Analytic Hierarchy Process (AHP) for the analysis of the viability of fish side streams valorisation

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Introduction

One of the most important hurdles and bottlenecks to overcome when implementing valorisation alternatives is the lack of a methodology to take the right decision while sorting, storing and managing conditions of different fish residual streams.

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 once they are generated. To overcome this challenge, one of the objectives of the WaSeaBi project has been to design a help decision making tool (1).

Multi-Criteria Decision Analysis (MCDA) allows to assess the viability of fish side-streams valorisation since it provides a reliable framework for procedures to rank alternative options and prioritise and it based on their assessment across selected criteria. Such methods have been widely and effectively applied in different environmental areas.

Analytic Hierarchy Process (AHP) is a MCDA method which allows partitioning the problem into smaller decision sets one at a time (2,3). The optimum decision about the sorting, storing and managing conditions of different fish residual streams is based on their potential for being converted to high value products and potential synergies with other fish residual side-streams generated close to them.

AHP methodology has been used in a broad range of applications in the field of urban waste management but have been never applied for making decisions on how to use aquatic side-streams in a full value chain approach.

Material and methods

The main categories that need to be evaluated were defined by a group of experts in the field of food waste management and valorisation according to their experience and a bibliography review. 1) Legal aspects 2) Technical aspects 3) Economic aspects 4) Environmental aspects.

The first step to construct an AHP was to identify the key viability criteria from the technical, legal, economic, and environmental point of view. Legal viability factors were extracted from the European legislation. Technical parameters for each valorisation options were defined by experts, setting the basic requirements and the value-added parameters. Capital Expenses (CAPEX) and Operational expenditures (OPEX) were calculated for each option and standard economical parameters were chosen as indicator. For the environmental analysis, main environmental impacts were chosen and calculated by a simplified LCA analysis, using ECOINVENT 3.0 data base.

Then, the limiting and conditioning ranges as well as the relative importance of each viability criterium were set up based on the potential for obtaining high value products. It must be done case by case and adapted to the subject of the study and stated by consensus. Afterwards, the decision matrices and the corresponding algorithms and functions to take right decision were defined to give a score for each category, a final score combining all categories and a final prioritization for the different scenarios.

Finally, the visualization of the results was set up to present to all viability calculations. The computational part of the tool was developed using Python3.7[®] and the Graphical User Interface (GUI) was designed using its PyQT5 library.

Results and discussion

The Legal viability (Figure 1) allows to verify the compliance of the studied side-stream of the legal viability constraints. The output for this analysis is a simple binary result of the type True/False.

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	Viability Factor	Units	Value	Sub-problem factor	Kind of factor	Limiting ranges	Conditioning ranges	Relative importance	Check legal viab	oility
1	Listeria monocytogenes	CFU/25g	0.0	Legal aspect/Raw material	Limiting	Absence	Not applicable	Not applicable	Add row	
2	Total viable cell count	CFU/g	0.0	Legal aspect/final product	Limiting	<=20000	Not applicable	Not applicable	Delete row	
3	Salmonella spp	CFU/25g	0.0	Legal aspect/final product	Limiting	Absence	Not applicable	Not applicable		_
4	Listeria monocytogenes	CFU/g	0.0	Legal aspect/final product	Limiting	Absence	Not applicable	Not applicable		
5	E. Coli	CFU/g	15	Legal aspect/final product	Limiting	<=20	Not applicable	Not applicable		
6	Staphylococcus aureus	CFU/g	0.0	Legal aspect/final product	Limiting	<=200	Not applicable	Not applicable		
7	Pseudomona aeruginosa	CFU/25g	0.0	Legal aspect/final product	Limiting	Absence	Not applicable	Not applicable		
8	Mould/yeast	CFU/g	0.0	Legal aspect/final product	Limiting	<=20	Not applicable	Not applicable		
9	Arsenic (inorganic)	mg/kg	0.0	Legal aspect/final product	Limiting	<=0.22	Not applicable	Not applicable		
10	Arsenic (organic)	mg/kg	0.0	Legal aspect/final product	Limiting	<=0.51	Not applicable	Not applicable		
1	Cadmium	mg/kg	0.0	Legal aspect/final product	Limiting	<=0.09	Not applicable	Not applicable		
12	Lead	mg/kg	0.0	Legal aspect/final product	Limiting	<=0.18	Not applicable	Not applicable	Logal vieb -	
10	Total Mercury	mg/kg	0.0	Legal aspect/final product	Limiting	<=0.03	Not applicable	Not applicable	ok	
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Figure 1 Legal viability panel

The Technical viability (Figure 2) consists of several chemical indicators related to the potential of fish by-products for obtaining high value compounds. The output is a positive number between 0 and 10, representing "0" a low technical viability and "10" a high technical viability. If a parameter is out of the limiting range, the score will be "0", whereas if it is insides the limiting range, the score will be proportional to the conditional range. The score of each parameter viability is balanced by applying its relative importance to obtain a weighted score.

Image: Second	😑 WAHPt: Waseabi A	HP tool								- □ >
Legal_viability Tech_viability Econom_viability Environ_viability Weights Results Sensitivity 0	🖹 📫 🖉 🕻)
Viability FactorUnitsValueMinimum Limiting rangeMaximum Limiting rangeCalculate technical viability2Generation Point 1_Quantities of raw material in month 2mi/month 200Add generation point4Generation Point 1_Quantities of raw material in month 3mi/month 200Delete row5Generation Point 1_Quantities of raw material in month 5mi/month 200Delete row6Generation Point 1_Quantities of raw material in month 6mi/month 0.0Delete row7Generation Point 1_Quantities of raw material in month 7mi/month 0.0<	Legal_viability	Tech_viability	Econom_viability	Environ_v	/iability \	Weights	Results Sensitivity			
1 Generation Point 1_Quantities of raw material in month 2 m3/month 2000 Image: Construct 1_Quantities of raw material in month 3 m3/month 2000 Image: Construct 1_Quantities of raw material in month 4 M3/month 2000 Image: Construct 1_Quantities of raw material in month 4 M3/month 2000 Image: Construct 1_Quantities of raw material in month 4 M3/month 2000 Image: Construct 1_Quantities of raw material in month 4 M3/month 2000 Image: Construct 1_Quantities of raw material in month 4 M3/month 2000 Image: Construct 1_Quantities of raw material in month 5 M3/month 100 Image: Construct 1_Quantities of raw material in month 6 M3/month 100 Image: Construct 1_Quantities of raw material in month 7 M3/month 100 Image: Construct 1_Quantities of raw material in month 6 M3/month 100 Image: Construct 1_Quantities of raw material in month 7 M3/month 100 Image: Construct 1_Quantities of raw material in month 1 M3/month 100 Image: Construct 1_Quantities of raw material in month 1 M3/month 100 Image: Construct 1_Quantities of raw material in month 1 M3/month 100 Image: Construct 1_Quantities of raw material in month 1 M3/month 100 Image: Construct 1_Quantities of raw material in month 1 M3/month 100 Image: Construct 1_Quantities of raw		Viability	/ Factor		Units	Value	Minimum Limiting range	Maximum Limiting range	-	Calculate technical viability
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4Generation Point 1_Quantities of raw material in month 4m3/month200IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	3 Generation	Point 1_Quantitie	s of raw material in r	month 3	m3/month	0.0				Delete row
5Generation Point 1_Quantities of raw material in month 5m3/month100IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	4 Generation	Point 1_Quantitie	s of raw material in r	month 4	m3/month	200				
6Generation Point 1_Quantities of raw material in month 6m3/month0.0Image: Constraint 1_Constraint 1_Constrai	5 Generation	Point 1_Quantitie	s of raw material in r	month 5	m3/month	100				
7Generation Point 1_Quantities of raw material in month 7m3/month0.0Image: Constraint 1_Constraint 1_Constrai	6 Generation	Point 1_Quantitie	es of raw material in r	month 6	m3/month	0.0				
8 Generation Point 1_Quantities of raw material in month 8 m3/month 0.0 Image: Control 1_Quantities of raw material in month 9 m3/month 0.0 Image: Control 1_Quantities of raw material in month 9 m3/month 0.0 Image: Control 1_Quantities of raw material in month 10 m3/month 0.0 Image: Control 1_Quantities of raw material in month 11 m3/month 0.0 Image: Control 1_Quantities of raw material in month 11 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 12 m3/month 0.0 Image: Control 1_Quantities of raw material in month 13 m3/month 0.0 Image: Control 1_Quantities of raw material in month 13	7 Generation	Point 1_Quantitie	es of raw material in r	month 7	m3/month	0.0				
9Generation Point 1_Quantities of raw material in month 9m3/month0.0Image: Constraint 1Image: Constraint 1 <td>8 Generation</td> <td>Point 1_Quantitie</td> <td>es of raw material in r</td> <td>month 8</td> <td>m3/month</td> <td>0.0</td> <td></td> <td></td> <td></td> <td></td>	8 Generation	Point 1_Quantitie	es of raw material in r	month 8	m3/month	0.0				
10Generation Point 1_Quantities of raw material in month 10m3/month0.0Image: Constraint 1Image: Constraint 1<	9 Generation	Point 1_Quantitie	es of raw material in r	month 9	m3/month	0.0				
11Generation Point 1_Quantities of raw material in month 1m3/month0.0Image: Constraint 1_Constraint 1_Constra	10 Generation	Point 1_Quantitie	es of raw material in r	month 10	m3/month	0.0				
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15 Generation Point 1_Store capabilitydays211.016 Generation Point 1_Initial protein content%20.10.117 Generation Point 1_Initial fact content%0.01018 Generation Point 1_Initial peroxide content%0.05019 Generation Point 1_Initial NaCl content%0400	14 Generation Point 1_Geographical dispersion					0.0	0	100	0.0	1.100
16 Generation Point 1_Initial protein content % 2 0.1 0.1 17 Generation Point 1_Initial fat content % 0.0 1 0 18 Generation Point 1_Initial peroxide content % 0.0 5 0 19 Generation Point 1_Initial NaCl content % 0 40 0	15 Generation	Point 1_Store cap	pability		days	2	1		1.0	
17 Generation Point 1_Initial fat content % 0.0 1 0 18 Generation Point 1_Initial peroxide content % 0.0 5 0 19 Generation Point 1_Initial NaCl content % 0 40 0	16 Generation	Point 1_Initial pro	tein content		%	2	0.1		0.1	
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	19 Generation	Point 1_Initial Na	CI content		%	0		40	0	
20 Generation Point 1_Initial glutamic acid content/protein % 2 1 1.0	20 Generation Point 1_Initial glutamic acid content/protein					2	1		1.0	
21 Generation Point 1_Total solid % 0.0 20 0	21 Generation	Point 1_Total soli	id		%	0.0		20	0	
22 Generation Point 1_XXX % 0.0 90 0	22 Generation	Point 1_XXX			%	0.0		90	0.	

Figure 2 Technical viability panel

The economical parameters selected for the economic analysis are: Net Present Value (NPV), Return on investment (ROI), Payback period (PP) and Gross Operation Profit (EBITDA). The number of years and the CAPEX and OPEX value for the calculation of the scenario can be modified by the user based on their experience. The economic profitability results are presented in the Figure 3.

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Legal_viability	Tech_viability	Econom_viability	Environ_vi	iability	Weights	Results	Sensitivity			
	Viability	Factor		Units		Year 1	Year 2	Y_	Calculate economic viabi	lity
5 Incomes du	ie to managemen	it costs saving	€/ye	ear		340400.000	382473.440	429	Delete year	
6 Process yie	ld		0-1			0.02			Generate projection	
7 Quantity of food final product			Tn/y	/ear		46.000	48.760	51.6	Investment per unit of material (euro	s): 250000
8 Sale price o	of the final product	t	€/Tr	n		3000	3180.000	337)	Unit of material (m3)	6240
9 Annual per	entage increase		%			6				0210
10 Incomes du	10 Incomes due to final product sales € 11 Total Investment €			€/year		138000.000	155056.800	174:		
11 Total Invest						92147.436				
12 Depredation period Y 13 % of own funds % 14 € of own funds €				Years % €		10				
						80				
						73717.949				
15 % of public funding (non-refundable)				%		0.0				
16 € of public funding (non-refundable)				€		0.000		-		
17 % of banks-public loan			%	%		20			Economic visb	
18 Loan interest			%			5			ok	
19 Years of credit repayment			Yea	ırs		10				
20 € of banks-public loan			€			19350.962				
21 List of expenses										
22 Quantities of raw material per year			m3/	year		2300.0	2438.000	258		
23 Logistics costs :			€/m	3 of raw	material	30	31.800	33.7		
24 Annual percentage increase			%			6				
25 Operating e	xpenses: Logistic	s	€/ye	ear		69000.000	77528.400	871		
26 Number of	noonlo		Unit			Ę	5.0	59	J	

Figure 3 Economic viability panel

The environmental impacts selected for the environmental assessment are Carbon and Water footprints and the Eutrophication. Based on a Life Cycle Assessment, the tool asks user data about the most important environmental aspects to calculate the selected impacts. The environmental viability results are presented in the Figure 4.

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Legal_viability Tech_viability Econom_viability Environ_via	ability Weights	Results	Sensitivity	
Inputs	Units	Value	Dataset	Calculate environmental viability
1 Quantities of raw material per year	m3/year	2300.0		Load single parameter file
2 Packaging, plastic, PP	kg/year	0.0	eb6c15a5-abcd-4d1a-ab7f-fb1cc36	Load parameter file for dropdown menus
3 Packaging, plastic, LDPE	kg/year	0.0	d327f4a5-93a1-4ead-856c-aeb8b2	Save parameters into xls file
4 Packaging, plastic, HDPE	kg/year	0.0	a3aefe5b-33c9-4f0c-87ec-d029144	
5 Packaging, aliminium	kg/year	0.0	95275ae7-af41-48aa-bef9-8259f1t	
6 Packaging, glass container	kg/year	0.0	c719be8c-51be-4c23-84c2-e45ea0	Carbon footprint
7 Packaging, liquid packaging board	kg/year	0.0	5ffc5f05-a5d3-42eb-90cb-547e0bf	(kg CO2 eq./kg product):
8 Packaging, corrugated board	kg/year	0.0	574bdb1e-2ed3-46f1-bd14-bb76f7	5.321e+03
9 Thermal energy use (choose from list)	✓ MJ/year	0.0		
10 Heat export (MJ)	MJ/year	0.0		
11 Electricity from grid (not certified)	kWh/year	299.000	34960d4d-af62-43a0-aa76-adc5fc1	
12 Electricity from grid (green certified)	kWh/year	0.0	ce479816-e2dd-44b6-aa54-153503	
13 Electricity, own generated (choose from list)	+ kWh/year	0.0		Eutrophication (kg NH4 eq./year):
14 Electricity export	kWh/year	0.0	34960d4d-af62-43a0-aa76-adc5fc1	1.6200+01
15 Tap water	m3/year	64.503	212b8494-a769-4c2e-8d82-9a6ef6	
16 Wastewater to treatment plant	m3/year	2783.000	8126980a-29e9-416c-991d-2aa5fc	
17 Plastic waste (choose from list)	✓ kg/year	0.0		
18 Paper and cardboard waste (choose from list)	✓ kg/year	0.0		
19 Municipal solid wastes (choose from list)	✓ kg/year	0.0		Water footprint:
20 Organic wastes (choose from list)	▼ kg/year	690.000		-2.787e+04
21 Distance to final destination by (choose from list)	✓ km/year	0.0		
20 Avoided product (choose from list)	Tkalupar	0.0		그

Figure 4 Environmental viability panel

The single score is generated based on the relative weight given for each viability. If there are more than one scenario, one-score projection of the different viability calculations for different scenarios is included based on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) technique. Its basic principle assumes that the chosen alternative should simultaneously have the shortest distance from the positive-ideal solution and the farthest distance from the negative-ideal solution.

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Legal_vial	bility Tech_viabilit	ty Econom_viat	oility Environ_v	iability Weights	Results Sensitivit	ty				
Legal v	viab Technical viab	Economic viab. Payback period	Economic viab.	Enviromental viab. Carbon footprint	Enviromental viab.	Enviromental viab. Water footprint	Default-weights result (0-1)	User result (0-1)	De-biased	a
1 ok	6.91416388	0.55400000	3940.42730136	5090.00000000	15.50000000	-26650.00000000	1 0.67085813	0.67085		
2 ok	7.15463106	0.53100000	4040.33814261	5321.00000000	16.20000000	-27870.00000000	2 0.65028328	0.65028		
3 ok	6.96541388	0.53100000	4040.33814261	5321.00000000	16.20000000	-27870.00000000	3 0.64666440	0.64666		
4 ok	6.91416388	0.61900000	3597.99295505	5090.00000000	15.50000000	-26650.00000000	4 0.43218275	0.43218		
5 <mark>ok</mark>	6.86416388	0.69400000	3368.20191498	4627.00000000	14.0900000	-24230.00000000	5 0.34971672	0.34971		

Figure 5 Calculated alternatives analysed by TOPSIS methodology

Conclusions

AHP method is an appropriate methodology for helping making decisions about waste management strategies.

This tool assesses different scenarios with a minimum effort and minimize the time required to evaluate and perform a sensitivity study of the different scenarios under study.

It will help to define fish by-product valorisation strategies reducing the effort, the environmental impacts and the costs comparing to the traditional procedure.

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