Department of Veterinary Medical Sciences, Alma Mater Studiorum University of Bologna, Via Tolara di Sopra 50, Ozzano Emilia, 40064 Bologna, Italy

## ARTICLE INFO

**Keywords:**  
Aquaculture  
Transition  
Maturity  
Readiness  
Circular economy  
European policies

## ABSTRACT

The present study introduces a conceptual model for the circular transition of European aquaculture farms. The model under consideration comprises two distinct sections for evaluation, namely circular readiness and circular maturity. The first component focuses on the key aspects the aquaculture companies need to understand to be ready to begin the transition process. The second component delineates the strategic road map to be embraced to advance within the circular maturation journey from non-existent to advanced level across different focus areas: Operations, Product and Service, Culture and Organization and Ecosystem. This study attempts to fill the research gap regarding the non-existence at the European level of a transition model integrating the multiple aspects of circularity by offering a generalized framework that can be applied to different aquaculture farms. The findings could enhance farmers' awareness while helping policymakers to monitor the sector's ongoing efforts.

## 1. Introduction

Over the past three decades, the global aquaculture supply has increased significantly, and in 2022, it exceeded the fisheries' production for the first time. Despite this result, the industry still needs to fully realize its development potential (FAO, 2024), and future scenarios elicit apprehensions regarding the efficacy of resource utilization (Das et al., 2023) and plausible societal and ecological consequences (Verreth et al., 2023).

The FAO Roadmap for the Blue Transition (FAO, 2022) lists the achievement of at least 35 % of the world's sustainable aquaculture production, as well as an increased employment and equitable distribution of benefits, among the outcomes to be achieved by 2030. With a projected world population of over 8.5 billion by 2030, there is concern about the quantity of fish products that can be secured. In addition, predicting the response of aquaculture in terms of resilience, production level, and pricing in a climate change scenario is challenging (O'Neill et al., 2022; Aarflot et al., 2024; Bjørndal et al., 2024).

At the EU level, according to the document "A New Strategic Vision for Sustainable Aquaculture Production and Consumption in the European Union - Blue Farming in the European Green Deal", is highlighted that European aquaculture has lagged behind other countries in growth and in meeting the rising demand for sustainable products. Moreover, doubts are raised about the sector's commitment and interest in a blue transition as a significant portion of the European Maritime Fisheries and

Aquaculture Fund 2014–2020 funds have not been spent (European Commission, for, D.-G., and Fisheries, 2021). The European Court of Auditors' Special Report (25/2023) also raised concerns about the sector's sustainability direction, partly due to a lack of data and proper contextualized impact assessments (European court of auditors, 2023). An example comes from the "Techno-economic analysis for the energy transition of the EU Fisheries and Aquaculture Sector" report, which clearly states that estimating energy use and CO<sub>2</sub> and emissions in EU aquaculture is very complex due to the diversity of species and farming methods and areas (European Commission, 2024).

To provide a shared vision and clarify the future trajectory for the ambitious goal of "a more sustainable and competitive European aquaculture", the European Commission proposes specific strategic guidelines for the 2021–2030 period. These guidelines (European Commission, 2021) urge the sector to advance towards economic, social, and environmental responsibility in alignment with the Green Deal, particularly regarding the Circular Economy Action Plan, Biodiversity, Farm to Fork, and Offshore Renewable Energy Strategies. In terms of economic and social responsibilities, the orientations suggest encouraging collective action, product diversification, and the development of higher-value products. They also emphasize the need to enhance administrative, regulatory, and monitoring frameworks to ensure animal welfare, traceability, and the sustainability of European aquaculture. Moreover, it highlights the importance of transferring knowledge and innovation as well as incentivizing collaboration among institutions, research entities,

\* Corresponding author.

E-mail addresses: [margherita.masi4@unibo.it](mailto:margherita.masi4@unibo.it) (M. Masi), [felice.adinolfi@unibo.it](mailto:felice.adinolfi@unibo.it) (F. Adinolfi), [ernesto.marrocco@unibo.it](mailto:ernesto.marrocco@unibo.it) (E.S. Marrocco), [yari.vecchio@unibo.it](mailto:yari.vecchio@unibo.it) (Y. Vecchio).

<https://doi.org/10.1016/j.aquaculture.2024.741819>

Received 30 July 2023; Received in revised form 21 October 2024; Accepted 27 October 2024

Available online 28 October 2024

0044-8486/© 2024 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

and industry to enhance profitability and social acceptance of aquaculture products. Concerning the environment, the strategies suggest promoting climate change mitigation and adaptation actions, spatial and water planning, and systems which offer ecosystem services with a lower environmental impact. What emerges from the given scenario is a clear call to implement circular practices, which encompass moving to renewable energy sources, implementing resource-recovery systems, establishing efficient waste disposal systems, and evaluating the impact of life-cycle products.

The adoption of circular economy (CE) principles is supported as a viable approach to mitigate waste and promote sustainability in the agri-food (Chiaraluce et al., 2021; De Rosa et al., 2021; Muscat et al., 2021) and in the aquaculture sectors, since it promotes material recovery, regeneration of nutrient cycles, and reduction of negative externalities (Pauli, 2017; Ruiz-Salmón et al., 2020; Verreth et al., 2023). To shift from linear to circular systems, the European Commission and the Directorate-General for Maritime Affairs and Fisheries propose four key principles aligned with the product lifecycle (Burch et al., 2019): eco-design, waste recovery, circular usage, and material recycling. “Eco-design” encompasses rethinking the production system by introducing sustainable inputs and adopting environmentally friendly production systems. “Waste recovery” focuses on resource valorization by establishing synergies with other economic sectors. “Circular use” regards the adoption of sharing, reuse, and repair strategies. Lastly, “material recycling” emphasizes the importance of adopting new approaches to minimize waste from technical materials in the marine environment.

Principles such as “eco-design” and “resource recovery” are the most applied in aquaculture. Recirculation systems, as well as experiences of integrated multi-trophic systems, such as IMTA (Checa et al., 2024), Aquaponics (Bordignon et al., 2024), or Biofloc (Khanjani et al., 2024) are vivid regenerative practices (Chary et al., 2024) in which the effluents of one cycle feeds a new one (Lothmann and Sewilam, 2023). Furthermore, inter-company synergies have been analyzed by researchers to make the input and output flows of aquaculture system more circular (Mutalipassi et al., 2021; Eroldoğan et al., 2022; de Korte et al., 2024; Masi et al., 2024a). For what concerns the input flow, there are efforts to reduce carbon fossil dependence by introducing renewable energy or adopting energy-savings strategies (Erdemir and Dincer, 2024) or to consider the use of alternative ingredients in the aquafeed formulation, avoiding wild fish stocks resources exploitation (Maroušek et al., 2023; Wang et al., 2023). Other studies (e.g., Ogburn et al., 2023) suggest using waste from different sectors, such as agricultural effluents, as an input for algal biomass production. About output streams, frequent examples concern the possibility of valorizing waste from the aquaculture system to produce bioactive compounds (Cutajar et al., 2022), biomaterials (Morris et al., 2019), fertilizers (Das et al., 2023) or energy (Azwar et al., 2022). Regarding the “material recycling” principle, there is undoubtedly a growing interest in literature on promoting recycled materials or biomaterials to prevent the dispersion of marine litter (Vázquez-Rowe et al., 2021; Gonella et al., 2023). In addition, several technologies are being developed to avoid nutrient loss in aquatic environments (Luo, 2022). Finally, scientific research on the “circular usage” principle is scarce. At the same time, there are many experiences reported by several Fisheries Local Action Groups (FLAGs) operating under the 2014–2020 EMFF (European Maritime and Fisheries Fund) programming on the application of sharing, repair and reuse strategies (Burch et al., 2019).

The previously mentioned CE principles lay down a path forward for change that may deliver the desired results if broadly adopted. Nevertheless, their adoption continues to be notably limited due to the existence of legislative obstacles (Regueiro et al., 2022), the absence of markets (Chary et al., 2024) and the substantial cost associated with technologies (Vecchio et al., 2023a). In addition, there is an urgent need for more circular literacy and a better introduction of CE principles into farm vision and governance (Masi et al., 2024b). According to Masi et al. (2024b), the circular transition of the aquaculture sector is considered as

too “operation” and “product-focused”, and Jacob et al. (2021) observed that most articles dealt with environmental aspects. Recent research provides several instances of this insufficiently systemic perspective and how this limits the sector’s long-term sustainable development. Examples are provided by van Riel et al. (2023), highlighting the importance of prioritizing aquafeeds where animal and plant resources do not compete with human consumption. Entrena-Barbero et al. (2023), Chary et al. (2024), and Aarflot et al. (2024) suggest aligning production systems more closely with human needs to ensure food nutrition security for the community served. On this matter, Fernández-Ríos et al. (2022) proposed an integrated framework, the water-energy-food approach, to integrate natural resources management and food diets better. Masi et al. (2024b) emphasize the significance of fostering a circular culture within farms, as this approach can enhance the communication of circular value to society and help dismantle wasteful and inefficient economic models. Creating an external ecosystem that supports the circular transition requires taking into account local expertise as well as significant adjustments to markets, organizations, policy and social norms (Muscat et al., 2021; Alleway et al., 2023; Chowdhury et al., 2024). Having regard to what is previously reported, the objective of this paper is to address the two following questions:

- What is the path that an aquaculture farm could follow to become circular?
- What are the key areas and related strategies that could be looked at?

This work attempts to fill the research gap regarding the non-existence of a circular transition model for European aquaculture farms. The present study supports the premise that thinking about achieving circularity objectives set by European Institutions and thus incentivizing a sustainable performance unrelated to a transition pathway is limited. In addition, the absence of a clearly defined set of strategies to be implemented across various domains, such as operations, may result in non-desirable scenarios. The model presents several focus areas within which to apply these strategies, as the underlying idea is that the circular transformation represents more than a simple extension of current practices. According to the findings of Lacy et al. (2020), Balestrucci (2020), and Uhrenholt et al. (2022), implementing circular strategies influences the development of products and services, operational processes, business vision, and the organization’s network. Following that, it is becoming increasingly important to delve into the multidimensionality of the intricacy that runs throughout the circular transition.

So far, the literature has focused on identifying indicators or methods to mainly measure the environmental performance of aquaculture productions, as socio-economic methodologies have not been truly explored (Jacob et al., 2021). Indeed, different research and academic institutions prioritize the study of the environmental assessments of the aquaculture system through a life cycle assessment (LCA) approach (Konstantinidis et al., 2020; Tamburini et al., 2020; Vélez-Henao et al., 2021; Tamburini et al., 2022). Despite potential, LCA presents several limitations, including high variability based on data availability and quality, assumptions and modelling scenarios, assessment methods, and system boundaries. Databases scarcely integrate specific geographical contextualization, avoiding the accuracy of impact assessment and reproducibility of studies (Bohnes and Laurent, 2018; Kalmykova et al., 2018; Regueiro et al., 2022; Vasquez-Mejia et al., 2023; Glencross et al., 2024). Beyond this, the exclusive use of a predetermined set of performance indicators is inherently restrictive when evaluating circularity. As Uhrenholt et al. (2022, p.2) reported, “the assessment outcomes give limited guidance to organizations; they provide numeric assessment scores while providing little to no guidance on how to progress further with CE transformation”. Only after developing a guiding model for the circular transition and thus a direction, it is possible to create and incorporate benchmarks and performance indicators that can define the sector’s contribution to the environment and society.

## 2. Theoretical background

There is considerable dispersion among research proposing a CE in the agri-food sector (Esposito et al., 2020). The subject matter's complex relationships with different sustainable domains, including industrial ecology, the bioeconomy, and the sharing economy, explain this occurrence (Scandurra et al., 2023).

Hamam et al. (2021) highlighted five research strands that deal with the CE in agri-food. The first one (Principato et al., 2019; Bloise, 2020) examined food loss and waste in agri-food supply chains and cleaner production methods to reduce production intensification (Hamilton et al., 2015; Das et al., 2023). A second line of research (Donner et al., 2020; Mehmood et al., 2021) focused on adopting circular business models that benefit the economy, society, and environment. A third strand concentrates on analytic methods for assessing impact and CE opportunities, including life cycle assessment (Corrado and Sala, 2018), material flow analysis (Pagotto and Halog, 2016), cost-benefit analysis, input-output model (Jacob et al., 2021; Raffray et al., 2022) and performance indicators (Poponi et al., 2022; Garlock et al., 2024). The fourth area of emphasis is the investigation of stakeholders' perspectives regarding the CE, as demonstrated by research conducted by Gonella et al. (2023), van Langen et al. (2021), and Borrello et al. (2017). The last line addresses a more holistic approach since it examines the sector's future directions, such as regenerative farming actions (Dudensing, 2023), the relationship between the CE and rural communities (Kristensen et al., 2016; Acharya, 2023), and the significance of promoting effective measures through a responsible policy and regulatory framework (Krause et al., 2015; Vecchio et al., 2023b).

In recent years, a new strand of research emerged in the agri-food sectors, and it deals with comprehending companies' circularity readiness (CR) and maturity (CM) (Sehnm et al., 2019a). The literature is still far behind, but there is a growing need to propose a circular transition framework capable of guiding companies to be ready to face new challenges and reach higher levels of maturity.

### 2.1. Circular readiness

Companies need to change their mindset profoundly to successfully embark on the transition process and realize a CE (Lacy et al., 2020). Before progressing circularity, the organization should initially demonstrate that it is ready to embark on a new path to effectively address forthcoming and unpredictable needs for change (Çınar et al., 2021). Studies commonly associate the concept of CR with readiness to change, as shown by Holt et al. (2007) and Wanberg and Banas (2000). The definition of readiness has been defined over the years by many studies (e.g., Hanpachern et al., 1998; Armenakis and Bedeian, 1999; Dalton and Gottlieb, 2003; Holt et al., 2010; Weiner, 2020), which can be summarized in the one proposed by Al-Tahitah et al. (2018), as a shared psychological state involving the co-evolution of organizational members and the expression of their commitment to implement organizational changes. CR has been defined as a prerequisite for initiating the evolutionary transition process towards a CE (Montag et al., 2021) that can be translated into the company's propensity to change (Singh et al., 2018) and the recognition of relevant elements (Kayikci et al., 2022) that it should be aware of before embarking the circular transition. The concept could, therefore, be pictured as a sort of "cognitive" readiness for circular transition.

### 2.2. Circular maturity

CM is a comprehensive framework that assists businesses in setting goals as they move through a hierarchical structure of maturity stages towards a circular transition (Becker et al., 2009; Salo et al., 2020). A maturity model is a qualitative approach used to guide efforts towards the most effective strategies in an area of study (McCormack et al., 2008; Kohlegger et al., 2009). Maturity models have the potential to offer

insights to the company to address inefficiencies, prioritize areas for intervention and advance the implementation of new strategies (Khoshgoftar and Osman, 2009). In the agri-food sector, there is a lack of research that assesses a company's level of CM (Sehnm et al., 2019b; Sacco et al., 2021), and the few extant studies mainly concentrate on specific aspects of circularity (Berzi et al., 2016; Mura et al., 2020). This is evidenced by the few literature reviews on the subject proposed by Gorecki (2019), Montag et al. (2021) and Kayikci et al. (2022).

Julkovski et al. (2022) offer a CM framework for Portuguese and Brazilian craft brewing companies based on the ReSOLVE strategies ("Re" Regenerate; "S" Share; "O" Optimize; "L" Loop; "V" Virtualize; "E" Exchange). Then, a circular business model was created adopting the maturity levels proposed by Grant and Pennypacker (2006): non-existent, executed, managed, established, predictable, and optimized. The lowest level is that no circular practices have been implemented in biological and technical cycles, while the highest level is their extensive integration. As the organization advances, it obtains more information and opportunities to take proactive action to mature. This shift stimulates knowledge acquisition, acceptance of best practices, and development of critical points.

Sehnm et al. (2019b) propose a Brazilian winery CM research. The ReSOLVE model and 5Rs framework are employed to create a circular business model that links maturity levels to circular activities. Based on Grant and Pennypacker (2006) and Sehnm et al. (2019c), the maturity levels proposed are non-existent, executed, managed, established, predictable, and optimized.

Scandurra et al. (2023) linked agri-food research strategies to CM levels in their systematic review. A combination of the Rs framework and circular strategies ("Reprocessing", "Sharing of resources", "Optimization of the production process", "Reprocessing", and "Incineration and Landfilling") was used to classify studies.

Ferreira et al. (2017) examine CM from an environmental standpoint to assess the maturity of several companies, including two pesticide manufacturers. As focus areas, they propose organizational structure, interface with other areas, environmental objectives, inclusion of environmental management strategies, and environmental focus. As maturity levels, reactive, preventive, and proactive are indicated.

The mentioned works have identified the key features of the CM framework: i) the focus areas and related elements and ii) levels of maturity.

## 3. Methodology

This study leverages a holistic viewpoint to guide aquaculture farms through transformation, offering a circular transition model (CTM) composed of the CR (3.1) and CM (3.2) frameworks. The CTM provides a transparent overview of the circular transition through the 3S approach: START, SCAN, SUGGEST (see Fig. 1).

The 3S represents the fundamental steps of a guided path to implementing circular strategies. A farm in the "START" phase should demonstrate awareness of the necessary information before embarking on a circular transition. Once the farm owns the CR, it can acknowledge its position in the circular journey ("SCAN" phase), where the maturity framework enables the farm to assess itself.

The following step is the "SUGGEST" phase, in which, based on the previously obtained results, farms can implement strategies within the specific areas of interest and then plan longer-term sustainability goals. As the output of this phase, several suggested strategies have been proposed, which aquaculture farmers could potentially consider as cues for improvement.

The transparency offered by this process allows farmers to understand the association between a greater circularity and the adoption of different strategies. It is increasingly required to propose approaches (e.g., Fernández-Ríos et al., 2022) that closely connect field actions with their economic, social, and environmental impacts to better align the challenges of production systems with societal needs. In fact, the

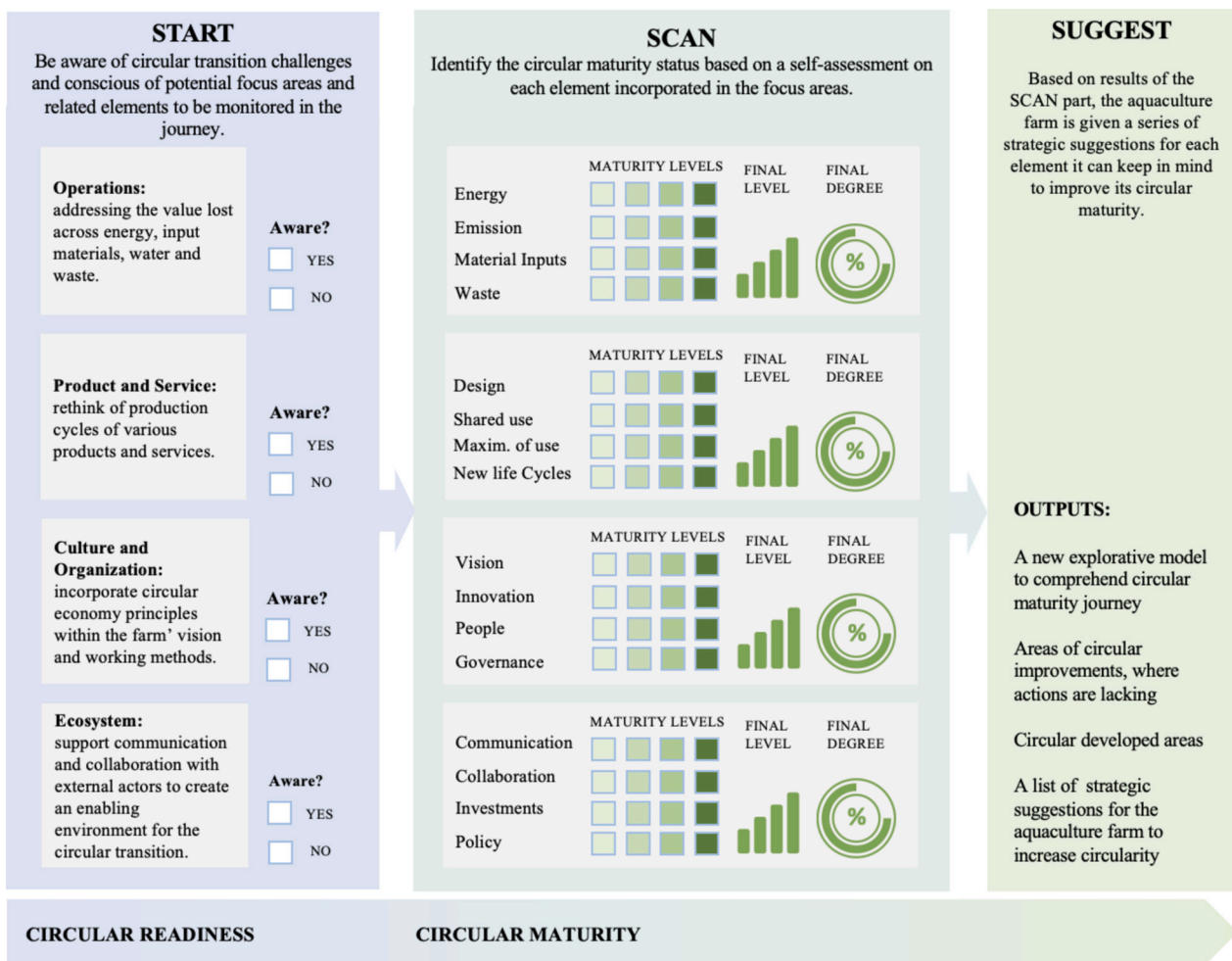


Fig. 1. Circular transition model for the aquaculture farm.

objective is to build a circular strategic plan integrating both the farm and the agri-food system. Adopting this strategic perspective entails a significant redefinition of their relationship: a crucial dependency emerges between the strategy formulation and the development of the environment in which the farm operates. Furthermore, a farm's pursuit of the optimal strategy can only be defined in relation to the structural framework of the sector, such as that proposed by the European strategies and policies.

### 3.1. START with circular readiness

This study conceptualized CR as the awareness of all essential elements needed to start a circular transition path or the prerequisite to building knowledge. Based on the framework proposed by Lacy et al. (2020), these elements have been grouped into four focus areas (Appendix – Table A1): Operations, Products and Services, Culture and Organization and Ecosystem. They represent the areas where the farm should demonstrate awareness and understanding before making circular progress. If the farm is unaware, building knowledge before proceeding with the maturity assessments is necessary. This step is crucial as some studies (e.g., Uhrenholt et al., 2022) have shown that companies frequently embark on the circular path without awareness, leading to perceiving the change as risky, acting unconsciously, and not understanding the real benefits.

### 3.2. SCAN the circular maturity

This phase aims to descriptively report a company's strategic changes in relation to a specific direction. The SCAN phase result is a snapshot of the aquaculture farm's current state of circularity, which provides an idea of which strategies it has implemented. The proposed CM framework will be further explored by describing the chosen components: the maturity levels (3.2.1) and the focus areas (3.2.2).

#### 3.2.1. Circular maturity levels

The maturity level increases progressively with an organization's commitment to a CE (Kohlegger et al., 2009). Each maturity tier necessitates formalizing strategies that add to a company's long-term circularity. Generally, the characterization of the chosen stages depends on the study's case (Fraser et al., 2002; Sehnem et al., 2019a). The present work draws inspiration for the taxonomic frameworks from Lacy et al. (2020), Sehnem et al. (2019b) and Uhrenholt et al. (2022), and starting from these studies, a conceptual model has been proposed to address the specific pathway of aquaculture farms effectively. Achieving the "ultimate" level, as suggested by Lacy et al. (2020) for other types of industries, would have been challenging for aquaculture due to 1) the increasingly complex and demanding challenges at the European level, 2) unpredictable climatic and environmental factors, and 3) the inherent biological cycles involved. For this reason, the final level was denominated "advanced". It was also chosen to streamline the maturity process by including the phase "In transition", which better conveys the concept of circular transformation, avoiding the use of intermediate stages like

“Established” (Sehnm et al., 2019b) or “Integrative” (Uhrenholt et al., 2022).

Four levels of maturity are proposed in this study:

- *Non-existing*: circular strategies are known, but the farm has not yet started the path.
- *Emerging*: the farm has begun to experiment with circular strategies.
- *In transition*: the farm has actively implemented circularity strategies.
- *Advanced*: circularity is a pillar of the farm’s vision, which is shared with other external actors.

Only farms that reach the advanced level actively interact with the external actors, striving to build a receptive environment to cooperation and change. This also means that if the company reports circularity maturity levels of “emerging” or “In transition”, it is implementing strategies that produce circularity shared within the farm’s boundaries. Indeed, the degree of CM achieved can be linked to a level of action:

- *On-farm*: circularity is shared within the farm.
- *Off-farm*: circularity is also shared with external actors.

3.2.2. Circular maturity focus areas

The taxonomy offered by Lacy et al. (2020) inspired the proposed

focus areas and related elements. According to Masi et al. (2024b), this is one of the few models that represents a system perspective in defining the dimensions that assess CM. Uhrenholt et al. (2022, p.2) highlight the limitations of existing maturity frameworks that “do not adopt a system perspective, but focus on evaluating certain geographical regions, organizational dimensions or fragments of CE, such as circular product design”.

The proposed taxonomy, which encloses the four areas of Operations, Culture and Organization, Product and Service and Ecosystem and related elements, has been adapted to be applied to the aquaculture sector (Appendix, Table A1). Indeed, Lacy et al. (2020)’s model was thought for economic sectors that do not include in their processes biological cycles.

3.2.2.1. Operations. The maturity approach recommends that operations capture the lost value around the elements of Energy, Emissions, Material inputs, and Waste, as shown in Table 1. The European Commission is promoting initiatives to prioritize conversion to renewable energy (“Energy”) and energy-saving and energy-efficient strategies in the food value chain (Muscat et al., 2021; De Vet et al., 2024). This is especially true for farms with high energy inputs that require feeding, ventilation and environmental control (Troell et al., 2004). Added to this are the emissions challenges, which farms are increasingly called upon to reduce to become carbon neutral. One opportunity regards offshore

**Table 1**  
Circular maturity in operations.

SCAN the CIRCULAR MATURITY JOURNEY					
Maturity Journey	Not existing	Emerging	In transition	Advanced	
<i>Energy</i> From heavy dependence on fossil fuels to being a self-sufficient farm that produces energy for the local community.	The farm is completely dependent on fossil fuels.	The farm has adopted some energy efficiency/savings strategies on technical means of production such as machinery, equipments and vehicles.	The farm has adopted energy efficiency/saving strategies on technical means of production, including buildings and partly produces energy from renewable sources.	The farm not only self-generates energy from renewable resources but also produces it for the community.	
<i>Emissions</i> From zero to define targets and activities to lowering direct emissions and being carbon positive.	The farm has not yet started the journey.	The farm has adopted new strategies to reduce emissions.	The farm conducted impact assessments to understand the most critical emission points and review operations.	The farm adopts targeted strategies to reduce emissions and sells carbon credits.	
<i>Material inputs</i> From zero to full adoption of circular biological and technical inputs, including water.	The farm is not introducing circular inputs, such as recycled or biodegradable materials, sustainable feed ingredient or recirculating water.	The farm is experimenting with some circular inputs.	The farm actively adopts circular inputs.	The farm actively adopts circular inputs and has disseminated the solutions to other stakeholders in the area, enabling their diffusion.	
<i>Waste</i> From disposed to full valorize biological and technical waste, including wastewater.	The farm sends all waste to landfill.	The farm is experimenting with some solutions to reduce waste from technical and/or biological cycles.	The farm is actively adopting some solutions to reduce waste from technical and/or biological cycles.	The farm has reached the point of valorizing, taking into account the limits of current regulations, all waste.	
<b>FINAL ASSESSMENT</b> STEP 1 - Scan the circular maturity level of the farm STEP 2 - Scan the degree of farm circular maturity					
	0%	25%	50%	75%	100%
<b>Actors' involvement for the effectiveness of strategies</b>	<b>ON-farm</b> : circularity is shared within the farm.				
	<b>OFF-farm</b> : circularity is also shared also off-farm actors.				




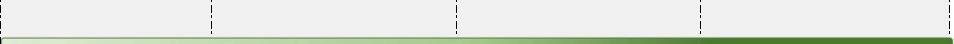
systems that are increasingly driven to use vessels less dependent on fossil fuels (e.g., solar-powered, hydrogen-powered) (“Emissions”). In addition, innovations in equipment and machinery (such as better insulated cold storage), as well as precision fish farming and novel aquafeed, would save on both energy and emissions costs from production to sale (Burch et al., 2019; Ridwan et al., 2024; De Vet et al., 2024). Strongly related to these concerns is the strategy of incorporating circular “Material inputs”, which consider those of a technical and biological nature, including water, on which Strategies of Farm to Fork and Biodiversity are highly focused. Concerning biological inputs, Colombo and Turchini (2021) and Colombo et al. (2022) suggest the replacement of fish meal and fish oil-dependent diets with new formulations which incorporate alternative raw materials such as insects, microbiological unicellular organisms, algae, and processed animal proteins. Regarding

technical materials, using recycled or biobased materials promotes the use of more sustainable inputs and reduces marine litter under the call of the Circular Economy Actions Plan (Pietrelli, 2022). Then, also biological waste can be recovered for different purposes like energy, food and feed, fertilizers and bio-activated compounds production (Klein et al., 2024; Masi et al., 2024a) (“Waste”). Finally, recirculating systems can be a solution to reduce water dependency that can be reused in new cycles and guarantee waste recovery (Ende et al., 2024).

3.2.2.2. *Product and service.* The second focus area (Table 2) pertains to strategies for the product life cycle of aquatic productions, encompassing the elements of *Design, Shared use, Maximization of use, and New life cycles.*

Regarding “Design”, the reference framework suggests reconsidering

**Table 2**  
Circular Maturity in Product and Service.

SCAN the CIRCULAR MATURITY JOURNEY					
Maturity Journey	Not existing	Emerging	In transition	Advanced	
<i>Design</i> From considering the cycle unchanged to redesign it to produce circular value.	The farm has not thought about rethinking the product life cycle to increase the circular value.	The farm has rethought some sustainability strategies with regard to materials and energy used in the process on the product and services offered.	The farm carried out impact assessments on its product and services, which enabled it to rethink the life cycle, improve efficiency and sustainability of the product.	The products offered by the farm are certified to offer circularity and offering the market a product with a higher economic value.	
<i>Shared use</i> Zero to adopt multi-actor sharing strategies.	The farm does not adopt sharing strategies (e.g. shared equipment, processing facilities; physical and digital platforms, local markets, etc.) to increase efficiency and reduce waste.	The farm is experimenting with some sharing strategies, from production to commercialisation.	The farm actively adopts sharing strategies on operational technical means such as equipment, monitoring tools and technologies to reduce individual costs and optimise the use of resources.	The farm also adopts advanced sharing strategies such as shared cleaning service, storage and processing facilities, shared local markets, or multistakeholder digital platforms that connect producer and consumer.	
<i>Maximization of use</i> From zero to adopt maximisation of use strategies that involve the local community.	The farm does not adopt strategies to maximise the material use in the production cycle, such as inventory monitoring technologies, instrument repairs; equipment rental contracts; advanced conservation techniques.	The farm is experimenting with maximisation strategies of materials use.	The farm actively adopts maximisation strategies of material use.	The farm adopts strategies to maximise material use involving other external actors such as donations and redistribution, rental contracts for equipment and means of production and distribution, involvement in repairing networks, awareness-raising campaigns against food waste.	
<i>New life cycles</i> From zero to support recovery and recycling strategies to reintroduce waste from biological and technical cycles as new raw materials into the food chain/other sectors.	The farm separates waste correctly, but does not adopt recovery and recycling strategies.	The farm is experimenting with some waste reduction programmes, some examples are the adoption of waste monitoring systems and employee training.	The company has initiated pilot projects to activate recovery and recycling strategies.	The farm has set up partnerships to valorise biological and technical waste, reintroducing them into new cycles, from agrifood to the cosmetics and energy sectors.	
<b>FINAL ASSESSMENT</b>	<b>STEP 1</b> - Scan the circular maturity level of the farm				
	<b>STEP 2</b> - Scan the degree of farm circular maturity				
	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>75%</b>	<b>100%</b>
<b>Actors' involvement for the effectiveness of strategies</b>	<b>ON-farm:</b> circularity is shared within the farm.				
	<b>OFF-farm:</b> circularity is also shared also off-farm actors.				

technical and biological cycles through a circular lens, following specific guidelines (Burch et al., 2019) of the European Commission and the Directorate-General for Maritime Affairs and Fisheries. Conducting impact assessments of both process and product inputs holds significant importance (Thomas et al., 2022; Penaranda et al., 2023), as it helps to identify resource-intensive materials/products and redesign them (Lacy et al., 2020).

“Shared use” and “Maximization of use” strategies, such as shared cleaning services, storage and processing facilities, local markets, or multistakeholder digital platforms connecting producers to consumers, are also recommended to be implemented in the food supply chain, according to Lacy et al. (2020) and Charatsari et al. (2023). Sharing opportunities are promising, especially in rural communities, where they can increase efficiency in resource usage and interpersonal relationships (Scandurra et al., 2023). Moreover, for what concerns the “Maximization of use”, vivid examples are donations and redistribution, rental contracts for equipment and means of production and distribution, and awareness-raising campaigns against waste (Burch et al., 2019; Amicarelli et al., 2021). In addition, the provision of maintenance (e.g., reconditioning of boats for multipurpose use, enhancing the conditions





of buildings and equipment), repair (e.g., including nets, equipment, collectors, crates), and remanufacturing (specifically involving boat engines, distribution vehicles, etc.) represent other significant examples.

The last element concerns the creation of “New life cycles” through activating recovery and recycling strategies to extend resource life. These collaborations are also crucial for effectively valorizing biological waste in food and non-food industries (Vu and Chi, 2024; Chary et al., 2024).

3.2.2.3. *Culture and organization.* The third focus area pertains to transferring CE principles to the “Culture and Organization” (Table 3). The recommended course of strategies is defined for the elements of *Vision, Innovation, People* and *Governance*.

The model emphasizes the need to build a circular “Vision”, which is necessary to set up a clear pathway towards specific objectives. To reach these goals, the model suggests providing employees’ training and engagement in projects dealing with CE principles, intending to disseminate them throughout all levels of the organization (People) (Lacy et al., 2020; Uhrenholt et al., 2022). Another aspect to consider in making progress towards CE is investing in innovative technological and

**Table 3**  
Circular Maturity in Culture and Organization.

SCAN the CIRCULAR MATURITY JOURNEY					
Maturity Journey	Not existing	Emerging	In transition	Advanced	
<i>Vision</i> From none towards a full integration of circular economy principles into farm vision, in all organisational levels, and supporting it beyond the farm boundaries.	The farm does not integrate circular economy principles into its business strategy.	The farm has set long-term circular goals as part of its sustainability strategy.	Circular objectives have been set, but are not yet linked to farm performance metrics.	Circular objectives are linked to farm performance metrics at all organisational levels and that farm fully supports and promotes the circular vision both inside and outside the operational boundaries.	
<i>Innovation</i> From non-adoption to adopt advanced innovative practices/technologies, and being involved in innovation hubs.	The farm does not adopt innovative practices or technologies to achieve the circular transition.	The farm is experimenting with some innovative practices/technologies to progress circularity.	The farm adopts innovative practices and technologies to progress circularity.	The farm is at an advanced level of adoption of new practices and technologies, and it is involved in innovation hub to share knowledge with external stakeholders.	
<i>People</i> From zero to train employees on circular economy principles and support circular ethics externally.	The farm does not promote circular ethics or offer training on the concept of circular economy.	The farm discusses with its employees about the importance of introducing circular practices in the company, but does not yet offer training courses.	The farm selects employees with basic knowledge on circular economy and trained them over time.	The farm encourages, through incentives, employees to carry out activities in line with the circular ethic and activates projects with partners who support the same vision.	
<i>Governance</i> From zero to the integration of circular principles into management and working methods.	There are no processes, procedures or policies that encourage knowledge, strategies and projects oriented towards the application of circular economy principles in the farm.	Some processes, procedures or policies have been introduced to improve resource efficiency, but implementation is still at an early stage.	The farm actively adopts processes, procedures or policies that encourage knowledge, strategies and projects oriented towards the application of circular economy principles.	The farm actively adopt a sustainable business model based on circularity principles.	
<b>FINAL ASSESSMENT</b>	STEP 1 - Scan the circular maturity level of the farm				
	STEP 2 - Scan the degree of farm circular maturity				
	0%	25%	50%	75%	100%
<b>Actors' involvement for the effectiveness of strategies</b>	<b>ON-farm:</b> circularity is shared within the farm.				
	<b>OFF-farm:</b> circularity is also shared also off-farm actors.				

non-technological practices (*Innovation*) (Sousa-Zomer et al., 2018; Asche et al., 2022; Vecchio et al., 2023a), as well as participating in multi-actor innovation hub (Rowan and Casey, 2021).





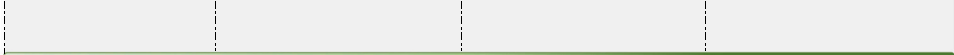
Pursuing this holistic view continues to develop responsible “Governance” and promote efficient policies, processes, and procedures to achieve a higher degree of circularity (Uhrenholt et al., 2022). In this context, applying CE principles to these working methods could foster the creation of integrated business models to achieve long-term sustainability goals (Mentink, 2014; Evans et al., 2017; Geissdoerfer et al., 2018). The literature on agri-food should emphasize the socio-cultural implications of adopting CE strategies, as it is becoming increasingly relevant to consider the broader externalities of their application (Brugere et al., 2023).

3.2.2.4. *Ecosystem*. The maturity model suggests this domain strategies for progressing in *Communication, Collaboration, Investments, and Policy* (Table 4). The “Communication” of results, information, and knowledge is advocated by many authors (e.g., Stiklestad et al., 2019) as the engine of change. This applies to spreading the benefits of adopting circular

practices inside and outside the farm (Vecchio et al., 2023b). Similarly, partnerships, organization of workshops, and events play a crucial role in disseminating good practices within the community and enhancing their scalability (“Collaboration”) (Leach et al., 2013; Krause et al., 2015; Burch et al., 2019). Following this view, establishing knowledge systems could stimulate synergetic work on the CE and sustainability challenges of the future (Vecchio et al., 2023a).

Another key element for advancing circularity is to make “Investments”. The choice to invest in these strategies is only a small part of the puzzle since not every farm can be financially healthy enough to sustain itself (Lososová and Zdeněk, 2024). Fostering an environment conducive to adopting circular strategies is a way to address even the most challenging aspects, such as establishing regulations and developing “Policy” measures that can support small and medium-sized farms in transitioning to these new solutions. These policies should also include rules to incentivize the allocation of waste to secondary markets, the diffusion of innovations, as well as the application of the Rs framework (Babbitt et al., 2018; Regueiro et al., 2022; Naylor et al., 2023).

**Table 4**  
Circular Maturity in Ecosystem.

SCAN the CIRCULAR MATURITY JOURNEY					
Maturity Journey	Not existing	Emerging	In transition	Advanced	
<i>Communication</i> From zero to achieve the sharing of information and circular results within and outside the farm.	The farm does not share opinions or results concerning business and environmental performance with employees or even externally.	The farm shares opinions and results with employees through regular meetings and internal communications.	The farm actively shares opinions and results within the farm through update meetings and digital platforms.	The farm has a mature, technology-supported approach to disseminate corporate performance and environmental results and communicates its achievements externally.	
<i>Collaboration</i> From zero to actively collaborate with public and private entities for the adoption of circular economy strategies.	The farm is not engaged in circularity-related initiatives/partnerships.	The farm follows the progress of active circularity initiatives for the aquaculture sector by participating in seminars or reading articles but is not yet involved in concrete collaborations.	The farm has taken part in some pilot project initiatives with research institutes to test new circular practices, and in the future will initiate concrete collaborations that go beyond experimentation.	The farm participates as an active promoter of public and private partnerships and consortia for the development of joint projects for the promotion of circular solutions.	
<i>Investment</i> From zero to making investments to accelerate circular strategies welcoming strategic partnerships.	The farm does not invest in the circular transformation of operations, nor in training.	The farm started to invest in experimenting with some circular practices, without offering to his employees training courses.	The farm has invested in training, and capital intensive technologies to consciously adopt circular practices.	The farm invests in training, capital intensive technology, leveraging strategic partnerships to progress circularity.	
<i>Policy</i> From zero to actively participate in local and national debates about circular economy to provide stimuli for the circular transition.	The farm does not monitor the circular agenda and does not provide stimuli for policy development.	The farm monitors relevant policies at local, national and international level.	The farm monitors policies with some regularity and contributes to circular economy goals through public funding.	The farm is actively involved in local and national policy discussions, taking funding for sustainable development of the aquaculture sector and socialising support for the circular economy agenda with external stakeholders.	
<b>FINAL ASSESSMENT</b>	STEP 1 - Scan the circular maturity level of the farm				
	STEP 2 - Scan the degree of farm circular maturity				
		0%	25%	50%	75%
<b>Actors' involvement for the effectiveness of strategies</b>	<b>ON-farm:</b> circularity is shared within the farm. <b>OFF-farm:</b> circularity is also shared also off-farm actors.				

### 3.3. SUGGEST

This last phase aims to offer suggestions on improving specific areas to enhance the level of CM for farmers. In the following table (Table 5), it has been collected a list of potential strategies following the main directions proposed by Institutions and Research concerning circular transition (e.g., AAC, 2024; European Commission, for, D.-G., and Fisheries, 2021; Chary et al., 2024).

Regarding the selected focus areas, the literature (e.g., Kohlegger et al., 2009) suggests adding a list of potential indicators (Appendix – Table A2) to the developed strategies, which could be suited to assess elements that are “in the maturation process”. The list partially represents the aspects to be monitored on the “bounded” journey proposed in this study. Still, it is intended as additional information to offer different points of reflection and possibilities for in-depth micro-aspects for research that address this study area. For these indicators, further research is needed to develop local benchmarks and allow performance to be weighed. Setting benchmarks, and thus potential competition between companies could also act as a catalyst for improvement, stimulating progress in response to sub-optimal performance.

## 4. A simulation of the 3S CTM application

This chapter aims to assess the circular journey transition of a simulated aquaculture farm (SF) to give an idea of the CTM’s application.

The provided example simulates a real interview, starting with a company being surveyed through a questionnaire that includes informed consent for data use. The questionnaire is divided into two parts: the first gathers information about the company’s socio-structural profile and operating context, while the second focuses on evaluating CR and CM within the 3S model. The socio-structural factors (e.g., farmer profile, farm size, technology used) and contextual aspects (e.g., production area, policy support, information channels) can help interpret the company’s readiness and implemented strategies in the four focus areas of the 3S model. This approach aligns with literature (e.g., Kumar et al., 2018; Joffre et al., 2019; Vecchio et al., 2023a), which stresses the importance of contextualizing the transfer of new practices/technologies and the adoption of new business models in aquaculture.

### 4.1. Case study

The SF is modelled on a medium-large structured Italian mariculture farm in the Tyrrhenian Sea managed by a sole administrator (owner), a 38-year-old man with a bachelor’s degree, who inherited the business from his father.

The company’s turnover is around €50 million, which has been financially stable in recent years with a downturn during the COVID-19 pandemic and the energy crisis. In recent years, it has also stabilized its EBITDA (earnings before interest, taxes, depreciation and amortization) at around €6 million. The company’s financial situation is in surplus, with a positive net financial position.

Currently, the company employs 27 staff members, divided into three departments: farming system, mobile operators, and headquarters, as Fig. 2 shows.

The SF is involved in rearing the most popular species of the Mediterranean area, such as gilt-head sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*), which account for 50 % and 30 % of production, respectively. Still, in smaller quantities, it is also involved in farming other species, including meagre (*Argyrosomus regius*) and amberjack (*Seriola dumerili*). Annual production accounts for around 5000 Tons divided among 75 in-shore floating cages located in three different maritime concessions (MC) a few nautical miles apart (Fig. 2). The farm operates nine fossil fuel-powered vessels of various sizes for routine tasks such as fish rearing, fishing, and cage maintenance.

The SF buys fries and aquafeed from external companies. The feeding

practice is carried out hybrid, as the operators feed some cages directly on small to medium-sized vessels, while others are fed by a centralized system using floating structures, also known as “feeding barges”.

The administrative office, the feed storage warehouse and the mechanical workshop for the maintenance of equipment and technical materials are located on the coast near a small harbor where the operating boats are docked.

The company’s commitment to circularity has increased in recent years. In particular, the company is investing in innovation. Among new practices, the company is experimenting with new feeding ingredients, as well in the field of genetics; while, regarding automation and technologies, it has adopted a semi-automatized feeding system, management software system to plan production and inputs purchase and photovoltaic panels to reduce energy consumption.

Furthermore, the commitment is being consolidated through participation in numerous projects, the activation of collaborations with various entities, and contributing to the goals of the national EMFAF (European Maritime, Fisheries and Aquaculture Fund) 2021–2027 policy. In addition, the owner is a member of the national sector association, he actively participates in the regional FLAG discussions and in sector fairs.

### 4.2. START

In a real interview with the farm, several questions would be employed to assess its awareness of its challenges in the circular transition across the four focus areas under analysis, along with the associated elements. In the case where the company is not aware of circular practices, the respondent is informed about the values and principles of the CE. The cognitive readiness of the SF may be influenced not only by the owner’s educational background but also by the external interactions and the various collaborations the company is engaged in.

In the simulated scenario, the farm showed a complete understanding of the strategies in the Operations, Products and Services, and Ecosystem dimensions. In contrast, it shows gaps concerning the Culture and Organization area.

### 4.3. SCAN

This section is designed to assess the SF’s CM and compare it with the simulated national average typological for “floating cage mariculture finfish farms” (NA). The respondent, in this case the company owner, self-assessed the level of CM by first identifying the specific maturity level (e.g. “Emerging”) for each element of the focus areas and then an estimated percentage of CM for the same. The results of the simulated survey are reported in the following paragraphs and briefly depicted in Fig. 3.

#### 4.3.1. Operations

SF is currently adopting energy-saving and energy-efficient strategies, as it is self-sufficient in the “energy” consumption of land-based structures using photovoltaic panels. Regarding the feeding practices, the farm is considering fully centralizing the process only through “feeding barges”, which are powered by fossil resources. For this purpose, the farm is adopting energy-self-sufficient feeding systems powered by generators that exploit tidal fluctuations to reduce fossil fuel “emissions” and dependence. However, it is complex for the farm to replace diesel-powered vessels with alternative “green” vehicles for farm activities.

Regarding “material inputs”, SF has commissioned the aquafeed mill its own formulated fish diet, which partially replaces fish and soybean meal with raw materials recovered from other livestock production, including poultry and pig byproducts. The farm is also introducing insect meal on an experimental basis. As for the supply of fry, the farm’s policies are moving towards hatcheries committed to using renewable energy in their production processes, as fry are generally produced in

**Table 5**  
Suggested strategies proposed within the reference CTM.

	Energy	Emissions	Material inputs	Waste
Operations	<ul style="list-style-type: none"> <li>- Investing in renewable energy</li> <li>- Improving energy efficiency and saving technical means and buildings (e.g., electrically propelled boats powered by renewable energy, high-insulation cold rooms, low-temperature washing cycle).</li> <li>- Purchasing of renewable energy certificates.</li> <li>- Reducing the dependency on water extraction.</li> <li>- Adopting a circular business model to identify the key resources associated with creating farm value.</li> </ul>	<ul style="list-style-type: none"> <li>- Adopting sustainable strategies related to raw material supply (larvae, fry, etc.) in early-stage development also considering their transportation.</li> <li>- Identifying critical points of emissions through the calculation of carbon footprint.</li> <li>- Investing in alternatives of fossil fuel-powered vessels, machinery, and equipment for farm management.</li> <li>- Investing in precision feeding and genetic strategies.</li> <li>- Improving the wastewater management.</li> <li>- Adopting a circular business model to identify the key activities associated with improving value capture from reducing environmental impact.</li> </ul>	<ul style="list-style-type: none"> <li>- Actuating water parameters monitoring through technologies.</li> <li>- Evaluating alternative water sources.</li> <li>- Adopting recirculating systems.</li> <li>- Integrating sustainable ingredients in the feeding strategies.</li> <li>- Adopting recycled or biodegradable technical materials (e.g., nets in mussel farming).</li> <li>- Adopting a circular business model to identify key resources associated with creating farm value.</li> </ul>	<ul style="list-style-type: none"> <li>- Adopting software and technologies to monitor materials flows.</li> <li>- Using alternative technical materials (e.g., recycled, biodegradable).</li> <li>- Adopting innovative waste management/treatment systems.</li> <li>- Adopting recirculating systems.</li> <li>- Adopting precision feeding techniques.</li> <li>- Eventual processing waste for secondary purposes (e.g., energy, food, feed, etc.).</li> <li>- Adopting a circular business model to identify the key activities associated with improving value capture from waste reduction.</li> </ul>
Product and Service	<ul style="list-style-type: none"> <li>- Carrying out environmental impact assessments to rethink the technical and biological product cycle and, based on available certification schemes, to externally communicate the circular value.</li> <li>- Replacing current inputs with more circular ones such as renewable energy, recycled or biodegradable materials, alternative ingredients to fish meal and oil, and recirculating water.</li> <li>- Adopting a circular business model to consolidate the applied circular strategies, such as the eco-design, to improve the value proposition.</li> </ul>	<ul style="list-style-type: none"> <li>- Adopting sharing strategies that can be applied from production to commercialization, such as shared equipment, processing and storage facilities, local markets or being part of digital sharing platforms.</li> <li>- Adopting a circular business model to consolidate the applied circular strategies, such as shared use, to improve the value proposition.</li> </ul>	<ul style="list-style-type: none"> <li>- Rethink material use by adopting strategies such as maintenance of technical equipment, monitoring technologies and inventory management, repair of equipment, advanced conservation techniques, rental agreements equipment, donations and redistribution.</li> <li>- Taking part in information campaigns to educate consumers on properly storing fish at home.</li> <li>- Adopting a circular business model to consolidate the circular strategies applied, such as maximization of use, to improve the value proposition.</li> </ul>	<ul style="list-style-type: none"> <li>- Activating partnerships to valorize and allocate biowaste in secondary markets.</li> <li>- Activating partnerships to valorize waste from the technical cycle for recycling purposes.</li> <li>- Activating a waste reduction program by adopting material monitoring systems or offering training courses to employees.</li> <li>- Adopting a circular business model to consolidate the applied circular strategies, such as recovery and recycling, to improve the value proposition.</li> </ul>
Culture and Organization	<ul style="list-style-type: none"> <li>- Setting short- and long-term goals to achieve circular transition.</li> <li>- Understanding the perspective of all employees about the circular economy to create a culture oriented towards sustainability.</li> <li>- Spreading the circular vision along the supply chain and strengthening the relationship with suppliers, customers, partners and other stakeholders who support it.</li> <li>- Adopting a circular business model to consolidate the company's vision.</li> </ul>	<ul style="list-style-type: none"> <li>- Adopting, starting from experimental to advanced level, of innovative practices and precision farming technologies.</li> <li>- Participating in multi-actor innovation hub.</li> <li>- Adopting a circular business model to understand the contribution of innovation in creating the circular value.</li> </ul>	<ul style="list-style-type: none"> <li>- Selecting employees with a basic knowledge of the circular economy and sustainability challenges related to the sector.</li> <li>- Involving employees in multi-actor projects concerning the circular economy, incentivizing them to perform circularly.</li> <li>- Adopting a circular business model that identifies the role of key stakeholders for farm value creation.</li> </ul>	<ul style="list-style-type: none"> <li>- Adopting the circular principles into working methods, from operations to consolidated internal policies.</li> <li>- Adopting a circular business model to consolidate an integrated governance that is able to create circular value.</li> </ul>
Ecosystem	<ul style="list-style-type: none"> <li>- Communicating performance results within the farm.</li> <li>- Participation in the innovation hub, digital platform, convening forums, and consortia to offer information to share experiences and results in circularity.</li> <li>- Activating bilateral and multilateral collaborations.</li> <li>- Developing social media communication to share circular values.</li> <li>- Adopting a circular business model to understand better how and through which channels circular value is delivered internally and externally.</li> </ul>	<ul style="list-style-type: none"> <li>- Being updated on the progress of the aquaculture sector on circularity.</li> <li>- Activating channels for active collaborations, such as with trade associations, research institutes, and FLAGS.</li> <li>- Evaluate the use of circular business models to understand better how circular value is created if the ecosystem of actors is considered.</li> </ul>	<ul style="list-style-type: none"> <li>- Understanding the benefits of circular transition through training courses.</li> <li>- Activating networks and partnerships to share the cost of investments.</li> <li>- Adopting a circular business model to understand better the financial flows through which circular value is captured.</li> </ul>	<ul style="list-style-type: none"> <li>- Being updated on local, national and European aquaculture policies.</li> <li>- Being updated on recent strategies such as European Green Deal Strategies and Guidelines for a more sustainable and competitive EU aquaculture.</li> <li>- Participating in local policy discussions.</li> </ul>

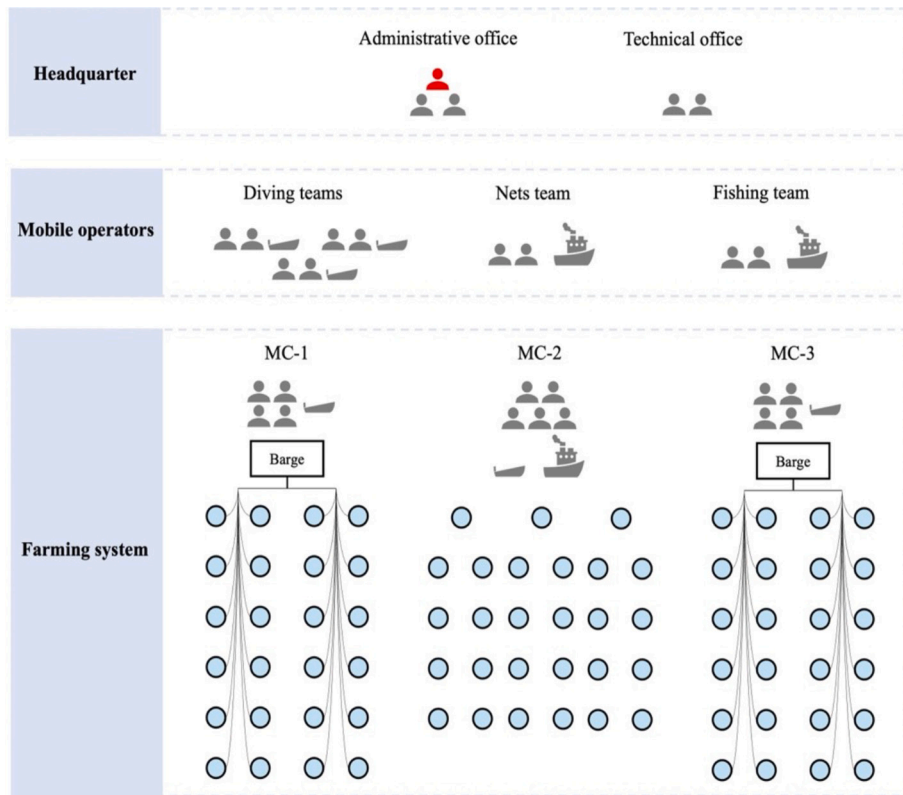


Fig. 2. Structural representation of the simulated farm.

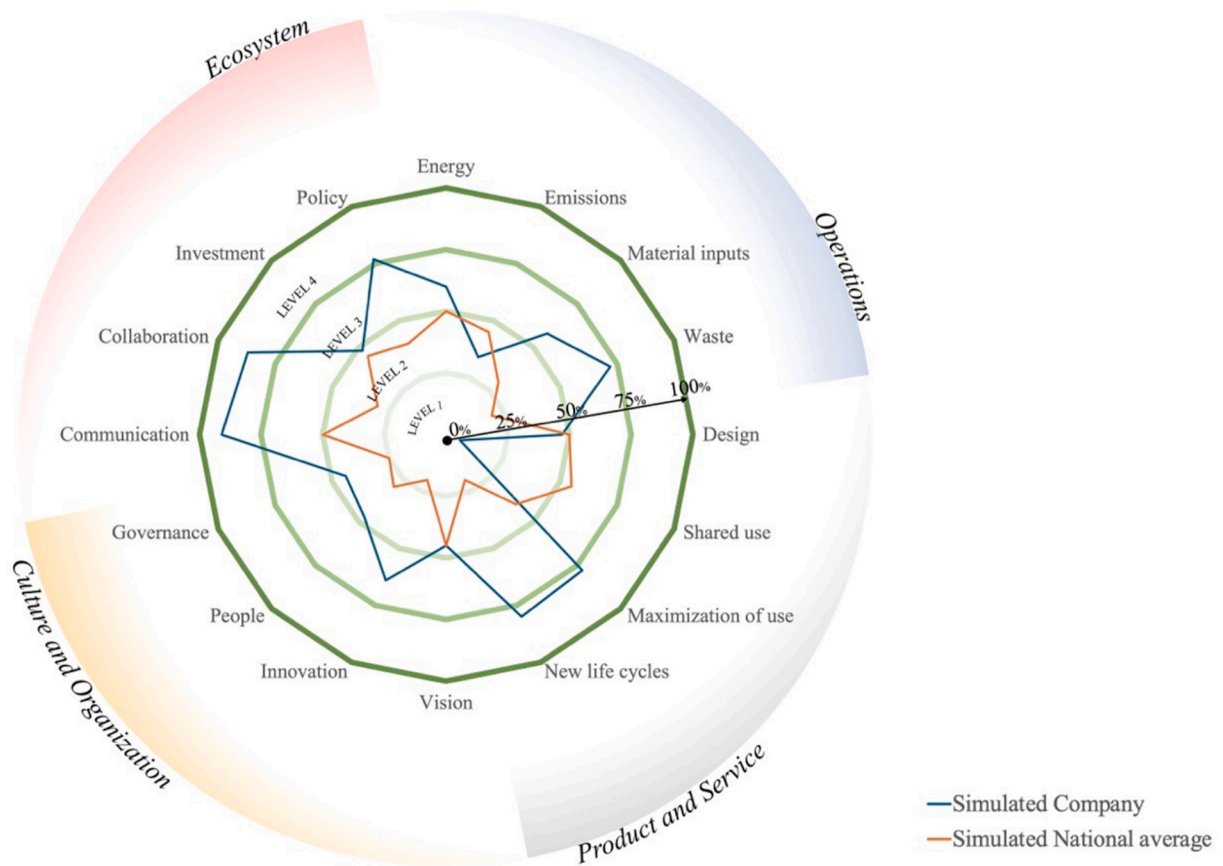


Fig. 3. Simulated circular maturity framework.

RAS systems known for their high energy consumption.

Biological “waste” is only fish mortality and the not consumed feed. To avoid the generation of the latter, the SF is studying new strategies offered by the market innovations of the aquaculture sector. Regarding technical waste, most of which comprises the plastics of feed sacks, breeding nets, and office and mechanical workshop waste, the farm follows the waste recovery rules imposed by the municipality where the facility is located.

#### 4.3.2. Product and service

As highlighted above, the farm has rethought its production cycle and implemented circular actions but is not yet measuring the circular value (“design”).

Given the farm’s location, its distance from other farms does not allow for the implementation of sharing (“shared use”) strategies with other actors of the sector, so it is placed at non existing level.

About the “maximization of use”, the nets of the floating cages are made of a specific polymer, UV rays and mechanical stress resistant, which significantly extends the life of the technical material compared to nylon nets. In addition, SF has set up a team of maintenance workers for the nets of the floating cages, who wash and repair any damage to them. Moreover, this service is not only for the company itself but is extended to other farms that deliver their nets directly to SF, refurbishing them and thus reducing the costs of buying new nets. These choices have determined an advanced level for this aspect of CM.

Regarding the “new life cycle”, the farm delivers the farmed fish to a slaughterhouse, which also takes care of the processing part. This company gives all the waste from its processing to the pet food industry, creating a new value for what is considered waste for human consumption.

#### 4.3.3. Culture and organization

SF’s corporate “vision” includes long-term goals in its sustainable strategies, and it is beginning to evaluate how to determine these in performance metrics.

Regarding the adoption of “innovation”, SF is evaluating the possibility of implementing an IMTA to recover effluent produced by fish in floating cages and precision farming techniques (e.g., cage sensors, precision feeding). The farm conducts various studies involving nutritional, genetic, and fish microbiome experiments in collaboration with the fry supplier and the feed company to develop precision diets. These efforts aim to optimize aquafeed formulations by maximizing the use of alternative raw materials different from fish and vegetable meals and oils. Furthermore, SF implemented a semi-automatized feeding strategy and a management software system to optimize production and photovoltaic panels to decrease energy consumption.

To date, the farm has kept its employees updated on the latest circular operating practices through refresher seminars (“people”). This enables employees to understand the relevance of their tasks and acquire a circular perspective.

In general, the firm is working on defining working methods, from operations to internal policies, based on the CE, and it has not yet integrated these principles into its business model (“governance”).

#### 4.3.4. Ecosystem

SF actively communicates its achievements and activities related to circular and sustainable practices, both internally and externally, through the most popular social networks and regularly organizes cooking events for its product in collaboration with various “HoReCa” (Hotel-Restaurant-Catering) professionals (“communication”). In these culinary events, dishes are also prepared using parts of the fish typically considered waste, thereby revalorizing elements like the stomach and swim bladder and promoting the circular use of food.

The SF actively participates and proposes initiatives regarding the implementation and experimentation of the sector’s circular practices through the national trade association to which it is associated

(“collaboration”). The company is also active in “policy” discussions and is committed to hosting and participating in publicly funded projects. In this sense, it reports to participate in trade fairs and actively in regional FLAG discussions.

Finally, in terms of “investments”, the farm is situated at the emerging level since investments in the circular transition have started and are progressively increasing, especially considering the introduction of new practices and technologies in operations. However, they have not yet been allocated towards training courses.

#### 4.4. SUGGEST

The results show a high degree of maturity since the general level can be summarized as a company “in transition” across most dimensions, except for “Culture and Organization”, which remains in an “emerging” situation on average. The findings reveal the SF’s interest in implementing CE actions. However, it primarily focuses on circular strategies aimed at rethinking the technological aspects of resource and material flows (e.g., photovoltaic panels, automatized feeding, waste-to-value strategies), with specific attention given to economic factors rather than social (e.g., employee training) and environmental (e.g., measuring the environmental impact of production) aspects. This outcome represents a partial adoption of the circular model, which has already been discussed in the literature (e.g., Buchmann-Duck and Beazley, 2020) and is common among large companies run by young owners, which tend to be more inclined to invest in technological innovation (Vecchio et al., 2023a). Furthermore, the SF has the capital to invest in innovation but is still evaluating whether to transfer these efforts into a concrete circular transition, shown by a low level of commitment in the “Culture and Organization” dimension. The SF is still building a solid circular vision; in fact, employees do not receive training or updates on the topic. However, the SF has understood the importance of fostering an external environment receptive to change. This is confirmed by numerous collaborations with public and private entities, communication strategies, and its participation in achieving the goals of the national EMFAP 2021–2027 policy.

Compared to the NA for the same farm type, the SF outperforms the NA in Emissions, Design, and Shared use. The simulated farm could improve its circular commitment by adopting specific strategies related to the elements in which it underperforms. Table 5 offers some strategic suggestions on the direction to be followed regarding circular strategies since they have been selected based on the pathway emphasized by research and institutions. These strategies provide the basis for increasing awareness of the challenges the aquaculture farm will face, considering the progress made by the reference farm type.

#### 5. Conclusion

The present study proposed a CTM for the European aquaculture sector, and its application can be observed in the simulated case. For each type of classification, the model allows comparison with the sector average. This lays the foundation for collecting data and creating farm type benchmarks to understand better where different European companies stand in the circular transition. Indeed, circularity assessments often lack contextualization, generalization, and replicability and are primarily concentrated on environmental aspects (Jacob et al., 2021; Alleway et al., 2023). The CTM results could offer important information on areas where farms are implementing circular strategies, encompassing the environmental, social and economic dimensions. In this sense, the authors have proposed a partial list of strategies offered by the literature that could be useful for progressing in the circular journey, especially for underdeveloped areas. The outputs equip farmers and policymakers with specific knowledge domains, from Operations to Ecosystems, offering relevant implications:

- For practitioners, the framework could guide farms to progress circularity across a defined pathway. Furthermore, the strategies proposed by the reference framework can be integrated into a circular business model to achieve economic, social and environmental sustainability goals.
- For policymakers, the CTM could represent a way to monitor the ongoing efforts on circularity. This would provide a clear understanding of the current level of circularity in aquaculture farms and identify the elements that need additional support. Furthermore, this snapshot can help build a dedicated knowledge system that can be integrated into aquaculture policies, which has only been developed for the agricultural scenario within the Common Agricultural Policy (CAP).

The CTM follows the form of heterodox economics models, which propose evaluations of companies at a specific moment. To enrich the model further in future research, it will be useful to incorporate the principles of evolutionary economic theories. These theories emphasize business strategies' dynamic and adaptive nature, highlighting how firms evolve through processes of variation, selection and replication of operational and strategic routines. From this perspective, aquaculture farms do not simply react passively to market or institutional conditions but actively develop and modify their capabilities and competencies over time in response to environmental and structural changes. In the context of the proposed transition model, adopting an optimal strategy can be seen as an evolutionary process in which companies experiment with different strategic options, learn from the results of these experiments and adapt accordingly. This evolutionary approach enriches understanding of the relationship between behavior and the adoption of circular strategies, adding a temporal and adaptive dimension that better explains how aquaculture farms adapt to systemic and sectoral changes. Integrating evolutionary models allows for consideration of the role of innovations and strategic responses over the long term in a context where farms are focused on optimizing their current performance and ensuring their survival and future success in a constantly changing environment. This is especially pertinent in sectoral transitions towards circular models, where aquaculture farms need to adapt to new regulations and evolving competitive dynamics.

Future research will focus on testing CTM on a pool of aquaculture farms in Europe to analyze CM for different farming systems. This could make it possible to start collecting farm type-specific benchmarks for other member states to start building robust databases to strengthen the results produced by the current assessment tools, as recent research (e.g., [Engle et al., 2023](#); [Boyd and McNevin, 2024](#)) is increasingly emphasized.

Beyond this, future developments should focus on the impacts of the circular model on the economy, society, and the environment. Strategic guidelines assert that sustainable aquaculture in the EU can significantly contribute to the provision of public goods, including ([European Commission, 2021](#), p. 16): “(i) nutritious and healthy food with a limited environmental footprint; (ii) economic development and job opportunities for coastal and rural communities; (iii) reducing pollution; (iv) preserving ecosystems and biodiversity; and (v) contributing to the fight against climate change”. Analyzing the theory behind CE models, such as the transition model proposed in this study, both society and the environment could benefit from this kind of models. However, several aspects still require further exploration, particularly the potential negative externalities that could arise from the CE approach and in this context, impact studies are increasingly necessary. For example, the effects these models might have on biodiversity, as highlighted by [Buchmann-Duck and Beazley \(2020\)](#),

represent a connection that has been insufficiently addressed in the literature. Their study emphasizes that biodiversity is often considered “natural capital” from which humans draw to produce goods and ecosystem services. While adopting CE strategies may reduce resource extraction from this natural capital, it does not necessarily provide evidence of adequate biodiversity protection. This is the case with provisioning services, regulation (e.g., carbon storage), supporting services (e.g., water balance), and cultural services, which, despite being recognized as popular CE strategies, risk offering limited benefits in areas with high human presence ([Girardello et al., 2019](#)). One example is the CE strategies linked to bioenergy production, which rely heavily on primary sectors, which could lead to significant biodiversity loss ([Bronfizio et al., 2019](#); [He et al., 2024](#)).

It is, therefore, essential to develop new knowledge and tools that enable a better understanding of how these nature-based solutions can support, on the one hand, the supply of goods and services and, on the other, ecosystem conservation ([Lisbjerg, 2022](#)). Additionally, it is crucial to analyze the effects of technological innovations, which play a central role in the discussion on circular transition ([Charatsari et al., 2022](#)).

The present CTM introduces a pathway that reflects the direction in which European policies and strategies are endorsed. However, as highlighted by [Geng et al. \(2019\)](#), future research should delve deeper into the connections between the CE and aspects such as biodiversity (strictly in terms of conservation and not merely as natural capital), food access, nutrition, and all dimensions of sustainability, which European literature, policies, and strategies still need to address to move beyond a vision of a circular model focused solely on material and energy flows.

#### CRediT authorship contribution statement

**M. Masi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **F. Adinolfi:** Writing – review & editing, Validation, Supervision, Funding acquisition. **E.S. Marrocco:** Writing – review & editing, Methodology. **Y. Vecchio:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

No data was used for the research described in the article.

#### Acknowledgements

The research leading to these results has been conceived under the International PhD Program “Innovative Technologies and Sustainable Use of Mediterranean Sea Fishery and Biological Resources” ([www.FishMed-PhD.org](http://www.FishMed-PhD.org)). This study represents partial fulfilment of the requirements for the PhD thesis of Dr. Margherita Masi. The authors wish to thank Dr. Emanuele Dolfi (University of Bologna) for his valuable contribution.

Appendix A

**Table A1**  
Methodological foundation of the proposed Circular Maturity model, adapted by Lacy et al. (2020).

Focus area	Element	Circular strategy
Operations	<i>Energy</i>	Determining strategies lowering energy use, boosting operational energy efficiency, and encouraging a shift from fossil fuels towards renewables.
	<i>Emissions</i>	Detecting sources of emissions and taking corrective measures.
	<i>Material inputs</i>	Minimizing the company's dependence on natural resources from biological and technical cycles, including water, and adopting saving strategies.
	<i>Waste</i>	Getting zero waste across operations.
Product and service	<i>Design</i>	Assessing material life cycles, rethinking production inputs.
	<i>Shared use</i>	Optimizing the usage of a product by offering it as a service.
	<i>Maximization of use</i>	Extensions of a circular product or service in its original form maximize value.
	<i>New life cycles</i>	Finding circular uses for end-of-life waste through recovering and recycling strategies.
Culture and organization	<i>Vision</i>	Setting long-term goals and milestones to become a circular organization.
	<i>Innovation</i>	Adopting new practices, technology and innovation at organizational levels.
	<i>People</i>	Encouraging circular performance through training and involving employees in circular projects and
	<i>Governance</i>	Making the circular economy core to the farm's structure, policies, processes, and procedures.
Ecosystem	<i>Communication</i>	Supporting circularity through sharing information, knowledge, and expertise.
	<i>Collaboration</i>	Performing partnerships to increase the adoption of circular solutions.
	<i>Investments</i>	Enhancing financial support to promote circularity
	<i>Policy</i>	Participating in local, national, and worldwide forums to promote circularity and provide stimuli to policy discussions.

**Table A2**  
Potential indicators to be considered to assess circularity in the four focus areas. Source: own elaboration.

Focus areas and elements	Indicators	Indicators from or inspired by	
<i>Energy</i>	Energy Utilization Rate	Machinery Energy Consumption Rate	
	Energy Use Efficiency Rate	Energy self-sufficiency Rate	
	Renewable Energy Share	Fuel Utilization Rate	
	Energy Efficiency Rate for Water Extraction		
<i>Emissions</i>	Nitrogen Utilization Rate	General Chemical Pollution Rate	
	Phosphorus Utilization Rate	Hormone Pollution Rate	
	Organic Pollution Rate	Heavy Metal Pollution Rate	
	Siltation Rate	Marine Ecological Footprint	
	Carbon footprint	Acidification Rate	
	Eutrophication rate	Carbon storage	
Operations	Water Scarcity Rate	Water Exploitation Rate	
	Blue Water Footprint	Water Productivity Rate	
	Water Dependence Rate	Water Stress Level Rate	
	Gray Water Footprint	Water Withdrawal Rate	
	<i>Material input</i>	Water Recirculation Rate	Forage Fish Dependency Ratio (FFDR)
		Fish-in Fish-out Index (FIFO)	Nutritional Cost Footprint
<i>Waste</i>	Sourcing Rate of Material & components from circular sources (e.g., recycled materials)		
	Organic Waste utilization rate of farmed species	Particulate Matter Rate	
	Accumulation of Phosphorus Rate	Mortality total quantity	
	Accumulation of Organic Matter Rate	Mortalities After Transport and Stocking Rate	
	Waste Sent to Landfill Rate	Total Losses Rate	
	Solid Waste Use Rate	Waste monitoring system	
Product and service	<i>Design</i>	Protein Conversion Ratio (PCR)	Nitrogen Use Efficiency Rate
		Fish Meal Ratio (FMR)	Feed Conversion Rate (FCR)
		Specific Growth Rate (SGR)	Recycled Material Rate

(continued on next page)

**Table A2** (continued)

Focus areas and elements	Indicators	Indicators from or inspired by
	Mortality rate Rate of Inputs Certified Protein Conversion Efficiency (PCE) Antiparasitic Use Rate Certified Products Rate Traceability Rate	Phosphorus Use Efficiency Rate Escape Rate of Aquatic Species Antibiotics Use Rate Land Space Use Rate Marine Space Use Rate
<i>Shared use</i>	Shared Equipment Sales Platform Rate Sharing of Resources Rate Shared local markets	Shared processing facilities Sharing Best Practices Rate Sharing platforms Shared storage facilities <a href="#">Kirchherr et al., 2017</a> ; <a href="#">Burch et al., 2019</a> ; <a href="#">Lacy et al., 2020</a> .
<i>Maximization of use</i>	Remanufacturing Rate of Components for Resale Rate of Resale and Marketing of Goods Amount of Maintenance and repair equipment	Amount of Renovation and modernization Adoption to Sustainable Systems Rate Leasing of Equipment and Machinery Rate <a href="#">Kirchherr et al., 2017</a> ; <a href="#">Burch et al., 2019</a> ; <a href="#">Lacy et al., 2020</a> .
<i>New life cycles</i>	Unsold Fish Sales Rate Sales Channels Distribution Rate Creation of a Secondary Market for Unused Materials	Intensity of Partnership with Recycling Companies Biological Waste Valorization Rate Value creation thought recovery and recycling strategies <a href="#">Graedel et al., 2011</a> ; <a href="#">Franklin-Johnson et al., 2016</a> ; <a href="#">Burch et al., 2019</a> ; <a href="#">Lacy et al., 2020</a> ; <a href="#">Pietrelli, 2022</a> ; <a href="#">Ximenes et al., 2021</a> ; <a href="#">Villar-Navarro et al., 2021</a> .
<i>Vision</i>	Circular Goals Achievement Circular Business Model Implementation	Stakeholders Engagement Circular Initiatives Progress Rate <a href="#">Burch et al., 2019</a> ; <a href="#">Masi et al., 2024b</a> .
<i>Innovation</i>	Intensity of Technology Adoption Rate Share of Spending on Research and Development Rate Impact of ICTs on New Services and Products Rate	Intensity of Local Competition Rate Innovative Product and Process Rate <a href="#">Vasa et al., 2018</a> ; <a href="#">Rowan and Casey, 2021</a> ; <a href="#">Vecchio et al., 2023a</a> .
<i>People</i>	Employment Trained Rate Local Economy Development Rate Employment Possibilities Rate	Employment of Local Workers Rate Intensity of Employee Education & Training <a href="#">Sgarbossa and Russo, 2017</a> ; <a href="#">Valenti et al., 2018</a> ; <a href="#">Vasa et al., 2018</a> ; <a href="#">Masi et al., 2024b</a> .
<i>Culture and organization</i>	Capital Utilization Rate for Circular Economy Internal Rate of Return (IRR) Repayment Period Benefit-Cost Ratio Return to Equity (ROE) Return on Investment (ROI) Return on Debt (ROD) Return on Asset (ROA) Leverage Financial Independence Gross Operating Margin (EBITDA) Net Operating Margin (EBIT) Cash Flow on Investment Rate Rate of circular working methods	Cash Flow on Sales Rate Cash Flow on Debt Rate Liquidity Return on Assets Rate Liquidity Index Added Value Rate Sustainability of Financial Expenses Rate Capital Adequacy Rate Social Security and Tax Liability Rate Average Farm Life Annual Income Rate Risk Assessment Rate Products and Services Traded Rate Turnover Rate Rate of circular internal policies <a href="#">Valenti et al., 2018</a> ; <a href="#">Ioannidou et al., 2020</a> ; <a href="#">Lacy et al., 2020</a> ; <a href="#">Vecchio et al., 2022</a> ; <a href="#">STEF, 2023</a> ; <a href="#">Fazzini, 2023</a> ; <a href="#">Lososová and Zdeněk, 2024</a> .
<i>Communication</i>	Participation in Innovation Hub Participation in Digital Platform Food preservation campaigns	Participation in Convening Forum Dissemination of Circular Economy Results <a href="#">Lacy et al., 2020</a> ; <a href="#">Rowan and Casey, 2021</a> .
<i>Ecosystem</i>	Participation in Out-of-Community Activities Participation in Consortia, Cooperative, Business Networks, Trade Association Collaborative Activities	Investment to Create Total Employment Rate Local Involvement Rate Level of trust and reciprocity in existing ties/relationships <a href="#">Borrello et al., 2017</a> ; <a href="#">Valenti et al., 2018</a> ; <a href="#">Burch et al., 2019</a> ; <a href="#">Lacy et al., 2020</a> ; <a href="#">De Rosa et al., 2024</a> .

(continued on next page)

Table A2 (continued)

Focus areas and elements	Indicators	Indicators from or inspired by
	Partnership For Waste Valorization Rate Number of new ties/relationships with actors from other sectors or in different positions of power (e.g., institutions)	Level of trust and reciprocity in new ties/relationships
<i>Investments</i>	Development capacity of the company or a sector Total Capital Investment Rate in Circular Economy Share of Investment in employee training and development for circular economy Funding Circular Innovation Initiatives & Projects for the Sector Rate of investments funded by EMFAF	Fixed Capital Investment Rate in Circular Economy Total Capital Investment Rate in Technologies Research and Development Investment Rate in Circular Innovation Resources allocated Rate to the circular economy Sgarbossa and Russo, 2017; Vasa et al., 2018; Valenti et al., 2018; Burch et al., 2019; Ioannidou et al., 2020; Lacy et al., 2020; Engle et al., 2023; Lososová and Zdeněk, 2024.
<i>Policy</i>	Level of Knowledge of Government & Sectorial Policies related to the Circular Economy Participation in Policy discussions Participation in Working Tables for Sector Policy	Internal Policies Regarding Circular Practices Involvement in Standard and Policy Creation Policy and Standard Monitoring Rizos et al., 2015; Tukker, 2015; Krause et al., 2015; Geissdoerfer et al., 2018; Burch et al., 2019; Lacy et al., 2020; Alleway et al., 2023; Vecchio et al., 2023b.

## References

- Aarflot, J.M., Bjørndal, V.R., Dunlop, K.M., Espinasse, M., Husson, B., Lindstrøm, U., Keulder-Stenevik, F., Ono, K., Siwertson, A., Skern-Mauritzen, M., 2024. Ecosystem risk from human use of ocean space and resources: A case study from the Norwegian coast. *Ocean Coast. Manag.* 256, 107299. <https://doi.org/10.1016/j.ocecoaman.2024.107299>.
- Abejón, R., Bala, A., Vázquez-Rowe, I., Aldaco, R., Fullana-i-Palmer, P., 2020. When plastic packaging should be preferred: life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. *Resour. Conserv. Recycl.* 155, 104666. <https://doi.org/10.1016/j.resconrec.2019.104666>.
- Acharya, G.D., 2023. Sustainable transformation of Agrifood systems: A circular economic and Agroecological perspective. *SAARC J. Agriculture* 21 (1), 1–12. <https://doi.org/10.3329/sja.v21i1.66340>.
- Alleway, H.K., Waters, T.J., Brummett, R., Cai, J., Cao, L., Cayten, M.R., Barry, A.C., Dong, Y., Brandstrup, C., Liu, S., Liu, Q., Shelley, C., Theuerkauf, S.J., Tucker, L., Wang, Y., Jones, R.C., 2023. Global principles for restorative aquaculture to foster aquaculture practices that benefit the environment. *Conserv. Sci. Pract.* 5 (8). <https://doi.org/10.1111/csp2.12982>.
- Al-Tahitah, A., Muthalif, M.M.A., Abdulrab, M., Al-Maamari, Q.A., 2018. Paper review on the relationship between transformational leadership and readiness for change. *Int. J. Energy Policy Manag.* 3 (1), 1–7.
- Amicarelli, V., Lagioia, G., Bux, C., 2021. Global warming potential of food waste through the life cycle assessment: an analytical review. *Environ. Impact Assess. Rev.* 91, 106677. <https://doi.org/10.1016/j.eiar.2021.106677>.
- Aquaculture Advisory Council (AAC), 2024. AAC Framework Recommendation for an Aquaculture Policy Reform – AAC-Europe. Aac-Europe.org, Brussels, Belgium. <https://aac-europe.org/en/publication/recommendations-for-an-aquaculture-policy-reform/>.
- Armenakis, A.A., Bedeian, A.G., 1999. Organizational change: A review of theory and research in the 1990s. *J. Manag.* 25 (3), 293–315. <https://doi.org/10.1177/014920639902500303>.
- Asche, F., Eggert, H., Oglend, A., Roheim, C.A., Smith, M.D., 2022. Aquaculture: externalities and policy options. *Rev. Environ. Econ. Policy* 16 (2), 282–305. <https://doi.org/10.1086/721055>.
- Azwar, E., Wan Mahari, W.A., Rastegari, H., Tabatabaei, M., Peng, W., Tsang, Y.F., Park, Y.-K., Chen, W.-H., Lam, S.S., 2022. Progress in thermochemical conversion of aquatic weeds in shellfish aquaculture for biofuel generation: technical and economic perspectives. *Bioresour. Technol.* 344, 126202. <https://doi.org/10.1016/j.biortech.2021.126202>.
- Babbitt, C.W., Gaustad, G., Fisher, A., Chen, W.-Q., Liu, G., 2018. Closing the loop on circular economy research: from theory to practice and back again. *Resour. Conserv. Recycl.* 135, 1–2. <https://doi.org/10.1016/j.resconrec.2018.04.012>.
- Badiola, M., Basurko, O.C., Piedrahita, R., Hundley, P., Mendiola, D., 2018. Energy use in recirculating aquaculture systems (RAS): A review. *Aquac. Eng.* 81, 57–70. <https://doi.org/10.1016/j.aquaeng.2018.03.003>.
- Balestrucci, F., 2020. Transition towards circular economy through a multi-readiness level model: an explorative study in the construction equipment industry. Master's Thesis in Innovation and Design Dissertation. <http://mdh.diva-portal.org/smash/get/diva2:1451586/FULLTEXT01.pdf>.
- Becker, J., Knackstedt, R., Pöppelbuß, J., 2009. Developing maturity models for IT management. *Bus. Inf. Syst. Eng.* 1 (3), 213–222. <https://doi.org/10.1007/s12599-009-0044-5>.
- Berzi, L., Delogu, M., Pierini, M., Romoli, F., 2016. Evaluation of the end-of-life performance of a hybrid scooter with the application of recyclability and recoverability assessment methods. *Resour. Conserv. Recycl.* 108, 140–155. <https://doi.org/10.1016/j.resconrec.2016.01.013>.
- Bjørndal, T., Dey, M., Tusvik, A., 2024. Economic analysis of the contributions of aquaculture to future food security. *Aquaculture* 578, 740071. <https://doi.org/10.1016/j.aquaculture.2023.740071>.
- Blaise, C., 2020. Collaboration in a circular economy. *J. Enterp. Inf. Manag.* 33 (4), 769–789. <https://doi.org/10.1108/JEIM0220190062>.
- Bohnes, F.A., Laurent, A., 2018. LCA of aquaculture systems: methodological issues and potential improvements. *Int. J. Life Cycle Assess.* 24 (2), 324–337. <https://doi.org/10.1007/s11367-018-1517-x>.
- Bordignon, F., Trocino, A., Gasco, L., Odon, S.B., Xiccato, G., Berton, M., 2024. Towards circularity in aquaculture systems: environmental impact of *Hermetia illucens* meal inclusion in diets for rainbow trout reared in aquaponics. *J. Clean. Prod.* 466, 142901. <https://doi.org/10.1016/j.jclepro.2024.142901>.
- Borrello, M., Caracciolo, F., Lombardi, A., Pascucci, S., Cembalo, L., 2017. Consumers' perspective on circular economy strategy for reducing food waste. *Sustainability* 9 (1), 141. <https://doi.org/10.3390/su9010141>.
- Borsato, E., Giubilato, E., Zabeo, A., Lamastra, L., Criscione, P., Tarolli, P., Marinello, F., Pizzol, L., 2019. Comparison of water-focused life cycle assessment and water footprint assessment: the case of an Italian wine. *Sci. Total Environ.* 666, 1220–1231. <https://doi.org/10.1016/j.scitotenv.2019.02.331>.
- Boyd, C.E., McNevin, A.A., 2024. Resource use and pollution potential in feed-based aquaculture. *Rev. Fish. Sci. Aquacult.* 32 (2), 306–333. <https://doi.org/10.1080/23308249.2023.2258226>.
- Boyd, C.E., Tucker, C., Mcnevin, A., Bostick, K., Clay, J., 2007. Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. *Rev. Fish. Sci.* 15 (4), 327–360. <https://doi.org/10.1080/10641260701624177>.
- Bronzizio, E., Diaz, S., Settele, J., Ngo, H.T., Guezee, M., Aumeeruddy-Thomas, Y., Bai, X., Geschke, A., Molnár, Z., Niamir, A., Pascual, U., Simcock, A., Jaureguiberry, P., 2019. Global assessment report on biodiversity and ecosystem services. Chapter 1: assessing a planet in transformation: rationale and approach of the IPBES global assessment on biodiversity and ecosystem services. IPBES secretariat.
- Brugere, C., Bansal, T., Kruijssen, F., Williams, M., 2023. Humanizing aquaculture development: putting social and human concerns at the center of future aquaculture development. *J. World Aquacult. Soc.* 54 (2), 482–526. <https://doi.org/10.1111/jwas.12959>.
- Buchmann-Duck, J., Beazley, K.F., 2020. An urgent call for circular economy advocates to acknowledge its limitations in conserving biodiversity. *Sci. Total Environ.* 727, 138602. <https://doi.org/10.1016/j.scitotenv.2020.138602>.
- Burch, M.V., Rigaud, A., Binet, T., Barthélemy, C., Vertigo, L., 2019. Circular Economy in Fisheries and Aquaculture Areas—Guide 17. FARNET, Brussels, Belgium. <https://data.europa.eu/doi/10.2771/916852>.
- Charatsari, C., Lioutas, E.D., De Rosa, M., Vecchio, Y., 2022. Technological innovation and agrifood systems resilience: the potential and perils of three different strategies. *Front. Sustain. Food Systems* 6, 872706.
- Charatsari, C., Michailidis, A., Francescone, M., De Rosa, M., Aidonis, D., Bartoli, L., La Rocca, G., Camanzi, L., Lioutas, E.D., 2023. Do agricultural knowledge and innovation systems have the dynamic capabilities to guide the digital transition of short food supply chains? *Information* 15 (1), 22. <https://doi.org/10.3390/info15010022>.

- Chary, K., van Riel, A., Muscat, A., Wilfart, A., Harchaoui, S., Verdegem, M., Filgueira, R., Troell, M., Henriksson, P.J.G., de Boer, I.J.M., Wiegertjes, G.F., 2024. Transforming sustainable aquaculture by applying circularity principles. *Rev. Aquaculture* 16 (2). <https://doi.org/10.1111/raq.12860>.
- Checa, D., Macey, B.M., Bolton, J.J., Brink-Hull, M., O'Donoghue, P., Cardozo, A., Poersch, L.H., Sánchez, L., 2024. Circularity assessment in aquaculture: the case of integrated multi-trophic aquaculture (IMTA) systems. *Fishes* 9 (5), 165. <https://doi.org/10.3390/fishes9050165>.
- Chiara, G., Bentivoglio, D., Finco, A., 2021. Circular economy for a sustainable Agri-food supply chain: A review for current trends and future pathways. *Sustainability* 13 (16), 9294. <https://doi.org/10.3390/su13169294>.
- Chowdhury, A., Kabir, K.H., McQuire, M., Burea, D.P., 2024. The dynamics of digital technology adoption in rainbow trout aquaculture: exploring multi-stakeholder perceptions in Ontario using Q methodology and the theory of planned behaviour. *Aquaculture* 594, 741460. <https://doi.org/10.1016/j.aquaculture.2024.741460>.
- Çınar, Z.M., Zeeshan, Q., Korhan, O., 2021. A framework for industry 4.0 readiness and maturity of smart manufacturing enterprises: A case study. *Sustainability* 13 (12), 6659. <https://doi.org/10.3390/su13126659>.
- Colombo, S.M., Turchini, G.M., 2021. Aquafeed 3.0: creating a more resilient aquaculture industry with a circular bioeconomy framework. *Rev. Aquac.* 13 (3), 1156–1158.
- Colombo, S.M., Roy, K., Mraz, J., Wan, A.H.L., Davies, S.J., Tibbetts, S.M., Øverland, M., Francis, D.S., Rocker, M.M., Gasco, L., Spencer, E., Metian, M., Trushenski, J.T., Turchini, G.M., 2022. Towards achieving circularity and sustainability in feeds for farmed blue foods. *Rev. Aquac.* 15 (3), 1115–1141. <https://doi.org/10.1111/raq.12766>.
- Corrado, S., Sala, S., 2018. Food waste accounting along global and European food supply chains: state of the art and outlook. *Waste Manag.* 120–131 (79), 120–131. <https://doi.org/10.1016/j.wasman.2018.07.032>.
- Cutajar, N., Lia, F., Deidun, A., Galdies, J., Arizza, V., Zammit Mangion, M., 2022. Turning waste into A resource: isolation and characterization of high-quality collagen and oils from Atlantic Bluefin tuna discards. *Appl. Sci.* 12 (3), 1542. <https://doi.org/10.3390/app12031542>.
- Dalton, C.C., Gottlieb, L.N., 2003. The concept of readiness to change. *J. Adv. Nurs.* 42 (2), 108–117. <https://doi.org/10.1046/j.1365-2648.2003.02593.x>.
- Dangelico, R.M., Pujari, D., 2010. Mainstreaming green product innovation: why and how companies integrate environmental sustainability. *J. Bus. Ethics* 95 (3), 471–486. <https://doi.org/10.1007/s10551-010-0434-0>.
- Das, S.K., Mondal, B., Sarkar, U.K., Das, B.K., Borah, S., 2023. Understanding and approaches towards circular bio-economy of wastewater reuse in fisheries and aquaculture in India: an overview. *Rev. Aquac.* 15, 1100–1114. <https://doi.org/10.1111/raq.12758>.
- de Korte, M., Bergman, J., van Willigenburg, G., Keesman, K.J., 2024. Towards a zero-waste aquaponics-centered eco-industrial food park. *J. Clean. Prod.* 454, 142109. <https://doi.org/10.1016/j.jclepro.2024.142109>.
- De Rosa, M., Di Pasquale, J., Adinolfi, F., 2021. The root towards more circularized animal production systems: from animal to territorial metabolism. *Animals* 11 (6), 1540. <https://doi.org/10.3390/ani11061540>.
- De Rosa, M., Charatsari, C., Lioutas, E.D., Masi, M., Vecchio, Y., Francescone, M., 2024. Contextualising digitalisation through ambidexterity and new territorial proximities. *J. Rural. Stud.* 109, 103322. <https://doi.org/10.1016/j.jrurstud.2024.103322>.
- De Vet, J.M., Gardner, H., Sala Pérez, M., Matheus, D., Mirambell Huguet, M., Bessin, A., Reyes, M., Pastres, R., Herpers, F., Nelissen, D., de Gelder, E., van Seeters, D., Raphaël, S., 2024. Technoeconomic analysis for the energy transition of the EU fisheries and aquaculture sector. *Publ. Office European Union*. <https://doi.org/10.2926/425550>.
- Del Borghi, A., Strazza, C., Magrassi, F., Taramasso, A.C., Gallo, M., 2018. Life cycle assessment for eco-design of product–package systems in the food industry—the case of legumes. *Sustain. Prod. Consump.* 13, 24–36. <https://doi.org/10.1016/j.spc.2017.11.001>.
- Di Maio, F., Rem, P.C., 2015. A robust Indicator for promoting circular economy through recycling. *J. Environ. Prot.* 06 (10), 1095–1104. <https://doi.org/10.4236/jep.2015.610096>.
- Donner, M., Gohier, R., de Vries, H., 2020. A new circular business model typology for creating value from agro-waste. *Sci. Total Environ.* 716, 137065. <https://doi.org/10.1016/j.scitotenv.2020.137065>.
- Dudensing, R., 2023. Role of value-added agriculture in promoting regenerative processes within a circular economy. *ACS Symp. Ser.* 1–10. <https://doi.org/10.1021/bk-2023-1449.ch001>.
- Ellen MacArthur Foundation, 2015. Growth within: a circular economy vision for a competitive Europe McKinsey center for business and environment. [www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation\\_Growth-Within\\_July15.pdf](http://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf).
- Ende, S., Henjes, J., Spiller, M., Elshobary, M., Hanelt, D., Abomohra, A., 2024. Recent advances in recirculating aquaculture systems and role of microalgae to close system loop. *Bioresour. Technol.* 131107.
- Engle, C.R., van Senten, J., Schwarz, M.H., Brayden, C., Belle, S., 2023. Developing production and financial benchmarks for marine aquaculture from farm data. *Aquac. Econ. Manag.* 27 (3), 352–381. <https://doi.org/10.1080/13657305.2022.2101711>.
- Entrena-Barbero, E., Ceballos Santos, S., Cortés, A., Esteve-Llorens, X., Moreira, M.T., Villanueva-Rey, P., Quiñoy, D., Almeida, C., Marques, A., Quintero, P., Dias, A.C., Laso, J., Margallo, M., Aldaco, R., Feijoo, G., 2023. Methodological guidelines for the calculation of a water-energy-food nexus index for seafood products. *Sci. Total Environ.* 877, 162845. <https://doi.org/10.1016/j.scitotenv.2023.162845>.
- Erdemir, D., Dincer, I., 2024. Development of renewable energy based green hydrogen and oxygen production and electricity generation systems for sustainable aquaculture. *J. Clean. Prod.* 434, 140081. <https://doi.org/10.1016/j.jclepro.2023.140081>.
- Eroldoğan, O.T., Glencross, B.D., Novoveská, L., Gaudêncio, S.P., Rinkevich, B., Varese, G.C., de Fátima Carvalho, M., Tasdemir, D., Safarik, I., Nielsen, S.L., Rebours, C., Lada, L.B., Robbens, J., Strode, E., Haznedaroğlu, B.Z., Kotta, J., Evliyaoglu, E., Oliveira, J., Girão, M., Vasquez, M.L., 2022. From the sea to aquafeed: a perspective overview. *Rev. Aquac.* 15 (3), 1028–1057. <https://doi.org/10.1111/raq.12740>.
- Esposito, B., Sessa, M.R., Sica, D., Malandrino, O., 2020. Towards circular economy in the agri-food sector. A systematic literature review. *Sustainability* 12 (18), 7401. <https://doi.org/10.3390/su12187401>.
- European Commission, 2021. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions empty: Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030. <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0236>.
- European Commission, European Climate, Infrastructure and Environment Executive Agency, 2024. In: Vet, J., Gardner, H., Sala Pérez, M., et al. (Eds.), *Techno-economic Analysis for the Energy Transition of the EU Fisheries and Aquaculture Sector*.
- European Commission, for, D.-G., & Fisheries, 2021. A new strategic vision for sustainable aquaculture production and consumption in the European Union – blue farming in the European green Deal. *Publ. Office European Union*. <https://doi.org/10.2771/961425>.
- European court of auditors, 2023. Special report EU aquaculture policy stagnating production and unclear results despite increased EU funding. [https://www.eca.europa.eu/ECAPublications/SR-2023-25/SR-2023-25\\_EN.pdf](https://www.eca.europa.eu/ECAPublications/SR-2023-25/SR-2023-25_EN.pdf).
- Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E.A., Barlow, C. Y., 2017. Business model innovation for sustainability: towards a unified perspective for creation of sustainable business models. *Bus. Strateg. Environ.* 26 (5), 597–608. <https://doi.org/10.1002/bse.1939>.
- FAO, 2022. Blue transformation - roadmap 2022–2030: A vision for FAO's work on aquatic food systems. *Rome*. <https://doi.org/10.4060/cc0459en>.
- FAO, 2024. The state of world Fisheries and aquaculture 2024. In: *FAO eBooks. Food and Agriculture Organization of the United Nations, Rome*. <https://doi.org/10.4060/cd0683en>.
- Fazzini, M., 2023. *Analisi di bilancio 2023. Ipsosa*.
- Fernández-Ríos, A., Laso, J., Amo-Setién, F.J., Abajas, R., Ortego, C., Fullana-i-Palmer, P., Bala, A., Batlle-Bayer, L., Balcells, M., Puig, R., Aldaco, R., Margallo, M., 2022. Towards water-energy-food Nexus and life cycle thinking: A new approach to environmental and nutritional assessment of potato chips. *SSRN Electron. J.* 789, 147936. <https://doi.org/10.2139/ssrn.4012468>.
- Ferreira, M.A., Jabbour, C.J.C., de Sousa Jabbour, A.B.L., 2017. Maturity levels of material cycles and waste management in a context of green supply chain management: an innovative framework and its application to Brazilian cases. *J. Mater. Cycles Waste Manage.* 19 (1), 516–525. <https://doi.org/10.1007/s10163-015-0416-5>.
- Franklin-Johnson, E., Figge, F., Canning, L., 2016. Resource duration as a managerial indicator for circular economy performance. *J. Clean. Prod.* 133, 589–598. <https://doi.org/10.1016/j.jclepro.2016.05.023>.
- Fraser, P., Moultrie, J., Gregory, M., 2002. The use of maturity models/grids as a tool in assessing product development capability. *IEEE Int. Eng. Manag. Conf.* 244–249. <https://doi.org/10.1109/iemc.2002.1038431>.
- Garlock, T.M., Asche, F., Anderson, J.L., Eggert, H., Anderson, T.M., Che, B., Tveteras, R., 2024. Environmental, economic, and social sustainability in aquaculture: the aquaculture performance indicators. *Nat. Commun.* 15 (1), 5274. <https://doi.org/10.1038/s41467-024-49556-8>.
- Geissdoerfer, M., Vladimirova, D., Evans, S., 2018. Sustainable business model innovation: A review. *J. Clean. Prod.* 198 (1), 401–416. <https://doi.org/10.1016/j.jclepro.2018.06.240>.
- Geng, Y., Sarkis, J., Bleischwitz, R., 2019. How to globalize the circular economy. *Nature* 565 (7738), 153–155. <https://doi.org/10.1038/d41586-019-00017-z>.
- Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *J. Clean. Prod.* 114 (7), 11–32. <https://doi.org/10.1016/j.jclepro.2015.09.007>.
- Girardello, M., Santangeli, A., Mori, E., Chapman, A., Fattorini, S., Naidoo, R., Svenning, J.C., 2019. Global synergies and trade-offs between multiple dimensions of biodiversity and ecosystem services. *Sci. Rep.* 9 (1), 5636. <https://doi.org/10.1038/s41598-019-41342-7>.
- Glencross, B.D., Bachis, Enrico, Robb, D., Newton, R., 2024. The evolution of sustainability metrics for the marine ingredient sector: moving towards holistic assessments of aquaculture feed. *Rev. Fish. Sci. Aquacult.* 1–17. <https://doi.org/10.1080/23308249.2024.2337426>.
- Gonella, J.S.L., Filho, M.G., Miller, G., Latan, H., Jabbour, J.C., 2023. Towards a regenerative economy: an innovative scale to measure people's awareness of the circular economy (CE). *J. Clean. Prod.* 421, 138390. <https://doi.org/10.1016/j.jclepro.2023.138390>.
- Gorecki, J., 2019. Circular economy maturity in construction companies. *IOP Conf. Ser. Mater. Sci. Eng.* 471 (11), 112090. <https://doi.org/10.1088/1757-899x/471/11/112090>.
- Graedel, T.E., Allwood, J., Birat, J.P., Buchert, M., Hagelüken, C., Reck, B.K., Sonnemann, G., 2011. What do we know about metal recycling rates? *Journal of Industrial Ecology* 15 (3), 355–366. <https://doi.org/10.1111/j.1530-9290.2011.00342.x>.
- Grant, K.P., Pennyacker, J.S., 2006. Project management maturity: an assessment of project management capabilities among and between selected industries. *IEEE Trans. Eng. Manag.* 53 (1), 59–68. <https://doi.org/10.1109/tem.2005.861802>.

- Hamam, M., Chinnici, G., Di Vita, G., Pappalardo, G., Pecorino, B., Maesano, G., D'Amico, M., 2021. Circular economy models in agro-food systems: A review. *Sustainability* 13 (6), 3453. <https://doi.org/10.3390/su13063453>.
- Hamilton, S.H., ElSawah, S., Guillaume, J.H.A., Jakeman, A.J., Pierce, S.A., 2015. Integrated assessment and modelling: overview and synthesis of salient dimensions. *Environ. Model Softw.* 64, 215–229. <https://doi.org/10.1016/j.envsoft.2014.12.005>.
- Hanpachern, C., Morgan, G.A., Griego, O.V., 1998. An extension of the theory of margin: A framework for assessing readiness for change. *Hum. Resour. Dev. Q.* 9 (4), 339–350. <https://doi.org/10.1002/hrdq.3920090405>.
- He, F., Zarfl, C., Tockner, K., Olden, J.D., Campos, Z., Muniz, F., Svenning, J.-C., Jähnig, S.C., 2024. Hydropower impacts on riverine biodiversity. *Nat. Rev. Earth Environ.* <https://doi.org/10.1038/s43017-024-00596-0>.
- Holt, D.T., Armenakis, A., Harris, S., Feild, H., 2007. Toward a comprehensive definition of readiness for change: A review of research and instrumentation. *Res. Organ. Chang. Dev.* 16 (1), 289–336. [https://doi.org/10.1016/s0897-3016\(06\)16009-7](https://doi.org/10.1016/s0897-3016(06)16009-7).
- Holt, D.T., Helfrich, C.D., Hall, C.G., Weiner, B.J., 2010. Are you ready? How health professionals can comprehensively conceptualize readiness for change. *J. Gen. Intern. Med.* 25 (Suppl. 1), 50–55. <https://doi.org/10.1007/s11606-009-1112-8>.
- Ioannidou, S.M., Pateraki, C., Ladakis, D., Papapostolou, H., Tsakona, M., Vlysidis, A., Kookos, I.K., Koutinas, A., 2020. Sustainable production of bio-based chemicals and polymers via integrated biomass refining and bioprocessing in a circular bioeconomy context. *Bioresour. Technol.* 307, 123093. <https://doi.org/10.1016/j.biortech.2020.123093>.
- Jacob, C., Noirot, C., Anglada, C., Binet, T., 2021. The benefits of integrating socio-economic dimensions of circular economy practices in the seafood sector. *Curr. Opin. Environ. Sci. Health* 22, 100255. <https://doi.org/10.1016/j.coesh.2021.100255>.
- Joffre, O.M., Poortvliet, P.M., Klerkx, L., 2019. To cluster or not to cluster farmers? Influences on network interactions, risk perceptions, and adoption of aquaculture practices. *Agric. Syst.* 173, 151–160. <https://doi.org/10.1016/j.agys.2019.02.011>.
- Julkovski, D.J., Sehnem, S., Ramos, M.C.P., Jabbour, C.J.C., 2022. Circular business models and the environment: maturity levels of the circular economy and innovation in greener craft breweries. *Bus. Strateg. Environ.* 32 (6), 3465–3488. <https://doi.org/10.1002/bse.3311>.
- Kalmykova, Y., Sadagopan, M., Rosado, L., 2018. Circular economy – from review of theories and practices to development of implementation tools. *Resour. Conserv. Recycl.* 135, 190–201. <https://doi.org/10.1016/j.resconrec.2017.10.034>.
- Kayikci, Y., Kazancoglu, Y., Gozacan-Chase, N., Lafci, C., Batista, L., 2022. Assessing smart circular supply chain readiness and maturity level of small and medium-sized enterprises. *J. Bus. Res.* 149, 375–392. <https://doi.org/10.1016/j.jbusres.2022.05.042>.
- Khanjani, M.H., Sharifinia, M., Coelho, G., 2024. Biofloc technology (BFT) in aquaculture: what goes right, what goes wrong? A scientific-based snapshot. *Aquacult. Nutr.* 2024 (1), 1–24. <https://doi.org/10.1155/2024/7496572>.
- Khosrogoftar, M., Osman, O., 2009. Comparison of maturity models. In: 2nd IEEE International Conference on Computer Science and Information Technology, pp. 297–301. <https://doi.org/10.1109/ICCSIT.2009.5234402>.
- Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, conservation and recycling* 127, 221–232. <https://doi.org/10.1016/j.resconrec.2017.09.005>.
- Klein, J., Schüch, A., Foth, S., Sprafke, J., Bischoff, A., Nelles, M., Palm, H.W., 2024. Enhancing energy recovery from aquaculture residual materials: a focus on anaerobic digestion of African catfish (*Clarias gariepinus*) sediment sludge. *Front. Sustain. Food Systems* 8, 1397491. <https://doi.org/10.3389/fsufs.2024.1397491>.
- Kohlegger, M., Maier, R., Thalmann, S., 2009. Understanding maturity models. Results of a structured content analysis, pp. 51–61. Na.
- Konstantinidis, E., Perdikaris, C., Gouva, E., Nathanielides, C., Bartzanas, T., Anestis, V., Ribaj, S., Tzora, A., Skoufos, I., 2020. Assessing environmental impacts of sea bass cage farms in Greece and Albania using life cycle assessment. *Int. J. Environ. Res.* 14 (6), 693–704. <https://doi.org/10.1007/s41742-020-00289-8>.
- Krause, G., Brugere, C., Diedrich, A., Ebeling, M.W., Ferse, S.C.A., Mikkelsen, E., Pérez Agúndez, J.A., Stead, S.M., Stybel, N., Troell, M., 2015. A revolution without people? Closing the people-policy gap in aquaculture development. *Aquaculture* 447, 44–55. <https://doi.org/10.1016/j.aquaculture.2015.02.009>.
- Kristensen, D.K., Kjeldsen, C., Thorsøe, M.H., 2016. Enabling sustainable agro-food futures: exploring fault lines and synergies between the integrated territorial paradigm, rural eco-economy and circular economy. *J. Agric. Environ. Ethics* 29 (5), 749–765. <https://doi.org/10.1007/s10806-016-9632-9>.
- Kumar, G., Engle, C., Tucker, C., 2018. Factors driving aquaculture technology adoption. *J. World Aquacult. Soc.* 49 (3), 447–476. <https://doi.org/10.1111/jwas.12514>.
- Lacy, P., Long, J., Spindler, W., 2020. CIRCULAR ECONOMY HANDBOOK: Realizing the Circular Advantage. Palgrave Macmillan.
- Leach, W.D., Weible, C.M., Vince, S.R., Siddiki, S.N., Calanni, J.C., 2013. Fostering learning through collaboration: knowledge acquisition and belief change in marine aquaculture partnerships. *J. Public Adm. Res. Theory* 24 (3), 591–622. <https://doi.org/10.1093/jopart/mut011>.
- Lisbjerg, D., 2022. Recommendations for applying Nature-Based Solutions as an approach for sustainable use of aquatic resources while achieving the policy goals of the biodiversity strategy. [https://scar-europe.org/images/FISH/Documents/SCAR\\_FISH\\_Recommendations\\_NBS.pdf](https://scar-europe.org/images/FISH/Documents/SCAR_FISH_Recommendations_NBS.pdf).
- Lososová, J., Zdeněk, Radek, 2024. Is the aquaculture industry in the Czech Republic financially healthy? A company-level analysis. *Aquac. Int.* 32 (3). <https://doi.org/10.1007/s10499-023-01300-7>.
- Lothmann, R., Sewilam, H., 2023. Potential of innovative marine aquaculture techniques to close nutrient cycles. *Rev. Aquac.* 15 (3). <https://doi.org/10.1111/raq.12781>.
- Luo, G., 2022. Review of waste phosphorus from aquaculture: source, removal and recovery. *Rev. Aquac.* 15 (3), 1058–1082. <https://doi.org/10.1111/raq.12727>.
- Maroušek, J., Strunecký, O., Maroušková, A., 2023. Insect rearing on biowaste represents a competitive advantage for fish farming. *Rev. Aquac.* 15 (3), 965–975.
- Masi, M., Adinolfi, F., Vecchio, Y., Agnusdei, G.P., Coluccia, B., 2024a. Toward the circular economy in the aquaculture sector: bibliometric, network and content analyses. *Sustainability* 16 (13), 5405. <https://doi.org/10.3390/su16135405>.
- Masi, M., La Sala, P., Coluccia, B., Adinolfi, F., Vecchio, Y., 2024b. Circular economy in aquaculture: the perspectives of aspiring future operators. *Br. Food J.* 126 (1), 489–505. <https://doi.org/10.1108/bfj-12-2022-1140>.
- McCormack, K., Bronzo Ladeira, M., Valadares, Paulo, de Oliveira, M., 2008. Supply chain maturity and performance in Brazil. *Supply Chain Manag. Int. J.* 13 (4), 272–282. <https://doi.org/10.1108/13598540810882161>.
- Mehmood, A., Ahmed, S., Viza, E., Bogush, A., Ayyub, R.M., 2021. Drivers and barriers towards circular economy in Agri-food supply chain: A review. *Bus. Strategy Dev.* 4 (4), 465–481. <https://doi.org/10.1002/bsd2.171>.
- Mentink, B., 2014. Circular business model innovation: a process framework and a tool for business model innovation in the circular economy. Master's thesis. [https://repositorio.tudelft.nl/file/File\\_9c14e9a0-6e9a-4ccf-8ed1-424e79084db7?preview=1](https://repositorio.tudelft.nl/file/File_9c14e9a0-6e9a-4ccf-8ed1-424e79084db7?preview=1).
- Montag, L., Klünder, T., Steven, M., 2021. Paving the way for circular supply chains: conceptualization of a circular supply chain maturity framework. *Front. Sustain.* 2. <https://doi.org/10.3389/frsus.2021.781978>.
- Morris, J.P., Backeljau, T., Chapelle, G., 2019. Shells from aquaculture: a valuable biomaterial, not a nuisance waste product. *Rev. Aquac.* 11 (1), 42–57. <https://doi.org/10.1111/raq.12225>.
- Mura, M., Longo, M., Zanni, S., 2020. Circular economy in Italian SMEs: A multi-method study. *J. Clean. Prod.* 245, 118821. <https://doi.org/10.1016/j.jclepro.2019.118821>.
- Muscato, A., de Olde, E.M., Ripoll-Bosch, R., Van Zanten, H.H.E., Metz, T.A.P., Termeer, C.J.A.M., van Ittersum, M.K., de Boer, I.J.M., 2021. Principles, drivers and opportunities of a circular bioeconomy. *Nature Food* 2 (8), 561–566. <https://doi.org/10.1038/s43016-021-00340-7>.
- Mutalipassi, M., Esposito, R., Ruocco, N., Viel, T., Costantini, M., Zupo, V., 2021. Bioactive compounds of nutraceutical value from fishery and aquaculture discards. *Foods* 10 (7), 1495. <https://doi.org/10.3390/foods10071495>.
- Naylor, R., Fang, S., Fanzo, J., 2023. A global view of aquaculture policy. *Food Policy* 116, 102422. <https://doi.org/10.1016/j.foodpol.2023.102422>.
- Ogburn, N.J., Duan, L., Subashchandrabose, S.R., Sorgeloos, P., O'Connor, W., Megharaj, M., Naidu, R., 2023. Agricultural wastes for brine shrimp *Artemia* production: A review. *Rev. Aquac.* 15 (3), 1159–1178. <https://doi.org/10.1111/raq.12784>.
- O'Neill, E.A., Morse, A.P., Rowan, N.J., 2022. Effects of climate and environmental variance on the performance of a novel peatland-based integrated multi-trophic aquaculture (IMTA) system: implications and opportunities for advancing research and disruptive innovation post COVID-19 era. *Sci. Total Environ.* 819, 153073. <https://doi.org/10.1016/j.scitotenv.2022.153073>.
- Pagotto, M., Halog, A., 2016. Towards a circular economy in Australian Agri-food industry: an application of input-output oriented approaches for analyzing resource efficiency and competitiveness potential. *J. Ind. Ecol.* 20 (5), 1176–1186. <https://doi.org/10.1111/jiec.12373>.
- Pauli, G.A., 2017. Blue Economy 3.0: The Marriage of Science, Innovation and Entrepreneurship Creates a New Business Model that Transforms Society. Xlibris, Gordon, Nsw.
- Penaranda, D., Bonnefond, H., Guihéneuf, F., Morales, M., Bernard, O., 2023. Life cycle assessment of an innovative rotating biofilm technology for microalgae production: an eco-design approach. *J. Clean. Prod.* 384, 135600. <https://doi.org/10.1016/j.jclepro.2022.135600>.
- Performfish, 2018. Deliverable 7.1 Set of KPIs for MMFF Sector "Integrating Innovative Approaches for Competitive and Sustainable Performance across the Mediterranean Aquaculture Value Chain" [http://performfish.eu/wp-content/uploads/2021/02/D7\\_1\\_Approved.pdf](http://performfish.eu/wp-content/uploads/2021/02/D7_1_Approved.pdf).
- Pietrelli, L., 2022. Polypropylene recovery and recycling from mussel nets. *Polymers* 14 (17), 3469. <https://doi.org/10.3390/polym14173469>.
- Poponi, S., Arcese, G., Pacchera, F., Martucci, O., 2022. Evaluating the transition to the circular economy in the Agri-food sector: selection of indicators. *Resour. Conserv. Recycl.* 176, 105916. <https://doi.org/10.1016/j.resconrec.2021.105916>.
- Principato, L., Ruini, L., Guidi, M., Secondi, L., 2019. Adopting the circular economy approach on food loss and waste: the case of Italian pasta production. *Resour. Conserv. Recycl.* 144, 82–89. <https://doi.org/10.1016/j.resconrec.2019.01.025>.
- Raffray, M., Martin, J.C., Jacob, C., 2022. Socioeconomic impacts of seafood sectors in the European Union through a multi-regional input output model. *Sci. Total Environ.* 850, 157989. <https://doi.org/10.1016/j.scitotenv.2022.157989>.
- Regueiro, L., Newton, R., Soula, M., Méndez, D., Kok, B., Little, D.C., Pastres, R., Johansen, J., Ferreira, M., 2022. Opportunities and limitations for the introduction of circular economy principles in EU aquaculture based on the regulatory framework. *J. Ind. Ecol.* 26 (6), 2033–2044. <https://doi.org/10.1111/jiec.13188>.
- Ridwan, R., Mubarak, M.A., Irawan, R., 2024. Optimization of energy utilization in aquaculture ponds by automation and IoT monitoring. *J. Hunan Univ. Nat. Sci.* 51 (3). <https://doi.org/10.55463/issn.1674-2974.51.3.2>.
- Rizos, V., Behrens, A., Kafyeke, T., Hirschnitz-Garbers, M., Ioannou, A., 2015. The circular economy: barriers and opportunities for SMEs. CEPS Working Document No. 412. [https://www.researchgate.net/publication/283121970\\_The\\_Circular\\_Economy\\_Barriers\\_and\\_Opportunities\\_for\\_SMEs](https://www.researchgate.net/publication/283121970_The_Circular_Economy_Barriers_and_Opportunities_for_SMEs) (ISBN 978-94-6138-479-9).
- Rowan, N.J., Casey, O., 2021. Empower eco-multi-actor HUB: a triple helix "academia-industry-authority" approach to creating and sharing potentially disruptive tools for addressing novel and emerging new green Deal opportunities under a United

- Nations' sustainable development goals framework. *Curr. Opin. Environ. Sci. Health* 21, 100254. <https://doi.org/10.1016/j.coesh.2021.100254>.
- Ruiz-Salmón, L., Margallo, María, Laso, J., Villanueva-Rey, P., Mariño, D., Quinteiro, P., Dias, Ana Cláudia, Nunes, Maria Leonor, Marques, A., Feijoo, G., Moreira, María Teresa, Loubet, Philippe, Sonnemann, G., Morse, A., Cooney, R., Clifford, E., Rowan, N., Méndez-Paz, D., Iglesias-Parga, Xesús, Anglada, C., 2020. Addressing challenges and opportunities of the European seafood sector under a circular economy framework. *Curr. Opin. Environ. Sci. Health* 13, 101–106. <https://doi.org/10.1016/j.coesh.2020.01.004>.
- Sacco, P., Vinante, C., Borgianni, Y., Orzes, G., 2021. Circular economy at the firm level: A new tool for assessing maturity and circularity. *Sustainability* 13 (9), 5288. <https://doi.org/10.3390/su13095288>.
- Salo, H.H., Suikkanen, J., Nissinen, A., 2020. Eco-innovation motivations and ecodesign tool implementation in companies in the Nordic textile and information technology sectors. *Bus. Strateg. Environ.* 29 (6), 2654–2667. <https://doi.org/10.1002/bse.2527>.
- Scandurra, F., Salomone, R., Caeiro, S., Gulotta, T.M., 2023. The maturity level of the Agri-food sector in the circular economy domain: A systematic literature review. *Environ. Impact Assess. Rev.* 100, 107079. <https://doi.org/10.1016/j.eiar.2023.107079>.
- Sehnm, S., Campos, L.M.S., Julkovski, D.J., Cazella, C.F., 2019a. Circular business models: level of maturity. *Manag. Decis.* 57 (4), 1043–1066. <https://doi.org/10.1108/md-07-2018-0844>.
- Sehnm, S., Ndubisi, N.O., Preschlag, D., Bernardy, R.J., Santos Junior, S., 2019b. Circular economy in the wine chain production: maturity, challenges, and lessons from an emerging economy perspective. *Prod. Plan. Control* 31 (11–12), 1014–1034. <https://doi.org/10.1080/09537287.2019.1695914>.
- Sehnm, S., Jabbour, C.J.C., Farias Pereira, S.C., de Sousa Jabbour, A.B.L., 2019c. Improving sustainable supply chains performance through operational excellence: circular economy approach. *Resour. Conserv. Recycl.* 149, 236–248. <https://doi.org/10.1016/j.resconrec.2019.05.021>.
- Sgarbossa, F., Russo, I., 2017. A proactive model in sustainable food supply chain: insight from a case study. *Int. J. Prod. Econ.* 183, 596–606. <https://doi.org/10.1016/j.ijpe.2016.07.022>.
- Singh, M.P., Chakraborty, A., Roy, M., 2018. Developing an extended theory of planned behavior model to explore circular economy readiness in manufacturing MSMEs, India. *Resour. Conserv. Recycl.* 135, 313–322. <https://doi.org/10.1016/j.resconrec.2017.07.015>.
- Sousa-Zomer, T.T., Magalhães, L., Zancul, E., Cauchick-Miguel, P.A., 2018. Exploring the challenges for circular business implementation in manufacturing companies: an empirical investigation of a pay-per-use service provider. *Resour. Conserv. Recycl.* 135 (8), 3–13. <https://doi.org/10.1016/j.resconrec.2017.10.033>.
- STEF, 2023. In: Nielsen, R., Virtanen, J., Guillen, J. (Eds.), Scientific, Technical and Economic Committee for Fisheries (STEF), Economic Report on the EU aquaculture (STECF-22-17). Publications Office of the European Union, Luxembourg. <https://doi.org/10.2760/51391,JRC132648>.
- Stiklestad, T., Westeren, K.I., Yeong, M., 2019. Knowledge utilization, communication and innovations in aquaculture in an international perspective. In: International Conference on Intellectual Capital and Knowledge Management and Organisational Learning, 322–330. <https://doi.org/10.34190/ikm.19.077>.
- Tamburini, E., Turolla, E., Fano, E.A., Castaldelli, G., 2020. Sustainability of mussel (*Mytilus galloprovincialis*) farming in the Po River Delta, northern Italy, based on a life cycle assessment approach. *Sustainability* 12 (9), 3814. <https://doi.org/10.3390/su12093814>.
- Tamburini, E., Turolla, E., Lanzoni, M., Moore, D., Castaldelli, G., 2022. Manila clam and Mediterranean mussel aquaculture is sustainable and a net carbon sink. *Sci. Total Environ.* 848, 157508. <https://doi.org/10.1016/j.scitotenv.2022.157508>.
- Thomas, J.E., Sinha, R., Strand, Å., Söderqvist, T., Stadmark, J., Franzén, F., Ingmannson, I., Gröndahl, F., Hasselström, L., 2022. Marine biomass for a circular blue-green bioeconomy?: A life cycle perspective on closing nitrogen and phosphorus land-marine loops. *J. Ind. Ecol.* 26 (6), 2136–2153. <https://doi.org/10.1111/jiec.13177>. 2136–2153.
- Troell, M., Tyedmers, P., Kautsky, N., Rönnbäck, P., 2004. Aquaculture and energy use. *Encyclopedia Energy* 1, 97–108.
- Tukker, A., 2015. Product services for a resource-efficient and circular economy – a review. *J. Clean. Prod.* 97, 76–91. <https://doi.org/10.1016/j.jclepro.2013.11.049>.
- Uhrenholt, J.N., Kristensen, J.H., Rincón, M.C., Adamsen, S., Jensen, S.F., Waehrens, B. V., 2022. Maturity model as a driver for circular economy transformation. *Sustainability* 14 (12), 7483. <https://doi.org/10.3390/su14127483>.
- Valenti, W.C., Kimpara, J.M., Preto, B., Moraes-Valenti, P., 2018. Indicators of sustainability to assess aquaculture systems. *Ecol. Indic.* 88, 402–413. <https://doi.org/10.1016/j.ecolind.2017.12.068>.
- van Langen, S.K., Vassillo, C., Ghisellini, P., Restaino, D., Passaro, R., Ulgiati, S., 2021. Promoting circular economy transition: A study about perceptions and awareness by different stakeholders groups. *J. Clean. Prod.* 316, 128166. <https://doi.org/10.1016/j.jclepro.2021.128166>.
- van Riel, A.J., Nederlof, M.A., Chary, K., Wiegertjes, G.F., de Boer, L.J., 2023. Feed-food competition in global aquaculture: current trends and prospects. *Rev. Aquac.* 15 (3), 1142–1158.
- Vasa, L., Angeloska, A., Trendov, N.M., 2018. Comparative analysis of circular agriculture development in selected Western Balkan countries based on sustainable performance indicators. *Economic Annals-XXI* 168 (11–12), 44–47. <https://doi.org/10.21003/ea.v168-09>.
- Vasquez-Mejía, C.M., Shrivastava, S., Gudjónsdóttir, M., Manzardo, A., Ólafur, Ö., 2023. Current status and future research needs on the quantitative water use of finfish aquaculture using life cycle assessment: A systematic literature review. *J. Clean. Prod.* 425, 139009. <https://doi.org/10.1016/j.jclepro.2023.139009>.
- Vázquez-Rowe, I., Ita-Nagy, D., Kahhat, R., 2021. Microplastics in fisheries and aquaculture: implications to food sustainability and safety. *Curr. Opin. Green Sustain. Chem.* 29, 100464. <https://doi.org/10.1016/j.cogsc.2021.100464>.
- Vecchio, Y., Di Pasquale, J., Pauselli, G., Masi, M., Adinolfi, F., 2022. Public health risk management during the Covid-19 pandemic, new amendments in the European maritime and Fisheries fund to meet fishers' needs. *Mar. Policy* 135, 104873. <https://doi.org/10.1016/j.marpol.2021.104873>.
- Vecchio, Y., Masi, M., Adinolfi, F., 2023a. From the AKAP to AKAIE model to assess the uptake of technological innovations in the aquaculture sector. *Rev. Aquac.* 15 (2), 772–784. <https://doi.org/10.1111/raq.12756>.
- Vecchio, Y., Masi, M., Del Giudice, T., De Rosa, M., Adinolfi, F., 2023b. Technological innovation in fisheries and aquaculture: what are the “discourses” of the Italian policy network? *Mar. Policy* 159, 105947. <https://doi.org/10.1016/j.marpol.2023.105947>.
- Vélez-Henao, J.A., Weinland, F., Reintjes, N., 2021. Life cycle assessment of aquaculture bivalve shellfish production — a critical review of methodological trends. *Int. J. Life Cycle Assess.* 26 (10), 1943–1958. <https://doi.org/10.1007/s11367-021-01978-y>.
- Verreth, J., Roy, K., Turchini, G.M., 2023. Circular bio-economy in aquaculture. *Rev. Aquac.* 15 (3), 944–946. <https://doi.org/10.1111/raq.12812>.
- Villar-Navarro, E., Garrido-Pérez, C., Perales, J.A., 2021. Recycling “waste” nutrients back into RAS and FTS marine aquaculture facilities from the perspective of the circular economy. *Sci. Total Environ.* 762, 143057. <https://doi.org/10.1016/j.scitotenv.2020.143057>.
- Vu, N.H., Chi, N.T.K., 2024. Stakeholders' assessment of feed produced from nutrients recovered from aquaculture waste in an emerging economy. *Aquaculture* 741333. <https://doi.org/10.1016/j.aquaculture.2024.741333>.
- Wanberg, C.R., Banas, J.T., 2000. Predictors and outcomes of openness to changes in a reorganizing workplace. *J. Appl. Psychol.* 85 (1), 132–142. <https://doi.org/10.1037/0021-9010.85.1.132>.
- Wang, J., Chen, L., Xu, J., Ma, S., Liang, X., Wei, Z., et al., 2023. C1 gas protein: A potential protein substitute for advancing aquaculture sustainability. *Rev. Aquac.* 15 (3), 1179–1197.
- Warren-Rhodes, K., Sadovy, Y., Cesar, H., 2004. Marine ecological footprint of the live reef fish food trade. *SPC Live Reef Fish Information Bulletin* 12, 10–16. <https://pacificdata.org/data/dataset/oai-www-spc-int-86a9c4a3-b021-4c84-a6e3-5e239ab120af>.
- Weiner, B.J., 2020. Chapter 8: A theory of organizational readiness for change. In: Nilsen, P., Birken, S.A. (Eds.), *Handbook on Implementation Science*. Edward Elgar Publishing, pp. 215–232. <https://doi.org/10.4337/9781788975995.00015>.
- Ximenes, J.C.M., de, A., Kochanska, E., & Bogel-Lukasik, R., 2021. Valorisation of Agri- and aquaculture residues via biogas production for enhanced industrial application. *Energies* 14 (9), 2519. <https://doi.org/10.3390/en14092519>.
- Zavell, M.D., Lindahl, O., Filgueira, R., Shumway, S.E., 2023. An estimate of carbon storage capabilities from wild and cultured shellfish in the Northwest Atlantic and their potential inclusion in a carbon economy. *J. Shellfish Res.* 42 (2). <https://doi.org/10.2983/035.042.0214>.
- Zhang, Z., Liu, H., Jin, J., Zhu, X., Han, D., Xie, S., 2024. Towards a low-carbon footprint: current status and prospects for aquaculture. *Water Biol. Security* 100290. <https://doi.org/10.1016/j.watbs.2024.100290>.