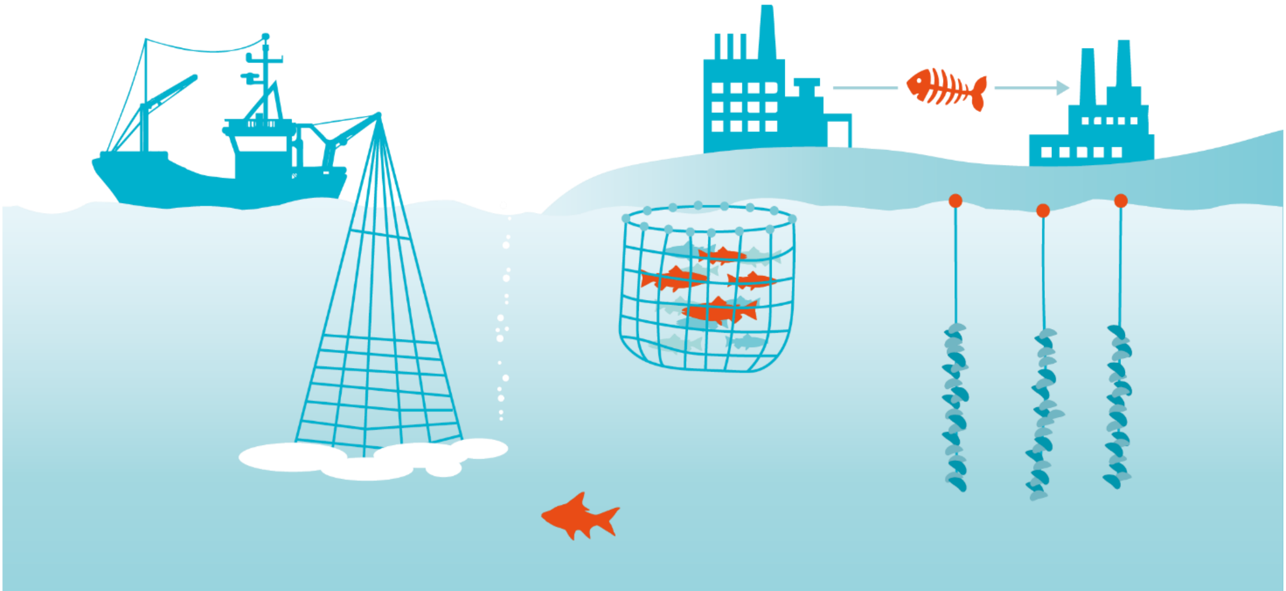
Optimal utilization of seafood side-streams through the design of new holistic process lines

D2.4 Methodology for the selection of optimum valorisation options of side streams



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1 Executive Summary

The main objective of the WP2 "Logistics and Supply Chain Management" is to maintain quality and safety of fish side-streams and by-catches for the next steps of the value-adding chain, stabilization solutions and aid in decision making are required. So, in this work package, innovative methodologies for logistics including sorting, storage, and decision making have been therefore investigated.

Within this framework, one of the most important hurdles and bottlenecks to overcome when implementing valorisation alternatives is the lack of a methodology which helps to take the right decision. Different fractions of fish side-streams have different potentials for obtaining high value products. However, the viability of these specific high value products from residual streams depends on a huge amount of viability factors, which are necessary to consider in a holistic way.

This deliverable D2.2 "*Methodology for the selection of optimum valorisation options of side streams*" is focused on the development of tools and methods to support decision-making that result in guidebooks and guidelines that describe the process and end-products including cost-benefit analysis.

The Analytic Hierarchy Process (AHP) methodology can help to take the optimum decision about the different fish residual streams valorisation strategies based on 1) their potential for being converted to high value products and 2) potential synergies with other fish residual side-streams generated close to them.

Regarding the potential for obtaining high value products, this methodology identifies and establishes the relative importance of the most important technical, legal, economic, and environmental viability factors for each valorisation alternative, and it develops the decision matrixes and rules with the corresponding algorithms and functions to take right decision about a valorisation strategy. In addition, it considers the potential synergies with other fish residual side-streams by considering the implication of adding them to the single scenario: quantities, logistics implications, etc.

Thus, this methodology helps to decide which fractions of the fish side-streams that should be sorted separately and how they must be stored and managed to enable and ensure enough quality for obtaining these high value products based on 1) their potential for a specific valorisation alternative and 2) the feasibility, profitability and sustainability considering potential synergies with other fish side-streams generated close to them.

In case of interest in using this methodology please contact info@azti.es including the reference to the "WASEABI-AHP".

2 About this document

This document describes a methodology for the selection of optimum valorisation options of side streams through the Analytic Hierarchy Process (AHP) method. It divides the decision-making process into four sub-problems: 1) legal viability, 2) technical feasibility, 3) economic profitability and 4) environmental sustainability assessment. A set of decision-making criteria which influence on each sub-problem are selected. In addition, the relative importance of each criterion on each sub-problem is determined by criteria weighing. Then, limiting and conditional ranges are also determined based on which the decision matrices and rules are created to solve each sub-problem under study. These decision matrices are performed considering that values for each criterion must be multiplied by its relative weight and then summed to get the global score. All possible values of each criterion are classified based on a scale from 1 (less unsuitable) to 10 (the most suitable), which indicates a higher or lower feasibility for each criterion. This classification is assigned according to international references and experts' experience (WP3 leaders). Then, a linear summarization of the score of each criterion is performed to calculate the final score. The calculated global score indicates if the global viability of a sub-problem is higher or lower based on a previously defined scale.

This report also includes a simulation example of the viability of valorisation of a by-product generation scenario based on real data by applying membrane filtration to obtain an aroma concentrate. The different results about 1) legal viability, 2) technical feasibility, 3) economic profitability and 4) environmental sustainability assessment, are presented based on the outputs of the tool.

3 Methodology

Analytic Hierarchy Process (AHP[1]) method divides the decision-making process into four sub-problems: 1) Legal viability; 2) Technical feasibility; 3) Economic profitability; 4) Environmental sustainability. Then, a set of decision-making criteria which influence on each sub-problem are selected. In addition, the relative importance of each criterion on each sub-problem is determined by criteria weighing. The following is to determine the limiting and conditional ranges based on which the decision matrices and rules are created to solve each sub-problem under study. These decision matrices are made considering that the values for each criterion must be multiplied by their relative weights and then added to obtain the global score. All possible values of each criterion are rated on a scale from 1 (less unsuitable) to 10 (the most suitable) which indicates a higher or lower feasibility for each criterion. This rate is assigned according to international references and experts' experience (WP3 leaders). Then, a linear summation of the score for each criterion is performed to calculate the final score. The calculated global score indicates if the global viability of a sub-problem is higher or lower based on a previously defined scale. The procedure is repeated upward for each sub-problem. The scenario with the highest score is considered as the most optimum option.

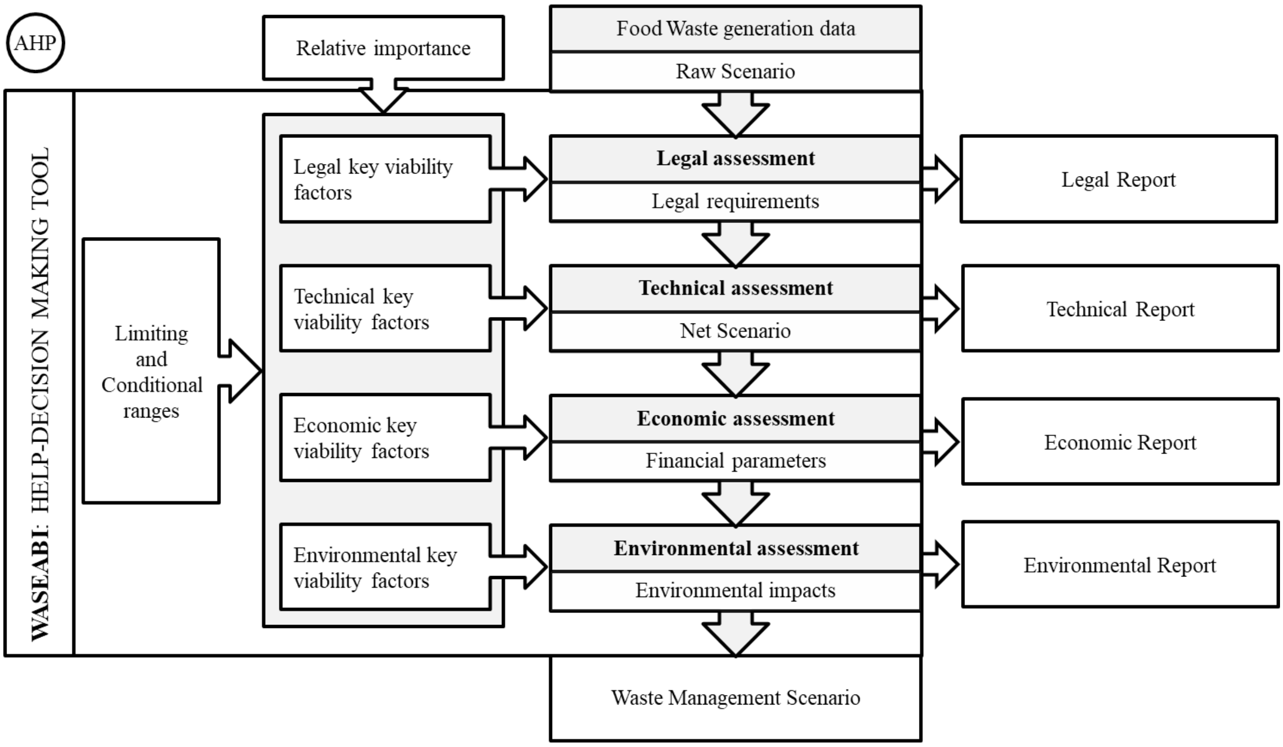


Figure 1: Scheme of the WASEABI AHP Tool

[1] Saaty T (1980) The Analytical Hierarchy Process, New York, USA: McGraw-Hill.

3.1 Criteria selection

The wide number of criteria that is necessary to consider in waste management[2] shows the importance of the conceptual and methodological work in this area. The principles applied for the criteria selection is:

- The systemic principle, in which the criteria scheme should roundly reflect the essential characteristic and the whole performance of the waste management solution.
- The measurability principle, in which the criteria should be measurable in quantitative value as possible or qualitatively expressed.
- The comparability principle, where the decision-making result is more rational when the comparability of criteria is more obvious.

The identified criteria are agreed by an external experts' panel (in this case the WP3 leaders). Finally, the criteria are normalized to allow comparing them properly.

3.2 Criteria weighting

It is important to point out that all these criteria may differ depending on the decision maker's priorities. Therefore, different methods followed for criteria weighing are agreed with the previously described external experts' panel (WP3 leaders). This panel recommended choosing the Objective rank-order for legislative criteria, the Subjective Rank-order for technical criteria and, finally, the Equal weighing method for economic and environmental criteria weighing:

- Objective rank-order weighting method. In this case, the judgments of decision-makers now depend on the quantitative measured data of waste management solution. The main reasoning behind the expert's panel decision to use the Objective rank-order weighing method for legislative criteria weighing was basically that the legal requirements are established by legislation and, therefore, its fulfilling is compulsory.
- Subjective rank-order weighting method. This method depends mostly on the requirements of decision-makers. The judgments of decision- makers depend on their available knowledge and information. The main reasoning behind the expert's panel decision to use the Subjective rank-order weighing method for technical criteria weighing was basically that the influence of the decision – maker's requirements is very important in the technical assessment and depends on their available knowledge and information.
- Equal weighting method. This method requires minimal knowledge of the decision - maker's priorities and minimal input from decision maker. This weigh method can be easily modified afterwards according to the decision-maker's priorities. Thus, while a public administration may give more weight to the environmental criteria, private investors may consider more important the economic ones. The main reasoning behind the expert's panel decision to use the Equal weighing method for economic and environmental criteria weighing was basically that the influence of the decision – maker's priorities in the economic and environmental assessment should be minimal.

[2] San Martin D, Orive M, Martínez E, Iñarra B, Ramos S, González N, Guinea de Salas A, Vázquez L, Zufía J (2017) Decision Making Supporting Tool Combining AHP Method with GIS for Implementing Food Waste Valorisation Strategies. Waste Biomass Valori 8: 1555-1567

3.3 Limiting and Conditional ranges

Limiting ranges are maximum and/or minimum values for a criterion related with a type of fish side-streams above and/or below which this kind of side-streams will be rejected as not viable for the valorisation option under study and should be rejected. For example, when a value of a fish side stream composition parameter established by law as a legal requirement is outside the established legal range (limiting range), it will be proposed as rejected for the study.

Conditional ranges are values within the limiting ranges which involves that a type of fish side-stream is suitable (viable) for the valorisation option under study. In this case, a higher or lower value (depending on whether the criterion is directly or inversely proportional) determines higher or lower viability. For example, a higher protein content in the raw material implies a higher viability in the case of final products based on protein concentrate.

3.4 Decision matrices

A decision matrix is a list of values in rows and columns which allows analysing and rating relationships between values and information. Therefore, decision matrices include criteria, weighs and limiting and conditional ranges. One decision matrix to solve each sub-problem is performed.

3.5 Decision rules

A decision rule is a function to estimate a parameter based on previously defined criteria. Therefore, decision rules include the necessary algorithms and equations to solve each sub-problem.

3.5.1 Legal assessment

The legal viability is calculated by verifying that each parameter falls inside the limiting ranges (legal requirements). The result is a Boolean value of type True/False.

3.5.2 Technical assessment

The result of technical viability is a real, positive number between 0 and 10. It is calculated as the weighted sum of the absolute scores associated to each technical parameter:

3.5.3 Economic assessment

The following parameters were calculated:

- Gross operating profit (EBITDA)
- Net Present Values (NPV)
- Enrichment Index (NVP/Initial Investment)
- Discount rate / Internal rate of return
- Payback period (PBT)
- Return on investment (ROI)
- Free cash flow

3.5.4 Environmental assessment

To calculate the selected environmental indicators, the Environmental Footprint (EF[3]) v3.0 method recommended by the European Union was considered. To calculate the potential impacts, the classification and characterization step are performed. Classification steps requires assigning the material/energy inputs and outputs gathered in the resource use profile and emissions to the corresponding impact category. For instance, during the classification phase, all inputs/outputs that give rise to the inputs/outputs that result in greenhouse gas emissions are assigned to the carbon footprint indicator. Characterization step refers to the calculation of the contribution magnitude of each classified input/output to their respective impact indicator, and the aggregation of the contributions within each impact indicator. This is done by multiplying the resource use and emissions values by the corresponding characterization factor (CF) for each impact indicator. For instance, the CF expressed as global warming potential for methane equals 25 CO_2 equivalents compared to the 1 CO_2 equivalent of 1 CO_2.

Three main impact categories have been selected:

Carbon footprint: This impact indicator, also called climate change, is presented by radiative forcing as global warming (GWP) potential. This category considers the IPCC (Intergovernmental Panel on Climate Change) 100-year reference model. It is represented in kg CO_2 eq.

Eutrophication (aquatic) Potential: This category expresses the degree of impact on ecosystems caused by nitrogen and phosphorus emissions mainly due to fertilizers, combustion, sewage systems. It is represented in kg P eq.

Water footprint: This category represents the depletion of available water based on local water scarcity and water requirements for human activities and ecosystem integrity. The result represents the relative value compared to the average m3 consumed in the world (the world average is calculated as a weighted average of consumption). This category is based on Available WAter REmaining (AWARE), as recommended by UNEP, 2016. The weighted deprivation potential of users is represented in global m^3 eq.

[3] European Commission, 2012. Product Environmental Footprint (PEF) Guide 154.

4 Definition of matrices and criteria

In this section, the decision matrices for the following valorisation options under study in the project are presented (see the figure 2). They include the viability factors (criteria) which influence in each subproblem (legal, technical, economic, and environmental assessment), their relative importance (criteria weighting), the limiting and conditional ranges and the decision rules.

Nº	Technological process	Type of Fish side-stream	Product obtained	Responsible	Partner	Example of fish side-streams studied in the WASEABI project
1	Membrane concentration	Liquid	Flavours / Aroma concentrate	Mónica Gutierrez	AZTI	Mussel cooking water
2	Flocculation	Liquid	Protein and lipids concentrate	Bita Forghani	Chalmer	Herring water Cod brine Mussel cooking water
3	pH shift	Liquid & Solid	Protein isolates	Mehdi Abdollahi	Chalmer	Cod brine Cod solid side-stream Herring liquid and solid side-stream Mussel cooking water
4	Enzymatic hydrolysis	Solid	Bioactive peptides	Ann-Dorit Moltke Sørensen Bruno Iñarra	DTU - AZTI	Whole mackerel Salmon solid side-stream Mussel shell Cod solid side-stream Herring solid side-stream
5	Enzymatic hydrolysis	Solid	Savoury compounds	Ann-Dorit Moltke Sørensen Carlos Bald	DTU - AZTI	Salmon solid side-stream Cod solid side-stream
6	Drying	Solid	Minerals	Ann-Dorit Moltke Sørensen Carlos Bald	DTU - AZTI	Fish bones

Figure 2: Valorisation options under study in the WaSeaBi project.

4.1 WASEABI AHP tool example

The WASEABI AHP tool has been programmed based on the decision matrices for each valorisation option under study.

The first decision that the user must take is to decide which valorisation option is going to be assessed for the scenario under study:

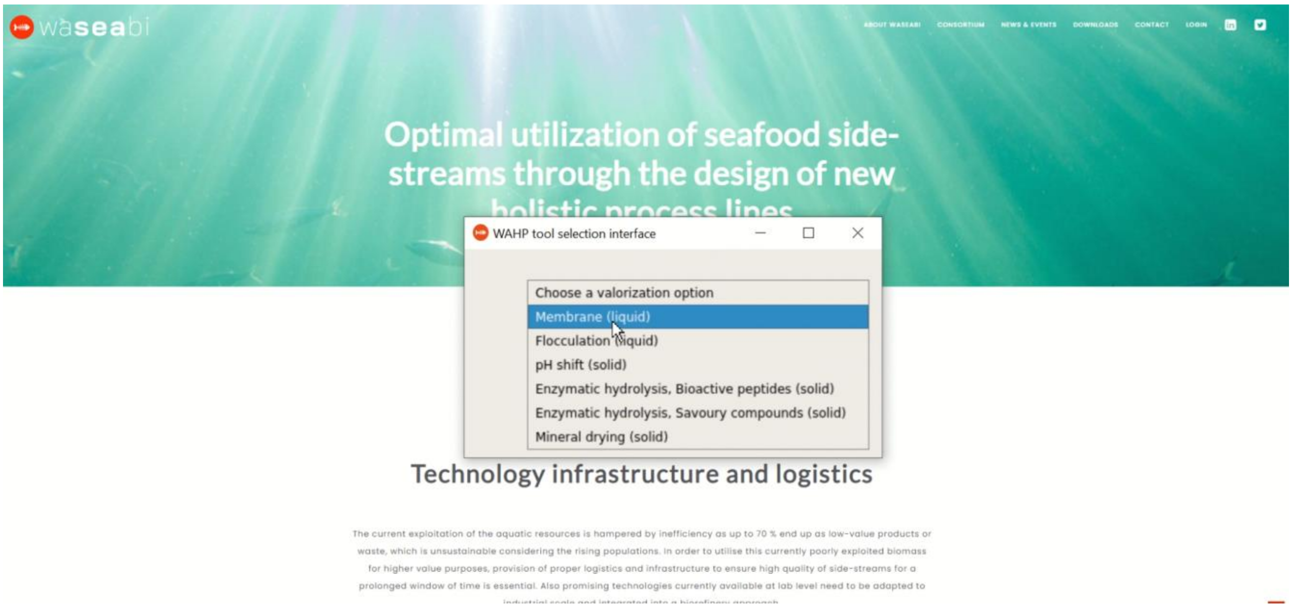


Figure 33: Selection of the Valorisation option to assess

Once this option is selected, user must provide the different values for all the criteria for each subproblem: 1) legal viability, 2) technical feasibility, 3) economic profitability and 4) environmental sustainability assessment.

From now on, this Deliverable is going to focus on the valorisation option of "*Membrane concentration*" to produce "*Flavours / Aroma concentrate*" with the objective of serving as an example to present the WASEABI AHP tool. Within this framework, the scenario of Pescados Marcelino about its generation of mussel cooking water has been used as the scenario under study. The different results obtained with the tool are shown below: Legal viability assessment.

The first assessment is the legal viability assessment to ensure the suitability of each generation point from its legal and safety point of view.

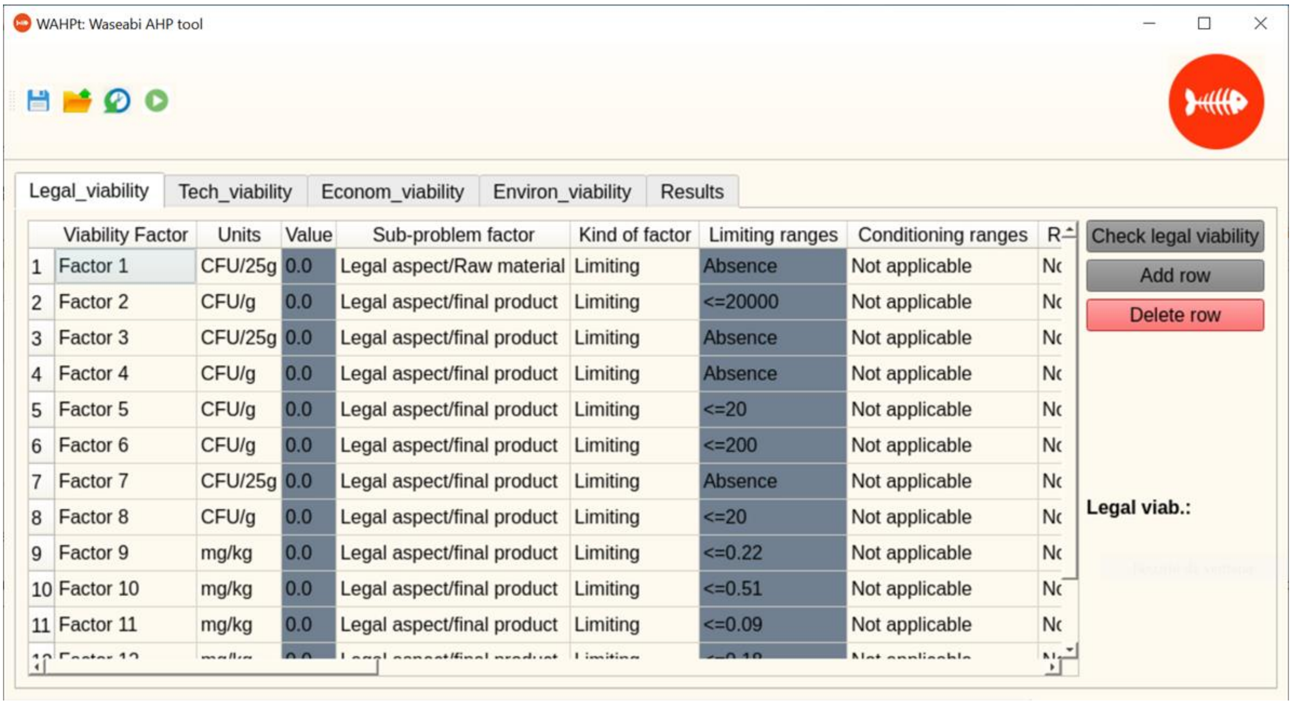
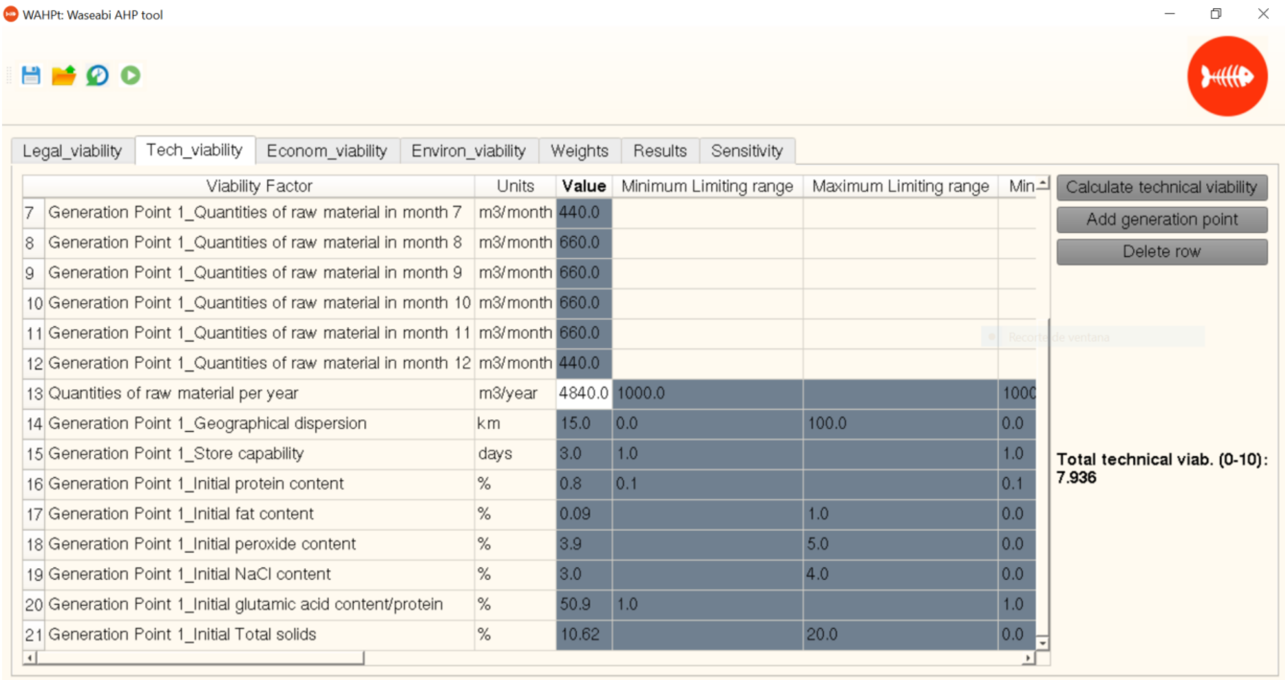


Figure 34: Output about Legal viability assessment

In this case, all the legal requirements have been fulfilled so the legal viability assessment is Ok. Otherwise, the tool will provide user an advertisement of the legal parameters that are out of the Limiting range.

4.1.1 Technical feasibility assessment

The second step is based on the selected criteria and their relative importance. The tool will propose to eliminate from the studied scenario the generation points that do not meet the required limit ranges. Then, the viability will be calculated based on the fulfilment of the conditional ranges of each technical criterion. Thus, the corresponding decision matrixes and rule provide a weighted viability score based on the relative importance weights of each technical criterion. 10 points is the maximum score of the evaluation and the scores close to 10 indicate that these by-products are fit and very interesting for this application. 1 point is the minimum score, and the scores close to 1 indicate that these by-products are not fit nor interesting.



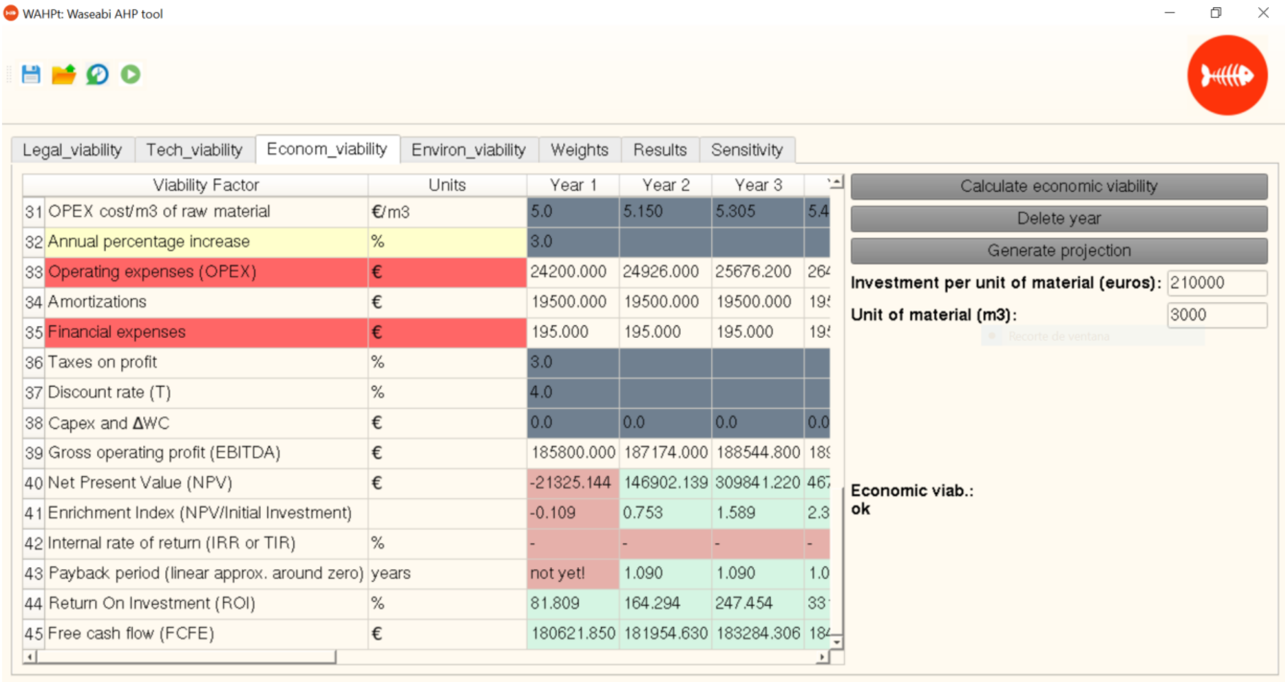
	Viability Factor	Units	Value	Minimum Limiting range	Maximum Limiting range	Min
7	Generation Point 1_Quantities of raw material in month 7	m3/month	440.0			
8	Generation Point 1_Quantities of raw material in month 8	m3/month	660.0			
9	Generation Point 1_Quantities of raw material in month 9	m3/month	660.0			
10	Generation Point 1_Quantities of raw material in month 10	m3/month	660.0			
11	Generation Point 1_Quantities of raw material in month 11	m3/month	660.0			
12	Generation Point 1_Quantities of raw material in month 12	m3/month	440.0			
13	Quantities of raw material per year	m3/year	4840.0	1000.0		100(
14	Generation Point 1_Geographical dispersion	km	15.0	0.0	100.0	0.0
15	Generation Point 1_Store capability	days	3.0	1.0		1.0
16	Generation Point 1_Initial protein content	%	0.8	0.1		0.1
17	Generation Point 1_Initial fat content	%	0.09		1.0	0.0
18	Generation Point 1_Initial peroxide content	%	3.9		5.0	0.0
19	Generation Point 1_Initial NaCl content	%	3.0		4.0	0.0
20	Generation Point 1_Initial glutamic acid content/protein	%	50.9	1.0		1.0
21	Generation Point 1_Initial Total solids	%	10.62		20.0	0.0

Figure 35: Output about Technical feasibility assessment

In this case, based on the criteria, the limiting and conditional range and the relative importance defined in the Decision matrix, the specific score for the technical feasibility assessment of this scenario is 7.936 of a maximum score of 10, which indicates a good technical feasibility. All the parameters are inside the limiting range, otherwise a warning will appear to the user informing that there is a key parameter out of the Limiting range.

4.1.2 Economic profitability assessment

The third output is an Economic Analysis with the aim of providing insight into the structure of cost and benefits. It includes the Gross operating profit (EBITDA), the Net Present Values (NPV), the Enrichment Index (NVP/Initial Investment), the Internal rate of return (IRR or TIR): the Payback period (PBT), the Return on investment (ROI) and the Free cash flow, which are widely accepted in economic-cum-environment studies for wide reasons.



	Viability Factor	Units	Year 1	Year 2	Year 3	
31	OPEX cost/m3 of raw material	€/m3	5.0	5.150	5.305	5.4
32	Annual percentage increase	%	3.0			
33	Operating expenses (OPEX)	€	24200.000	24926.000	25676.200	264
34	Amortizations	€	19500.000	19500.000	19500.000	19
35	Financial expenses	€	195.000	195.000	195.000	19
36	Taxes on profit	%	3.0			
37	Discount rate (T)	%	4.0			
38	Capex and ΔWC	€	0.0	0.0	0.0	0.0
39	Gross operating profit (EBITDA)	€	185800.000	187174.000	188544.800	18
40	Net Present Value (NPV)	€	-21325.144	146902.139	309841.220	46
41	Enrichment Index (NPV/Initial Investment)		-0.109	0.753	1.589	2.3
42	Internal rate of return (IRR or TIR)	%	-	-	-	-
43	Payback period (linear approx. around zero)	years	not yet!	1.090	1.090	1.0
44	Return On Investment (ROI)	%	81.809	164.294	247.454	33
45	Free cash flow (FCFE)	€	180621.850	181954.630	183284.306	18

Figure 36: Output about Economic profitability assessment

In this case, the obtained results are based on the data provided by user (incomes, costs, funding conditions, etc.) and the main important result is a Payback period of 1 year which means that the investment is retrieved in 1 year.

4.1.3 Environmental sustainability assessment

The fourth step is the Environmental Assessment which is based on the life cycle thinking philosophy. It includes the estimation of carbon footprint (climate change indicator); the Eutrophication Potential and Water footprint (water use) based on the Environmental Footprint v3.0 (recommended by the European Union) which are identified as the most relevant environmental indicators for the marine waste management sector.

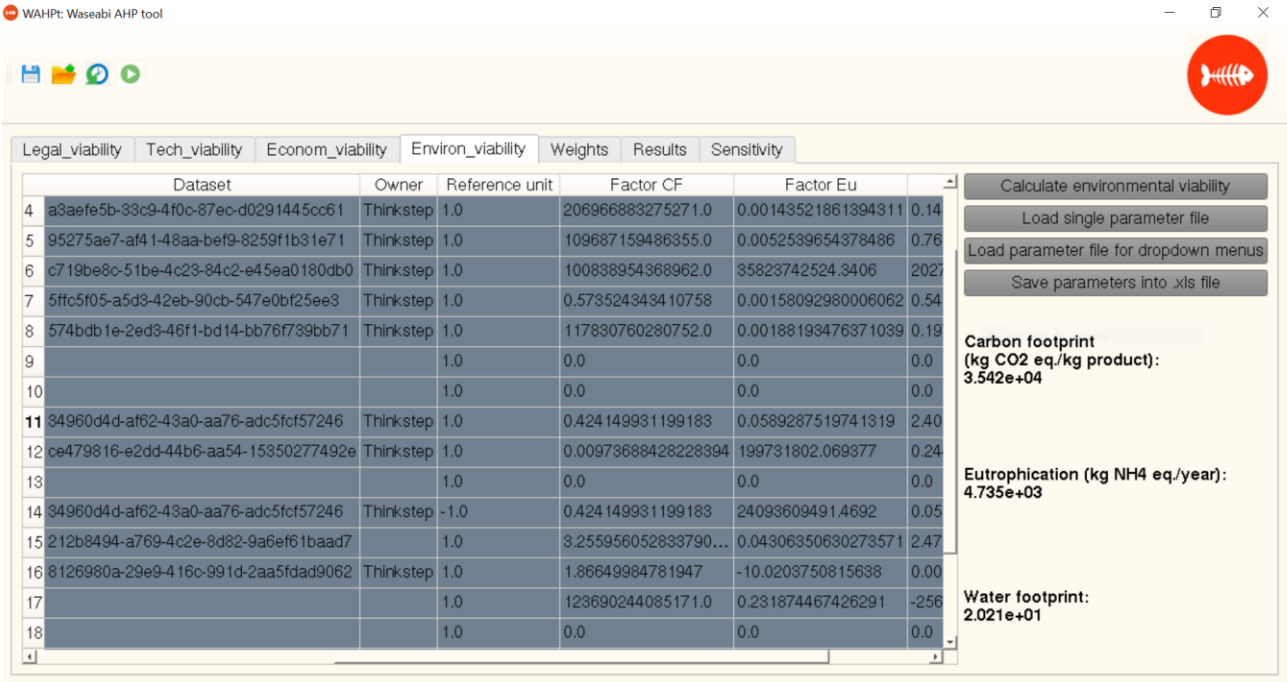


Figure 37: Output about Environmental sustainability assessment

In this case, the outputs are a Carbon footprint of 3.542 e+04 kg Co2 eq./kg product; a Eutrophication of 4.735 e+03 kg NH4 eq./year and a Water footprint of 2.021 e+01 litres water / kg product. If the user wants to compare these results with the current situation, they must quantify which are their current impacts in these environmental indicators.

5 Conclusions

Analytic Hierarchy Process (AHP) is a powerful methodology for helping making decisions about waste management strategies. WASEABI AHP tool includes all the parameterization of these methodologies for assessing the viability of food waste valorisation scenarios for six valorisation alternatives (Membrane concentration; Flocculation, pH shift; Enzymatic Hydrolysis for bioactive peptides; Enzymatic hydrolysis for savoury compounds; Drying for minerals).

WASEABI AHP tool gives public or private waste managers the opportunity of assessing a defined scenario from a holistic point of view, including in the same tool the legal viability, technical feasibility, economic profitability, and environmental sustainability assessment.

Moreover, this tool allows to assess a high number of scenarios with a minimum effort in comparison with current methodologies. It reduces the time required to evaluate and perform a sensitivity study of the different scenarios under study. This grants the defining of the optimal food waste valorisation strategy before investing in the valorisation facilities as well as the identification of potential food waste synergies.

In addition, since the limiting and conditional ranges were defined by a participatory approach that involves different stakeholders, it makes WASEABI AHP tool assessments rational and realistic.

Summarizing, WASEABI AHP tool helps public waste management authorities or other private organisations to define bioeconomy-based side-stream management strategies and to reduce the risk associated with the implementation of a food side-stream valorisation plant, by reducing the effort, the environmental impacts and the costs comparing to the traditional procedure.

This tool can be updated periodically to ensure its accuracy and to improve its capacities.

In case of interest in using this methodology please contact info@azti.es including the reference to the "WASEABI-AHP".