D7.5. INITIAL POLICY BRIEF

VALORISH

GREEN VALORISATION CASCADE APPROACH OF FISH WASTE AND BY-PRODUCTS THROUGH FERMENTATION TOWARDS A ZERO-WASTE FUTURE

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EXECUTIVE SUMMARY

Fish processing generates large volumes of side-streams that are still often treated as waste, despite their high potential to support circular economy and sustainable food systems. The VALORISH biorefinery approach demonstrates how fish side-streams can be safely and efficiently converted into high-value products through an integrated cascade biorefinery approach. The project focuses on the generation of bioproducts such as oils, bioactive compounds, collagen and calcium-rich powder with applications in food, nutraceuticals and additives. Additionally, the project combines the implementation of the bioprocessing units with computational tools and modelling platforms to guide process design, optimisation and scale-up. This approach reduces technical risk and supports progress towards pilot-scale validation.

An overview of the current policy framework identifies several barriers to wider uptake. These include **restrictive by-product** and **waste** classifications, complex approval procedures for **novel** ingredients, lack of harmonised standards for **marine-derived products,** limited access to pilot and **demonstration infrastructure**, **high investment costs, feedstock variability**, and low industrial and **societal confidence** in emerging circular technologies. Based on these findings, VALORISH highlights the need for clearer and harmonised by-product and End-of-Waste pathways for marine biomass/residues, clarity in regulatory procedures for innovative bioproducts from End-of-Waste raw materials, stronger *financial* incentives for pilot-scale implementation, and the harmonisation of EU standards for marine-derived products. Future adaptations to policies should focus on coordination across the several EU policy areas and designated efforts to enhance industry uptake to encourage the transition to circular marine biorefineries. The key categories of policy recommendations that are synthesised in this ***Deliverable 7.5: Initial Policy Brief*** are summarised below:

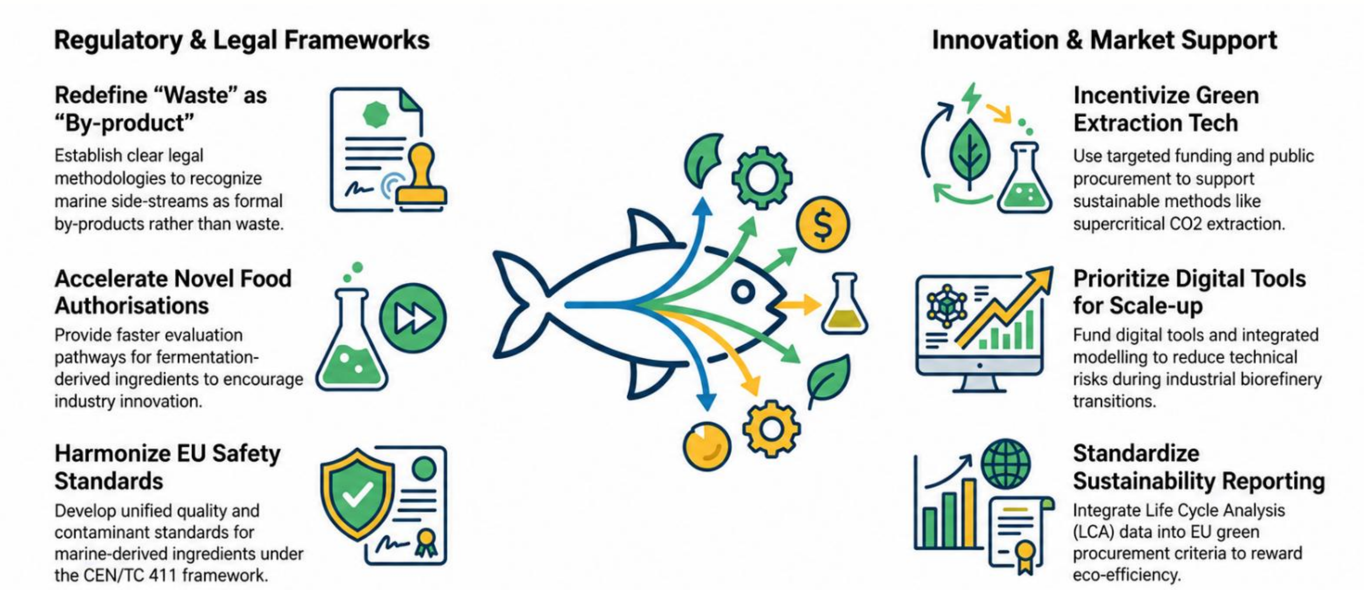

Figure 1:Policy roadmap for accelerating the transition towards the VALORISH biorefinery. The roadmap classifies the recommendations into two main categories: Regulatory and legal framework and Innovation and market support. This is associated to the actions identified through the VALORISH project to facilitate the industrial uptake of fish by-products.

LIST OF FIGURES

LIST OF ACRONYMS

Abbreviation	Definition
TRL	Technology Readiness Levels
EFSA	European Food Safety Authority
LCA	Life Cycle Analysis
s-LCA	Social Life Cycle Analysis
TEA	Tecno-economic Analysis
FPH	Fish Protein Hydrolysis
NCTC	National Collection of Type Cultures
CECT	Spanish Collection of Standard Cultures
FHSCC	Food Hygiene and Safety Culture Collection
NADES	Natural Deep Eutectic Solvents
GEM	Genome-scale Metabolic Model
SMEs	Small and Medium-sized Enterprises
PCB	Polychlorinated Biphenyls
MDO	Multidisciplinary Design Optimization

1. INTRODUCTION

1.1 DESCRIPTION OF THE DOCUMENT AND PURSUE

The VALORISH project focuses on the valorisation of wastes and residues from the fishing industry through sustainable approaches and green technologies. This document seeks to translate key innovative results, into policy-relevant knowledge, by showcasing evidence-based messages to support informed decision-making, regulatory alignment and long-term societal impact. Additionally, other projects with a similar focus have clearly stated the need for Policymakers to support circular economy initiatives, enforce stricter waste regulations, and incentivize innovation in waste valorisation. However, the actual implementation in regulatory frameworks has been limited and uneven. Most of the recent progress has been seen in discard bans, landing obligations[1] and within the EU Common Fisheries Policy, promoting the use of captured biomass as well as encouraging sustainable, circular practices in fisheries[2]. Nevertheless, despite the large-scale propagation of circular economy frameworks and valorisation strategies, their direct translation into binding regulations remains limited. Progress in pilot projects such as WaSeaBi, FAROS and VALORAFOOD 2.0, are only restricted to voluntary industry initiatives, and research-driven demonstration plants, rather than comprehensive national laws[3,5].
Due to the limited adaptation of the regulatory frameworks to the upcoming technologies and solution provided through the different projects is evident in the current statistics; at least 50% of the current fish harvest is discarded creating several economic and environmental concerns[4].Therefore, the aim of this policy brief is to gather actionable outcomes from the key innovations made within the VALORISH project, such as, the current status of the sustainable technologies and modelling tools, that could be relevant for developing evidence-based regulatory frameworks for effective marine waste valorisation. The barriers identified highlight the need for large-scale adoption and targeted interventions. It urges the use of tools such as life cycle assessments and techno-economic analysis to make informed decisions on the environmental impact, resource efficiency, and profitability, thereby facilitating their contribution to comprehensive national laws/policies. Such assessments would help policymakers to prioritize solutions that align with sustainability and circular economy goals[5]

[1] Hederman, J. (2019). The landing obligation. Quo Vadis Common Fisheries Policy?. https://doi.org/10.1002/9781119576907.ch6.
[2] Coppola, D., et al. (2021). Marine Drugs https://doi.org/10.3390/md19020116.
[3] Gill, J., et al. (2025). Bioresource technology, 132050 . https://doi.org/10.1016/j.biortech.2025.132050.
[4] Samarajeewa, U. (2024). Safety, Processing, and Utilization of Fishery Products. Fishes. https://doi.org/10.3390/fishes9040146.
[5] Cooney, R., et al. (2023).Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2023.136283.

2. PROJECT CONTEXT AND RESEARCH

VALORISH demonstrates a fully integrated pathway from marine and fishing residues to safe, high-value bio-products through modelling, pilot validation and sustainability assessment. It contributes to the EU's circular economy, blue bioeconomy and climate-neutrality goals by unlocking the potential of residual biomass through innovative and circular technologies.

2.2 Innovation within the VALORISH approach

VALORISH develops an integrated, computationally assisted cascade biorefinery that enables the full valorisation of fish by-products, moving from raw residues to high-value ingredients while advancing processes to TRL 5 (Figure 2). Through the cascade approach, this project demonstrates how heterogeneous fish side-streams can be transformed into market-relevant products, including fish oils, fish protein hydrolysates, bioactive compounds, collagen and calcium-rich powder. The retrieved bioproducts could target the food, nutraceutical and additive markets, supporting EU objectives on waste minimisation and maximum biomass valorisation.

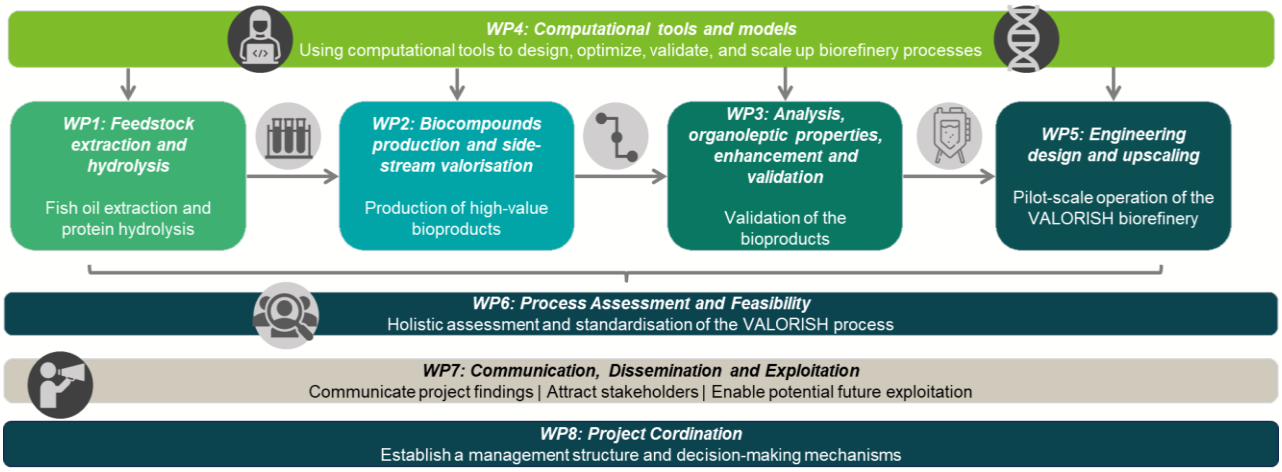

Figure 2. Overview of work package objective and distribution within the VALORISH project.

A key innovation of VALORISH lies in its use of advanced computational tools to support each component of the cascade biorefinery. Modelling tools composed of genome-scale metabolic models, process models and multi-disciplinary optimisations reduce uncertainty in fermentation and extraction routes, helping identify the most efficient pathways or microbes before scale-up. This model-based approach supports effective use of resources, lowers implementation risks and accelerates industrial deployment.

Beyond technical performance, VALORISH places strong emphasis on sustainability and societal impact. Environmental, economic and social assessments through life cycle, social and technoeconomic analysis provide evidence on feasibility, market readiness and acceptance, ensuring that the proposed solutions are not only technically viable but also aligned with EU sustainability goals and stakeholder expectations.

2.3 Positioning VALORISH innovations within the EU regulatory framework

WP1| Feedstock extraction and hydrolysis: Focuses on the management and preparation of the by-products from the fishing industry, aligning directly with the Waste Framework Directive (2008/98/EC) that enable safe circulation of secondary raw materials. The activities also respond to the Circular Economy Action Plan and the EU Bioeconomy Strategy by promoting high-value use of marine biomass. Compliance with food hygiene regulations (Reg. 852/2004 and 853/2004), the directive on extraction solvents (2009/32/EC) and contaminants limits (Reg. 2023/915) ensures that oils and protein hydrolysates meet EU food safety standards. In the cases where some of the feedstock may fall outside the food chain, WP1 would also deal with the Animal By-Products Regulations (1069/2009 and 142/2011).

WP2| Biocompounds production and side-stream valorisation: Contributes to EU circularity and industrial symbiosis objectives by converting fermentation-derived streams into high-value microbial products. These activities interface with the Novel Foods Regulation (2015/2283) for innovative fermentation ingredients. Valorisation through anaerobic digestion supports renewable energy objectives and the broader Circular Economy Action Plan.

WP3| Bio-product Analysis: Will evaluate whether all bioproducts delivered by the project will comply with the EU's food safety and contaminants legislation, including the General Food Law (Reg. 178/2002), the hygiene package (Reg. 852/2004 and 853/2004) and the maximum contaminant levels set in Reg. 2023/915 and maximum histamine in fishery products (Reg. 1019/2013). Analytical and sensory validation aligns with European Food Safety Authority (EFSA) guidance and ISO 22000, supporting Farm to Fork objectives on food quality and consumer safety. The chemical analyses will be performed in accordance with ISO 17025 and sensory evaluation in accordance with 13299.

WP4| Computational tools and models: Advances the EU's digital and green transitions by introducing integrated modelling and optimization approaches that enhance resource efficiency and reduce environmental burdens. The modelling framework is consistent with Life Cycle Analysis (LCA) and Techno Economic Analysis (TEA) approaches promoted in the EU Taxonomy and contributes to the formulation of Best Available Techniques under the Industrial Emissions framework.

WP5| Engineering design and upscaling: Supports the translation of laboratory results into pilot-scale operations, contributing to EU priorities on strengthening demonstration infrastructure and accelerating industrial deployment. Scale-up activities are informed by circularity rules governing material flows and align with the objectives of EU bio-based industrial development pathways[6].

WP6| Process Assessment and Feasibility Provide the environmental, economic and social evidence base required for policy uptake. Through LCA, TEA, standardisation and social-LCA, WP6 aligns VALORISH processes with

[6] https://environment.ec.europa.eu/strategy/bioeconomy-strategy_en#:~:text=The%20bioeconomy%20includes%20biomass%20production,combating%20biodiversity%20loss%20and%20pollution.

the EU Taxonomy, CEN/TC 411[7] standards for bio-based products and the Zero Pollution Action Plan. The inclusion of social innovation methodologies contributes to EU priorities on socially inclusive and responsible innovation.
WP7| Communication, Dissemination and Exploitation: Ensures that VALORISH results are effectively communicated and integrated into EU policy dialogues. Activities follow Horizon Europe exploitation guidelines on open science practices and support knowledge uptake in the European Research Area. Engagement and collaboration with other projects from the blue bioeconomy and circular economy stakeholders strengthens and gathers inputs for enhancing the policy relevance of VALORISH outputs and supports future regulatory alignment.

3. KEY RESULTS

During its first 18 months, the VALORISH project has achieved significant advancements towards the first phase of the biorefinery cascade. As illustrated in the workflow diagram (Figure 3), the coloured process steps represent the key components of this approach: 1) feedstock management and pretreatment, 2) proteolytic fermentation and downstream processing, 3) fish oil extraction, early 4) bioproduction activities using FPH-based substrates, and 6) the initial process assessment work. The subsequent policy brief will then contain the full set of technical, environmental and socio-economic findings.

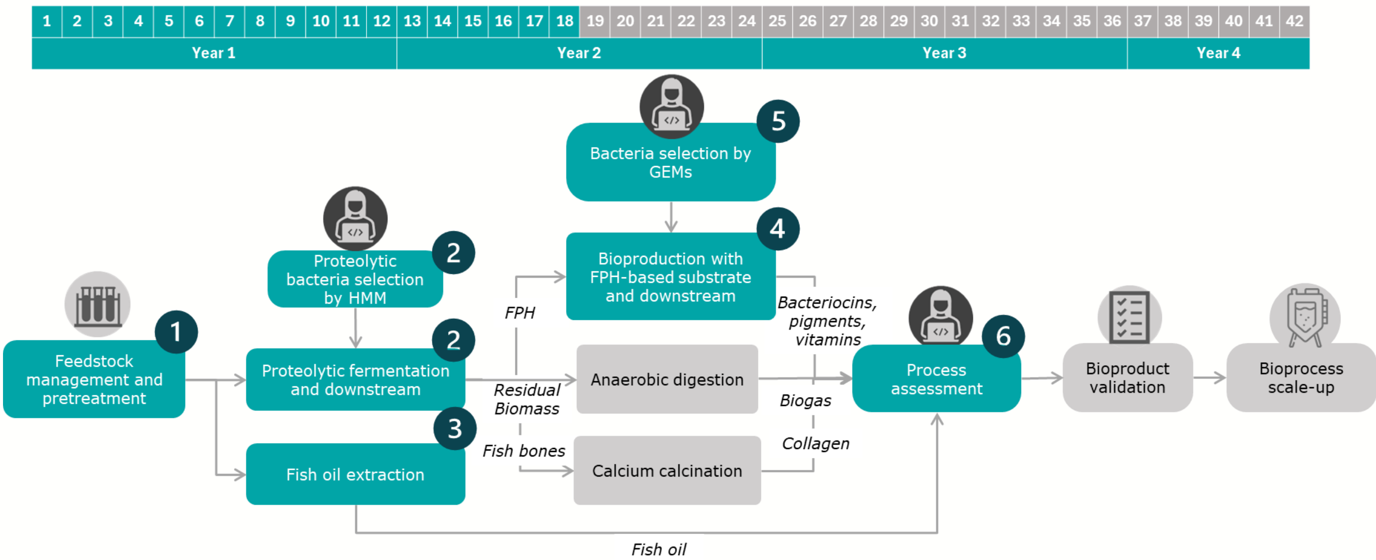

Figure 3. Schematic overview of the VALORISH cascade biorefinery. The coloured boxes represent the key accomplishments within the cascade biorefinery.

[7] https://www.biobasedeconomy.eu/centc-411-bio-based-products/#:~:text=CEN/TC%20411%20Bio%2Dbased,on%20for%20instance%20product%20declarations)

1 Feedstock management, analysis and preparation

Detailed chemical profiling reveals the true composition and variability of fish residues (pH, moisture, ashes, total lipids, total proteins, total carbohydrates, total sugars and salt content) by species, processing method, and factory. Within the VALORISH project PESCANOVA has characterised the composition of fish by-products or feedstocks, as this translates into variations in the bioproduct yields that are obtained at each step. To demonstrate applicability for a wide range of feedstocks, PESCANOVA selected: **a) processed chilled products**: such as cooked shrimp or light salted cod, **b) processed frozen products**: such as breaded hake products or surimi products, and **c) canned products:** such as canned tuna or sardines were analysed for their suitability in the VALORISH approach, and their findings are reported in the public **Deliverable D1.1**. Knowing the precise chemical makeup will allow the policymakers to visualise how the composition of the byproducts determines the most suitable valorisation routes (protein hydrolysates, collagen, oils), maximizing value recovery and minimizing waste. It supports the development of cascade biorefinery models, where each fraction of the waste is directed at its highest-value use. This step also ensures that valorised products adequately meet food, feed, and environmental safety standards in terms of their origin, thereby supporting the development of clear regulatory frameworks and consumer protection policies.

2 Bioproduction of fish protein hydrolysates

ANFACO led the microbiological (enzymatic and fermentation-based) production of highly bioactive FPH from residues that were obtained from hake, surimi and shrimp by-products. **The degree of hydrolysis achieved demonstrates that fish waste can be reliably converted into high-value, bioactive FPHs** with desirable nutritional and functional (e.g., antioxidant, antihypertensive, antimicrobial) properties, high protein recovery, digestibility, and compliance with food safety standards, which is essential for regulatory acceptance and public health protection. IDENER used computational tools to screen genomic data to identify 17 candidate bacteria, four of which were tested for proteolytic digestion by ANFACO. These were screened from standard collections like National Collection of Type Cultures (NCTC), Spanish Collection of Standard Cultures (CECT), or Food Hygiene and Safety Culture Collection (FHSCC) to comply with the microbial candidates allowed for food grade applications. More information regarding the protocol developed and applied can be found in the public **Deliverable 4.1**.

3 Fish oil green extraction

For the extraction of oil from the salmon by-products, ANFACO is currently exploring three different techniques: super-critical CO_2, sub-critical extraction with water as a solvent, and natural deep eutectic solvents extraction. The extraction yield achieved for each technique, including the yield for poly-unsaturated fatty acids suggest that they can act as harmless, sustainable alternatives to traditional, hazardous solvents for extracting oil from fish residues. For instance, **Natural Deep Eutectic Solvents (NADES)** are made from natural, food-grade components sugars, amino acids, organic acids), are biodegradable, and have low toxicity[8]. **Sub-critical extraction is often performed with water or alcohol** at subcritical conditions, which are less hazardous than conventional organic solvents[8]. They are also carried out at lower temperatures and pressures than traditional extraction, reducing energy consumption and greenhouse gas emissions[8]. Similarly, after extraction with super-critical CO_2, the CO_2 simply evaporates, leaving no solvent residues in the oil or waste, which is critical for food, feed, and pharmaceutical applications[9].

4 High-value bioproducts production

SINTEF performed the first set of fermentation experiments with the FPHs produced by ANFACO from shrimp, hake and surimi by-products to demonstrate that **these can replace commercial peptones in microbial media, often supporting equal or superior microbial growth and bioproduct yields**. In addition to other published studies, this further confirms FPHs as viable, cost-effective alternatives, justifying their inclusion in policy frameworks for waste valorisation and bioproduct manufacturing. Ongoing testing ensures that bioproducts (bacteriocins, vitamin B12, pigments) produced using FPHs meet established quality standards, which is essential for regulatory approval and market acceptance. Additionally, utilizing FPHs from fish by-products also gives the VALORISH process an economic advantage by lowering production costs and supporting local, circular economies. Soon, pilot and lab-scale studies will confirm the industrial viability of FPH-based processes, providing policymakers with confidence to support scale-up and investment.

5 Genome-scale metabolic models

Employing **Genome-scale Metabolic Models (GEMs)** in VALORISH to identify and assess bacteria for bioproduct synthesis (bacteriocins, vitamin B12, astaxanthin) provides **robust, predictive, and transparent scientific**

[8] Melgosa, R., et al. (2020). The Journal of Supercritical Fluids. https://doi.org/10.1016/j.supflu.2020.104943.
[9] Jamalluddin, N., et al. (2022). Bioresources and Bioprocessing, 9.

evidence that is highly valuable for policy development in fish waste valorisation. GEMs allow for in silico simulation of metabolic pathways, enabling the prediction of which bacterial strains are most efficient at converting FPH into specific high-value bioproducts[10]. This reduces trial-and-error in bioprocess development and provides policymakers with confidence that recommended processes are grounded in rigorous, systems-level science[10]. So far, IDENER has provided the first round of candidate strains that have the capacity to produce the target bioproducts, and then a second round of simulations to quantify their response to the amino acids present in the FPH. Within the timeline until the next policy brief, these will GEMs provide detailed maps of metabolic routes, allowing for the identification of potential by-products, bottlenecks, or safety concerns (unwanted metabolites or toxins). This supports the creation of regulatory standards and safety guidelines for new bioprocesses. It also encourages standardized, reproducible approaches to strain selection and process design, which is essential for regulatory clarity and industry adoption[11].

6 Process assessment, certification and standardisation

LCA provides evidence-based data to policymakers for promoting circular bioeconomy principles. Integration of LCA within similar projects in the past, has shown that turning large volumes of fish processing waste (approximately 60% of biomass) into valuable products, can substantially reduce environmental impact and waste disposal issues[12]. Similarly, in VALORISH, through the collaboration of BLUES and IDENER, LCA has been initiated from validated processes to provide data for setting sustainability targets and incentives. At present, a baseline inventory for the fishmeal production plant has been assessed and will be used to compare the greenhouse gas reduction capacities within the VALORISH chain. This allows for the development of clear guidelines and standards for FPH production, quality, and safety, making it easier to integrate into regulatory frameworks. It also helps address the policymaker's concerns about contaminants, allergens, and bioactivity, which are critical for policy and market acceptance. processes give industry stakeholders confidence to invest, supporting policy measures that mandate or incentivize fish waste valorisation[12,13].

[10] Gu, C., et al. (2019).. *Genome Biology*, 20. https://doi.org/10.1186/s13059-019-1730-3.
[11] Bi, X., et al. (2022). Biomolecules, 12. https://doi.org/10.3390/biom12050721.
[12] Coppola, D., et al. (2021). Marine Drugs. https://doi.org/10.3390/md19020116.
[13] Vázquez, J., et al. (2020). Biomolecules, https://doi.org/10.3390/biom10020310.

4 BARRIERS TO IMPLEMENTATION AND INDUSTRIAL UPTAKE

4.1 Barriers identified within similar projects in the past

Previous EU-funded projects on seafood side-stream valorisation have identified barriers that are also relevant for VALORISH. The WaSeaBi project highlighted technical challenges, including the need for sufficient space, skilled personnel and appropriate technological tools[14]. It also showed that limited access to sophisticated technology or skilled labour among industry and policymakers can slow the adoption of valorisation solutions. Infrastructural and market barriers were identified in small-scale fisheries, where weak value chain organisation, limited product traceability and low influence over pricing restrict market access and value creation[7]. Financial challenges were addressed in the LIFE REFISH project[15], which demonstrated the commercial potential of fish side-stream valorisation but also showed the need for sustained investment to move beyond pilot scale. Regulatory barriers were highlighted in the BlueBioChain project, mainly due to the lack of clear and harmonised standards, which creates uncertainty and reduces confidence for long-term industrial investment[16].

4.2 Barriers identified during the implementation journey of the VALORISH Biorefinery

This section outlines *the total landscape of financial, operational, and regulatory hurdles* currently hindering the scale-up of the VALORISH circular bioeconomy. It details the restrictive legal classification of marine side-streams as "waste" across fragmented EU departments. Furthermore, it encompasses the inherent technical difficulties of scaling up interconnected biorefinery processes, which is compounded by an overarching absence of harmonised EU standards for food grade products that creates significant market uncertainty and industrial hesitation

4.2.1 A. Technical barriers

- **A1. Variability in feedstock composition:** Species, seasonality and processing method affect protein, lipid and bone composition, making it challenging to standardise processes or guarantee consistent product yield.
- **A2. Difficulty in scaling up complex, interconnected processes:** Processes spanning extraction of fish oil, hydrolysis, fermentation and

[14] https://www.waseabi.eu/
[15] https://liferefish.com/
[16] https://jpi-oceans.eu/en/bluebiochain

calcination could potentially behave differently at industrial scale compared to the lab-scale demonstrations, requiring investment of high-skilled technical experts, and adequate financial resources until their optimal performance is achieved.

- **A3. Challenges achieving consistent sensory and functional properties:** Food-grade applications require stable flavour, odour and texture profiles, which can be difficult to maintain across several batches of FPH or oils.
- **A4. Specific technical expertise required for using advanced modelling tools:** Industry may not have internal expertise for interpreting findings from GEM-based design, multi-disciplinary optimization, or other modelling tools, that negatively affects the uptake of these innovations.

4.2.2 B. Infrastructural and market barriers

- **B1. Limited access to open-access pilot and demonstration facilities:** Many Small and Medium-sized Enterprises (SMEs) lack the equipment needed to test pre-processing, extraction or fermentation steps at intermediate scale, hindering technology validation.
- **B2. Weak or undeveloped value chains for circular marine products:** Few established buyers exist for collagen powders, FPHs, bioactive peptides or marine-derived minerals, slowing market uptake.
- **B3. Low industrial interest due to perceived risk and lack of familiarity**: Many food and biotech companies remain hesitant to integrate marine bio-waste residues or side-stream-derived ingredients until standards, consumer acceptance and profitability are clearer.

4.2.3 C. Financial barriers

- **C1. High investment costs for advanced biorefinery equipment:** Technologies such as super critical CO_2 extraction, membrane filtration or innovative calciners require capital-intensive installations, which limit adoption by SMEs and mid-sized processors.
- **C2. Limited economic incentives for valorising marine side-streams:** Current funding and subsidy schemes favour conventional waste treatment or terrestrial biomass waste streams due to less developed technologies and lower awareness in policy frameworks for marine residues.
- **C3. Uncertain market value for emerging bio-based ingredients**: The low level of acceptance and uncertainty in markets, specifically for bio-based FPHs, collagen or hydroxyapatite makes long-term financial planning difficult and slows industrial uptake.

4.2.4 D. Regulatory barriers

- **D1. Strict waste/by-product classifications restrict high-value uses[17]:** Marine side-streams are often classified under Animal By-Products Categories 2 or 3 or remain "waste" under the Waste Framework Directive, preventing their use in food, feed or high-value materials without appropriate justification.
- **D2. Novel Food authorisation for fermentation-derived products:** Applications require significant data generation and exceedingly long review times, delaying market entry for innovative ingredients and deterring innovators, particularly SMEs.
- **D3. Complex compliance with contaminants legislation:** The continuously changing limits for dioxins, Polychlorinated Biphenyls (PCBs) and heavy metals require continuous monitoring and analytical capacity, increasing unforeseen costs during the projects and slowing scale-up.
- **D4. Insufficient EU standards for marine-derived bioproducts[18,19]:** No harmonised standards exist for FPHs, collagen, hydroxyapatite or calcium powders within food-grade applications for human consumption, creating uncertainty for both regulators and buyers.
- **D5. National inconsistencies in regulatory interpretation:** Differences in how each member state in the EU applies the Animal By-Products rules or hygiene regulations create uneven conditions for industrial deployment across Europe.

4.2.5 E. Political and institutional barriers

- **E1. Limited prioritisation of marine bioeconomy streams:** Policy attention is still largely directed at plant-based or agricultural biomass, resulting in fewer targeted initiatives for fisheries side-streams.
- **E2. Slow adaptation of policy frameworks to new circular technologies**: Innovations like NADES extraction, fermentative valorisation or integrated biorefineries evolve faster than the regulatory environment, creating lag and uncertainty.
- **E3. Fragmentation across EU departments and policymaking areas:** FOOD (DG SANTE), ENVIRONMENT (DG ENV), CIRCULAR ECONOMY (DG ENVI), INDUSTRY (DG GROW) and FISHERIES (DG MARE) often operate separately, slowing coherent decision-making.
- **E4. Low public awareness and political sensitivity around "side-stream-derived" foods**: Lack of consumer understanding for reutilization of industrial side-streams can make policymakers risk-averse regarding market authorisation or promotion of such products.

[17] Rudovica, V., et al. (2021). Valorisation of Marine Waste: Use of Industrial By-Products and Beach Wrack Towards the Production of High Added-Value Products. https://doi.org/10.3389/fmars.2021.723333.
[18] Bee, S., et al. (2020). Ceramics International, 46, 17149 17175. https://doi.org/10.1016/j.ceramint.2020.04.103.
[19] Patil, U., et al. (2024). Turkish Journal of Fisheries and Aquatic Sciences. https://doi.org/10.4194/trjfas25347.

5 Tracing VALORISH technical advancements to address specific barriers and generate policy messages

This section highlights *empirical evidence generated by the VALORISH project to date*. By leveraging validated project results, such as the safe processing of feedstocks from diverse fish by-products and residues, the demonstration of green oil extraction techniques, and modelling tools, this section highlights the results that have inspired **policy messages** as well as the **barriers** they have addressed.

5.1 Marine biomass classification and handling

- **Project-generated evidence:** The project successfully analysed 10 different fish industry by-products (including salmon heads, hake sawdust, and shrimp residues), demonstrating that when collected and preserved under strict hygiene conditions (ultra-freezing at the factory), these materials can be safely processed into high-quality feedstocks for food applications. Evidence presented in *Deliverable 1.1*.
- **Barriers targeted:** *Technical barriers: A1; Infrastructure and market barriers: B2, B3; Regulatory barriers: D1;*

  Side streams, residues and other by-products from the fishing industry are frequently classified as "waste" under the Waste Framework Directive, or they fall under Animal By-Products (Categories 2 or 3). This strict legal classification inherently restricts these materials from being repurposed into food, feed, or other high-value applications unless substantial justification is provided. The regulation of marine biomass spans multiple EU departments, including those responsible for Food (DG SANTE), Environment (DG ENV), Circular Economy, Industry, and Fisheries (DG MARE), that often operate separately, which significantly slows down coherent policymaking and the adaptation of frameworks to new circular technologies
- **Policy message** →Policymakers should establish a clearer methodology to legally recognise marine side-streams and biowastes as formal "by-products" under the Waste Framework Directive, rather than "waste." The EU should also develop harmonised end-of-waste criteria and sector-specific guidance for applying food hygiene regulations to these innovative marine streams

5.2 Adoption of Green extraction technologies

- **Project-generated evidence:** The project successfully demonstrated that innovative green extraction methods: specifically, $scCO_2$, SWE, and

NADES, can achieve oil extraction yields exceeding 40%, recovering more than 50% of the initial polyunsaturated fatty acids. Evidence presented in *Deliverable 1.2*.

- **Barrier targeted:** *Financial barriers: C1 and C2 Political and institutional barriers: E2, Infrastructural and market barriers: B1;*

  Implementing more sustainable biorefinery equipment, specifically for greener technologies like supercritical CO_2 extraction, requires a change in the existing installations. These require high upfront costs significantly that limits their adoption. Additionally, there is limited access to open-access pilot and demonstration facilities across the industry as many industries/SMEs lack the specialised equipment needed to test these extraction steps at a higher scale. Therefore, the essential validation of these green technologies is hindered. Successfully navigating this scale-up requires adequate financial resources until optimal performance is achieved.

- **Policy message** ⟶The EU should actively support the industrial adoption of these safe, green extraction technologies by providing targeted funding and integrating them into green public procurement incentives

5.3 Fermentation bioproducts and regulatory approval

- **Project-generated evidence:** Using both experimental and computational screening that were supported by metabolic models the project evaluated 81 bacterial strains and successfully identified 17 viable candidates that were capable of converting FPHs into safe, high-value bioproducts (like astaxanthin and bacteriocins) while predicting potential safety concerns or unwanted metabolites. Subsequently, some of these candidates were tested in lab-scale fermenters to evaluate the performance in terms of growth, product yield and substrate consumption of the microbial-based bioprocesses. Evidence presented in *Deliverable 4.1*, *Deliverable 2.1, Deliverable 4.2, Deliverable 3.1.*
- **Barrier targeted:** *Technical barriers: A2; Infrastructure and market barriers: B3; Financial barriers: C3; Regulatory barriers: all; Political and institutional barriers: E2*

  Obtaining approval for fermentation-derived products requires generating significant amounts of data and facing exceedingly long review times. Additionally, there are national inconsistencies in how different EU member states interpret and apply Animal By-Products rules and hygiene regulations. Innovations like microbial-based fermentation or waste valorisation evolve much faster than the regulatory environment, creating a lag that stifles progress

- **Policy message** ⟶ Because the current regulatory landscape doesn't incentive adequately the novel methods of microbial-based bioprocesses, policymakers must adapt the Novel Foods Regulation to provide faster evaluation pathways for fermentation-derived ingredients. Furthermore, the EU needs to clarify Animal By-Products rules and contaminants legislation to reduce regulatory uncertainty for such side-streams to reconnect to the food chain

5.4 Digital tools for scale-up and risk reduction

- **Project-generated evidence:** VALORISH demonstrated that in silico simulation of metabolic pathways and process modelling significantly reduces the trial-and-error traditionally required in bioprocess development, providing a scientifically rigorous foundation for industrial scale-up. This was done through metabolic models to simulate metabolic pathways in silico. This computational tool allows researchers to predict which bacterial strains most efficiently convert FPHs into high-value bioproducts without relying solely on trial-and-error. *Deliverable 4.1, Deliverable 2.1, Deliverable 4.2, Deliverable 3.1.*
- **Barrier targeted:** *Technical barriers: A4; Infrastructure and market barriers: B2; Regulatory barriers: D3 and D4; Political and institutional barriers: E2*

  Scaling up complex, interconnected biorefinery processes (such as fish oil extraction, hydrolysis, fermentation, and calcination) is inherently difficult because these processes may behave differently at an industrial scale than they do in lab-scale demonstrations. Navigating these differences requires significant financial resources and highly skilled technical experts to ensure the processes reach optimal performance. Limited access to sophisticated digital and modelling tools and insufficient infrastructural space can significantly slow down the adoption of these advanced valorisation solutions

- **Policy message** ⟶The EU should incentivise the broader adoption of these digital tools by providing dedicated funding for digital tools and modelling technologies (and skillset) and integrated biorefinery modelling in circular bioeconomy projects. Additionally, advanced modelling guidance should be integrated into the EU's "best available techniques" reference documents for marine industries.

5.5 Environmental assessment and market standardisation

- **Project-generated evidence:** The project's initial LCA proved that while a multi-product biorefinery generates higher absolute emissions than a simple fishmeal plant, it achieves a superior eco-efficiency. When economic allocation is applied, the VALORISH system delivers an approximate 60% reduction in carbon intensity (kg CO_2 equivalent per euro generated) compared to the baseline. *Deliverable 4.3, Deliverable 6.1*, *Deliverable 7.4*

- **Barrier targeted:** *Infrastructure and market barriers: B3; Regulatory barriers: D1, D2 and D3; Financial barriers: all; Political and institutional barriers: E4*

  Currently, there is an absence of harmonised EU standards for marine-derived bioproducts, such as fish protein hydrolysates FPHs, collagen, hydroxyapatite, and calcium powders from the standpoint of human food-grade applications. The lack of clear, established standards creates significant uncertainty for both regulators and buyers, which in turn reduces confidence for long-term industrial investment. Food and biotechnology companies are often hesitant to integrate ingredients derived from marine bio-waste or side-streams because the standards, consumer acceptance, and overall profitability are not yet clear, leading to low industrial interest.

- **Policy message** ⟶VALORISH advocates for embedding social-LCA and social acceptance indicators directly into EU funding and regulatory assessment frameworks. To build market confidence and overcome industry hesitation, the EU must accelerate the development of harmonised quality and safety standards for bio-based marine ingredients under the CEN/TC 411 framework. It also recommends supporting broader awareness-raising and education campaigns to communicate the safety and sustainability of marine circularity solutions, while strengthening early dialogue platforms between research consortia and those in charge of regulatory frameworks.

6 POLICY RECOMMENDATIONS

6.1 For marine biomass classification and green oil extraction

- Establish a clearer methodology for recognizing marine side-streams and biowastes as by-products under the **Waste Framework Directive** to facilitate their circulation as secondary raw materials[20].
- Develop **harmonized EU guidance** for end-of-waste criteria for fish-based streams to reduce administrative barriers.

[20] Sileshi, G., et al. (2025). Earth System Science Data. https://doi.org/10.5194/essd-17-369-2025.

- Support the adoption of safe and green **extraction technologies** (supercritical CO_2, NADES) through targeted funding and public procurement incentives.
- Create **sector-specific** guidance for applying food hygiene regulations to innovative valorisation routes involving marine biomass.

6.2 For microbial-based bioproduct synthesis and side-stream valorisation

- Update the **Novel Foods authorisation** process to provide faster evaluation pathways for fermentation-derived compounds from circular bio-based processes without compromising consumer safety.
- Strengthen **industrial symbiosis** incentives to encourage the uptake of fermentation-based bioproducts in the food, feed and biotech sectors.
- Clarify **ABP rules** for a heterogenous selection of by-products intended to re-enter the food chain after processing, reducing regulatory uncertainty especially when intended for human consumption.

6.3 Facilitating regulatory approval for novel routes of valorisation and bioproducts

- Enhance EU-level **guidance on contaminants monitoring** for emerging marine-derived ingredients to support compliance with Reg. 2023/915.
- Promote harmonised **sensory and nutritional quality standards** for fish protein hydrolysates and marine oils to enable market acceptance.
- Strengthen **EFSA-aligned methodologies** for safety evaluation of multifunctional bioproducts (antimicrobial, antioxidant, bioactive properties).
- Support public procurement schemes for sustainable and safe bio-based food additives and ingredients.

6.4 Integration of digital tools and effective process assessment

- Promote the adoption of **digital modelling** and optimisation tools (Multidisciplinary Design Optimization, process simulation) through EU-funded demonstration initiatives.
- Integrate **advanced modelling guidance** into EU best available techniques reference documents for bio-based and marine industries.
- Support standardised **LCA/TEA** data requirements to harmonise sustainability reporting under the EU Taxonomy.
- Provide funding incentives for **digital tools and integrated biorefinery modelling** in the upcoming projects in the circular bioeconomy sectors.

6.5 Environmental, economic and social assessment; standardization

- Accelerate the development of standards for bio-based marine ingredients under **CEN/TC 411** to support interoperability and market confidence.
- Embed **social-LCA** and social acceptance indicators in EU funding and regulatory assessment frameworks.
- Integrate **LCA/TEA** results into EU green public procurement criteria to promote sustainable marine-derived products.

6.6 Communication, dissemination and exploitation

- Strengthen mechanisms or platforms for **early dialogue** between research consortia and regulators to ensure anticipatory policy alignment.

- Expand **EU-level clustering platforms** to connect blue bioeconomy projects with policymakers and industry associations.
- Support **awareness-raising and education campaigns** on the value, safety and sustainability of marine circularity solutions.

6.7 Other recommendations

Promoting cross-sector collaboration between the bio-waste, food, and bio-based industries unlock the new business around marine residues. scale up sustainable valorisation technologies to obtain real measurements of environmental and socio-economic benefits. Such partnerships help overcome technical and economic challenges by sharing knowledge on advanced extraction methods, microbial fermentation, and enzymatic treatments, improving process efficiency and product quality[21]. Scaling up these technologies requires to be supported by real measurement of environmental benefits, from reduced waste and resource use, and socio-economic benefits, including job creation and new market development[22]. Therefore, communication, education, and stakeholder engagement across sectors are critical to facilitate implementation, acceptance, and demand for valorised marine biomass products, supporting circular economy principles[22].

[21] Shawky, E., et al. (2025). Bioresource technology. https://doi.org/10.1016/j.biortech.2025.132640.
[22] Cooney, R., et al. (2023). Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2023.136283.