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D5.2. Life Cycle Sustainability – Circularity

Author(s):

Carlos León (Sustainn)

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Contact person	Dorinde Kleinegris (Project Coordinator) - dokl@norceresearch.no		
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Deliverable Contributors				
	Name	**Organisation (acronym)**	**Title**	**E-mail**
Deliverable Leader	Carlos León	SUSTAINN	Chief Innovation Officer	carlos@wearesustainn.com
Reviewer n°1	Dorinde Kleinegris	NORCE	Senior scientist	dokl@norceresearch.no
Reviewer n°2	Maria Roca Ayats	ALGEMY	Senior Product Scientist	maria@algemy.eu
Reviewer n°3	Sandra Balsells	LEITAT	Senior Researcher	sbalsells@leitat.org
Final review & quality approval	Dorinde Kleinegris	NORCE	Project coordinator	dokl@norceresearch.no

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List of Acronyms

Abbreviation / Acronym	Description
D	Deliverable
EC	European Commission
EPD	Environmental Product declaration
EPS	Expanded Polystyrene
EU	European Union
IMTA	Integrated Multitrophic Aquaculture
KPI	Key performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Cost Assessment
LCSA	Life Cycle Sustainability Assessment
M	Month
MS	Milestone
PCR	Product Category Rules
RAS	Recirculating Aquaculture Systems
SLCA	Social Life Cycle Assessment
SDG	Sustainable Development Goal
T	Task
UNEP	United Nations Environment Programme
WP	Work package

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Executive Summary

This document, Deliverable 5.2 (D5.2), is the first release at month 18 of the results of Task 5.3 of the INNOAQUA project and describes the approach to be followed within Task 5.3 for the Life Cycle Sustainability and Circularity assessment of the solutions developed throughout INNOAQUA project.

The deliverable begins with detailing the close relationship and interaction between WP5 and WP2, WP3 and WP4. Since the data needed to perform the sustainability and circularity assessments are related to raw materials, waste, energy consumption, and system configurations, it will be collected from INNOAQUA value chain processes during: a) land-based RAS-IMTA technology demonstration and industrialization; b) procedures to obtain extracts from microalgae, macroalgae and fish processing waste, and; c) characterization of ingredients and products formulation.

Subsequently, the deliverable defines the scope of the sustainability - circularity assessment, differentiating the assessment at two levels:

- Sustainability - circularity impacts at the project level, and
- Sustainability – circularity impacts at the final seafood products and ingredients level.

Further on, the deliverable describes the methodology to carry out the sustainability – circularity impacts assessment throughout the project. The methodology contains 2 phases:

- **Phase 1: Sustainability - circularity impacts assessment,** which will be done at project level and ingredients and products level.
- **Phase 2: Alignment to international policies.** At this step, the process for the analysis of contribution of the project to most relevant sustainability related international policies is described, such as SDGs, Green Deal and Farm to Fork (F2F) Strategy, and EU Resilience Dashboards.

Since most of the tasks needed to collect data for these assessments are under development, the results of the implementation of the methodology will be compiled and presented in the updated versions of this deliverable i.e., in the Deliverable 5.7 (to be released in M30), and in

the Deliverable 5.8 - the final Life Cycle Sustainability – Circularity report (to be released in M48).

1. Introduction

The INNOAQUA project – Innovative approaches for an integrated use of algae in sustainable aquaculture practices and high-value food applications – aims to pave the path towards the upcoming sustainable and diversified EU in-land aquaculture industry by leaning on the demonstration and mainstreaming of innovative algae-based foods and solutions, using ecology, circularity and digitalization approaches.

When global food systems are challenged by expected population growth, resource impoverishment and other environmental constraints, seafood was identified as a vital source of food and a key component of a healthy diet. Decades of unsustainable overfishing practices have been depleting aquatic ecosystems. Currently, because nearly one-fifth of all animal protein consumed by humans comes from seafood (FAO, see reference [1]), aquaculture has gained traction over wild fisheries. To ensure the future viability of the aquaculture sector and to unlock its potential to provide food with a lower carbon footprint (as stated in the Farm to Fork (F2F) Strategy of the European Green Deal, see reference [2]), it is imperative to improve current technologies and management strategies, incorporating circular economy principles, optimising resources, reducing the operational costs, and minimising the environmental footprint. In this sense, algae (both microalgae and seaweed) have much potential, both for improving the sustainability of the production processes and as a direct food source to increase the seafood offer to consumers.

Within this context, INNOAQUA proposes an ambitious and efficient R&I workplan to develop and mainstream several solutions for the aquaculture industry involving the use of algae. Relying on a multidisciplinary consortium of renowned research centres, associations and companies with high industrial presence (11 companies) it is:

(i) Demonstrating the feasibility and benefits of multi-trophic in-land cultivation management practices (i.e. RAS and IMTA) enhanced by the use of the latest digital technologies.

(ii) Contributing to the improvement of the sustainability and competitiveness of already-established value chains through the implementation of circular economy principles to minimise waste production in cultivation and processing facilities.

(iii) Extracting high-added value ingredients from algae biomass and fish by-products to be used in the formulation of innovative seafood products, focusing from the beginning on social innovation approaches aimed at improving their societal acceptance and market penetration.

All this, enhanced by a robust outreaching strategy aimed at fostering knowledge transfer through an active engagement of relevant European and international actors, ultimately helping to maximize the project's scope and impact.

1.1. Purpose of the document

One of the goals of the INNOAQUA project is to demonstrate its contribution to the improvement of the sustainability and competitiveness of already-established value chains through the implementation of circular economy principles to minimise waste production in cultivation and processing facilities. To achieve this, it is fundamental to evaluate the sustainability and circularity performance of the products and ingredients to be developed within the project.

WP5's main goal is to evaluate the sustainability performance (environmental, economic and social), circularity, and to perform regulatory and safety assessments of the proposed technologies, innovations and products developed within the project.

In the INNOAQUA project proposal, the evaluation of sustainability and circularity primarily focuses on the life cycle of the solutions developed within the project. However, based on a review of the current state of the art and the methodology used in the impact evaluation of socio-economic aspects, the scope of the sustainability and circularity assessment has been broadened. This expanded evaluation will not only assess the sustainability and circularity of the product life cycle but will also consider the project's overall impacts on sustainability and circularity.

In this context, the goal of Task 5.3 is to carry out sustainability and circularity assessment at two different levels, aiming to assess a) sustainability - circularity impacts resulting from INNOAQUA innovations and developments as a project and b) sustainability - circularity impacts from the ingredients and products to be developed within the project.

The results will be reported and updated throughout the project in deliverables D5.7 (M30) and D5.8 (M48), assuming that the development of the ingredients and products is progressing as originally planned.

1.2. Structure of the document

This document is divided into 5 sections:

This section (i.e., **Section 1**) serves as an introduction to the project and WP5, a description of the purpose of the document and a map of interactions of WP5 activities and deliverables with WP2, WP3 and WP4 work packages.

Section 2 summarises the state-of-the-art review of regulations, standards, methodologies and tools related to sustainability – circularity assessment of food ingredients and products.

Section 0 defines the scope of the sustainability – circularity assessment both at a) the project level and at b) the ingredients and products level.

Section 4 describes the methodology for the sustainability – circularity assessment detailing how to the assess the impacts at the project level and at ingredients and products level. It includes the analysis of alignment and contribution of the project to most relevant international policies related to sustainability and circularity.

Finally, **Section 0** will present the results obtained from the application of the methodology described in Section 4 in updated versions of this deliverable (D5.7 and D5.8).

1.3. Relation to other project deliverables

Task 5.1 of the project defined the goal and scope for the socio-economic impacts and sustainability – circularity assessments of the ingredients and products to be developed within INNOAQUA project, to be performed within Work Package 5 activities Task 5.2 and Task 5.3.

The goal of the assessments was defined as:

- Task 5.2 will carry out the assessment of the socio-economic impacts of the products and ingredients to be developed within the project, developing a LCC and a SLCA of ingredients and products
- Task 5.3 will carry out a sustainability - circularity assessment of the products and ingredients to be developed within INNOAQUA project, developing an LCA of ingredients and products and then combining economic, social and environmental impacts assessments to carry out sustainability – circularity assessment of ingredients and products.

As a result of state-of-the-art review performed and following main references and most relevant projects related to INNOAQUA, goal of sustainability - circularity assessments will be expanded, as described in Section 1.1, to:

- Sustainability - circularity impacts at a project level on the different project stakeholders
- Sustainability - circularity impacts at ingredients and products level

The scope of the socio-economic impacts and sustainability-circularity assessments was adjusted according to D4.1, where the ingredients and products to be developed have been identified and the number of prototypes at the kitchen stage have been defined. Scope of life-cycle assessments at ingredients and products level is described in Section 3.2.

Tasks T5.2 and T5.3 are planned to produce two deliverables in M18 (D5.1 and D5.2) and update them in M30 (D5.5, D5.7) and again in M48 (D5.6, D5.8). The scheduling of deliverables is aligned with the progress on WP2, WP3 and WP4. Legal analysis to be performed within T5.4 (reported in D5.3 and updated in D5.9 with the development of the different products) will be considered to reflect the latest legislation trends, standards and industry recommendations for the socio-economic and sustainability – circularity assessments.

Figure 1 shows the overview of relations of WP5 activities and deliverables to other INNOAQUA deliverables throughout the development of the project (from M1 to M48).

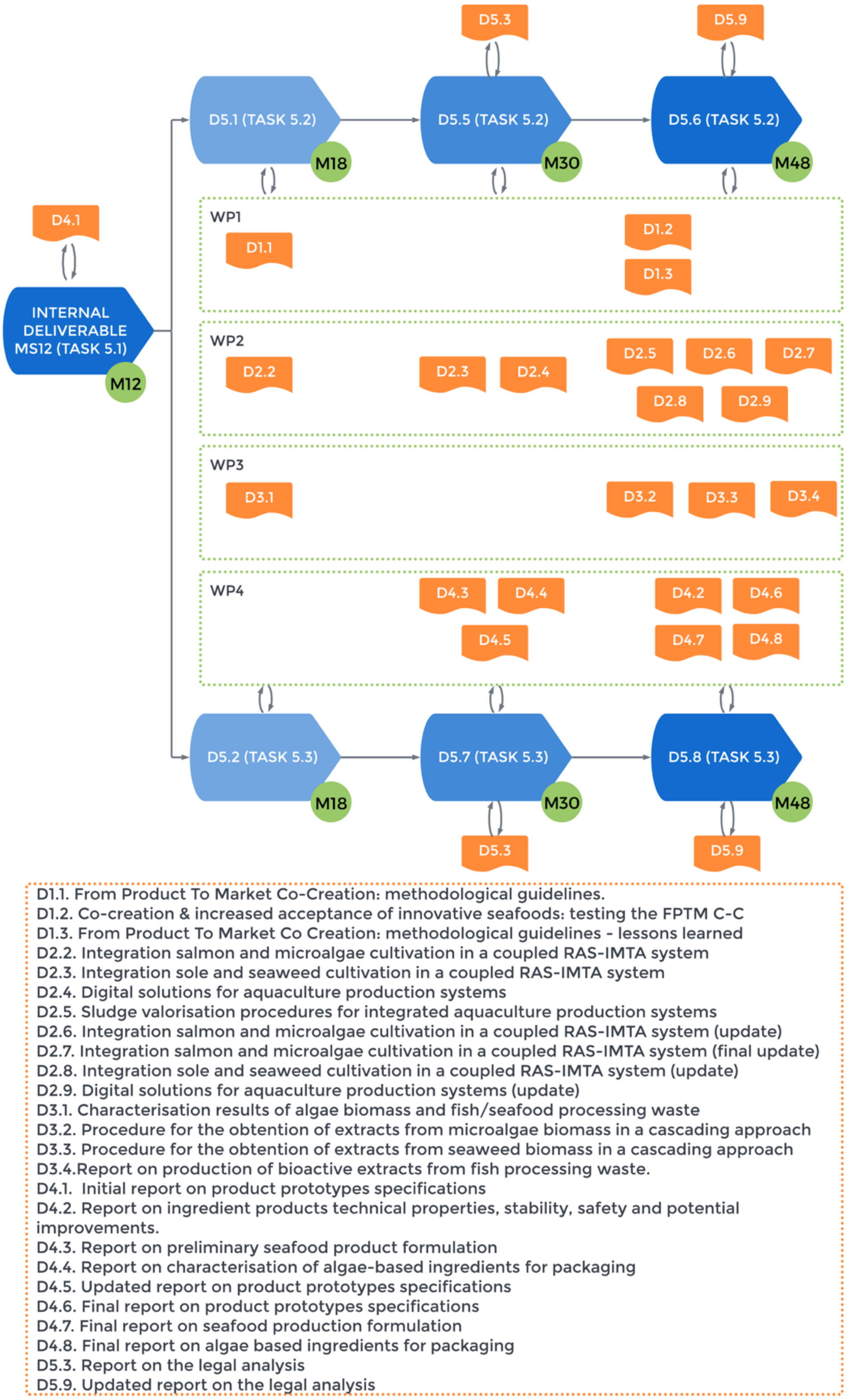


Figure 1 Relation of WP5 activities and deliverables to other INNOAQUA deliverables

T5.2 and T5.3 have a close relationship with WP1 regarding the identification of stakeholders and the compilation of their needs and expectations.

Related to WP2 activities, T5.2 and T5.3 will collect all the data needed related to raw materials, species, system configuration, etc. to perform the assessments resulting from the development of the demo sites in D2.2, D2.3, D2.5, D2.6, D2.7 and D2.8. Identification of relevant KPIs from sustainability and circularity perspectives to be carried out within T5.2 and T5.3 on the kitchen development stage will be provided for the development of digital solutions to increase biomass production (D2.4, D2.9).

In relation to WP3 activities, the characterization results of algae biomass and fish/seafood processing waste (D3.1) and the procedures for the obtention of extracts from microalgae, seaweed biomass and fish processing waste (D3.2, D3.3 and D3.4) will be fundamental input for the development of T5.2 and T5.3 all along the project.

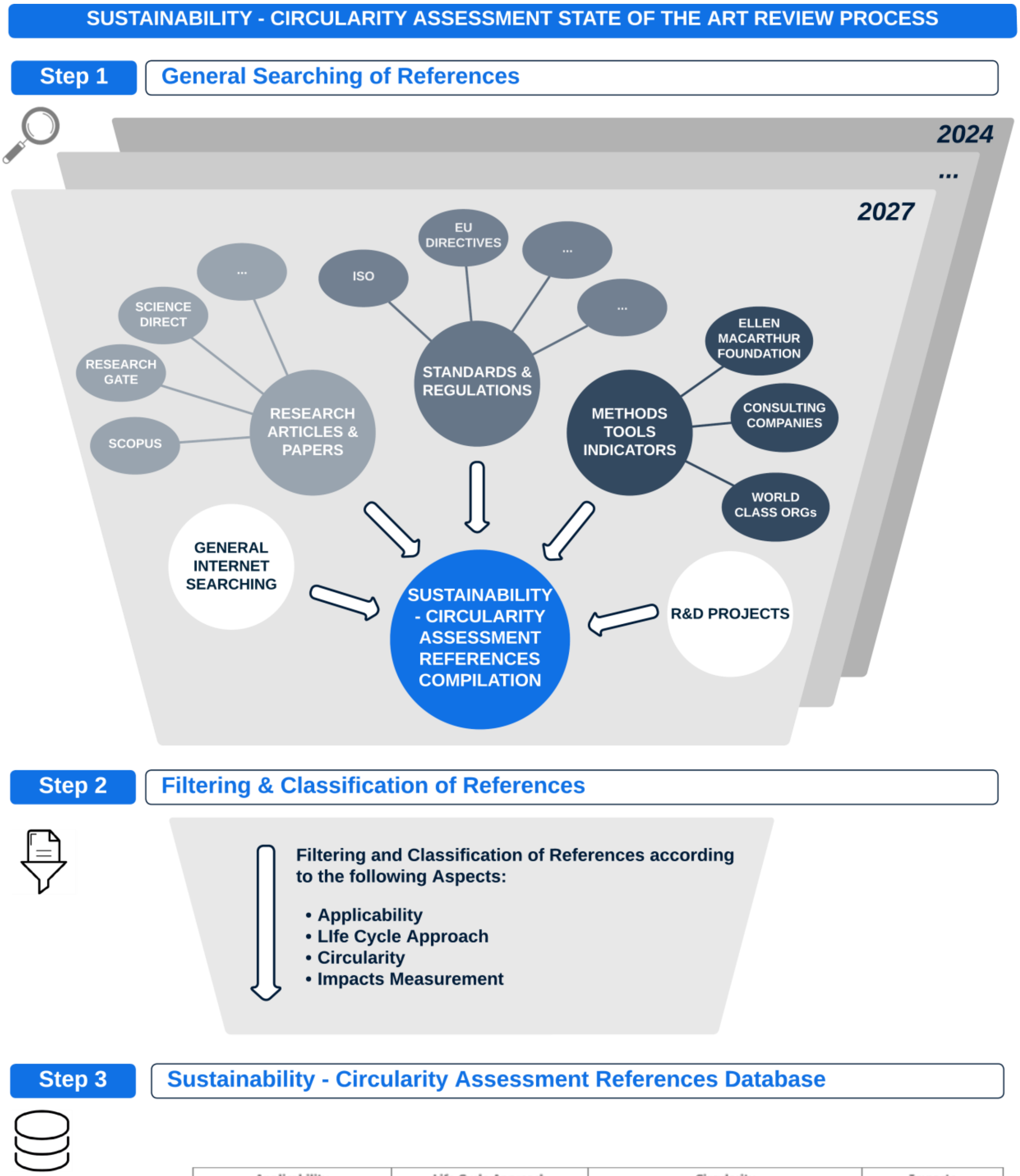
Finally, related to WP4, results from the activities to define the ingredients and products (D4.1, D4.5 and D4.6) the ingredients' technical properties (D4.2), seafood products formulation (D4.3, D4.7) and ingredients for packaging (D4.4, D4.8), will be also a key input for the development of T5.2 and T5.3 throughout the project.

Results from economic (LCC) and social impact (SLCA) assessments of the life cycle of ingredients and products to be obtained from Task 5.2 (and reported in deliverable D5.1) at ingredient and product levels will be an input to Task 5.3 (and deliverable D5.2) for the sustainability - circularity assessment of the ingredients and products developed within INNOAQUA project. It is described more in detail within section 4.1.

2. State-of-the-art review

To ensure that the sustainability and circularity assessments to be conducted in T5.2 and T5.3 are aligned with the latest developments, a comprehensive state-of-the-art review process will be carried out all along the project. This process will regularly evaluate regulations, standards, methodologies, and tools related to the sustainability and circularity assessment of food ingredients and products throughout the project's duration.

See the process overview in the following figure (Figure 2).



		Applicability			Life Cycle Approach						Circularity						Impacts			
References	Document Type	Scale	Sub-Scale	Approach	Approach	DD	MAN	T&I	O&M	DIS	Recirculation	Materials	Water	Energy	Waste	...	LCC	LCA	SLCA	LCSA
Reference 1	Article	Macro	Region	Qualitative	Partial					✓			✓		✓					
Reference 2	Standard	Micro	Organization	Qualitative	Partial		✓					✓			✓			✓		
Reference 3	Guideline	Meso	System	Qualitative	Partial		✓	✓					✓	✓	✓			✓		
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Reference n	Toolkit	Nano	Product	Quantitative	Partial		✓	✓	✓		✓	✓		✓	✓			✓		

Circularity Assessment References Database is to be updated periodically throughout the project development to have the most real picture of the state of the art on standards, regulations, methodologies, tools, indicators, papers and articles related to circularity assessments of products.

Figure 2. Overview of sustainability - circularity assessment state of the art review process

Step 1: General Searching of References

The aim of step 1 is to do a general searching of references related to perform circularity and sustainability assessments of different scopes, such as products, components, etc. Searching is focused on the following sources:

- General internet searching

  Initially, the general searching has been done through the keyword "circular economy" in combination with "assessment", "methodology", "indicator" and "tool".

  As a starting point, the related documents and fundamental references derived from the circular economy plans and the European Green Deal from European Commission will be analysed.

- Research articles and papers

  A general literature review of research articles and papers with the same combination of keywords described above has been conducted using mainly academic literature databases, such as:

  - Scopus database, from Elsevier (reference [5])
  - ResearchGate (reference [6])
  - ScienceDirect (reference [7])
  - Web of science (reference [8])
  - Wiley online library (reference [9])

- Standards and regulations

  As the transition towards the Circular Economy is progressing, standards and regulation are being developed to guide and help implementing its principles in countries, regions and organizations. So, a specific search has been conducted, mainly focused on international and national standardization, certification and regulation bodies, such as ISO, EN, AFNOR, AENOR, BSI and UL.

- Guidelines, methodologies and tools

  A particular searching for specific methodologies, tools and indicators related to the implementation of circular economy has been done on worldwide circular economy reference organizations, such as Ellen Macarthur Foundation, specialized top consulting companies and world class organizations working and promoting sustainability.

- R&D Projects

  The most relevant R&D projects related to the development of novel food and algae-based products are analysed in terms of the sustainability and circularity approach.

Step 2: Filtering & Classification of References

Aim of this step is to review, filter and classify all the references collected from the different information sources according to the following aspects:

- Applicability
- Life Cycle Approach
- Impacts Measurement
- Circularity

These aspects have been defined to evaluate the different Sustainability - Circularity Assessment references found.

Step 3: Sustainability - Circularity Assessment References Database

At this step, all the references found are listed and organized in the Sustainability - Circularity Assessment References Database, which gives a practical overview of their applicability to INNOAQUA project, giving advantages and drawbacks and extracting the main concepts to be applicable to perform the socio-economic and sustainability – circularity assessments to be conducted in Task 5.2 and Task 5.3.

Since there are a lot of initiatives running and researching activity about circular economy implementation, General Searching of References (Step1) will be repeated all along the INNOAQUA project development (from 2024 to 2027, as showed in Figure 2).

A state-of-the-art review tool (reference [10]) has been developed and will be updated periodically throughout the project. It will monitor the regulations, standards, methodologies and tools related to sustainability – circularity assessment of food ingredients and products in general and INNOAQUA project related ingredients and products in particular.

See an overview of the contents of the state-of-the-art tool in the following figure.

	SUSTAINABILITY - CIRCULARITY ASSESSMENT STATE OF THE ART REVIEW	Version:	Draft
		Date:	19/5/2024
		Developed by:	Sustainn

1 Sustainability - Circularity Assessment References

It contains the most relevant references related to circularity assessment of regions, organizations, products, services, etc. References are sorted out in different categories, such as regulations, standards, guidelines & methodologies and reports, articles and papers.

2 Environmental Impacts Substitute Products References

It contains the most relevant references of environmental impacts (carbon footprint, EPD, LCA) of product and ingredients that INNOAQUA Project is aiming to substitute

3 Standards summary

It compiles the most relevant standards related to circularity assessment of products with a brief identification of the main aspects potentially applicable to INNOAQUA Project.

4 Guidelines & methodologies summary

It compiles the most relevant guidelines and methodologies related to circularity assessment of products with a brief identification of the main aspects potentially applicable to INNOAQUA Project.

5 Reports, articles and papers summary

It compiles the most relevant reports, articles and papers related to circularity assessment of products with a brief identification of the main aspects potentially applicable to INNOAQUA Project.

Figure 3. Index of contents of Sustainability - Circularity Assessment State-of-the-art Review Tool

Main conclusions extracted from state-of-the-art review analysis conducted until now are:

- No methodology or reference developed ad hoc has been found at this moment to carry out a sustainability - circularity assessment of algae-based products and applications. However, many relevant aspects can be used to develop a specific methodology and tools to perform it combining circularity and sustainability assessments, considering LCC, LCA and SLCA approaches.
- No specific regulations have been developed yet to perform circularity assessment of products.
- Regarding life cycle approach, most of the methodologies, tools, metrics and indicators are considering some particular phases of the life cycle of a product or service, but very few are considering the full life cycle.
- A remarkable effort is being done around the world to develop standards, guidelines and methodologies to assess circularity of territories, cities, organizations, products and components. Remarkably, ISO 59000 series on circular economy have been released to help measure circularity of organizations and products. Regarding standards, guidelines, methodologies, tools, reports, articles and papers, main conclusions are:

- The 3 dimensions of sustainable development (economical, environmental and social) are to be considered to analyse circularity and sustainability, according to some standards (XP X30-901) and methodologies (LCSA approach from Orienting project). Environmental impact, cost impact and social impact can be measured and developed through LCA, LCC and SLCA indicators.
- LCSA (Life Cycle Sustainability Assessment) is increasingly accepted as an assessment method to support decision making on sustainability of alternative solutions of a product.
- LCSA approach is taken as the basis for the development of a methodology to assess sustainability of a product combining environmental LCA, social LCA and life cycle costing (LCSA = LCA + S-LCA + LCC) and integrating circularity assessment.

- A key insight from the review of the related R&D projects is that sustainability - circularity assessment should be conducted not only at the products or technologies level, but also at the project level.

3. Scope of the sustainability - circularity assessment

Following the main references and most relevant projects related to INNOAQUA, the evaluation of sustainability and circularity will not only assess the sustainability and circularity of the ingredients and products life cycle but will also consider the project's overall impacts on sustainability and circularity.

Task 5.3 goal is to carry out the sustainability – circularity assessment at two different levels, evaluating:

- Sustainability - circularity impacts at a project level, and
- Sustainability - circularity impacts at ingredients and products level.

The detailed scope for both levels is outlined in the following chapters.

3.1. Project level

Project Approach – From Technology to Market

INNOAQUA project is focused on the technology development, demonstration and mainstreaming of the ingredients, products and packaging solutions, described in Section 3.2.

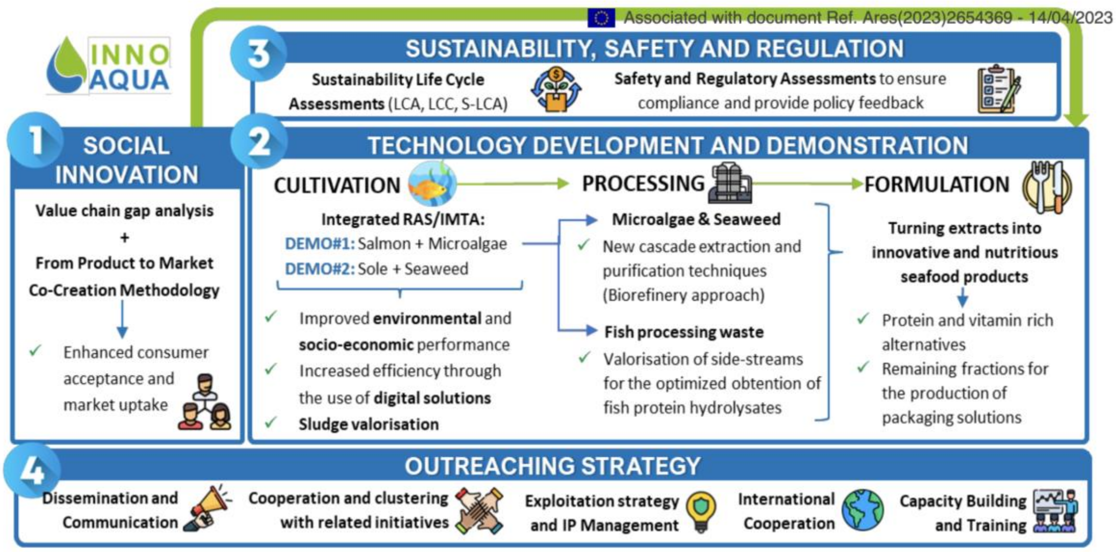


Figure 4. INNOAQUA project overall concept

Two different phases related to the maturity of the validated and demonstrated technologies should be distinguished:

- technology development validation for the integrated cultivation of algae at two demo sites, development of the cascade extraction processes at laboratory scale and formulation of the seafood products and packaging solutions at kitchen scale, and
- industrialization of the ingredients, products and packaging solutions.

Commercialization and serial production of the ingredients and products is outside the scope of the project.

INNOAQUA Processes Value Chain

One of the goals of the INNOAQUA project is to demonstrate processing methods to obtain to obtain algae-based ingredients and fish protein hydrolysates, to be formulated into innovative seafood products and packaging solutions. These components possess numerous benefits for high-added-value food applications widely sought after in the current market, especially as low-carbon protein-rich alternative sources. Thus, to achieve this goal, INNOAQUA partners expect to extract high-added value ingredients from algae biomass, as well as from fish by-products, to later use them in the formulation of different innovative seafood products and packaging solutions. This process will be a multi-stage chain, starting from the algae and fish by-products biomass, and ending with the different seafood and packaging products (see Figure 5). The whole chain will be subsequently upscaled, starting with laboratory/kitchen tests and ending with the industrial production of the final food products. Some of them will be packed inside trays developed within the process.

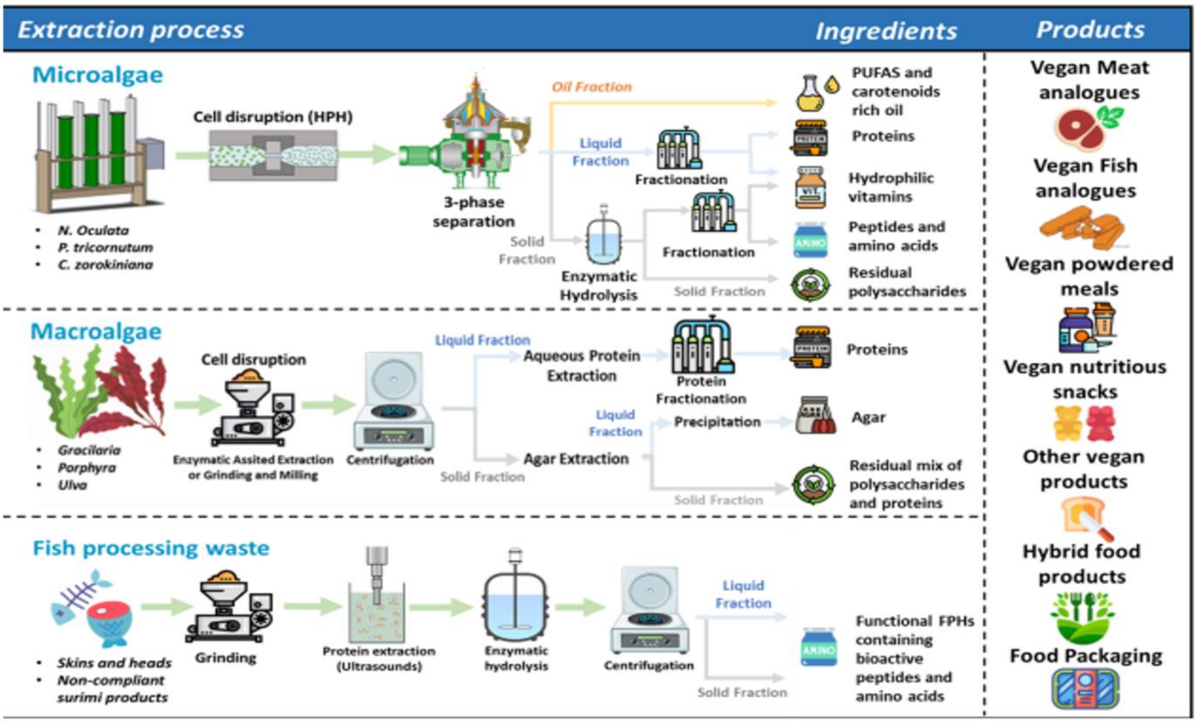


Figure 5. Overview of the INNOAQUA project multi-stage process

Scope of Sustainability and Circularity Assessments at Project Level

The assessment of sustainability - circularity at the project level will focus then on the entire INNOAQUA processes value chain. This analysis will involve understanding the needs and expectations of stakeholders regarding sustainability and circularity associated with the development and outcomes of the project.

Therefore, sustainability - circularity assessment at a project level will take into account:

- From technology to market approach, considering all the project development phases and subsequent commercialization of ingredients and products, since there will be different stakeholders that could affect the project or be impacted by the project;
- Impacts derived from the entire INNOAQUA value chain, considering all the phases starting from as cultivation, extraction and ending with the different seafood and packaging products.

3.2. Ingredients and products level

Ingredients and Products to be developed

Resulting from the proposed INNOAQUA processes value chain, a list of seafood ingredients and products and packaging solutions to develop has been approved within WP4 and described in D4.1 (reference [19]).

Products were allocated into the following product categories: vegan meat analogues, vegan fish analogues, vegan powdered meals, vegan snacks, other vegan products, hybrid products and packaging solutions. The technology development process was approved for a total of 21 prototypes until the kitchen-scale stage, while at least 14 of them (12 seafood products and 2 packaging solutions) will be finally industrialized.

Table 1 shows the approved list of product prototypes, their product category and the assigned partner in charge of the development.

Table 1. Approved list of the seafood and packaging prototypes to be produced

Product Prototypes		
Product category	**Product**	**Producer**
Vegan meat analogues	Vegan Sausages	VIVA MARIS
	Vegan Nuggets	LEITAT
Vegan fish analogues	Vegan Surimi	PESCANOVA
	Vegan fillets	PESCANOVA
	Vegan burgers	PESCANOVA
	Vegan battered/breaded fish portions	PESCANOVA
Vegan powdered meals	Shakes	ALGEMY
	Breakfast bowls	ALGEMY
	Soups	ALGEMY
Vegan snacks	Cookies	ALGEMY
	Gummy bears	ALGEMY/LEITAT
	Energy bars	ALGEMY
	Energy balls	ALGEMY
Other vegan products	Vegan Shots	VIVA MARIS
	Bread spreads	VIVA MARIS
Hybrid products	Fish & algae fillets	PESCANOVA
	Hybrid sausages	VIVA MARIS
	Hybrid nuggets	LEITAT
	Hybrid bread spreads	VIVA MARIS
Biodegradable packaging	Lidding films	ERANOVA
	Trays	ERANOVA

For the formulation of each of the seafood prototypes (T4.3) and packaging solutions (T4.4), one or more than one ingredient obtained from algae (microalgae or macroalgae) produced as part of WP2 or fish by-products will be used. These ingredients will be produced as part of WP3 after being subjected to different cascade extraction protocols and characterized in T4.2. A total of 5 different ingredients obtained from 3 different species of microalgae will be produced, as well as 3 different ingredients obtained from 3 different species of seaweed, and 1 ingredient obtained from a fish by-product (either non-compliant surimi sticks or fish skins and heads from salmon).

Finally, microalgae and macroalgae residual fraction will be used to obtain plastic resin.

Table 2 shows the list of ingredients to be obtained.

Table 2. Approved list of the different ingredients to be produced

<table>
<tr><th colspan="3">Ingredients</th></tr>
<tr><th>Biomass of origin</th><th>Ingredient</th><th>Partner in charge</th></tr>
<tr><td rowspan="5">Microalgae (NORCE):
- Chlorella sorokiniana
- Phaeodactylum tricornutum
- Nannochloropsis oculata</td><td>Microalgae protein</td><td>ALGEMY</td></tr>
<tr><td>Microalgae PUFA’s and carotenoids rich oil</td><td>ALGEMY</td></tr>
<tr><td>Microalgae hydrophilic vitamins</td><td>ALGEMY</td></tr>
<tr><td>Microalgae peptides and AA’s</td><td>ALGEMY/LEITAT</td></tr>
<tr><td>Microalgae residual fraction</td><td>ALGEMY/LEITAT</td></tr>
<tr><td rowspan="3">Macroalgae (A4F):
- Ulva
- Porphyra
- Gracilaria</td><td>Macroalgae Proteins</td><td>A4F</td></tr>
<tr><td>Macroalgae Agar</td><td>A4F</td></tr>
<tr><td>Macroalgae Residual fraction</td><td>A4F</td></tr>
<tr><td>Fish waste:
-Fish skins and heads from salmon (VIKINGAQUA)
-Non-compliant surimi sticks (PESCANOVA)</td><td>Functional Fish protein Hydrolysates (FPHs)</td><td>LEITAT</td></tr>
<tr><td>Microalgae and macroalgae residual fraction</td><td>Plastic resin</td><td>ERANOVA</td></tr>
</table>

Life Cycle Approach

According to the existing international standards (ISO 14040, reference [3]; ISO14067, reference [11]), Product Environmental Footprint Category Rules (PEFCR) used for the Environmental Product Declarations (EPDs), a life cycle approach should be followed to carry out environmental impacts assessment and carbon footprint quantification of products. So, all the life cycle phases of a product should be considered, starting from the conception and development of a product, manufacturing, transportation and installation, operation and maintenance (or consumption) and disposal.

The same approach should be followed in Task 5.2 to perform LCC (life cycle costing) assessment of products, according to IEC 61300-3-3 standard (reference [12]), considering all the costs throughout the life cycle of the products, and to analyse the social impact of products (SLCA), as identified in recognized methodologies (such as UNEP Guidelines for Social Life Cycle Assessment of Products, reference [4]).

Moreover, the sustainability performance of the products and ingredients will be assessed following the LCSA (Life Cycle Sustainability Assessment) approach according to the latest state-of-the-art references and developments (i.e.: ORIENTING Project, reference [13]). Circularity assessment of products will complement sustainability assessment following the ISO59000 series with a life cycle approach.

Scope of Sustainability and Circularity Assessments at Ingredients and Products Level

Considering all the aspects described previously, such as:

- INNOAQUA project approach "From technology to market"
- INNOAQUA project value chain processes,
- ingredients and products to be developed within the project, and
- life cycle approach.

Scope of the sustainability – circularity assessment at ingredients and products level is showed in the following figure and explained below.

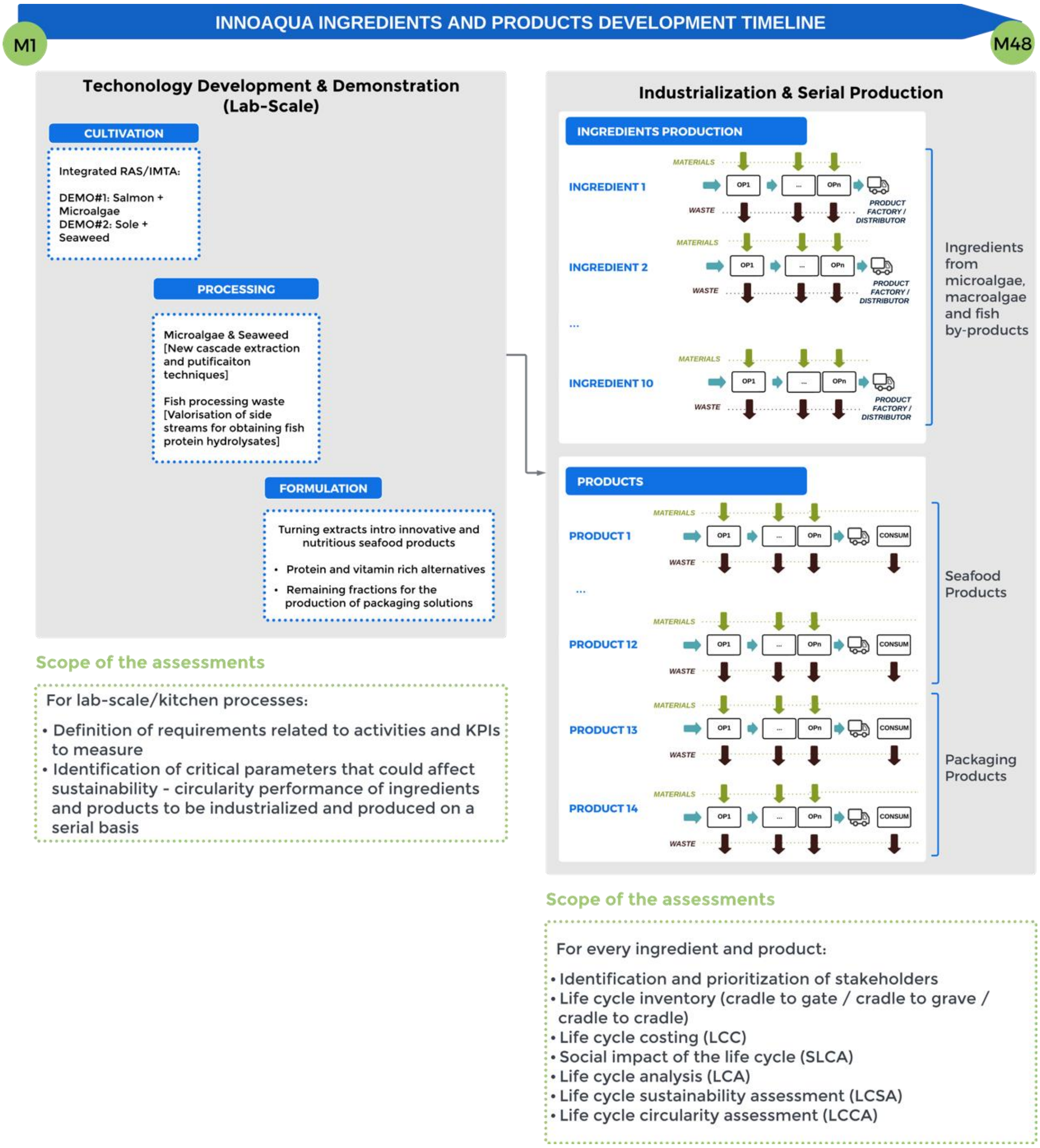


Figure 6. Scope overview of socio-economic impacts assessment and sustainability – circularity assessment of ingredients and products

Within the **industrialization and serial production phase**, sustainability - circularity assessment will be focused on the life cycle of 10 ingredients and at least 14 products identified in WP4.

4. Methodology for the sustainability – circularity assessment

Aim of the methodology is to guide assessing sustainability and circularity of the INNOAQUA project innovations and developments, both at project level and at ingredients and products level.

The methodology for assessing sustainability and circularity of the INNOAQUA project innovations contains 2 different phases:

- **Phase 1: Sustainability – circularity assessment.** Assessment of the sustainability - circularity impacts will be done at 2 different levels:
    - Sustainability - circularity impacts at a project level
    - Sustainability - circularity impacts at ingredients and products level, where:
        - Within the environmental dimension, LCA of ingredients and products will be performed to calculate the carbon and environmental footprints of the products and ingredients to be developed within the project.
        - Then, a circularity assessment of the ingredients and products will be carried out to know the alignment of the life cycle of ingredients and products to the circular economy principles.
        - Later, a sustainability assessment of the ingredients and products will be worked out combining economic, social and environmental impacts assessments done previously.
        - Next, results from LCA, LCC and s-LCA will be normalised and weighted to obtain an overall single sustainability score.
        - Finally, the combination of sustainability and circularity will be assessed to identify critical parameters related to sustainability and circularity aiming to obtain optimum ingredients and products in terms of sustainability and circularity.

As indicated in Figure 7, results from social impact assessment (SLCA) and cost assessment (LCC) throughout products and ingredients life cycle carried out within Task 5.2 and reported in Deliverable 5.1 will be an input for the life cycle sustainability and circularity assessment.

- **Phase 2: Alignment to international policies.** At this step, the process for the analysis of the project contribution to most relevant sustainability-related international policies (incl. SDGs, Green Deal and Farm to Fork (F2F) Strategy, EU Resilience Dashboards) is described.

Figure 7 shows an overview of the methodology, phases and main activities to carry out.

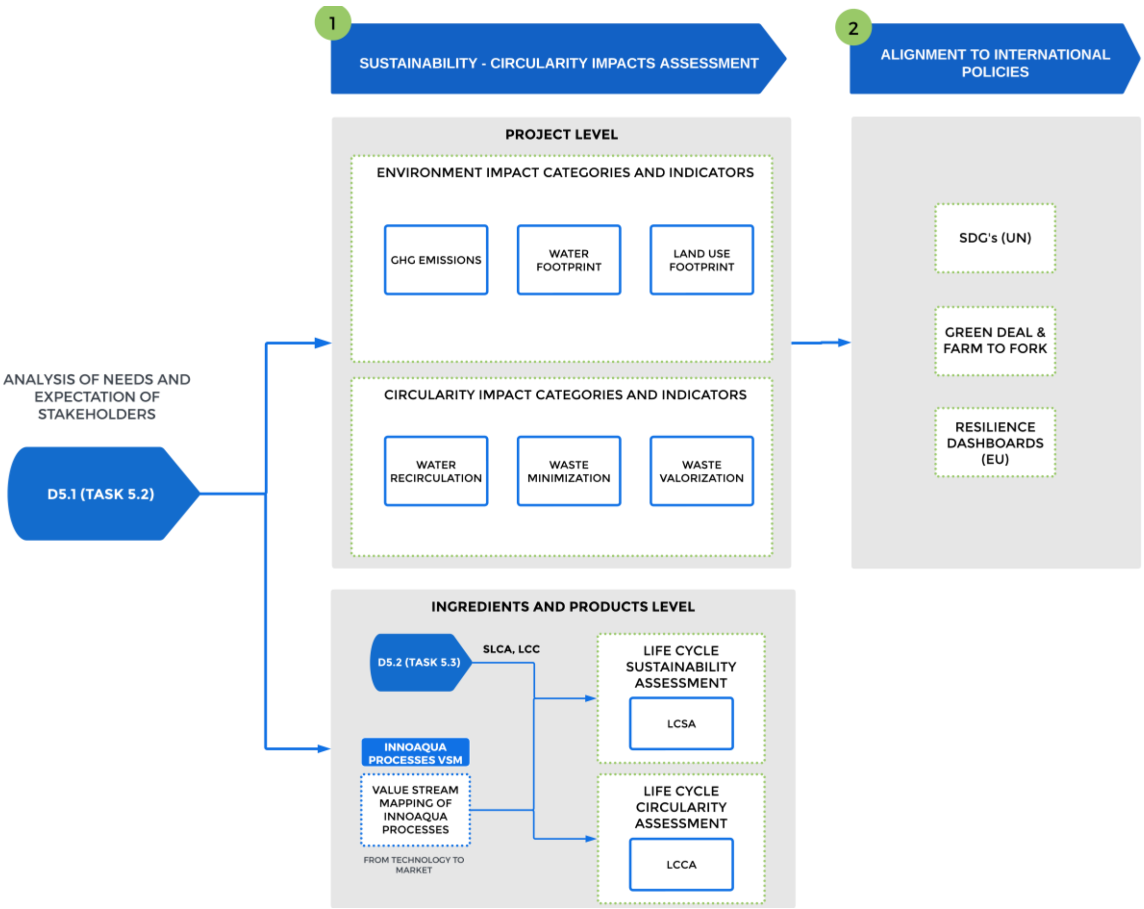


Figure 7. Overview of methodology for the sustainability - circularity assessment

As showed in the figure, an input for both phases will be the results of the needs and expectations from stakeholders related to sustainability and circularity assessments, compiled within Task 5.2 and reported in Deliverable D5.1.

These phases and activities are described in detail in the next sections.

4.1. Sustainability – circularity assessment

4.1.1. Project level

According to the organization of tasks and deliverables within the project, the assessment of sustainability impacts at the project level is organized into two distinct tasks as follows:

- Task 5.2 will evaluate the social and economic dimensions of sustainability.
- Task 5.3 will assess the environmental dimension of sustainability.

Quantification of the indicator values, both for environmental and circularity impacts, will be performed in the next months and reported in the updated version of this deliverable (Deliverable 5.7), to be released in month 30 (M30).

4.1.1.1. Environmental impacts assessment

As shown in Figure 7, sustainability at a project level will be then evaluated here in the following environmental impact categories, which will be described in detail in the following points:

- GHG emissions
- Water footprint
- Land footprint

4.1.1.1.1. GHG emissions

Aligned with EU Taxonomy objectives 1 and 2[1] (see reference [20]), this impact category will evaluate 2 different aspects:

- Potential carbon footprint that ingredients and products developed within the project could generate once they are eventually commercialized.

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[1] Objectives of EU Taxonomy:
Objective 3: Sustainable use and protection of water and marine resources
Objective 4: Transition to a circular economy

- Avoided emissions, estimating greenhouse gas emissions that will be avoided because of the commercialization and potential market growth of the ingredients and products developed within the project compared to conventional products already in the market

4.1.1.1.2. Water footprint

This impact category will evaluate 2 different aspects:

- Potential water footprint that ingredients and products developed within the project could generate once they are eventually commercialized.
- Avoided water footprint, estimating water footprint that will be avoided because of the commercialization and potential market growth of the ingredients and products developed within the project, compared to conventional products already in the market

4.1.1.1.3. Land use footprint

This impact category will evaluate 2 different aspects:

- Potential land use footprint that ingredients and products developed within the project could generate once they are eventually commercialized.
- Avoided land use footprint, estimating reduction of land use because of the commercialization and potential market growth of the ingredients and products developed within the project, compared to conventional products already in the market

4.1.1.2. Circularity impacts assessment

As shown in Figure 7, circularity impact at a project level will be evaluated in the following circularity impact categories, which will be described in detail in the following points:

- Water recirculation
- Waste minimization
- Waste valorisation

4.1.1.2.1. Water recirculation

This impact category will evaluate 3 different aspects:

- Water recirculation along the project itself, estimating the water recirculated all along the project activities from the cultivation, extraction and scale up of ingredients and products
- Potential water recirculation and minimization of water uptake that ingredients and products developed within the project could generate once they are eventually commercialized.
- Reduction of water uptake, estimating reduction of freshwater consumed because of the commercialization and potential market growth of the ingredients and products developed within the project, compared to conventional products already in the market

4.1.1.2.2. Waste minimization

This impact category will evaluate 3 different aspects:

- Waste minimization along the project itself, estimating the waste of the different kind generated all along the project activities from the cultivation, extraction and scale up of ingredients and products
- Potential waste of any kind that ingredients and products developed within the project could generate once they are eventually commercialized.
- Reduction of waste of most relevant types, estimating reduction of waste generated because of the commercialization and potential market growth of the ingredients and products developed within the project, compared to conventional products already in the market.

4.1.1.2.3. Waste valorisation

This impact category will evaluate 3 different aspects:

- Waste valorisation along the project itself, estimating the waste recirculated (reuse all along the project activities from the cultivation, extraction and scale up of ingredients and products

- Potential waste valorisation that ingredients and products developed within the project could generate once they are eventually commercialized.
- Increment of waste valorised of most relevant types, because of the commercialization and potential market growth of the ingredients and products developed within the project, compared to conventional products already in the market

4.1.2. Ingredients and products level

The aim of this part of the sustainability and circularity assessment is to measure impacts in the separate sustainability dimensions (social, economic, environmental) and to evaluate sustainability and circularity of the life cycle of the ingredients and products to be developed within INNOAQUA. It will be implemented in 4 different steps, as showed in Figure 8, which are detailed in the following sections.

To point out that SLCA and LCA, developed within the socio-economic impacts assessment in Task 5.2 (and reported in Deliverable D5.1) will be inputs to the implementation of this methodology at this point, as showed in Figure 7.

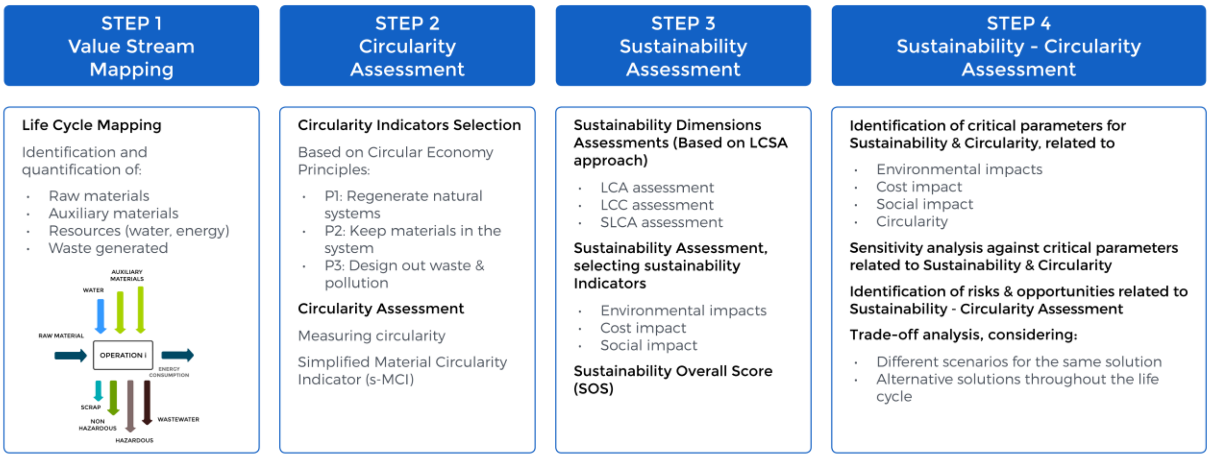

Figure 8. Sustainability - Circularity Assessment Methodology Overview

4.1.2.1. Step 1: Value stream mapping

In this step, the value stream mapping of the life cycle of the ingredients and products is to be carried out, identifying all the materials and substances, auxiliary raw materials and resources (water, energy) consumed in the different operations throughout the life cycle, as well as the waste generated.

Value stream mapping is also developed to perform LCA and SLCA within Task 5.2.

4.1.2.1.1. The value stream mapping concept

As a previous step to the socio-economic, environmental impacts assessments and subsequent circularity-sustainability assessment of the ingredients and products, all the operations throughout their life cycle are to be mapped. To point out that the common life cycle phases to consider, according to ISO 14040 (reference [3]) and IEC 60300-3-3 (reference [12]) are:

Figure 9. Typical life cycle phases of a product

Within each phase, all operations must be mapped to the maximum detail possible, identifying the inputs and outputs in each operation (environmental aspects), showed as arrows in “Operation i” in Figure 10, such as:

- Inputs
    - Consumption of resources (water, energy)
    - Consumption of raw materials
    - Consumption of auxiliary materials
- Outputs
    - Waste, considering its different types (hazardous and non-hazardous waste, scraps, wastewater, etc.)
    - Emissions, considering emissions to air as the environmental aspect, if generated (for example in a chimney)

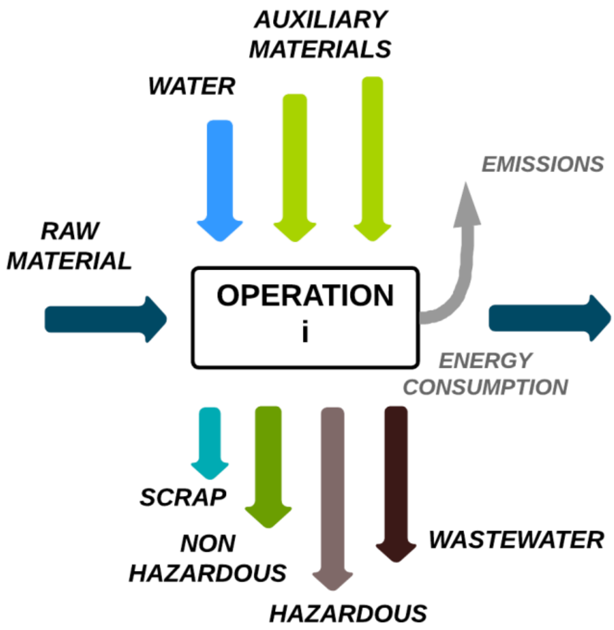

Figure 10. Operation i scheme with common inputs and outputs

The following figures show the representation of the value stream of a food ingredient, a product and a product including its packaging.

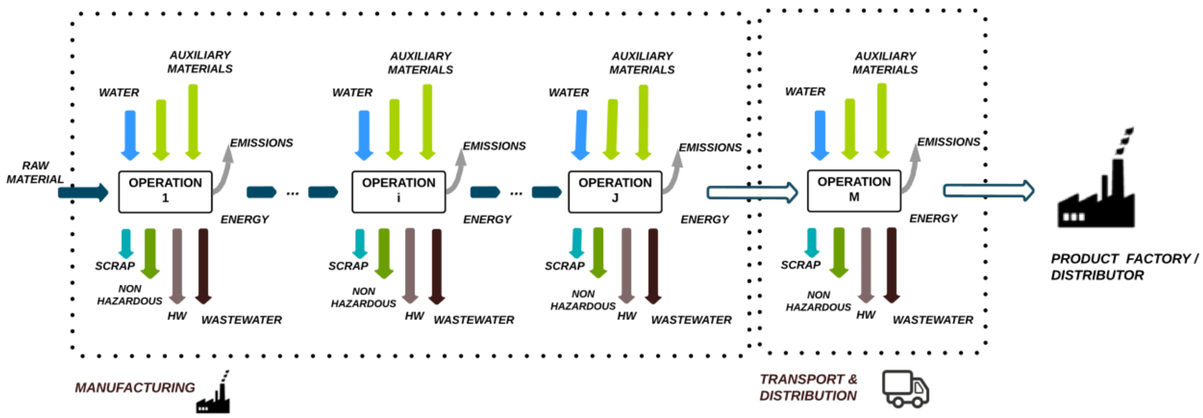

Figure 11. Scheme of phases and activities of a life cycle of a food ingredient

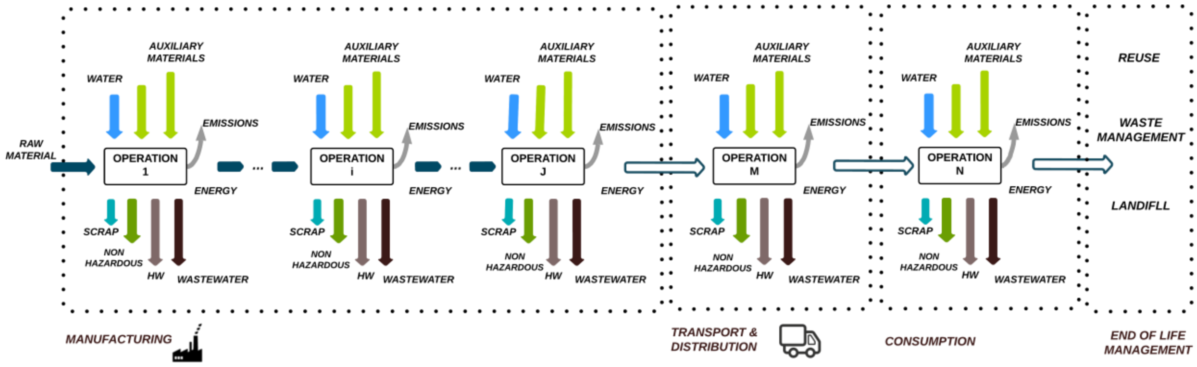

Figure 12. Scheme of phases and activities of a life cycle of a food product

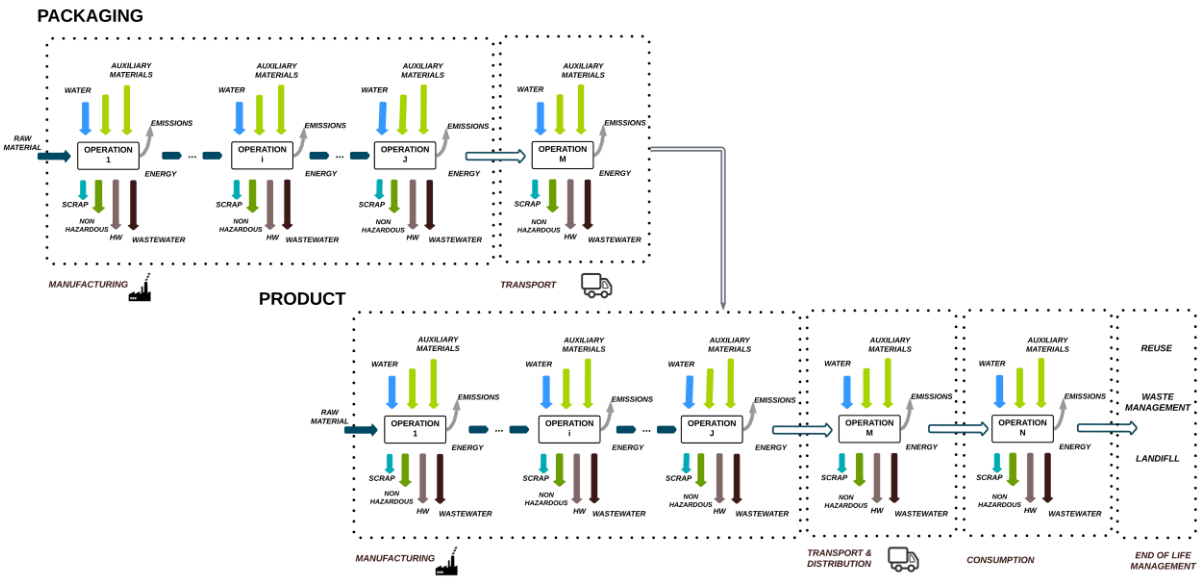

Figure 13. Scheme of phases and activities of a life cycle of a food product including packaging

4.1.2.1.2. Scenarios to be considered

On top of that, it will be key to consider the different scenarios that can occur throughout the ingredients and products' life cycles, because of:

- Supply chain alternatives, depending on the alternative suppliers that manufacturers of ingredients and products could develop for raw materials, substances or ingredients.
- Distribution, consumption and end-of-life alternatives, depending on the different distribution and end-of-life paths (mainly on packaging). Different distribution flows could be carried out from the manufacturing shop, the different users downstream (1st user level, 2nd user level), the waste management and recycling systems.

Identification of different scenarios will be fundamental to know the hotspots and critical parameters from sustainability and circularity perspectives, to be able to make sensitivity analyses against them and to identify risks and opportunities related to adapt the solution (material, product, waste management system, recycling process) to the upcoming trends coming from the market, sector, customer requirements or legislation changes.

As an example, the next picture shows a representation of two different scenarios that could happen within the distribution, consumption and end-of-life management phases of an EPS fish box (source: Oceanwise project, see reference [14]).

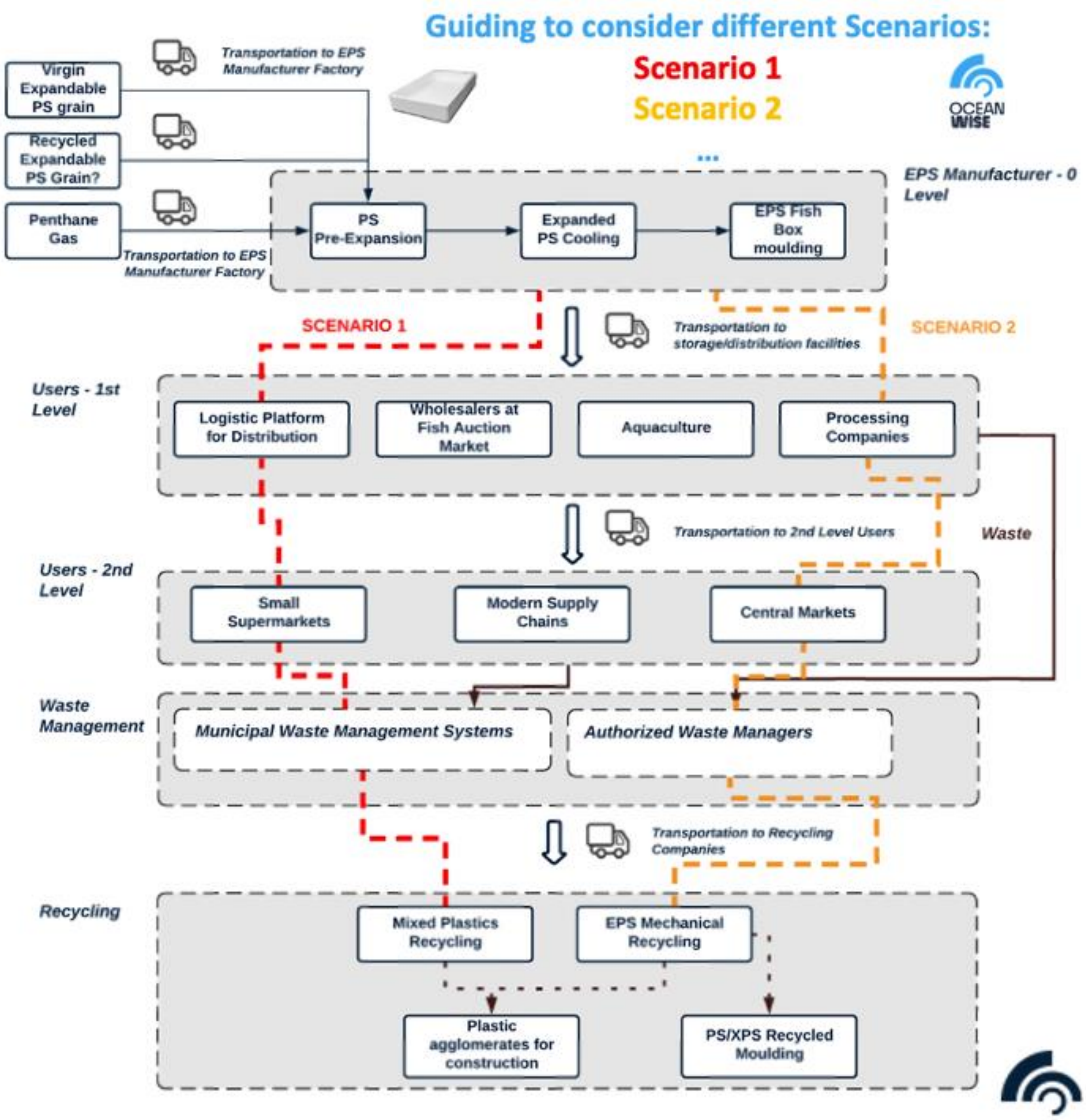

Figure 14. Overview of different potential scenarios identified on an EPS fish box

Therefore, the most representative scenarios combining alternatives upstream and downstream will be considered for any ingredient and product to be assessed within the industrialization and serial production phase. See in Figure 15 and Figure 16 a schematic representation of different scenarios that should be analysed for ingredients and products.

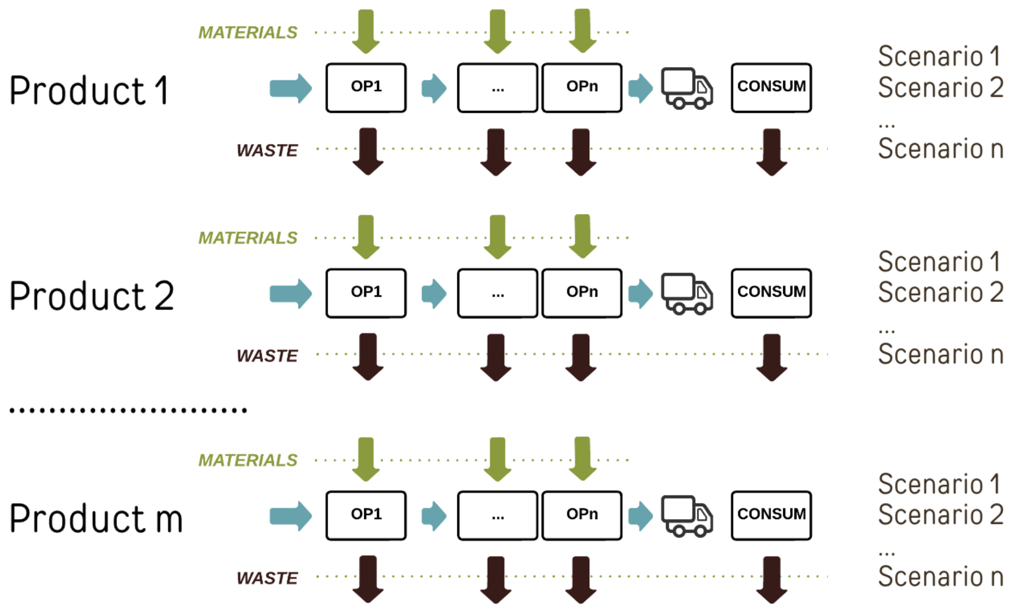

Figure 15. Schematic representation of different scenarios to analyse for every product

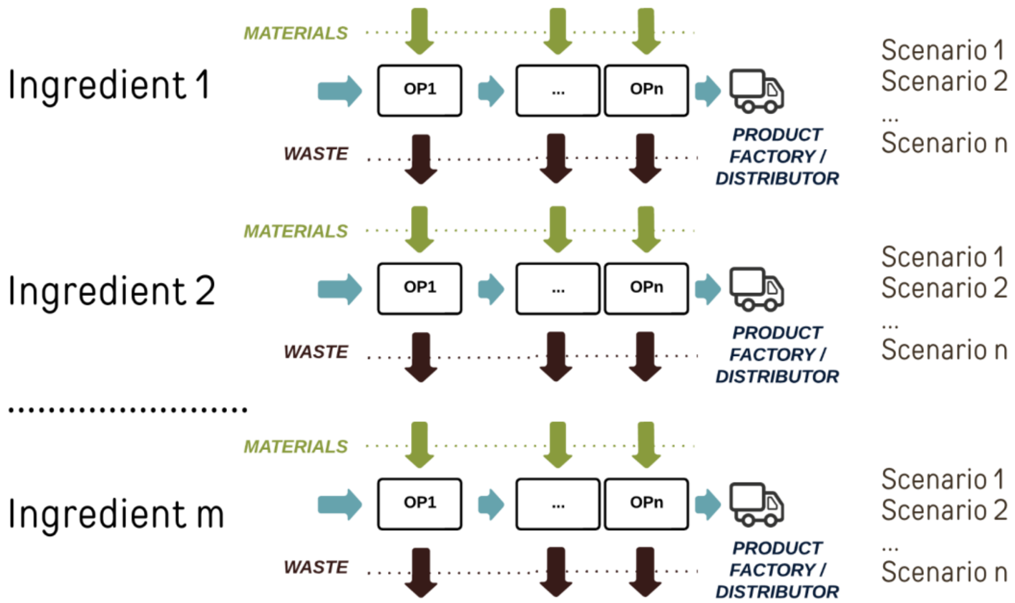

Figure 16. Schematic representation of different scenarios to analyse for every ingredient

In the most relevant scenarios, after mapping operations and identifying inputs and outputs, values will be assigned to each input and output in their respective units.

Before assigning values, the unit of the product has to be clearly defined and measurable. As described in ISO14040, life cycle assessments are structured around a functional unit or declared unit[2]. This functional unit defines what is studied and the quantification of the identified functions (performance characteristics) of the product. LCIs (life cycle inventories) and subsequent life cycle assessments should be relative to that functional unit, like all inputs and outputs in the value stream mapping.

Functional unit definition depends on the type or category of products. Specific Product Category Rules (PCR)[3] are available for different product categories, which define the corresponding functional unit or declared unit to use. The corresponding and applicable PCRs for the ingredients, food and packaging products will be selected for the assessments within the project.

As an example, PCR applicable for Fish and Fish Products (PCR 2021:05, reference [15]) according to *The Internation EPD System* establishes that "the declared unit shall be defined as 1 kg of edible product plus its packaging".

For the case study of a packaging application, and according to NPCR023 (Packaging products and services, see reference [16]) from the Norwegian EPD Foundation, the functional unit for cradle-to-grave analysis for a single and multiple use packaging product is defined as "one delivery of one unit of packaging for a defined good or group of goods". According to PCR 2019:2013 (see reference [17]) from The International EPD System, the functional unit is 1 packaging unit.

[2] As per ISO14040, the primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results. Comparability of LCA results is particularly critical when different systems are being assessed, to ensure that such comparisons are made on a common basis.

[3] Product Declaration) for a specific product category (https://www.environdec.com/product-category-rules-pcr/the-pcr)

To map the whole life cycle, all the inputs and outputs values should be calculated/estimated per the functional/declared unit defined for all the operations, as described above. It is recommended to use value stream mapping tools, which help to map all the operations and identify inputs, outputs and assign the corresponding values to raw materials, auxiliary materials and resources consumed, as well as generated waste.

Additionally, considering that full industrialization of products and ingredients will depend on the priorities of developers and manufacturers and that it is possible that the manufacturing processes could not be fully developed and optimized at the end of the project, we will face data gaps (e.g., about costs, consumption of materials and resources, generation of waste, etc). Estimations of social, economic and environmental impacts will be carried out to perform the socio-economic impacts and sustainability - circularity assessments.

4.1.2.1.3. Value Stream Mapping of INNOAQUA processes

Therefore, a fundamental step before carrying out an evaluation of socio-economic, environmental, sustainability and circularity impacts at the level of ingredients and products is to map all the processes and their operations in the INNOAQUA project. The following figure shows an overview of INNOAQUA processes.

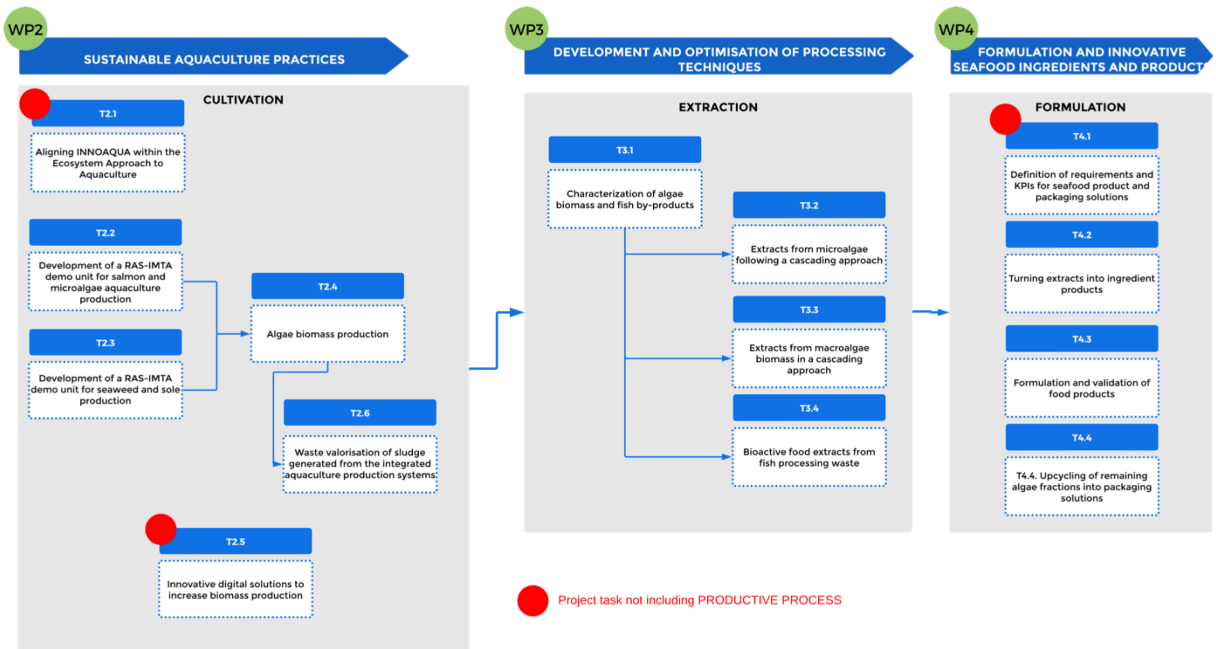

Figure 17. Overview of INNOAQUA processes

As indicated in Figure 17, there are some activities within the project that are not productive process[4]. These are marked with ● "Project task not including productive process".

As the INNOAQUA Project is focused on the technology development and demonstration and mainstreaming of the integrated RAS-IMTA fish and algae production processes, as well as the development of a biorefinery approach to obtain ingredients, and subsequent formulation of seafood products and packaging solutions, with the subsequent scale-up to industrialization (from technology to market approach), socio-economic impact and sustainability - circularity assessments at ingredients and products level should cover all these phases. Therefore, value stream mapping of INNOAQUA processes will be carried out for:

- Lab-scale and kitchen tests,
- Pre-ingredients scale,
- Scale up into industrialization.

Goal of mapping these phases in detail is to identify critical parameters related to social and economic, sustainability and circularity impacts that might affect the commercialization and serial production of the ingredients and products.

WP5 is working in close collaboration with the rest of the project partners in mapping each of the project's processes showed in the previous figure. Considering that many of the tasks are under development and some of them have not yet started, processes that have been mapped already are presented next.

Value Stream Mapping of WP2 Processes

The following figures show the mapping of the processes developed to date that are carried out in the different activities of WP2:

- T2.2 Development of a RAS-IMTA demo unit for salmon and microalgae aquaculture production

[4] A "productive process" means a process related to the cultivation, extraction and formulation of ingredients and products.

T2.2 Development of a RAS-IMTA demo unit for salmon and microalgae aquaculture production (M1-M42)

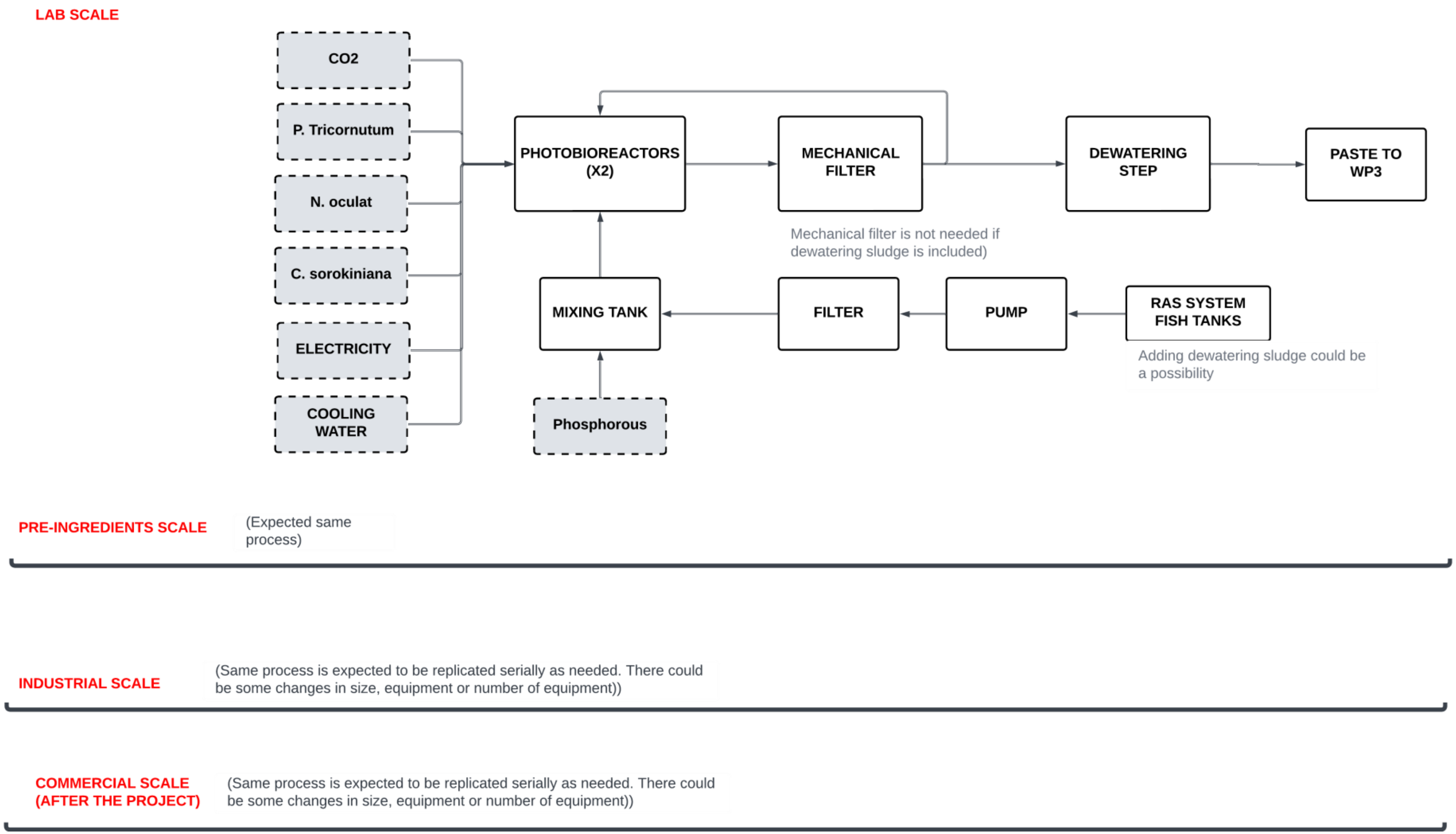

Figure 18. VSM Task 2.2. Development of a RAS-IMTA demo unit for salmon and microalgae aquaculture production

The value stream maps corresponding to the following activities are under development:

- T2.3 Development of a RAS-IMTA demo unit for seaweed and sole production
- T2.4 Algae biomass production
- T2.6 Waste valorisation of sludge generated from the integrated aquaculture production systems

Value Stream Mapping of WP3 Processes

The following figures show the mapping of the processes developed to date that are carried out in the different activities of WP3:

- T3.2 Extracts from microalgae following a cascading approach
- T3.4 Bioactive food extracts from fish processing waste

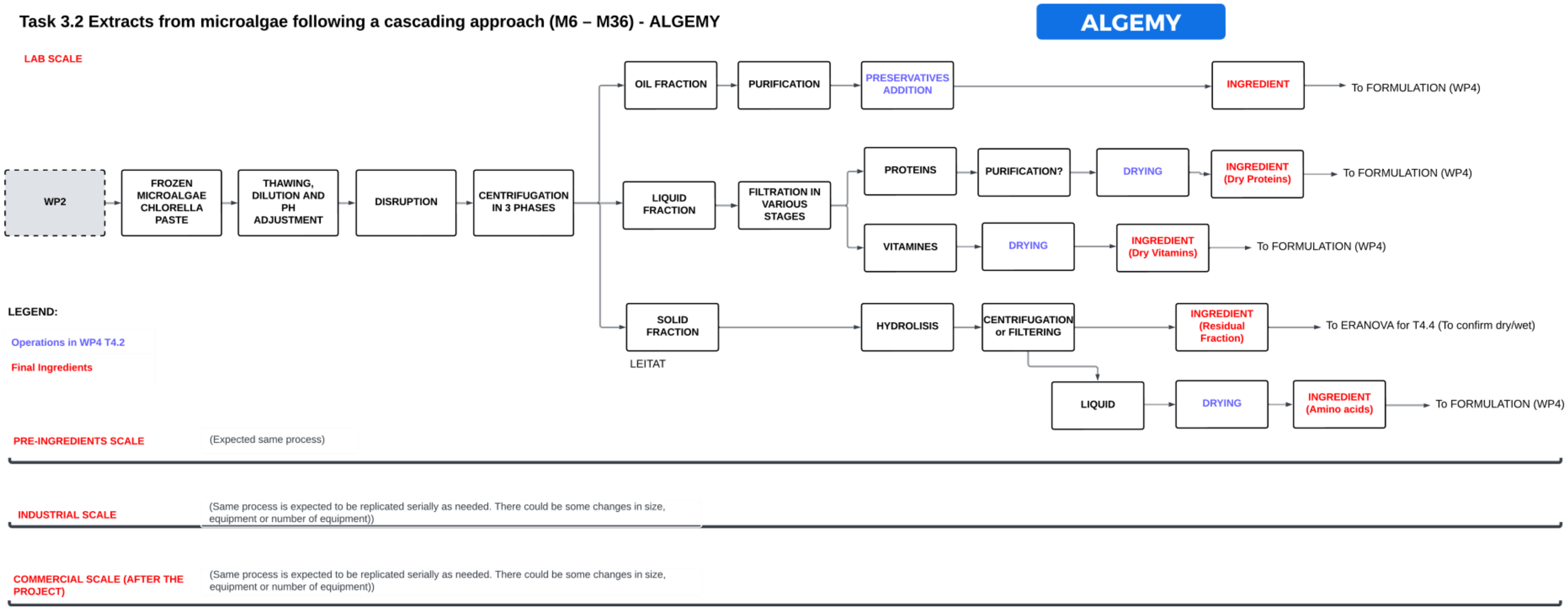

Figure 19. VSM Task 3.2. Extracts from microalgae following a cascading approach

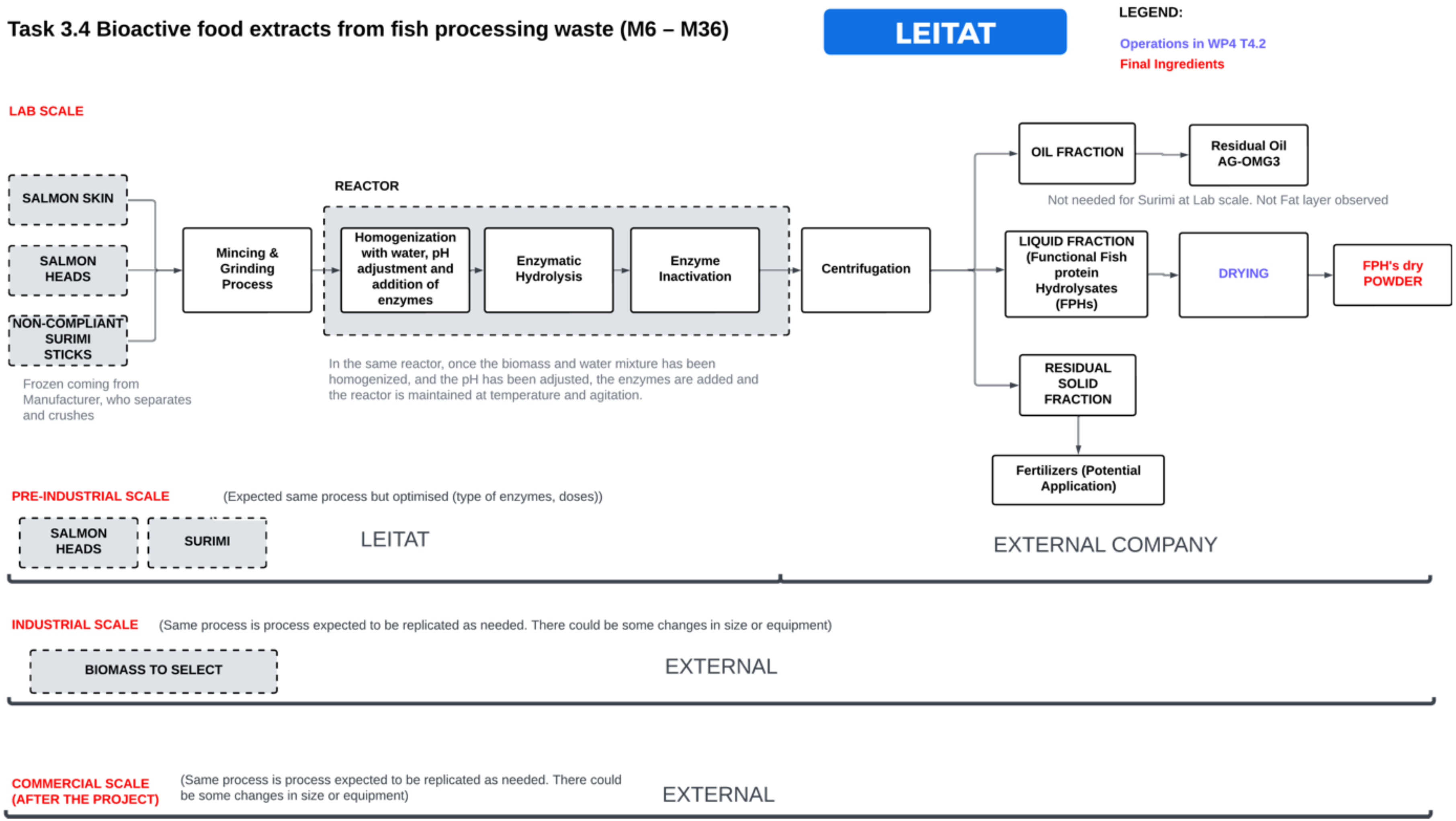

Figure 20. VSM Task 3.4. Bioactive food extracts from fish processing waste

The value stream maps corresponding to the following activities will be generated in the coming months:

- T3.1 Characterization of algae biomass and fish by-products
- T3.3 Extracts from macroalgae biomass in a cascading approach

Value Stream Mapping of WP4 Processes

As the following WP4 activities are developed in the next months, the different operations maps will be generated:

- T4.2 Turning extracts into ingredient products, which has mostly already been included in Figure 19 and Figure 20
- T4.3. Formulation and validation of food products
- T4.4. Upcycling of remaining algae fractions into packaging solutions

Next steps

Once all the processes are mapped and the different operations are identified, the next step will be to identify and quantify inputs and outputs, such as:

- Consumption of raw materials and substances,
- Consumption of resources (water, energy),
- Generation of different type of waste.

Next, we will identify the critical parameters related primarily to the life cycle costs and environmental impacts of both ingredients and seafood products during the lab scale, pre-ingredients, and scale-up phases. The objective is to analyse the potential impact of these critical parameters and their variability on the commercialization of ingredients and products. This analysis will help producers define requirements for serial production processes (see deliverable D4.1, reference [19]) and mitigate the risks that may arise during commercialization and serial production.

Complete value stream maps containing identification and quantification of inputs and outputs will be presented and developed in updated versions of this deliverable, which are Deliverable 5.7, to be released in month 30 (M30), and life cycle sustainability – circularity final report in Deliverable 5.8, to be released at the end of the project (M48).

4.1.2.2. Step 2: Circularity assessment

At this step, the evaluation of the circularity of the life cycle of the ingredients and products is to be carried out, analysing the alignment of the life cycle of the ingredients and products to the circular economy principles, defined as follows:

- Principle 1: Regenerate natural systems

Preserve and enhance natural capital by controlling finite stocks and balancing resource flows, meaning that technology and processes are chosen wisely according to their use of renewable or better-performing resources.

- Principle 2: Keep products and materials in use

Optimize resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles; meaning designing for remanufacturing, refurbishing and recycling to keep technical components and materials circulating in the economy, preserving embedded energy and other value. It also refers to encouraging biological nutrients to re-enter the biosphere in the safest way possible to become valuable feedstock for a new cycle.

- Principle 3: Design out waste and pollution

Foster system effectiveness by revealing and designing out negative externalities; this includes reducing damage to human utility, such as food, mobility, shelter, education, health and entertainment, and managing externalities, such as land use, air, water and noise pollution, release of toxic substances and climate change.

A simplified Material Circularity Indicator (S-MCI) is proposed to measure the extent to which linear flows have been minimised and restorative flows maximised for the materials and resources all along the life cycle of a ingredients and products.

Latest development from ISO 59000 series standards (more specifically ISO59020 and ISO 59040) will be considered to define circularity indicators and to perform circularity measurement.

4.1.2.3. Step 3: Sustainability assessment

Sustainability assessment of the life cycle of ingredients and products is to be done following the life cycle sustainability assessment approach (LCSA), combining the following assessments in the 3 dimensions:

- LCA (Life Cycle Assessment)
- LCC (Life Cycle Cost Assessment)
- SLCA (Social Life Cycle Assessment)

LCC and SLCA are developed within Task 5.2 and reported in Deliverable D5.1. LCA approach is described in section 4.1.2.3.1.

Sustainability indicators are extracted then from the impact categories assessed for every of the 3 dimensions evaluated, and a Sustainability Overall Score (SOS) is to be built combining the selected sustainability indicators.

We need to point out that the sustainability indicators are of different magnitudes and units, even within the environmental domain, so specific techniques are needed to combine them.

Since there could be several criteria to follow, multiple objectives to achieve and requirements to meet, Multi Criteria Decision Analysis (MCDA) and Multi Objective Decision Making (MODM) methods should be used to compare solutions with the environmental impact indicators and costs indicators selected (see reference [13]).

For this reason, sustainability will be evaluated by comparison, either between alternative solutions or comparing a specific solution against maximum or minimum values of specific indicators that can be established as requirements. These methods should be used for material or product development to compare different alternatives, since there is always a need to meet multiple requirements, such as:

- Cost requirements from the market
- Environmental impacts requirements to reduce their carbon footprint
- Continuous improvement measures taken internally by a company to reduce the carbon footprint or environmental impacts.

- Potential threshold values from future legislation to specific impacts, such as carbon footprint
- Etc…

Since there is relatively little experience applying them to sustainability assessment (see reference [13]), the following simplified method is proposed.

We suggest using normalization and weighting techniques to combine and compare them properly. Normalization and weighting is a very widely used technique for supporting multi-criteria decision making process based of heterogeneous inputs.

The following formula is proposed to normalize the different indicators (environmental, costs and social impact dimensions). It is oriented to normalize a specific indicator compared to maximum and minimum values of product alternatives for the same indicator.

$$v_i = \frac{a_i - \min a_i}{\max a_i - \min a_i}$$

Next tables show an example of application of the formula to environmental impact indicators for a simulated case study of 4 product alternatives.

DATA

Product Alternative Solution	Environmental Impact [pt]							
	Global Warming Potential (GWP) [kg CO2 eq]	Acidification potential (AP) [mol H+ eq]	Eutrophication potential (EP) [kg P eq]	Photochemical ozone creation potential (POCP) [kg NMVOC eq]	Ozone depletion potential (ODP) [kg CFC 11 eq]	Abiotic depletion potential (ADP) for minerals & metals [kg Sb eq.]	Abiotic depletion potential (ADP) for fossil resources [MJ]	Water deprivation potential (WDP) [m3 eq]
Product 1	0,077	3,20	0,145	1,600	1,730	6,300	3,200	2,100
Product 2	0,081	3,52	0,16	1,36	1,90	6,615	3,360	2,520
Product 3	0,085	3,87	0,14	1,16	1,64	6,946	3,528	2,394
Product 4	0,089	4,26	0,15	0,98	1,81	7,293	3,704	1,915

NORMALIZATION PROCEDURE $v_i = \frac{a_i - \min a_i}{\max a_i - \min a_i}$

Product Alternative Solution	Environmental Impact [pt]							
	Global Warming Potential (GWP)	Acidification potential (AP)	Eutrophication potential (EP)	Photochemical ozone creation potential (POCP)	Ozone depletion potential (ODP)	Abiotic depletion potential (ADP) for minerals and metals	Abiotic depletion potential (ADP) for fossil resources	Water deprivation potential (WDP)
Product 1	0,000	0,000	0,333	1,000	0,333	0,000	0,000	0,306
Product 2	0,317	0,302	1,000	0,611	1,000	0,317	0,317	1,000
Product 3	0,650	0,634	0,000	0,281	0,000	0,650	0,650	0,792
Product 4	1,000	1,000	0,633	0,000	0,633	1,000	1,000	0,000

Table 3. Example of application of normalization formula to environmental impact indicators

On top of that, we need to combine different indicators from different dimensions, considering that the goal of the solutions is usually to be competitive in costs with the minimum environmental impacts.

Therefore, in addition to normalization, the simplified method to obtain a SOS (Sustainability Overall Score) proposes to carry out weighting in 2 different levels:

- 1st level: Weighting within separate sustainability dimensions (environmental, cost, social impact)
- 2nd level: Weighting of the three sustainability dimensions

4.1.2.3.1. LCA (Life Cycle Assessment)

Life Cycle Assessment (LCA), as defined in ISO14040 (reference [3]), is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle, addressing from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal. Environmental impacts in the LCA context refer to adverse impacts on the areas of concern such as ecosystem, human health, and natural resources.

According to ISO14040, LCA studies comprises four phases:

- Goal and scope definition
- Inventory analysis
- Impact assessment and
- Interpretation.

First step is to define the goal and scope of the assessment. Corresponding applicable Product Category Rules to the product under study guides to define the functional unit, systems boundaries and life cycle phases to consider.

A *cradle to grave* approach should be applied to assess the environmental impacts throughout all the life cycle phases according to the corresponding applicable Product Category Rules (PCR) to the ingredients and products under study.

Scope of the assessment should include the identification of the potential scenarios (Figure 14), as described in Step 1 (Value Stream Mapping), in order to have a clear perspective of the variability of environmental impacts to the different scenarios and to identify later on the critical parameters related to circularity and sustainability assessment.

Life Cycle Inventory has been done previously in Step 1 mapping all the operations throughout life cycle of the product, and identifying inputs and outputs for the functional unit defined, which are all the materials, auxiliary raw materials and resources (water, energy) consumed in the different operations, as well as the waste generated.

Then, all the Life Cycle Inventory data have to be imported to a recognized LCA software, such as GaBi, Simapro or openLCA, to build Life Cycle Inventory as a needed step to perform Life Cycle Impact Assessment and calculate environmental impacts.

Applicable PCR (Product Category Rules) also defines the environmental impact categories and impacts assessment methods for the estimation of environmental impacts. Following table 4 shows the list of default environmental impact categories and indicators according to the International EPD System[5].

Table 4. List of the default environmental impact and inventory indicators

Environmental Impact Categories	Unit
Global Warming Potential (GWP)	kg CO2 eq
Acidification potential (AP)	mol H+ eq
Eutrophication potential (EP)	kg P eq
Photochemical ozone creation potential (POCP)	kg NMVOC eq
Ozone depletion potential (ODP)	kg CFC 11 eq
Abiotic depletion potential (ADP) for minerals and metals (non-fossil resources)	kg Sb eq.
Abiotic depletion potential (ADP) for fossil resources	MJ
Water deprivation potential (WDP)	m3 eq.

A brief description of these environmental impact categories:

- Global Warming Potential: Indicator of potential global warming due to emissions of greenhouse gases to air. Divided into three subcategories based on the emission source: (1) fossil resources, (2) bio-based resources and (3) land use change.

[5] Environmental Performance Indicators (https://www.environdec.com/indicators). The International EPD System

- Acidification: Indicator of the potential acidification of soils and water due to the release of gases such as nitrogen oxides and sulphur oxides
- Eutrophication is defined as the potential to cause over-fertilisation of water and soil, which can result in increased growth of biomass
- Photochemical ozone creation potential (POCP), quantifies the relative abilities of volatile organic compounds (VOCs) to produce ground level ozone
- Ozone depletion potential (ODP), indicates the potential of emissions of chlorofluorohydrocarbons (CFCs) and chlorinated hydrocarbons (HCs) for depleting the ozone layer
- Abiotic depletion potential (ADP) for minerals and metals (non-fossil resources), refers to the removal of abiotic resources from the earth, or the depletion of non-living natural resources. In this case for non-fossil based resources (minerals and metals)
- Abiotic depletion potential (ADP) for fossil resources
- Water deprivation potential (WDP). It quantifies the potential of water deprivation, to either humans or ecosystems, and serves in calculating the impact score of water consumption at midpoint in LCA or to calculate a water scarcity footprint as per ISO 14046

So, once life cycle inventory is built within the LCA software for the scope and scenarios defined, impact assessment method is chosen and then environmental impacts for these impact categories will be obtained.

4.1.2.4. Step 4: Sustainability – circularity assessment

In this step a circularity – sustainability assessment is to be carried out combining the most relevant circularity and sustainability indicators, aiming to obtain optimum technical solutions in terms of sustainability and circularity.

At this point, the most critical parameters influencing circularity and sustainability indicators have to be identified in order to conduct the different sensitivity analyses against these critical parameters.

Then, identification of risks and opportunities for the different alternatives related to competitiveness, sustainability and circularity is to be carried out, considering mainly the following aspects:

- Availability and cost volatility of raw materials and resources
- Legislation trends (Europe, national, regional)
- Market, sector & customer requirements trends
- Technology trends

To finish this step, a trade-off analysis of the different alternatives for the ingredients and products under study will be carried out, in order the obtain an optimal technical solution in terms of circularity and sustainability.

- Different scenarios for the same solution
- Alternative solutions in any phase of the life cycle

4.2. Alignment with and contribution to international policies

Aim of this part is to analyse and estimate the contribution of INNOAQUA's sustainability and circularity impacts to the most relevant international policies, such as:

- Sustainable Development Goals (SDGs; United Nations),
- Green Deal and Farm to Fork Strategy (European Union),
- Resilience Dashboards (European Union).

4.2.1. SDGs (Sustainable Development Goals)

The identification of the SDGs and their specific applicable targets to which the project contributes will be carried out and an estimate of the quantification of the project will be made for each of the identified goals.

The project contributes to the following SDGs related to environmental sustainability and circularity:

- **SDG9: Industry, Innovation and Infrastructure**. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. Ensure sustainable consumption and production patterns.

- INNOAQUA drives innovation in the aquaculture and ingredient production sectors through the implementation of advanced technologies such as integration of land-based production of fish and algae, as well as ultrasound-assisted extraction and enzymatic treatment in the biorefinery approach. This encourages the modernization of industrial infrastructure, improves efficiency and promotes research and development of new products derived from aquatic resources.
- INNOAQUA promotes sustainable management of aquatic resources, contributing to the reduction of waste in the aquaculture. By recycling byproducts that are traditionally discarded, the project supports the conservation of marine and aquaculture resources.

- **SDG12: Responsible Consumption and Production**. Ensure sustainable consumption and production patterns.
  - INNOAQUA's focus on waste reuse and resource optimization contributes to a more efficient and responsible production model. By reducing waste and maximizing the value of by-products, the project helps minimize the environmental impact of the fishing and aquaculture industry, while promoting more responsible consumption of marine resources.
- **SDG14: Life Below Water**. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
  - The conservation of marine ecosystems and the reduction of fishery waste are key objectives for SDG 14. INNOAQUA promotes the sustainable management of marine resources by reducing the amount of waste generated by the fishing industry and encouraging practices that minimize the overexploitation of species. By taking advantage of waste and transforming it into useful products, the project contributes to a more balanced and sustainable exploitation of aquatic ecosystems.

Quantification of the indicators values applicable to the SDGs specific targets, will be carried out in the next months and reported in the updated version of this deliverable (Deliverable 5.7), to be released in month 30 (M30).

4.2.2. Farm to Fork Strategy

The Farm to Fork Strategy aims to accelerate our transition to a sustainable food system that should:

- have a neutral or positive environmental impact,
- help to mitigate climate change and adapt to its impacts,
- reverse the loss of biodiversity,
- ensure food security, nutrition and public health, making sure that everyone has access to sufficient, safe, nutritious, sustainable food,
- preserve affordability of food while generating fairer economic returns, fostering competitiveness of the EU supply sector and promoting fair trade.

Regarding sustainability and circularity impacts, the analysis of the alignment and contribution of the INNOAQUA project will focus on:

- have a neutral or positive environmental impact
- help to mitigate climate change and adapt to its impacts
- reverse the loss of biodiversity
- ensure food security, nutrition and public health, making sure that everyone has access to sufficient, safe, nutritious, sustainable food

4.2.3. EU Resilience Dashboards

Resilience is a new compass for EU policies. Building a more resilient society calls for enhancing the capacity for adaptation and transformation, urging to shift towards a paradigm of a more sustainable growth and societal development path. Through a broad set of indicators, the resilience dashboards assess the relative strengths and weaknesses of countries. They also help Member States to identify areas for further analysis and potential policy actions. The indicators span four dimensions: social and economic, green, digital, and geopolitical. INNOAQUA's alignment and contribution to relevant indicators on the green dimension will be assessed.

5. Results

Since most of the tasks needed to collect data for these assessments are under development, results of the implementation of the methodology will be compiled and presented in updated versions of this deliverable, which are Deliverable 5.7, to be released in month 30 (M30), and life cycle sustainability – circularity final report in Deliverable 5.8, to be released at the end of the project (M48).

5.1. Sustainability – circularity assessment

To be completed in Deliverable 5.7.

5.2. Alignment with and contribution to international policies

To be completed in Deliverable 5.7.

6. Conclusions

This document defines the scope and the methodology to carry out the sustainability - circularity assessment throughout the project. Methodology contains 2 different phases:

- **Phase 1: Sustainability - circularity assessment**, which will be done at 2 different levels:
  - Sustainability - circularity impacts at a project level
  - Sustainability - circularity impacts at ingredients and products level
- **Phase 2: Alignment to international policies.** At this step, the process for the analysis of contribution of the project regarding environmental sustainability and circularity, to most relevant sustainability related international policies is described, such as SDGs, Green Deal and Farm to Fork (F2F) Strategy and EU Resilience Dashboards.

Results of the implementation of the methodology will be compiled and presented in a first step in an updated version of this deliverable, Deliverable 5.7, to be released in month 30 (M30).

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