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From Cradle to Plate: Analysing the Life Cycle Sustainability of Fish Feed Composition

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Abstract **– Sustainability is defined as balancing environmental, economic and social factors, and various methodologies and tools are available to assess sustainability across sectors and scales. The demand for food has increased due to the increase in the population and the consumption of aquatic food in the world has increased significantly and is growing by an average of 3 % per year, while the population is growing by 1.6 % per year. As the aquaculture industry expands worldwide, it is important to consider the environmental impact of the industry and choose environmentally friendly alternatives to reduce its impact. The aim of this study is to assess the composition of five different fish feeds based on environmental, economic and social parameters using life cycle analysis (LCA), life cycle costing (LCC), social life cycle analysis (S-LCA) as well as technical considerations. The impact of alternatives to the main feed ingredients was analysed separately, while the development of fish feed focused on the protein source used in the feed and the oil used, as halieutic resources are used as raw material in their production, and alternatives are being considered. The best alternatives, considering all four dimensions, were the alternatives where fishmeal protein was partially replaced by Black Solder fly and Yellow Mealworm protein, as the proportion replaced is different for each alternative. By evaluating fish feed along several dimensions, the aim is to improve fish welfare while reducing the environmental impact of feed production.**

Keywords **– Assessment; environmental; economic; social; technical; fish feed.**

1. INTRODUCTION

It is expected that the world population will increase to 9 billion in 2050 and with it the demand for food will grow by 60 % and protein sources production grow will rise for meat nearly 70 %, aquaculture 90 % and dairy 55 %, but this challenge must be realized in a sustainable and safe way [1]. Over the past two decades, the industrial compound feed industry has experienced slow and steady growth, owing to market expectations from livestock and aquaculture farmers for effective compound feed that meets increasingly stringent performance and quality standards [2]. The Asia-Pacific region produces the most feed and in 2022 it was 37 % of the total feed production, followed by Europe with 21 % and North America with 21 % [1], see Fig. 1. However, most of the feed is consumed by poultry 44 % of the total amount of feed, followed by pigs 28 % [1], see Fig. 2.

The feed raw material production stage of animal products accounts for the largest share of GHG emissions, especially for pork, poultry, eggs, and farmed fish, where the share ranges

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from 70 % to 80 % [3]. The circular feed concept is based on the recovery and reduction of nutrient losses and can be divided into several dimensions that make up the circular feed – food/feed grade status; proximity to the feed mill; land use ratio; nutrient digestibility [4].

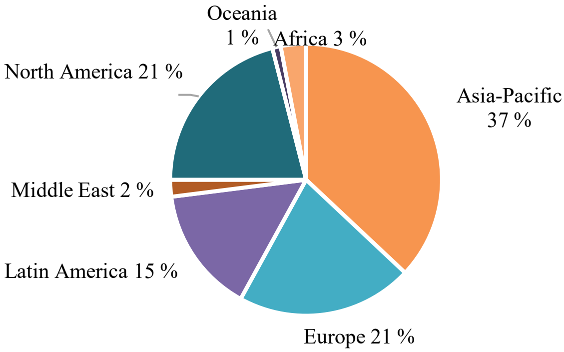


Fig. 1. Feed production by region in 2022 [1].

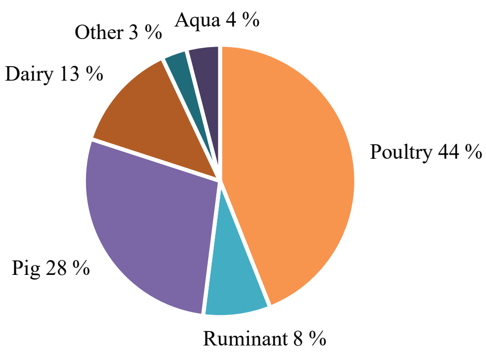


Fig. 2. Global feed market by species – 2022 estimates [1].

The use of new feed ingredients and raw materials in feed production can create new challenges [5]. However, the safety of feed and ingredients can be determined by identifying inputs with potential hazards used in feed production, understanding the production process and conducting a risk characterization of the final product [5]. There are some regulations in the European Union related to feed, like Regulation (EC) No. 178/2002 on the marketing and use of feed with the aim of ensuring a high level of feed safety [6], as well as Regulation (EC) No 1831/2003 aimed at the use, marketing, supervision and labelling of feed additives and premixes in order to promote the use of high quality additives and premixes [7]. Also, Product Environmental Footprint Category Rules (PEFCR) Feed for Food-Producing Animals gives a set of guidelines on the environmental impact of feed production used by the food industry [8].

The industry is facing the challenge of improving feed compliance with fish production demand and improving feed sustainability is focused on partial replacement of marine resources with plant resources or another alternative [9]. The risk of halieutic resource depletion is related to fish feed, as traditional fish feed uses wild fish to produce fish meal and fish oil [10]. To reduce the environmental impact of fish farming, specific problems must be considered, such as the use of traditional fish meal and fish oil in feed, increasing the use of by-products or using microorganisms and insects as raw materials for feed [3]. As well as preventing wastage of aquaculture feed, as uneaten/unconsumed fish feed is like a surplus that settles at the bottom of deep water [10]. In order to reduce the loss of nutrients, attention must be paid to the control of feed distribution, to improve the retention of feed in water, and the duration of flotation increases and the sedimentation of feed is delayed, as well as the recovery of nutrients, for example from fish feces, in order to grow algae that can then be used as feed [10]. Alternatives to avoid using aquatic alive resources in feed as raw materials [10]:

1. The first priority is to use the scraps of wild and farm-raised fish from the processing processes and there is a benefit in the circular bioeconomy.
2. The second priority is to use proteins, oils and fats from farmed insects that are fed with by-products and promote a circular economy.
3. The third priority is to use natural resources from lower trophic levels, but the use of these resources should be studied so as not to affect marine biodiversity and the balance of ecosystems.

The aim of this study is to assess the sustainability of different fish feed alternatives considering environmental, economic, social and technical parameters. Life Cycle Analysis (LCA) to assess environmental impacts, Life Cycle Costing (LCC) to assess economic impacts, Social Life Cycle Analysis (S-LCA) to assess social impacts and a technical dimension to assess the important parameters of fish feed. LCA complies with: ISO 14040 (2006) and ISO 14044 (2006) [11], [12]. LCC estimates the total costs over the life cycle - capital costs, consumption costs, operating costs, and the residual value of an asset at the end of its life cycle [13]. Social impact or risk can be assessed using a database method or according to the United Nations Environment Program (UNEP) guidelines method that is used for this study [14]. Technical parameters such as marine biodiversity, nutritional value of feed and origin of raw materials. Also, the MCDA method TOPSIS was used to perform a long-term assessment of the selected alternative according to environmental, economic, social and technical criteria.

2. METHODS

The development and improvement of fish feed must take into account that commercially produced fish feed must provide a comprehensive diet to support the optimal growth and health of the fish and most often fish feed consists of: proteins (18–50 %), lipids (10–25 %), carbohydrates (15–20 %), ash (<8, 5 %), phosphorus (<1.5 %), water (<10 %) and some vitamins and minerals [15]. Protein is one of the most expensive feed materials, and traditional feed used fish meal as a protein source, but land plants, single-cell proteins, microalgae, macroalgae and insect meal are used as alternatives [16]. Lipids are used to partially replace proteins and have almost twice the energy density of proteins [15]. Vegetable oil can be used as an alternative to fish oil - soybean, linseed, rapeseed, sunflower, palm oil and olive oil, and replacing fish oil with an alternative is not only an environmental benefit, but also an economic benefit [17]. Optimum use of carbohydrates in fish feed is a good source of energy and carbon, and optimal inclusion in fish feed increases protein and lipid retention, as well as improves stability and buoyancy of feed pellets [18]. However, an important component of the feed is the pigment that gives the colour of fish flesh and salmonids, and trout have a characteristic pink colour of fish flesh, which is mainly from the pigment astaxanthin [19]. This pigment must be obtained from the feed because fish do not synthesize carotenoids and astaxanthin has been a widely used feed additive for several decades in aquaculture and commercially available astaxanthin (>90 %) is produced synthetically from a petrochemical source, but it is also possible to obtain this pigment from green algae, red yeast or from soil bacteria [19].

The methodology for assessing the sustainability of fish feed (Fig. 3) consists of four phases.

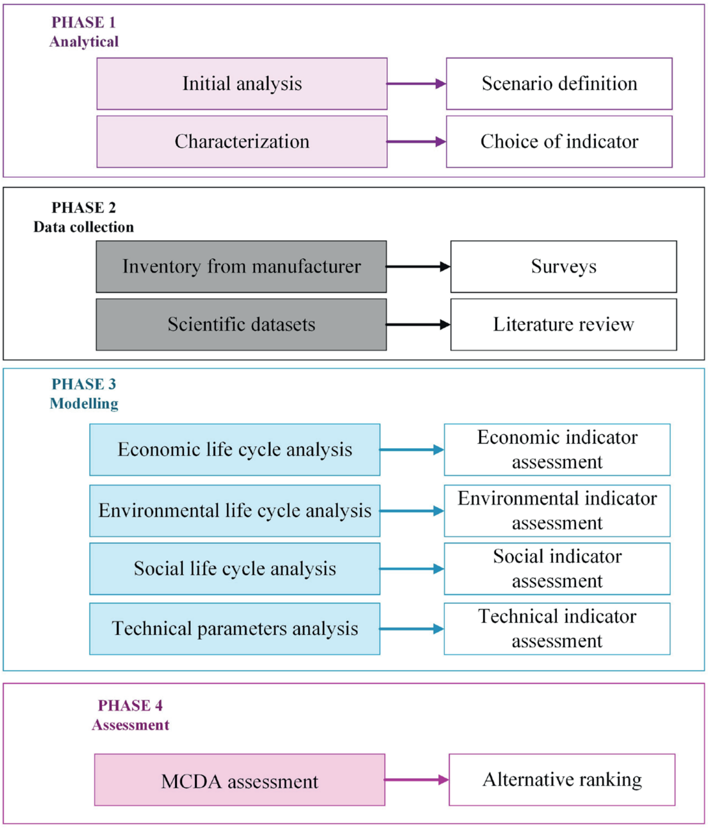


Fig. 3. Fish feed sustainability methodology.

2.1. Analytical Phase

The first phase is the analytical phase, where parameters and criteria are selected to test the sustainability of the fish feed. In this case, five fish feeds are compared, where the proportion of the other fish feed ingredients varies according to the protein source:

- A1 – traditional protein – fish meal;
- A2 – traditional protein – fish meal and 5 % of traditional protein replaced by Black Solder fly protein;
- A3 – traditional protein – fish meal and 10 % of traditional protein replaced by Black Solder fly protein;
- A4 – traditional protein – fish meal and 15 % of traditional protein replaced by Yellow Mealworm protein;
- A5 – traditional protein – fish meal and 30 % of traditional protein replaced by Yellow Mealworm protein.

The five fish feeds are compared on environmental (results from LCA), economic (results from LCC), social (results from S-LCA) and technical (results from comparisons on marine biodiversity, feed nutritional value and raw material origin) parameters.

2.2. Data Collection Phase

During the development of the fish feed, several alternatives with alternative ingredients were developed, tested in the laboratory and tested on fish. The five fish feeds selected are those that performed best in the previous tests. All ingredient proportions of the fish feeds are commercially secret and are not published in this article. A comparison of alternative fish feed ingredients – protein (black soldier fly, yellow mealworm and soybean) [20], oil (microalgae, rapeseed and fish oil) [21] and pigment (microalgae and synthetic astaxanthin) [22] results are available, but publicly available data were used for modelling and expert comments were considered.

Necessary data to use for LCA, LCC, S-LCA and technical comparison were obtained from publicly available information – scientific articles, reports. The collected data is transformed into the necessary input data for the modelling phase.

2.3. Modelling Phase

The modelling of each dimension is slightly different and depends on the available data to make the assessment. LCA assesses the impact of the environment and is performed for all fish feed, LCC assess the economic impact and is performed for all fish feed, S-LCA assess social impact and is performed for protein and oil raw materials used in fish feed and technical dimension to evaluate the important parameters for fish feed and is performed for all fish feed.

2.3.1. Environmental Assessment – LCA

Function unit for LCA is 1 tonne animal feed based on Product environmental footprint category rules (PEFCR) Feed for food-producing animals [8]. This LCA is “cradle to gate” and system boundaries the impact of raw materials is considered. Life cycle inventory data are collected from publicly available scientific articles as well as from the *Ecoinvent* 3.9 database.

Life cycle impact assessment is based on Product environmental footprint category rules (PEFCR) Feed for food-producing animals, where the necessary parameters are defined to characterize the environmental impact indicators. The method used in *SimaPro* 9.5 software is Environmental Footprint (EF) 3.0, which incorporates the PEFCR as an impact assessment method.

Result interpretation is based on environmental performance results for fish feed considering all input material flows. Weighted results for fish feed alternatives expressed in mPt value. Pt is the unit of the eco-indicator where one thousand of annual environmental load of an average European citizen is considered as 1 Pt [23].

2.3.2. Economical Assessment – LCC

Function unit for conventional LCC is EUR to 1-tonne feed and system boundaries for conventional LCC is cost of raw input materials. Life cycle inventory data for conventional LCC is compiled from publicly available data. Life cycle impact assessment is based on cost (EUR) and amount (ton) of raw material.

The result interpretation is based just on raw material cost, EUR/t fish feed.

2.3.3. Social Assessment – S-LCA

The scope of the social risk assessment is based on two major ingredients that are used in fish feed because these raw materials make up at least half of the fish feed composition. Social risks were identified in the category of employees, local community, value chain participants and society. The categories of consumers and children were not considered, as the boundaries were only considered in the context of production and raw materials.

Life cycle inventory data is based on publicly available data about raw material production country for worker and society category and raw material industry reports on local community and value chain actor category. Impact assessment is evaluated as social performance evaluation scale from +2 to −2 [24]. The assessment of the social dimension was based on the countries from which the protein and oil for fish feed are sourced. The result interpretation is based on the obtained evaluations into subcategories and proportionally distributed according to the ratio of fish feed ingredients.

2.3.4. Technical Assessment

Technical parameters are important for fish feed, so this dimension has been added with criteria on marine biodiversity, nutritional value of feed and origin of raw materials. The marine biodiversity criterion considered whether marine species are produced as an ingredient in the fish feed, and this was analysed in the ingredients. The nutritional value criterion was taken from the results of fish feed tests. For the raw material origin criterion, it was examined from which resources the raw materials for fish feed production are obtained. The assessment of technical parameters was carried out by quantitative evaluation, but in the criteria where qualitative novelty was obtained this was converted to a qualitative evaluation – a scoring system.

2.4. Assessment Phase

In the fourth phase, the obtained results from the modelling phase are considered and for five fish feed assessment is used multi-criteria decision analysis (MCDA) method TOPSIS to determine the best fish feed according to environmental, economic, social, and technical parameters.

One of the input data in the TOPSIS method is the importance or weight of the selected criteria, and in this process the weights will be the same for all criteria: environmental criteria (25 %), economic criteria (25 %), social criteria (25 %) and technical criteria (25 %). It is also important to define the better value of the criterion (min or max) and in this process environmental criterion (min is the best value), economic criterion (min is the best value), social criterion (min is the best value), and technical criterion (min is the best value) values as input data in TOPSIS matrix is as ranking values from best to worst (1 to 5).

To obtain the results of the TOPSIS method, the normalized matrix, the weighted normalized matrix, the distance from the ideal and anti-ideal solution and the calculate the relative closeness to the ideal solution [25], [26]. As a result, in the TOPSIS method, the best result is with the result closest to the ideal. Also, sensitivity analysis was also performed for all criteria to determine which criterion had the greatest influence on the results.

3. Results

Table 1 shows the results of the modelling phase by dimension. In the S-LCA and technical dimension, there is a ranking based on the number of points obtained.

TABLE 1. MODELLING RESULTS

	A1	A2	A3	A4	A5
LCA, mPt	2.10E+02	1.89E+02	1.67E+02	2.13E+02	2.40E+02
LCC, EUR/t	9266	8346	7480	8146	9430
S-LCA, ranking	5	4	3	2	1
Technical, ranking	4	1	3	2	3

Fig. 4 shows TOPSIS results for five fish feeds of different composition. Alternative A1 has the lowest rating in this case and this is the conventional fish feed composition. Alternative fish feed ingredients are used in the composition of A2, A3, A4, A5 fish feed composition. However, the best alternatives are A3 and A4, although slightly different proportions of ingredients and different alternative protein raw materials are used, but the same result was obtained.

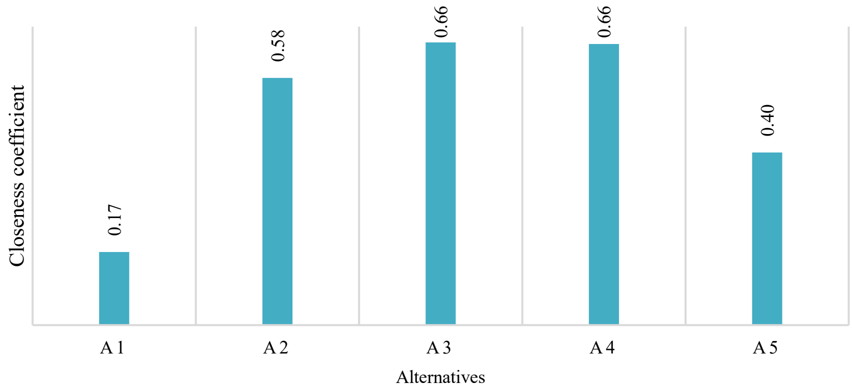
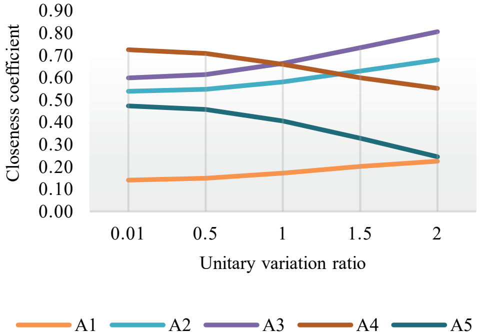
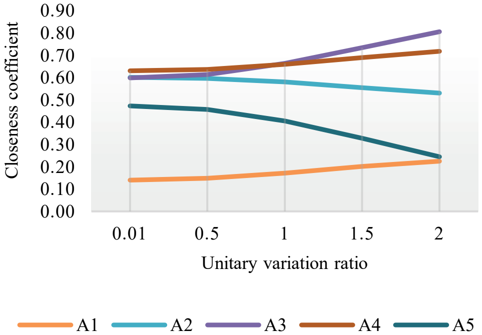


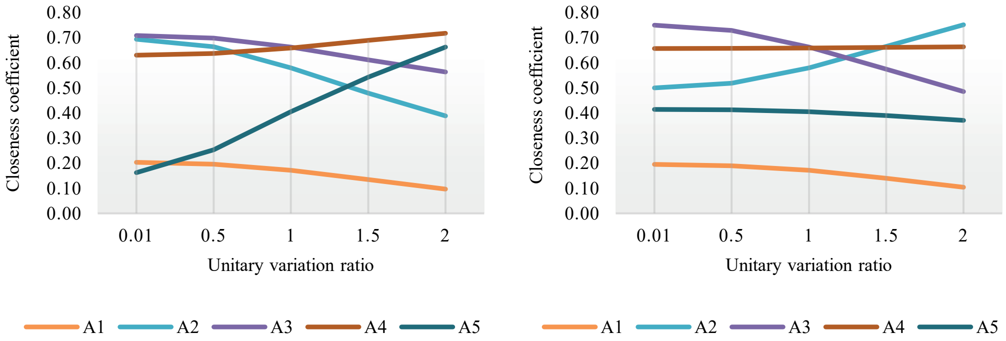
Fig. 4. TOPSIS results.



a) Sensitivity analysis for environmental criteria



b) Sensitivity analysis for economic criteria



c) Sensitivity analysis for social criteria

d) Sensitivity analysis for technical criteria

Fig. 5. Sensitivity analysis.

Fig. 5 shows the sensitivity analysis for environmental, economic, social, and technical criteria to clarify the most sensitive criterion. The biggest changes are in the sensitivity analysis of social criteria and the smallest change is in the technical criterion.

4. Conclusion

The aim of the study was to carry out a sustainability assessment considering the environmental, economic, social, and technical dimensions of several fish feeds with different compositions and to determine the best fish feed alternative. As a result, the two best fish feed alternatives were obtained, since the same results were obtained with the TOPSIS method. Alternative A3 showed the best results in the environmental and economic dimensions, but alternative A4 showed the second-best result in the economic, social, and technical dimensions. A sensitivity analysis was also performed, and the social dimension is more sensitive than all the dimensions. This shows that by choosing a different weight distribution for the dimensions, the results will be drastically different.

The obtained results show that making small changes in the composition and proportions of fish feed already has a positive effect on the environment, but it is necessary to consider all aspects, not only the effect of the environment or the composition of the feed on fish, which was not considered in this study. It is possible to improve the research and supplement the energy consumption and transportation stages considered to obtain a more comprehensive assessment of fish feed production, as well as to consider how fish take in and develop in the growth and development processes from a changed fish feed composition. Of course, the composition of fish feed depends on the species of fish and the phase of growth and development of the fish, therefore the composition of fish feed and the sustainability of the feed will differ.

Conventional fish feed is increasingly being replaced by sustainable alternatives, but the alternatives tend to have a negative impact on the development and growth of the fish, and a comprehensive analysis of possible alternatives is required for the fish feed to become even more sustainable and reduce the impact on the environment.

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