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Authors: Sander van den Burg (lead), Jon Barlow, Jeroen Westrate, Klara van Mierlo

WP/WP-leader: WP4 / Wout Abbink, Wageningen Research

Task/Task leader: Task 4.3 / Sander van den Burg, Wageningen Research

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Table of Contents

List of tables

List of figures

Executive summary

Aquaculture is a growing sector both in quantity and in terms of technologies and type of fish which is grown. Currently aquaculture provides 58% of the fish market. However, it is responsible for a series of impact including climate change, eutrophication, fine particulate matter, toxicity, land use and resource scarcity. In this report the main results of the economic assessment, environmental assessment and True Pricing accounting are presented. The models and method used are described in Deliverable 4.9.

The methodological choices described follow a review of the available economic models and environmental assessment models and approaches from literature, EU research project report, and model websites. Criteria for the review included the complexity, the data requirement and the applicability of these methodologies in the assessment of finfish and shellfish, cage systems, Integrated Multitrophic Aquaculture (IMTA).

The (partial) substitution of marine- and terrestrial animal co-product ingredients by plant based ingredients resulted in a higher environmental impact for almost all of the impact categories analyzed. The production of feed ingredients has the largest contribution to all of the impact categories analyzed. Optimizing the feed ingredient production practices (e.g. cultivation of crops, production of animals) and to a lesser extend sourcing locally (if no adverse effects on impacts during the production), can contribute to a lower environmental impact of the studied feeds. This result goes for both the production of seabass and seabream in cages in Greece (reported in this deliverable) and the production of salmon in cages (reported in Goglio et al., 2022).

The alternative feed is more expensive and this reduces the economic profitability of fish farming. The higher environmental impacts and higher production mean the True Prices are also higher, although it must be said that various impacts categories are left out of the equation. To make alternative feed more attractive, from an economic and environmental perspective, innovation in their production process is needed.

Introduction

The global population is expected to grow to around 9.7 billion in 2050 (United Nations Department of Economic and Social Affairs, 2022). This continuous population growth places increasing pressure on vital resources such as energy, food and water (Yuan et al., 2018). Seafoods are increasingly acknowledged to play a vital role in global food security and nutrition (FAO, 2022). In many countries seafood is the main source of protein in the diet (Bohnes & Laurent, 2019) and seafoods are a rich source of bioavailable micronutrients like calcium and zinc (Hicks et al., 2019).

Traditionally, fisheries were the main source of seafood products. However, the majority of wild fish stocks are overfished or are exploited unsustainably by fishing activities (Bohnes & Laurent, 2019). This is threatening ocean ecosystems and people's food security and livelihoods. The production of seafoods in aquaculture ecosystems has steadily increased over the past decade, now being the largest source of seafoods worldwide (FAO, 2018).

Aquaculture is a growing sector both in quantity and in terms of technologies and type of fish which is grown rapdily. Currently aquaculture provides 58% of the fish market. It is often seen in developing countries as a way to supply protein to the local population (UN and World bank, 2017). The rising development and importance of fish farming has risen concerns regarding its sustainability, such as emissions leading to climate change, eutrophication, toxic and ecotoxic impacts, use of antibiotics, land use and water use for feed production, loss of biodiversity, introduction of exotic species, spread/amplification of parasites and disease, genetic pollution, dependence on capture fisheries, and socio-economic concerns (Henriksson et al., 2012). All these can also concur in habitat disruption. These environmental impacts have only been partially addressed in several LCA studies. However, several authors highlight the need for consistency in the methodological approach (Bohnes and Laurent, 2019). The same authors report the lack of methodology to assess the impact of fish escape on the marine ecosystems and the impact of medicines used in fish farming which are released in the marine environment (Bohnes and Laurent, 2019).

The impact related to climate change, eutrophication, pollution, resource use is related to the C, N, P cycle (Bohnes and Laurent, 2019; Henriksson et al., 2012). Indeed fish excretion is responsible for the release of ammonia which is a precursor in the atmosphere of nitrous oxide, a potent greenhouse gas (Myhre et al., 2013). On the other hand, respiration, degradation of residues and sediments can cause carbon dioxide emissions therefore affecting climate change.

The overall objective of FutureEUAqua is to effectively promote sustainable growth of resilient to climate changes, environmental friendly organic and conventional aquaculture of major fish species and low trophic level organisms in Europe, to meet future challenges with respect to the growing consumer demand for high quality, nutritious and responsibly produced food. To this end, FutureEUAqua will promote innovations in the whole value chain, including genetic selection, ingredients and feeds, non-invasive monitoring technologies, innovative fish products and packaging methods, optimal production systems such as IMTA and RAS.

WP4 investigates the innovations on sustainability and resilience in production types RAS, IMTA and open cage aquaculture systems within the frame of nutrient flows and treatment, and water quality, with an emphasis on production, economic profitability and environmental impact. In RAS, new and innovative water quality evaluation methods such as particle size distribution and bacterial activity measurements will be tested in addition to traditional water quality parameters, such as organic matter and nitrogenous compounds to create a complete view of the water quality. For IMTA, the functioning of a commercial IMTA farm will be examined and its production and nutrient fluxes compared to those of a similar yet conventional farm. The concept salmonid/IMTA is emerging and needs further improvement and testing at small scale. There is a need and big commercial interest to get IMTA implemented in commercial scale to recapture nutrients lost to the open water by the fish and get the nutrients transformed in e.g. sea weed and shellfish, thus providing environmental services and keep environmental sustainability in salmonid farming. The environmental impact of breeding, nutritional and technological innovations will be benchmarked against current practices in open cage farming in terms of nutrient discharges. The innovations coming from WP1 (breeding), WP2 (feed), WP4 (systems) and WP6 (quality and safety) will be assessed in an economic model and an environmental model and compared to the current value chain.

Objective

This report (D4.10) is the last deliverable in WP4 and presents the results of running the environmental model, the economic model and True Price accounting. The impact of FutureEUAqua innovations for the aquaculture sector are analysed. The economic assessment also looks at the impact of inflation and energy price rises.

Methodology

This deliverable present the results of the environmental and economic assessment. The methods used are described in detail in deliverable 4.9.

Figure 1 below visualizes how activities conducted are related to each other to come to an integrated assessment.

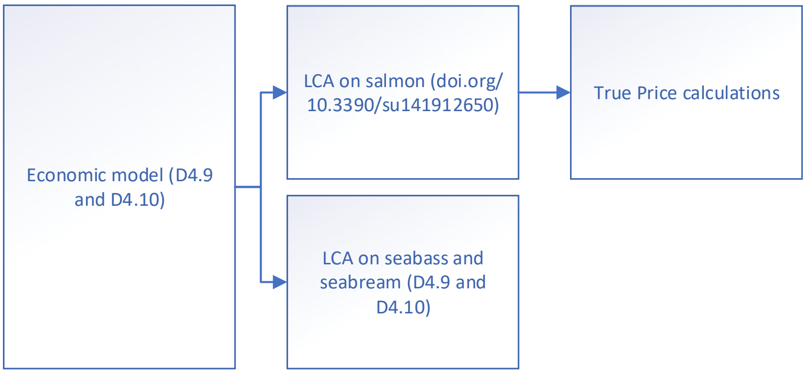


Figure 1 Integration of models used

Important to emphasize that the LCA results reported in D4.10 (method described in this deliverable below) do not feed into the True Price calculations. Not enough data was available for this. Instead, the True Price calculation integrate the economic model (described here and in D4.10) and the LCA on salmon, reported in Goglio et al. (2022).

Results of the LCA (environmental model)

In this section the results of the LCA are presented in three sub-sections: the absolute results, contribution analysis, and sensitivity analysis.

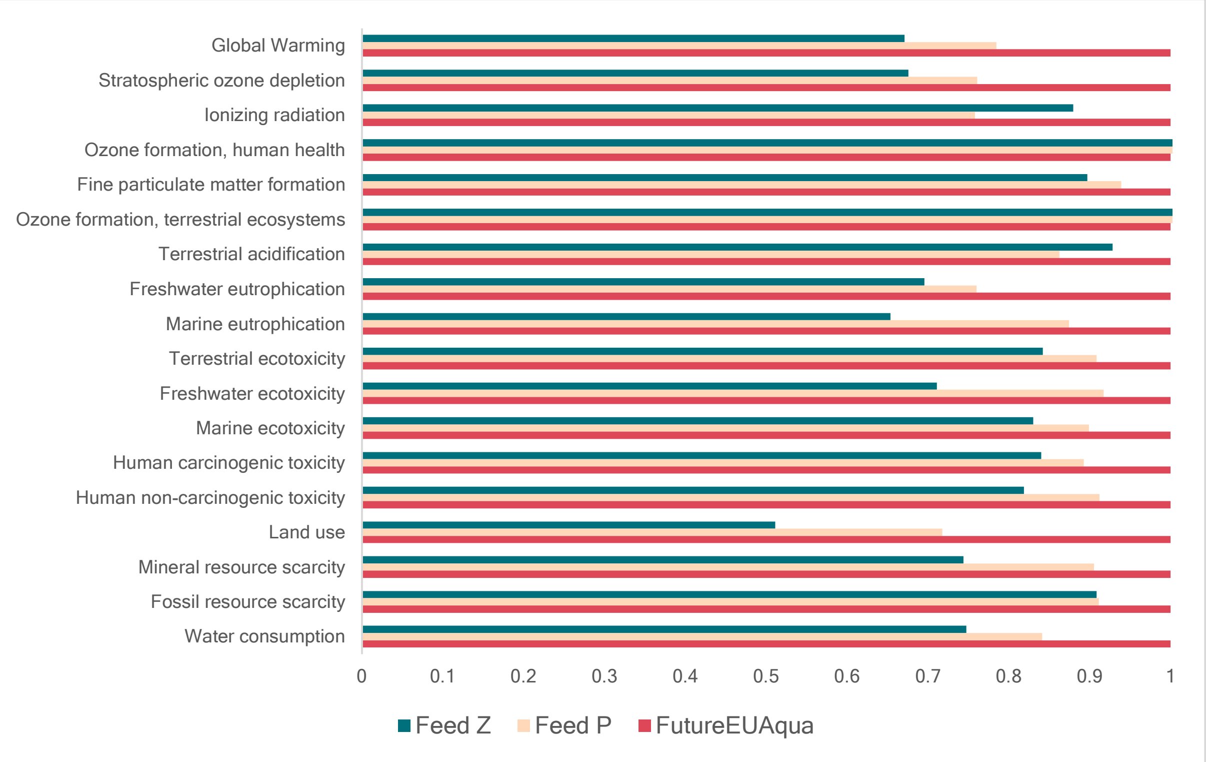
Absolute results

The results of the LCA are provided in Table 1 and Figure 2 for all impact categories of the LCIA method used.

Table 1 Characterized results per impact category per 1.000 kg of fish feeds under study

Impact category	Unit	Feed Z	Feed P	FutureEUAqua feed
Global Warming	kg CO2 eq	1.28E+03	1.49E+03	1.90+E03
Stratospheric ozone depletion	kg CFC11 eq	4.52E-03	5.09E-03	6.69E-03
Ionizing radiation	kBq Co-60 eq	4.54E+01	3.92E+01	5.17E+01
Ozone formation, human health	kg NOx eq	5.89E+00	5.96E+00	5.65E+00
Fine particulate matter formation	kg PM2.5 eq	2.43E+00	2.55E+00	2.71E+00
Ozone formation, terrestrial ecosystems	kg NOx eq	6.97E+00	6.81E+00	6.56E+00
Terrestrial acidification	kg SO2 eq	7.26E+00	6.74E+00	7.82E+00
Freshwater eutrophication	kg P eq	5.75E-01	6.29E-01	8.27E-01
Marine eutrophication	kg N eq	4.92E-01	6.58E-01	7.52E-01
Terrestrial ecotoxicity	kg 1,4-DCB	6.25E+03	6.75E+03	7.43E+03
Freshwater ecotoxicity	kg 1,4-DCB	8.72E+01	1.12E+02	1.23E+02
Marine ecotoxicity	kg 1,4-DCB	6.27E+01	6.78E+01	7.55E+01
Human carcinogenic toxicity	kg 1,4-DCB	4.72E+01	5.02E+01	5.62E+01
Human non-carcinogenic toxicity	kg 1,4-DCB	1.30E+03	1.45E+03	1.59E+03
Land use	m2a crop eq	1.68E+03	2.36E+03	3.29E+03
Mineral resource scarcity	kg CU eq	2.92E+00	3.56E+00	3.93E+00
Fossil resource scarcity	kg oil eq	3.33E+02	3.34E+02	3.67E+02
Water consumption	m3	2.28E+01	2.56E+01	3.04E+01

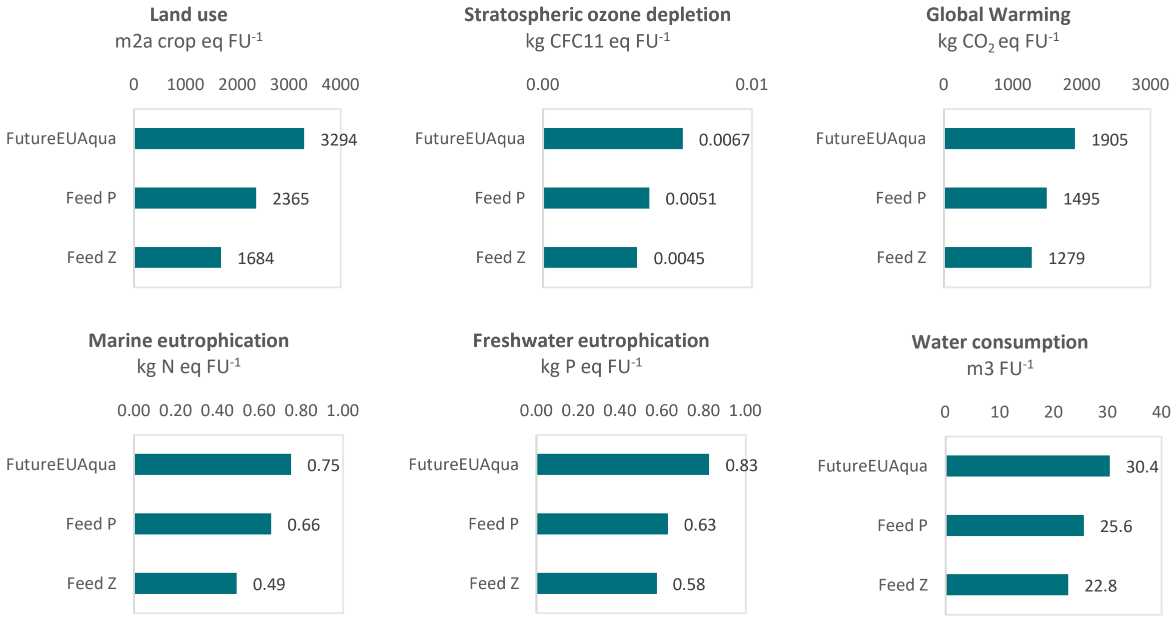
Figure 2 Relative results per impact category of the of Feed Z and Feed P, compared to the FutureEUAqua which is scaled to 1.



Compared to feed Z and P the FutureEUAqua feed obtained a higher environmental impact for almost all impact categories analyzed. For the impact categories ozone formation (human health and terrestrial ecosystems) a lower environmental impact was observed for the FutureEUAqua feed. The largest differences between the three feeds was observed for land use. Little difference was observed for the impact category ozone formation (human health).

As illustrated in Figure 3, major differences were observed among the feeds for the impact categories land use, stratospheric ozone depletion, global warming, marine eutrophication, freshwater eutrophication and water consumption. Feed Z shows the lowest impact in terms of all these impact categories.

Figure 3 Absolute results for the impact categories showing the largest variation in environmental impact.



Contribution analysis

As illustrated in Table 2, the production of feed ingredients is the main determinant in the environmental impact for all impact categories and all feeds (83.5% on average), followed by the transport to the feed mill (10.2% on average) and the feed compounding activities at the feed mill (6.3% on average).

For feed Z, the largest contribution to the environmental impact was observed for the production of marine ingredients (20.5% on average), followed by the production of other plant based ingredients (19.2% on average) and livestock ingredients (14.8% on average). For feed P the largest contribution to the environmental impact was observed for the production of other plant based ingredients (23.0% on average), followed by soybean ingredients (20.0% on average) and marine ingredients (17.4% on average). For the FutureEUAqua feed, the largest contribution to the environmental impact was observed for the production of soybean ingredients (26.9% on average), followed by the other plant based ingredients (24.7% on average) and the wheat ingredients (16.9% on average).

As stated earlier, major differences between feeds were observed for the impact categories land use, stratospheric ozone depletion, global warming, marine eutrophication, freshwater eutrophication and water consumption. Below a contribution analysis is performed per impact category, to identify what is causing these differences between the feeds.

Land use

The land use impact category relates to the use (occupation) and conversion (transformation) of land area by human activities. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation. Land transformation considers the extent of changes in land properties (e.g. quality) and the area affected. Land use is expressed in m2a crop equivalents, which represents the occupation of land in area and time, with the area crop land as a reference.

As illustrated in Figure 4, the FutureEUAqua feed obtained the highest impact on land use of all feeds (3294 m2a crop eq). The lowest land use was observed for feed Z (1684 m2a crop eq), which is 48.9% lower compared to the FutureEUAqua feed. An impact of 2365 m2a crop eq was observed for feed P, which is 28.2% lower compared to the FutureEUAqua feed.

For all feeds, the soybean ingredients (38.2% on average), wheat ingredients (27.3% on average) and other plant based ingredients (22.0% on average) are the main drivers of the impact on land use. The impact on land use changes almost proportionally with the ingredient content in the feeds.

Figure 4 Contribution analysis per ingredient group for the impact category land use

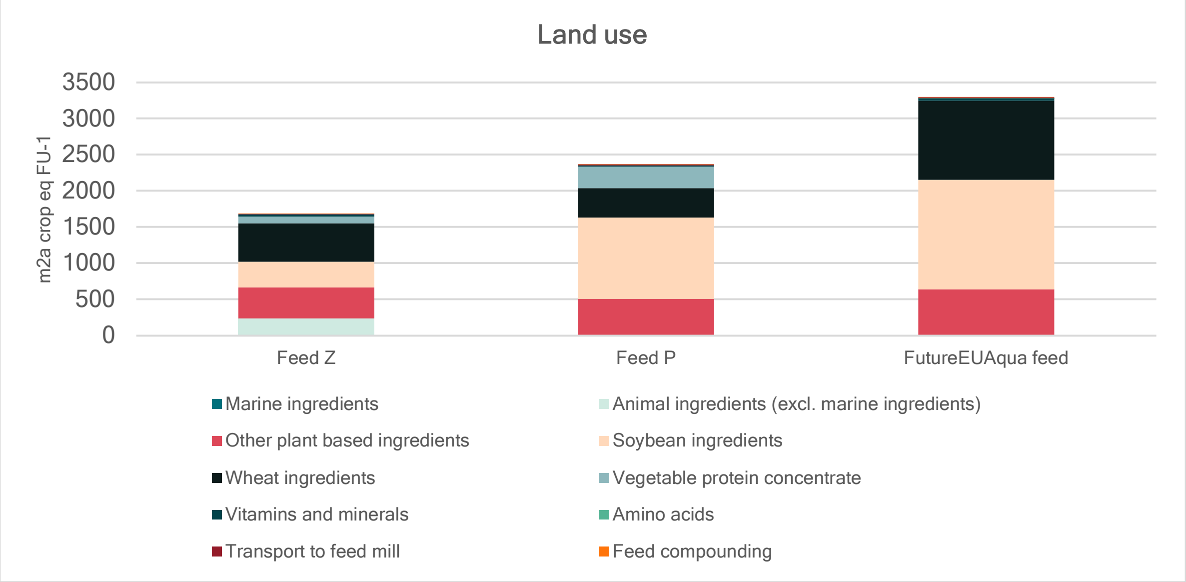


Table 2 Contribution analysis for the three fish feeds analyzed, per impact category expressed in percentage over the total impact consistent with the defined system boundary

		Feed ingredient production								Transport	Feed mill
Impact category	**Feed**	**Marine ingredients**	**Animal ingredients**	**Other plant based ingredients**	**Soybean ingredients**	**Wheat ingredients**	**Vegetable protein concentrate**	**Vitamins and minerals**	**Amino acids**	**Transport to feed mill**	**Feed compounding**
Global warming	Feed Z	27.43%	20.35%	11.43%	9.71%	7.38%	2.65%	2.57%	-	12.07%	6.41%
	Feed P	21.05%	0.00%	13.14%	36.10%	6.50%	7.08%	2.13%	0.00%	9.93%	4.07%
	FutureEUAqua Feed	10.82%	-	12.57%	46.79%	14.58%	-	1.94%	0.47%	8.53%	4.30%
Stratospheric ozone depletion	Feed Z	2.76%	18.33%	27.04%	18.84%	25.24%	3.78%	1.33%	-	1.72%	0.95%
	Feed P	2.22%	0.00%	32.51%	33.79%	17.68%	10.50%	0.92%	0.00%	1.60%	0.78%
	FutureEUAqua Feed	1.09%	-	29.72%	41.67%	24.17%	-	0.95%	0.42%	1.33%	0.65%
Ionizing radiation	Feed Z	20.71%	33.83%	24.27%	3.70%	3.17%	1.07%	2.01%	-	6.58%	4.67%
	Feed P	19.64%	0.00%	39.27%	16.54%	6.02%	3.89%	2.75%	0.00%	7.34%	4.55%
	FutureEUAqua Feed	10.58%	-	40.23%	25.18%	11.40%	-	2.00%	0.23%	6.27%	4.10%
Ozone formation, human health	Feed Z	43.84%	8.23%	10.58%	4.89%	7.28%	1.70%	1.41%	-	19.47%	2.60%
	Feed P	39.39%	0.00%	13.26%	11.37%	5.13%	5.26%	1.43%	0.00%	21.92%	2.23%
	FutureEUAqua Feed	27.02%	-	17.55%	18.11%	10.53%	-	1.72%	0.19%	22.17%	2.70%
Fine particulate matter formation	Feed Z	25.44%	16.03%	19.76%	4.68%	7.29%	3.33%	2.37%	-	13.55%	7.54%
	Feed P	21.52%	0.00%	27.80%	9.74%	6.97%	9.94%	3.25%	0.00%	15.14%	5.64%
	FutureEUAqua Feed	13.47%	-	31.57%	15.94%	15.41%	-	3.17%	0.22%	13.46%	6.76%
Ozone formation, terrestrial ecosystems	Feed Z	37.74%	8.11%	12.09%	7.21%	12.71%	1.98%	1.21%	-	16.70%	2.25%
	Feed P	35.13%	0.00%	15.97%	12.25%	7.59%	6.33%	1.27%	0.00%	19.45%	2.01%
	FutureEUAqua Feed	23.74%	-	20.56%	19.80%	12.43%	-	1.50%	0.16%	19.41%	2.39%
Terrestrial acidification	Feed Z	20.37%	27.76%	19.01%	4.06%	6.48%	2.34%	2.40%	-	12.07%	5.51%
	Feed P	19.36%	0.00%	30.60%	10.09%	7.68%	7.86%	3.69%	0.00%	15.82%	4.90%
	FutureEUAqua Feed	11.08%	-	31.97%	15.24%	20.51%	-	3.33%	0.28%	12.46%	5.12%
Freshwater eutrophication	Feed Z	14.78%	13.82%	14.05%	8.34%	10.17%	2.86%	2.98%	-	5.21%	27.80%
	Feed P	12.22%	0.00%	18.98%	27.05%	7.46%	8.18%	3.59%	0.00%	4.36%	18.16%
	FutureEUAqua Feed	6.00%	-	16.43%	34.30%	17.20%	-	2.98%	0.10%	3.66%	19.34%
Marine eutrophication	Feed Z	1.54%	28.75%	28.57%	13.23%	16.49%	7.29%	2.00%	-	0.23%	1.89%
	Feed P	1.05%	0.00%	32.22%	33.26%	14.03%	17.03%	1.06%	0.00%	0.38%	0.97%
	FutureEUAqua Feed	0.63%	-	32.07%	34.57%	29.30%	-	1.35%	0.35%	0.48%	1.24%
Terrestrial ecotoxicity	Feed Z	14.28%	4.24%	14.78%	4.88%	4.30%	3.91%	8.69%	-	42.51%	2.40%
	Feed P	12.13%	0.00%	15.25%	10.80%	3.69%	11.33%	10.13%	0.00%	34.80%	1.87%
	FutureEUAqua Feed	7.16%	-	17.41%	15.69%	10.96%	-	9.58%	0.01%	37.16%	2.02%
Freshwater ecotoxicity	Feed Z	13.69%	11.51%	26.66%	12.65%	15.98%	5.19%	5.89%	-	3.16%	5.27%
	Feed P	9.74%	0.00%	25.63%	34.95%	6.64%	12.58%	5.39%	0.00%	2.26%	2.81%
	FutureEUAqua Feed	5.85%	-	28.85%	43.35%	10.38%	-	5.44%	0.01%	2.38%	3.74%
Marine ecotoxicity	Feed Z	24.87%	10.18%	16.43%	7.08%	11.32%	3.37%	8.57%	-	8.11%	10.06%
	Feed P	21.06%	0.00%	20.89%	17.51%	6.87%	9.73%	10.66%	0.00%	6.83%	6.45%
	FutureEUAqua Feed	12.38%	-	22.60%	24.55%	15.14%	-	9.84%	0.02%	7.10%	8.35%
Human carcinogenic toxicity	Feed Z	30.25%	8.00%	9.11%	4.26%	5.32%	1.86%	9.55%	-	13.62%	18.02%
	Feed P	25.79%	0.00%	12.19%	9.17%	5.22%	5.47%	17.76%	0.00%	12.50%	11.89%
	FutureEUAqua Feed	15.01%	-	12.89%	12.96%	16.04%	-	15.74%	0.02%	12.19%	15.14%
Human non-carcinogenic toxicity	Feed Z	15.29%	12.62%	19.89%	5.56%	13.56%	5.37%	6.82%	-	7.51%	13.38%
	Feed P	12.38%	0.00%	23.87%	18.31%	8.10%	15.05%	8.11%	0.00%	6.04%	8.15%
	FutureEUAqua Feed	7.37%	-	26.22%	28.77%	12.47%	-	7.71%	0.04%	6.46%	10.96%
Land use	Feed Z	0.33%	13.58%	25.60%	21.02%	31.44%	5.59%	1.82%	-	0.54%	0.08%
	Feed P	0.25%	0.00%	21.05%	47.64%	17.27%	12.43%	0.86%	0.00%	0.44%	0.06%
	FutureEUAqua Feed	0.10%	-	19.27%	45.96%	33.26%	-	0.97%	0.00%	0.40%	0.04%
Mineral resource scarcity	Feed Z	38.06%	6.01%	12.60%	5.56%	8.55%	2.79%	13.63%	-	10.69%	2.12%
	Feed P	28.79%	0.00%	14.66%	14.88%	6.30%	7.16%	18.27%	0.00%	8.60%	1.36%
	FutureEUAqua Feed	16.88%	-	16.16%	20.82%	19.17%	-	16.69%	0.15%	8.55%	1.58%
Fossil resource scarcity	Feed Z	32.95%	15.15%	10.09%	5.30%	5.10%	1.77%	2.28%	-	15.76%	11.60%
	Feed P	30.05%	0.00%	13.79%	16.68%	5.01%	5.52%	2.51%	0.00%	14.83%	11.62%
	FutureEUAqua Feed	17.58%	-	15.33%	27.47%	10.94%	-	2.37%	0.86%	14.90%	10.54%
Water consumption	Feed Z	4.15%	9.40%	43.28%	13.28%	12.08%	8.90%	5.29%	-	1.15%	2.47%
	Feed P	4.46%	0.00%	49.03%	6.04%	6.84%	24.72%	6.19%	0.00%	1.02%	1.71%
	FutureEUAqua Feed	2.55%	-	52.88%	13.44%	19.46%	-	5.63%	3.17%	1.01%	1.85%

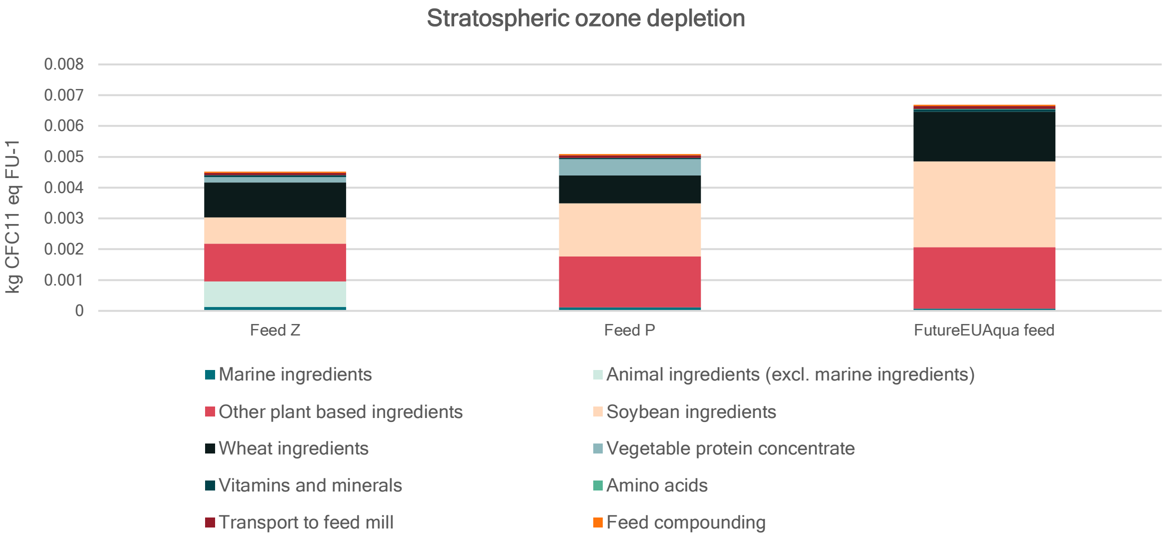
Stratospheric ozone depletion

The impact category stratospheric ozone depletion relates to the degradation of stratospheric ozone due to emissions of ozone-depleting substances. The stratospheric ozone layer protects humans from hazardous ultraviolet radiation. When ozone depletion substances are emitted, the ozone layer breaks down, this depletion increases risk of skin cancer by humans and cataract cases in humans and damage to plants. Stratospheric ozone depletion is expressed in kg CFC11 equivalents.

As illustrated in Figure 5, the highest impact on stratospheric ozone depletion is observed for the FutureEUAqua feed (0.0066 kg CFC11 eq.). Followed by Feed P (0.00051kg CFC11 eq) and Feed Z (0.0045kg CFC11 eq).

The main drivers of the impact on stratospheric ozone depletion for all feeds are the soybean ingredients (31.4 % on average), other plant based ingredients (29.7 % on average) and wheat ingredients (22.4% on average). For all these ingredients groups, the largest contribution of the impact is coming from either direct or indirect dinitrogen monoxide (N_2O) emissions from fertilizer application, manure application or crop residues. Therefore, the relative high impact of the FutureEUAqua feed can be clarified by the higher content of plant based ingredients compared to the other feeds.

Figure 5 Contribution analysis per ingredient group for the impact category stratospheric ozone depletion.



Global warming

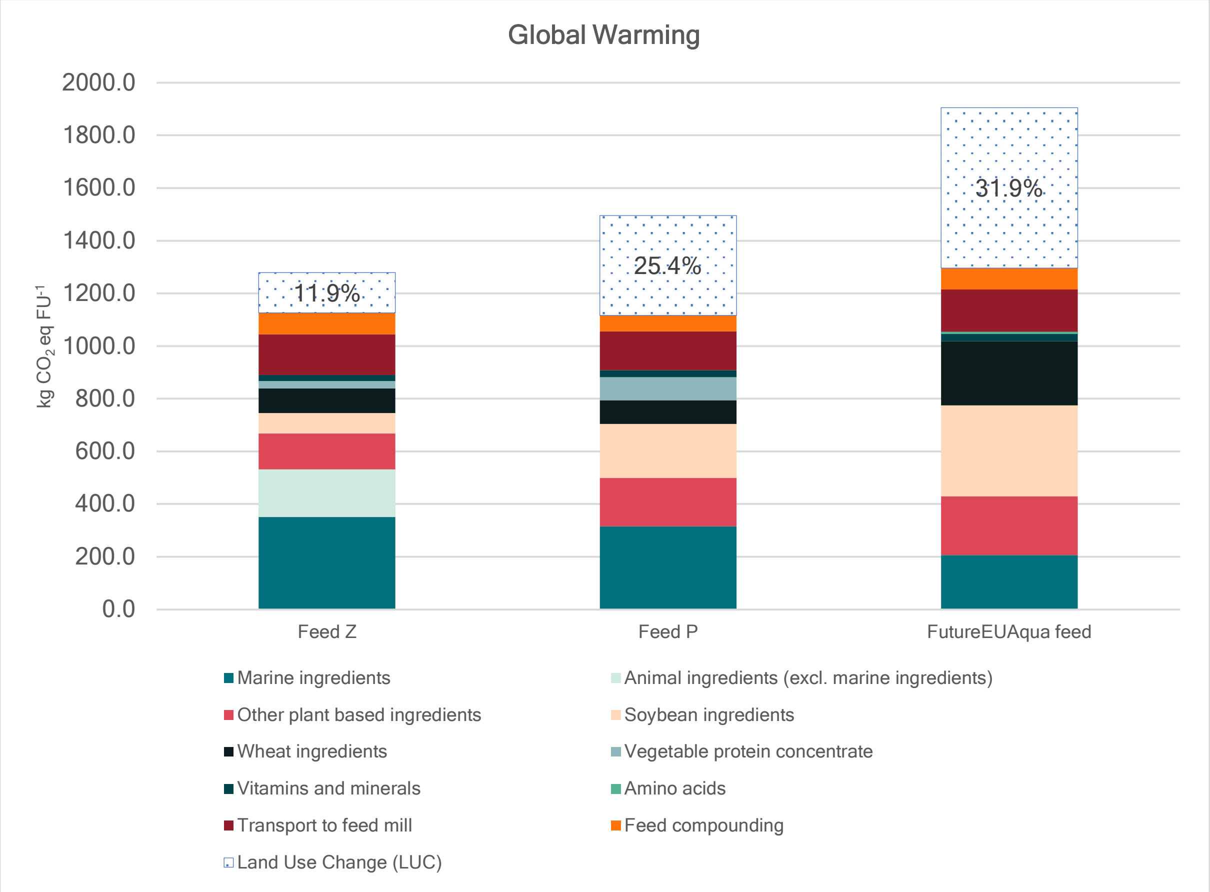
The impact category global warming refers to the capacity of greenhouse gases to influence changes in the global average surface air temperature and subsequent change in various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc. Global warming is expressed in CO_2 equivalents for a time horizon of 100-years. As mentioned earlier, this impact category also accounts for emissions originating from carbon stock changes caused by land use change. This impact category can also be referred to as “carbon footprint”.

As illustrated in Figure 6, the highest carbon footprint was observed for the FutureEUAqua feed (1905 kg CO_2 eq.), followed by Feed P (1517 kg CO_2 eq.). The lowest carbon footprint was observed for Feed

Z (1279 kg CO_2 eq.). For Feed Z, most of the impact related to global warming is due to the use of marine ingredients (27.4%) and livestock ingredients (20.4%). For the marine ingredients, this impact is rather a result of the energy intensive processing of marine ingredients (e.g. drying) than due to upstream processes (e.g. fishing activities). Most of the marine- and animal ingredients are considered to be a co- or waste product, meaning only little (livestock ingredients) or no (marine ingredients) impact from upstream processes is allocated to the product. For Feed P, most of the impact related to global warming is due to the use of soybean ingredients (35.6%) and marine ingredients (20.8%). The impact of soybean ingredients to global warming is relative high, while the feed only consists for 21.1% of soybean ingredients. For the FutureEUAqua feed, most of the impact related to global warming is due to the use of soybean ingredients (46.8%), this while the feed formulation only consist for 30.4% of soybean ingredients.

LUC emissions do heavily influence the results of the global warming impact for all the feeds. Especially for Feed P (25.1%) and the FutureEUAqua feed (31.9%) LUC emissions make up a substantial share of the global warming impact. On average, 69.5% of all the LUC emissions are directly related to the production of soybean ingredients. However, in Feed Z also a considerable share is related to the production of animal ingredients (51.9%) which is indirectly related to the cultivation of soybeans for feed.

Figure 6 Contribution analysis per ingredient group for the impact category global warming.



Marine eutrophication

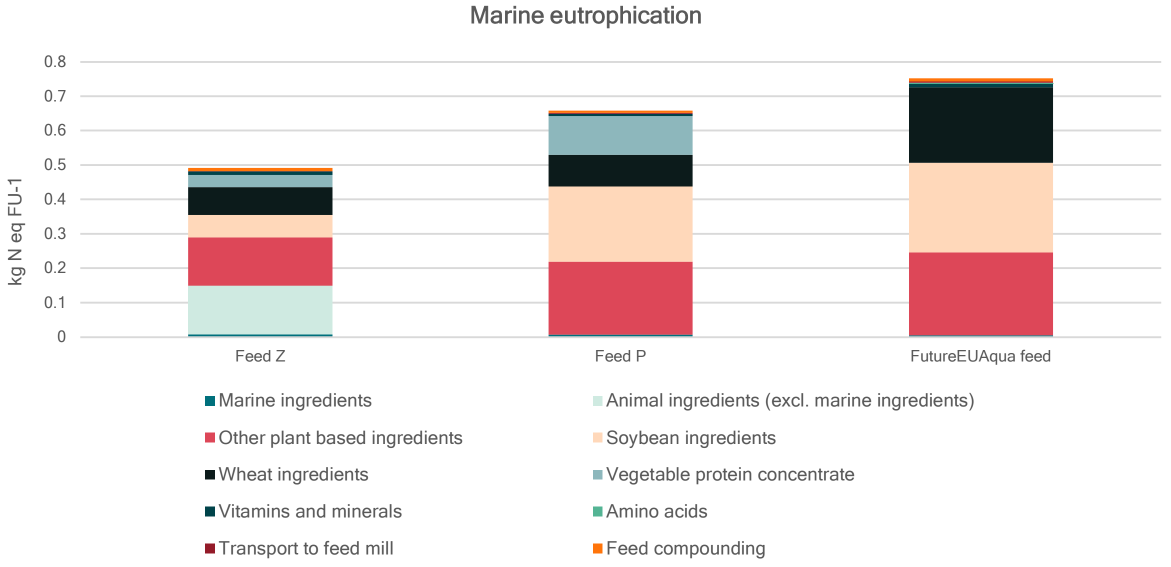
The eutrophication impacts on marine ecosystems is due to emissions of substances containing nitrogen (N). N emissions are caused largely by the use of fertilizers and combustion processes. If too much N is added, algae and other plants may grow in excess. This may have potential adverse ecological effects, for example by creating anoxic zones which has negative consequences for the entire marine ecosystem. The impact category marine eutrophication is expressed in kilograms of nitrogen equivalents, meaning the potential impact of substances contributing to marine eutrophication are converted to the equivalent of kilograms of nitrogen.

As illustrated in Figure 7, the highest impact for the impact category marine eutrophication is observed for the FutureEUAqua feed (0.75 kg N eq). For Feed P a 12.2% lower impact was observed (0.66 kg N eq) and for Feed Z a 34.6% impact was observed (0.49 kg N eq).

For all the feeds, the other plant based ingredients (30.9 % on average), soybean ingredients (27.0 % on average) and wheat ingredients (19.9% on average) are the main drivers of the impact on marine eutrophication. The underling activities causing the impacts are the nitrate emissions to water resulting from the application of fertilizers and manure and from crop residues during cultivation of feed ingredients.

For feed Z the animal ingredients (excl. marine ingredients) contribute also substantially (28.7%) to the impact on marine eutrophication. Almost all of the impact can be traced back to the crop cultivation of the feed ingredients in the compound feed being fed to broilers. The broilers are slaughtered and by-products are used for the production of poultry-, feather- and blood meal.

Figure 7 Contribution analysis per ingredient group for the impact category marine eutrophication.



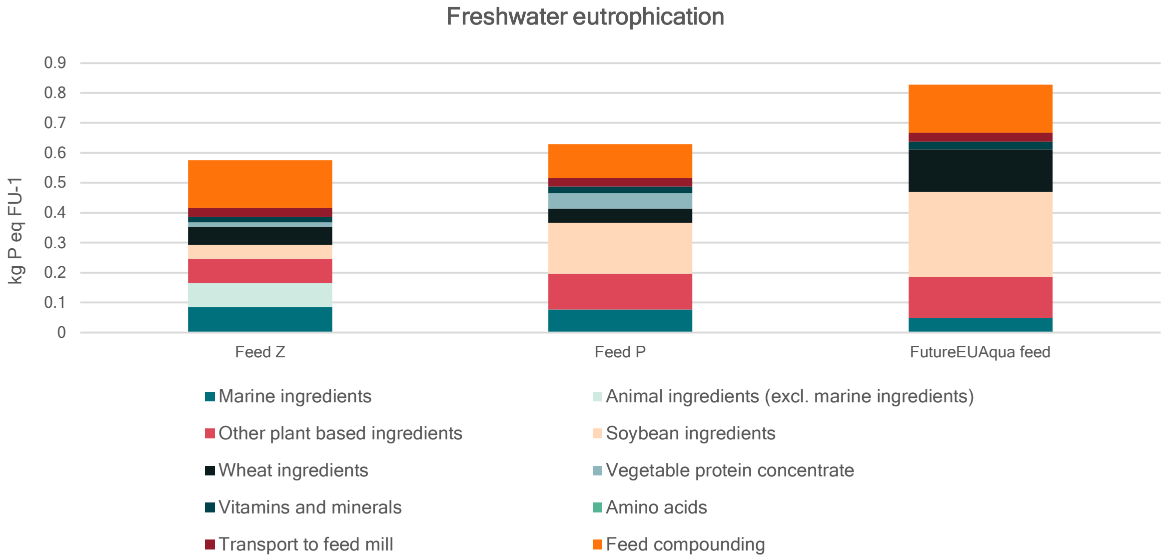
Freshwater eutrophication

Eutrophication impact on aquatic freshwater ecosystems is due to emission of substances containing phosphorus (P). In the aquatic environment, P is considered a limiting factor. If too much P is added, algae grows too rapidly. This may have adverse effects, such as leaving water without enough oxygen for fish to survive. The impact category freshwater eutrophication is expressed in kilograms of phosphorus equivalents, meaning the potential impact of substances contributing to marine eutrophication are converted to the equivalent of kilograms of phosphorus.

As illustrated in Figure 8, the highest impact on the impact category fresh water eutrophication is observed for the FutureEUAqua feed (0.82 kg P eq), followed by Feed P (0.67 kg P eq). The lowest impact was observed for Feed Z (0.58 kg P eq).

On average the largest contribution to this impact category is coming from the feed compounding (23.6% on average) and the production of soybean ingredients (22.6% on average). For the feed compounding the impact is mainly related to electricity use and its production (95%). During the production of electricity lignite is used. During the mining processes, spoil of the mining processes containing phosphate is emitted to groundwater. For the soybean ingredients the main impact is coming from phosphorus emissions to water due to the application of fertilizers.

Figure 8 Contribution analysis per ingredient group for the impact category freshwater eutrophication.



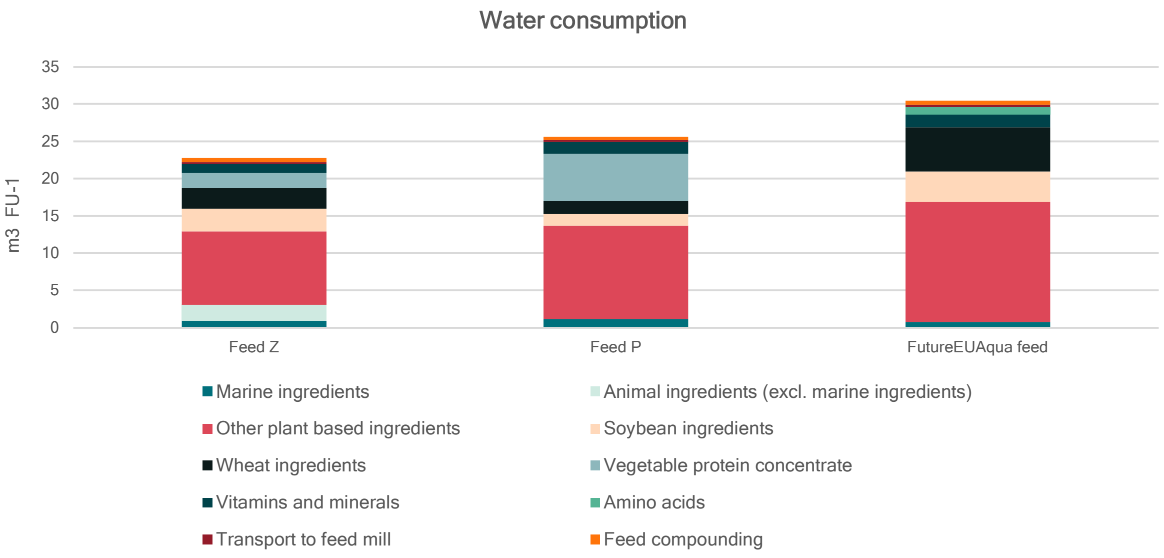
Water consumption

The impact category water consumption relates to the use of water in such a way that the water is evaporated, incorporated into products, transferred to other watersheds or disposed into the sea in a way that the water is not available anymore in the watershed of origin for humans or ecosystems. The impact category water consumption is expressed in cubic meters (m3). It should be noted that the impact category water consumption within the ReCiPe 2016 LCIA method does not consider the availability or scarcity of water in the regions where activity takes places.

As illustrated in Figure 9, the highest water consumption is observed for the FutureEUAqua feed (30.4 m3), followed by Feed P (25.7 m3). The lowest impact was observed for Feed Z (22.8 m3).

For all feeds, the production of other plant based ingredients are the most dominant ingredient group driving the score on water consumption (48.3% on average). This is mainly due to irrigation water used during cultivation. Noticeable is also the contribution of vegetable protein concentrate in Feed P (24.6%), for which also a considerable amount of irrigation water is used during the production of the ingredients for the concentrate’s constituents.

Figure 9 Contribution analysis per ingredient group for the impact category water consumption.



Sensitivity analysis

In this section we describe the results of the sensitivity analysis as described in deliverable 4.9.

Marine ingredients

In all the feeds a considerable amount of marine ingredients are used. These marine ingredients are either derived from wild fish capture activities or from fish processing by-products. As previously stated, in our allocation approach, no upstream processes are allocated to the by-products due to the fact the assumption is commonly made that their economic value can be neglected. In our study, we received primary data from the fish feed producer on the share of feed ingredients -products derived from fisheries and fisheries by-products. In this scenario we try to examine what the impact is of including marine ingredients either completely derived from fisheries (scenario 1) or from by-products (scenario 2) for the Feed Z, Feed P and the FutureEUAqua feed (baseline scenario).

Detailed results of this sensitivity analysis are represented in

Figure 10 for the impact categories analyzed in more detail.

The inclusion of marine ingredients completely derived from fisheries (scenario 1) results in a higher impact on all impact categories analyzed, in all the feeds. The largest difference was observed for Feed Z (4.91% on average), whereas a difference of respectively 3.74% and 3.72% was observed for Feed P and the FutureEUAqua feed (compared to the baseline results). For scenario 2 a lower impact was observed for all impact categories in all feeds. The largest difference was again observed for Feed Z (5.31% on average), followed by Feed P (4,92% on average) and the FutureEUAqua feed (2.77%). The lower variation in results for FutureEUAqua feed can be attributed to the lower share of marine ingredients in the feed formulation. Although Feed Z and P both contain an almost equal share of marine ingredients, the effects of the inclusion of either no or 100% by-products in the marine ingredients of Feed Z tends to be higher. This relates mainly to a larger share of fish meal in Feed Z, as fish meal receives a higher allocation factor compared to fish oil due to its higher economic value. Compared to scenario 1, the difference observed between Feed Z and P is less. This can be explained by the lower inclusion share of marine by-products in Feed Z compared to Feed P, as a result of which more emissions have already been allocated to the baseline results of Feed Z.

Compared to the baseline scenario’s, almost no variation between the scenarios were observed for the impact categories stratospheric ozone depletion, marine eutrophication, land use and water consumption for all feeds. However, for the impact categories global warming, ozone formation (human health and terrestrial ecosystems), human carcinogenic toxicity and mineral-, and fossil resource scarcity a greater gap was observed compared to the baseline results and the two scenario’s for all feeds. For all these impact categories the variation is somehow related to the energy use during fisheries or due to upstream processes in the production of this energy (e.g. GHG emissions, nickel emissions, chromium emissions).

The results of the sensitivity analysis show that the magnitude of the variation is determined by a combination of (I) the total inclusion of marine ingredients in the fish formulation, (II) the share between fish meal and oil and (III) the inclusion ratio of by-products. Furthermore, the results of this sensitivity analysis shows that the results (with the current feed formulation) can vary between 4.91% higher and 5.31% lower depending on the factor allocated to the ingredients.

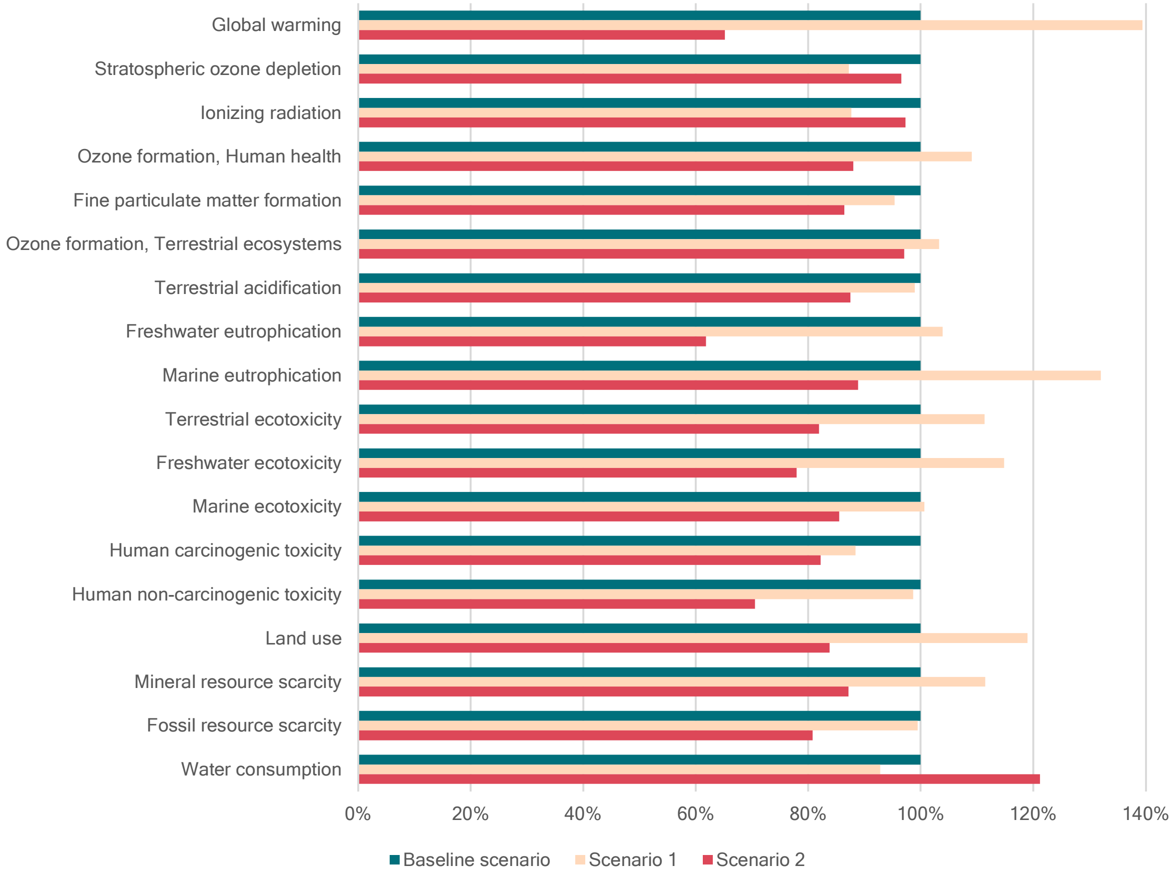
Figure 10 Results sensitivity analysis

Sourcing location soybean ingredients

Deforestation and emission from other land use change event remain big, 11% of the global GHG emissions are resulting from LUC events. The expansion of agricultural practices are the main driver of land use change. One of the most exemplary examples of this is the production of soybeans in Brazil. In the result section, we observed 31.9% of the carbon footprint of the FutureEUAqua feed is related to emissions from LUC. Almost 70% of these emissions are directly related to the production of soybean ingredients in Brazil. The fish feed producer already sources a part of the soybean ingredients in Europe. In this sensitivity analysis we examine what the effects are from sourcing all soybean ingredients in Brazil (scenario 1) vs. sourcing all soybean ingredients in Europe (scenario 2). Although the Global Warming impact category is relevant to look into, we included also the other impact categories to identify potential trade-off's.

As illustrated in Figure 11, the sourcing all soybean ingredients in Brazil (scenario 1) results in a on average in a 5.2% higher impact for the impact categories included compared to the baseline scenario. Sourcing all soybean ingredients form Europe resulted on average in a 14.5% lower impact for the impact categories analyzed.

Figure 11 Relative difference per for the two scenario analysed scenarios compared to the baseline scenario



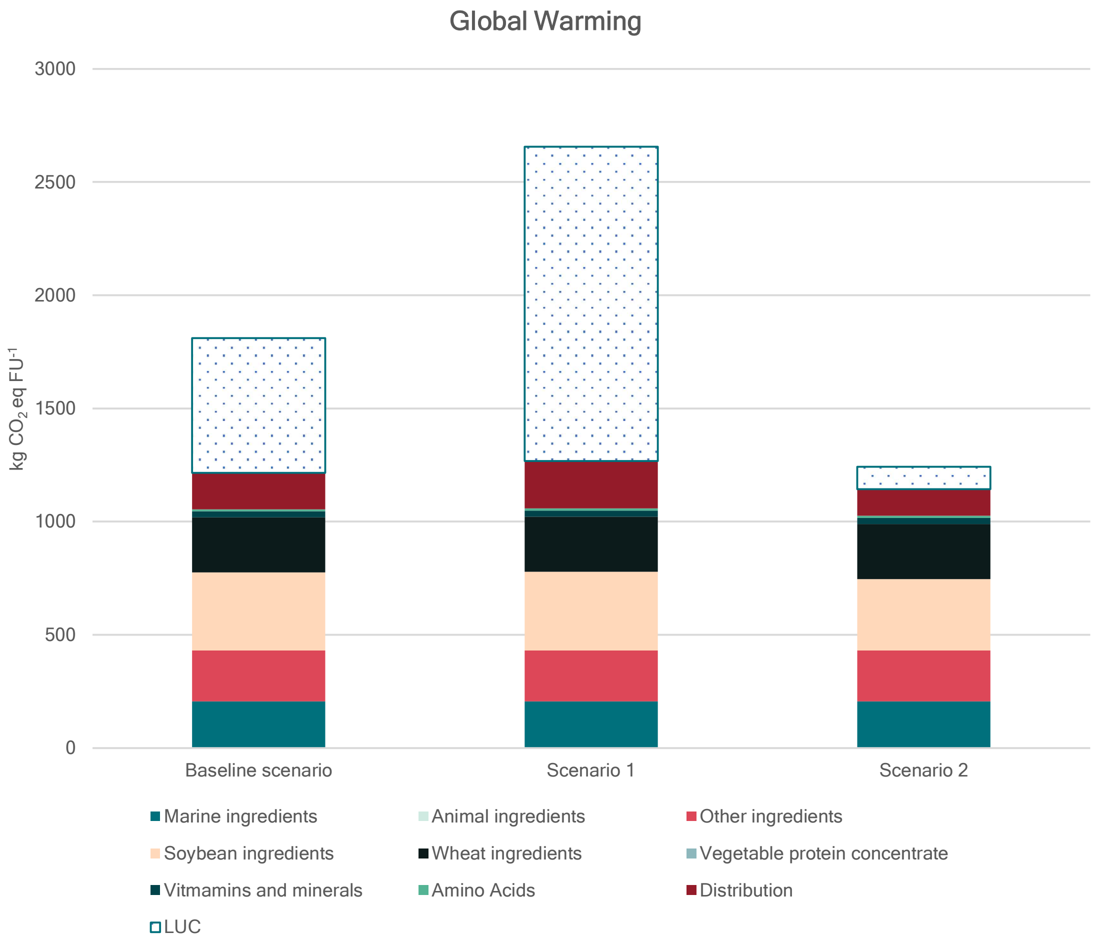
It should be mentioned considerable trade-off's can be observed for various impact categories, with the most considerable being the water consumption which compared to the baseline scenario is estimated to decrease with 7.2% in scenario 1 and estimated to increase by 21.2% in scenario 2. This is due to the assumption of a higher use of irrigation based on country specific water requirements.

It should be mentioned the ReCiPe method only accounts for water consumption, not taking into account the amount of water remaining in a watershed after the demand of humans and aquatic ecosystems has been met. To include this in LCAs, the AWARE method is frequently used. This method provides in characterization factors (CFs) that can be interpreted as a surface-time eq. to obtain unused water in a specific region. The CF's are limited to a range from 0.1 to 100, where 1 corresponds to the world average, and 10 for example, for a region where there is 10 times less available water remaining per area than the world average. Brazil and Greece have a CF (for irrigated areas) of respectively 2.653 and 69.360, meaning adapting a CF accounting for water scarcity will result in more divergent results.

The largest variation in impact was observed for the impact category global warming, where compared to the baseline scenario a 39% higher impact was observed for scenario 1 (2737 CO_2 eq.) and a 35% lower impact for scenario 2 (1323 CO_2 eq.) (see

Figure 12). The variation is mainly related to the differences in LUC emissions in both countries, and to less extend from the distribution and emissions during production (excl. LUC).

Figure 12 Contribution analysis per ingredient group for the impact category global warming.



Discussion

This study examined the effects of the (partial) replacement of marine- and terrestrial animal co-product ingredients in fish feeds with plant-based ingredients (soybean ingredients, wheat, etc.), by executing a comparative attributional LCA of three fish feeds. The results show that the substitution of marine and livestock products with plant-based ingredients generally leads to a higher environmental impact per kg feed. Our study concluded the feed ingredient production has on average the largest contribution in all feeds and to all impact categories analyzed. This is consistent with pre-existing knowledge (*PEFCR Feed for Food-Producing Animals*, 2020).

In this section we discuss how modelling choices affected the results of our LCA study. We elaborate on the allocation approach used for marine ingredients, emissions related to land use change and about the influence of digestibility, feed conversion ratio (FCR) and growth performance.

Allocation of marine ingredients

In our study we observed the use of marine ingredients resulted in a lower contribution to almost all impact categories analyzed. However, marine ingredients derived from by-products are modeled based on a cut-off principle in our study, because the economic value is considered to be negligible for the producer. Meaning that they are modeled as a waste stream and no upstream impacts are allocated to the marine ingredients. Although this is common approach in LCA's of fish feeds, this allocation approach has proven to be one of the most controversial methodological challenges in LCA, due to its substantial effects on the results. Below we briefly reflect on this issue, not without denoting the production of marine ingredients is strongly interconnected, as fish oil cannot be produced without the production of fish meal and vice versa.

Ayer et al. (2007) argues the gross chemical energy supply should be used as allocation key, as the aim of food is to supply energy. While this may be true, this approach does not reflect the behavior and the causal relationships in a system, and also does not account for other function of marine ingredients in fish feeds (e.g. digestibility). Economic allocation instead, tends to better reflect the behavior and causal relationships in a system. Guinee et al (2004) argues economic allocation is the most suitable and consistent allocation method. Economic allocation is also the preferred approach of the European Commission in the PEFCR Feed for food producing animals. Although economic allocation tends to be a suitable and consistent approach for handling multifunctionality of marine ingredients, with rising prices and a growing demand for marine ingredients, the economic value of by-products is likely not to be zero and likely to rise (Stevens et al., 2018). This might result in a somewhat higher allocation factor for by-products, leading to an overall higher environmental footprint of feeds containing marine ingredients.

With regards to marine ingredients, it should also be noted that their use has raised concerns about its effects on marine biodiversity as a result of fishing activities. In present LCAs the impact related to the removal of biomass is not included, due to missing impact pathways. It is worth mentioning a new approach that includes characterization factors (CFs) to quantify the impact on the depletion of fish stocks at regional and global scale is in development and about to be published, which might be implemented in the new version of ReCiPe.

Land use change emissions

In our study, the results for global warming impact category were heavily influenced by GHG emissions related to land use change (23.0% on average). These emissions are either directly or in-directly caused by land use change event occurring in the production of soybeans for soybean ingredients (69.5 – 86.7% on average).

It should be mentioned that two modelling choices potentially influence these results. First and foremost it should be mentioned that no check has been executed whether (and if so: when) land use change has taken place on the sourcing location of soy ingredients. In case land use change events have not taken place or outside the responsibility window (20 years), the results of the global warming impact would be substantially lower and the impact on global warming of the three feeds would be closer together. Secondly, we applied a default modelling approach (as described in Discussion). Methods such as the SBTi Forest Land use and Agriculture (FLAG) guidelines and the GHG protocol Land Sector and Removal Guidance which are recently (or about to be) published, adopted another approach compared to PAS 2050. With the main discontinuity triggered by applying linear amortization method, placing more weight on years right after the LUC event. Depending on whether and when land use change events have taken place, the results on the impact category global warming might be (substantially) higher or lower.

Digestibility, feed conversion ratio (FCR) and growth performance

In this study we only examined the environmental impact of the feeds up to feed mill-gate. From pre-existing knowledge, it is well known that fish feed formulation might have a substantial impact on feed digestibility, feed conversion ratio and the growth performance of fishes fed with the feed. Also, the (partial) substitution of marine ingredients with plant ingredients might compromise the nutritional value of the fish being fed with the feed. In trials to test fish growth performance of the feeds some issues have been identified with the digestibility of the feeds due to antinutritional factors that exist in the plant ingredients. This might relate to the (partial) substitution of marine ingredients.

Aforementioned factors might influence the overall environmental impacts substantially, as more or less feed is needed to fulfill the same amount or nutritional content of live weight fish. Although not addressed in this study, these are relevant factors in decision making.

Results of the economic analysis

Linkages to FutureEUAqua KER

The objective of the economic model was to evaluate the impact of FutureEUAqua's Key Exploitable Results on the business cases. The project team reviewed KER to select those subject to the economic analysis. Criteria for selection included:

- Relevance for aquaculture business case
- Availability of, and willingness and ability to share information

The review of KER for relevance if presented below in Table 3.

Table 3 Review of FutureEUAqua KER for inclusion

KER	Potential economic impact	KER used in economic model?
1.1 Demonstration of climate resilience in Atlantic salmon and European seabass in semi-commercial and experimental conditions	Climate change is a key uncertainty facing the aquaculture industry as changing weather patterns including storms a higher variation in temperatures could impact fish growth and have implications for commercial breeding programmes. The uncertainty could affect investor confidence, having impacts on the availability and cost of capital. The results indicate that the fish material from the commercial breeding programmes selected for rapid growth will perform well across diverging production environments (salmon) and is resilient to rapid temperature changes experienced in the Mediterranean (seabass). This suggests there will be limited long term risk.	No. While the finding has important implications for investment choices in the aquaculture industry, it was determined that modelling these impacts would be too challenging / theoretical at this stage. Observable impact in future may be negligible as the negative impacts on investor confidence can be avoided.
1.2 Identification of consistent QTL/SNPs affecting survival	The finding has the potential to reduce mortality rates among trout, allowing for increased	No. It was intended to review the impact of this FutureEUAqua innovation on

against infectious pancreatic necrosis in rainbow trout.	biomass production with the same inputs. The findings will have strong industrial implications, for example, performing strong selection for parents carrying loci linked with resistance to producer multiplier and/or production groups should avoid losses in case of IPNV outbreaks. It is believed that the innovation could reduce mortality. To account for the higher quality juvenile stock, costs of juveniles are assumed to increase.	the Danish Trout RAS case study, to assess the impact of increasing the biomass production and the juvenile costs. Exact information to include in the model was not available on time.
1.3 Novel feeds for conventional and organic sea bream and sea bass aquaculture	Use of more sustainable materials is anticipated to increase resilience in the feed supply chain. With an estimated TRL of 7, and as the resilience benefits will be observed over a long time horizon, it is hard to estimate exactly how much the costs of feedstock will change.	Yes. This FutureEUAqua innovation was applied to the Italian and Greek Sea bream and Sea bass case study, to assess the impact of changing feed costs
1.4 Policy recommendation: Availability of production sites for aquaculture in Europe	Analysis of aquaculture regulation in five European countries. The analysis of challenges and conflicts related to availability of production sites for different aquaculture productions, and subsequent suggestions for revision of to remedy these. The analysis could help the aquaculture industry in a number of ways such as by lowering operational costs from better site selection – e.g. closer to the sea shore. Less use of treatments (chemicals, abiotics, etc) and potentially from lower upfront capital expenditure costs.	No. While the report has potential to have significant indirect benefits to the aquaculture industry, size of impacts highly uncertain.

1.5 Guidelines for communication strategies towards consumers	By providing guidelines for communication strategies that will increase consumer awareness and acceptance of different aquaculture production systems, this KER has the potential to benefit the aquaculture industry in a number of key areas, including by potentially allowing for a price premium if consumers can identify the value of EU farmed fish, and potentially an increased market share for EU fish farmers. This may come with an increased sales cost as farmers adopt the communications strategy.	Yes, this KER can help to increase prices receive for aquaculture products.
1.6 Simulation model to evaluate the economic effect of production, feed ingredients, by-products, different breeds, production system and packaging	This model	N/a
1.7 Data for Life Cycle Assessment	This model	N/a
1.8 Simulation model to evaluate the economic effect of production, feed ingredients, by-products, different breeds, production system and packaging	This model	N/a
1.9 Innovative water quality descriptors	The benefits of the exploited process/methods include: • Improvement of consumers' awareness, perceptions and acceptability of the European aquaculture products and methods • Contribution to the creation of improved sustainable aquaculture systems and implement productive and	No, it is not believed that this KER will change cost structure of aquaculture production.

	resilient aquaculture practices that maintain healthy aquatic ecosystems • Improvement of the professional skills and competences of those working and being trained to work within recirculating aquaculture systems.	
1.10 Biomass estimation sensing system and novel machine learning techniques	Biomass estimation sensing system and novel machine learning developed based on stereo vision provides a way to accurately measure fish in their cages in a non-invasive manner and without the need to physically access the off-shore installation. The KER could reduce labour input requirements and feed costs by improving feed intake.	Yes. For the purposes of this analysis, it is assumed that aquaculture industries adopting the technology will be able to: • Reduce their personnel costs required to make samples by approximately one Full-Time Equivalent day per month (ie 1/30th reduction in personnel costs). • Reduced feed costs by 1% due to better feed management.
1.11 Wireless Sensor Network to enhance fish welfare and environmental sustainability	The real-time wireless communication system and sensor network envisaged for the FutureEUAqua large scale demonstration activities includes a cloud platform that communicates wireless underwater. This KER could help farmers in a large variety of ways such as increasing feed efficiency, improving growth rates, and reducing mortality.	No. Potential impacts similar to KER 1.10 and so not tested.
1.12 Novel non-thermal sanitation	Plasma assisted sanitation system aimed at increasing the shelf-life of fish products. The KER could benefit the aquaculture industry by giving a	No, it is not believed that this KER will change the cost-structure of aquaculture production.

	price premium due to improved freshness of fish, Avoid use of heat and potentially increase the shelf life to get more distant fish markets? Price premium due to freshness – say, 10-15% (would need a reference)? Additional costs to get on the market.	
1.13 Novel processing methods for fish products	The developed novel processing methods are based on the use of pulsed electric fields (PEF) and on cryo-smoking. The KER could benefit the aquaculture industry by giving a price premium due to improved freshness of fish.	No. Potential impacts similar to KER 1.12 and so not tested.
1.14 Innovative uncooked seabream processed product with high nutritional value and desired sensorial characteristics	The developed fish commodity is a novel product, consisting of seabream fillets sanitised by the application of cold plasma, obtained through an innovative equipment developed. The KER could benefit the aquaculture industry by increasing shelf life and widening market access for European aquaculture products.	No. Potential impacts similar to KER 1.13 and so not tested.
1.15 Innovative cold-smoked salmon product with high nutritional value and desired sensorial characteristics	The novel cryo-smoked salmon fillets are obtained through an innovative equipment developed. The KER could benefit the aquaculture industry by increasing shelf life and widening market access for European aquaculture products.	No. Potential impacts similar to KER 1.13 and so not tested.
1.16 Innovative ready-to-cook product containing minced flesh	Innovative ready-to-cook product containing minced flesh	No, it is not believed that this KER will change the cost-structure of aquaculture production.

In the FutureEUAqua consortium meeting, the selection of scenario's to include in the economic analysis was discussed. At that time, concerns about energy prices and inflation were high on the agenda and it was deemed relevant to add scenario's on the two aspects.

As the exact impact of most KER could not be assessed, it was also decided to include a generic scenario with a 20% decrease in off-farm sales price and a generic scenario with a 20% increase in sales price.

Table 4 gives an overview of the assumed chances, tested for impact on the economics of aquaculture.

Table 4 Overview of chances tested for

	Impact type	S1: Salmon cages in Ireland	S2: Seabass and seabream cages in Greece	S3: Seabass and seabream cages in Italy	S4: Trout recirculation systems in Denmark
a) Feed composition	Change in cost of feed input	10%	10%	10%	0%
b) Impact of an increase in energy cost	Real energy cost inflation	24%	37%	33%	41%
	Real energy cost inflation - S1	49%	74%	65%	82%
	Real energy cost inflation - S2	12%	19%	16%	21%
	Real electricity cost inflation (S3)	29%	132%	47%	84%
c) Impact of inflation/salary increases	Salary cost inflation	10%	10%	10%	10%
d) Price down	Reduced sales price for produce	-20%	-20%	-20%	-20%
e) Price up	Increased sales price for produce	-20%	-20%	-20%	-20%

Estimates for changes in the cost of feed input were made together with FutureEuAqau consortium partners, taking into account differences in FCR of various feeds.

Estimates for changing costs of energy and inflation are based on Eurostat Harmonised Indices of Consumer Prices[1] data and consumer prices reported under EUMOFA.

Applying the economic model

The economic model, prepared in Microsoft Excel, examines the performance of the average aquaculture enterprise in key producing countries of the particular fish species selected. This does imply that the cost of production is assumed to be linear, that is, costs increase at the same rate at any scale of production. While such an assumption is not likely to hold in reality, it is difficult to assess varying scales of production with the data available. This is due to a combination of reasons, such as the fact that production data is either not differentiated by enterprise size or does not specify enterprise size at all, and there are intrinsic differences in production size even among key countries.

The overall objective of the model is to illustrate how changes in input parameters affect the economic performance of four scenarios. The four scenarios are:

1. cages in Ireland
2. Seabass and seabream cages in Greece
3. Seabass Salmon and seabream cages in Italy
4. Trout recirculation systems in Denmark

The economic model aimed to assess the expected economic impacts of FutureEUAqua Key Exploitable Results (KERs). In discussion with the consortium partners, the decision was made to focus on the following changes in input parameters

- Changes in costs of feed input, taking into account the results of the experiments in FutureEUAqua
- Impact of increase in energy cost
- Impact of inflation/salary increases
- A generic decrease in the off-farm sales price
- A generic increase in the off-farm sales price

Results

Salmon cages in Ireland

Table 5 below summarizes the results of the analysis, looking into the effect of changes in input parameters on total operating costs, gross value added, gross operating surplus and net profit for salmon cage farming in Ireland. All results of under the assumption that all other parameters remain equal (ceteris paribus). Thus, for example, it is not assumed that higher costs of production can be passed on to retail and/or consumers.

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[1] Overview - Harmonised Indices of Consumer Prices (HICP) - Eurostat (europa.eu)

Table 5 Results of analysis for salmon cage farming in Ireland

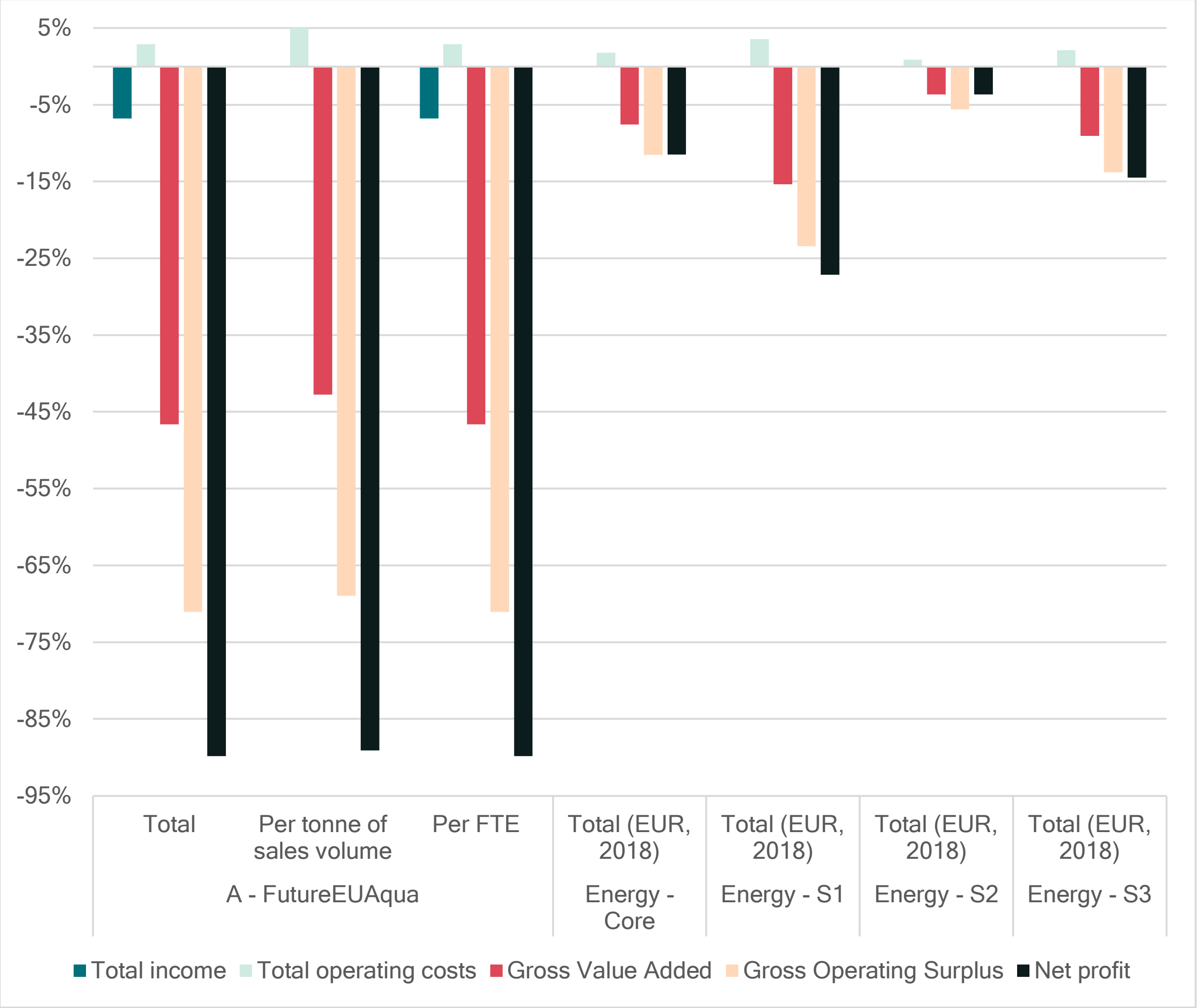
Scenario	Result	Total income	Total operating costs	Gross Value Added	Gross Operating Surplus	Net profit
A - FutureEUAqua	Total	-7%	3%	-47%	-71%	-90%
	Per tonne of sales volume	0%	10%	-43%	-69%	-89%
	Per FTE	-7%	3%	-47%	-71%	-90%
Energy - Core	Total (EUR, 2018)	0%	2%	-8%	-12%	-11%
	Per tonne of sales volume (EUR, 2018)	0%	2%	-8%	-12%	-11%
	Per FTE (EUR, 2018)	0%	2%	-8%	-12%	-11%
Energy - S1	Total (EUR, 2018)	0%	4%	-15%	-23%	-27%
	Per tonne of sales volume (EUR, 2018)	0%	4%	-15%	-23%	-27%
	Per FTE (EUR, 2018)	0%	4%	-15%	-23%	-27%
Energy - S2	Total (EUR, 2018)	0%	1%	-4%	-6%	-4%
	Per tonne of sales volume (EUR, 2018)	0%	1%	-4%	-6%	-4%
	Per FTE (EUR, 2018)	0%	1%	-4%	-6%	-4%
Energy - S3	Total (EUR, 2018)	0%	2%	-9%	-14%	-14%
	Per tonne of sales volume (EUR, 2018)	0%	2%	-9%	-14%	-14%
	Per FTE (EUR, 2018)	0%	2%	-9%	-14%	-14%
C - Salary	Total	0%	1%	0%	-5%	-3%
	Per tonne of sales volume	0%	1%	0%	-5%	-3%
	Per FTE	0%	1%	0%	-5%	-3%

D - Price Down	Total	-20%	0%	-100%	-153%	-197%
	Per tonne of sales volume	-20%	0%	-100%	-153%	-197%
	Per FTE	-20%	0%	-100%	-153%	-197%
E - Price Up	Total	20%	0%	101%	154%	206%
	Per tonne of sales volume	20%	0%	101%	154%	206%
	Per FTE	20%	0%	101%	154%	206%

The results show that the net profit decreases under all scenarios. The use of FutureEUAqua feed will increase total operating costs by 3% and reduce net profit by 90%. The impact on net profit is not only the result of higher feed costs (and thus higher total operating costs) but also of lower turnover due to lower growth performance. This effect is not there under the energy costs and salary scenarios.

Figure 13 visualises the impact of changes in cost of feed input, distinguishing between total change, change per tonne of sales volume and per FTE, and the impact of various changes in the energy costs (Energy-core, Energy – S1, Energy – S2, energy – S43).

Figure 13 Impact of changes in cost of feed input



Seabass and seabream cages in Greece

Table 6 below summarizes the results of the analysis, looking into the effect of changes in input parameters on total operating costs, gross value added, gross operating surplus and net profit for seabass and seabream cages in Greece. All results are under the assumption that all other parameters remain equal (ceteris paribus). Thus, for example, it is not assumed that higher costs of production can be passed on to retail and/or consumers.

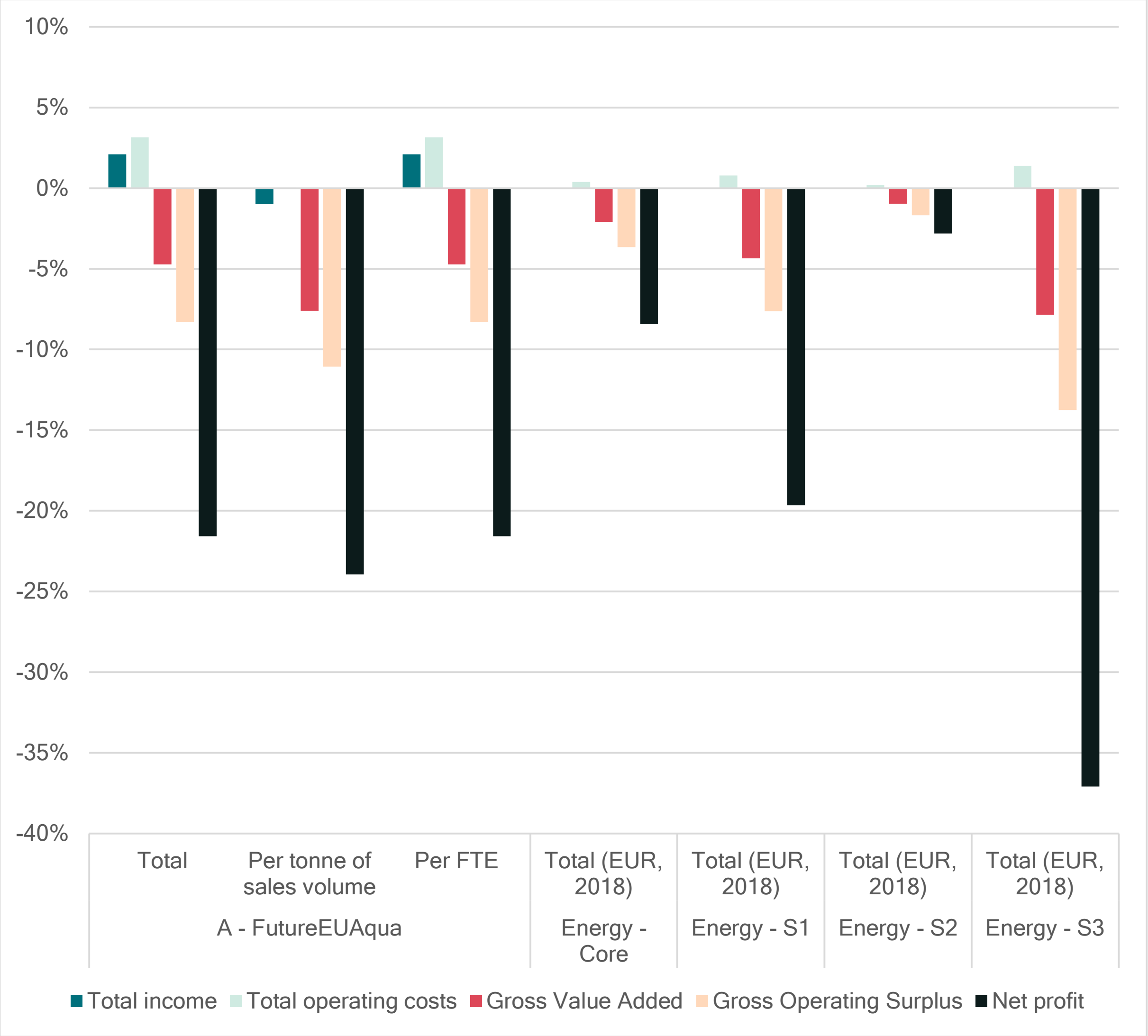
Table 6 Summarization of the analysis results (Greece)

Scenario	Result	Total income	Total operating costs	Gross Value Added	Gross Operating Surplus	Net profit
A - FutureEUAqua	Total	2%	3%	-5%	-8%	-22%
	Per tonne of sales volume	-1%	0%	-8%	-11%	-24%
	Per FTE	2%	3%	-5%	-8%	-22%
Energy - Core	Total (EUR, 2018)	0%	0%	-2%	-4%	-8%
	Per tonne of sales volume (EUR, 2018)	0%	0%	-2%	-4%	-8%
	Per FTE (EUR, 2018)	0%	0%	-2%	-4%	-8%
Energy - S1	Total (EUR, 2018)	0%	1%	-4%	-8%	-20%
	Per tonne of sales volume (EUR, 2018)	0%	1%	-4%	-8%	-20%
	Per FTE (EUR, 2018)	0%	1%	-4%	-8%	-20%
Energy - S2	Total (EUR, 2018)	0%	0%	-1%	-2%	-3%
	Per tonne of sales volume (EUR, 2018)	0%	0%	-1%	-2%	-3%
	Per FTE (EUR, 2018)	0%	0%	-1%	-2%	-3%
Energy - S3	Total (EUR, 2018)	0%	1%	-8%	-14%	-37%
	Per tonne of sales volume (EUR, 2018)	0%	1%	-8%	-14%	-37%
	Per FTE (EUR, 2018)	0%	1%	-8%	-14%	-37%
C - Salary	Total	0%	1%	0%	-7%	-19%
	Per tonne of sales volume	0%	1%	0%	-7%	-19%
	Per FTE	0%	1%	0%	-7%	-19%

D - Price Down	Total	-13%	0%	-85%	-149%	-421%
	Per tonne of sales volume	-13%	0%	-85%	-149%	-421%
	Per FTE	-13%	0%	-85%	-149%	-421%
E - Price Up	Total	13%	0%	85%	150%	427%
	Per tonne of sales volume	13%	0%	85%	150%	427%
	Per FTE	13%	0%	85%	150%	427%

Figure 14 visualises the impact of changes in cost of feed input, distinguishing between total change, change per tonne of sales volume and per FTE, and the impact of various changes in the energy costs (Energy-core, Energy – S1, Energy – S2, energy – S3).

Figure 14 Visualisation of the impact of changes in cost of feed input (Greece)



Seabass and seabream cages in Italy

Table 7 below summarizes the results of the analysis, looking into the effect of changes in input parameters on total operating costs, gross value added, gross operating surplus and net profit for seabass and seabream cages in Italy. All results of under the assumption that all other parameters remain equal (ceteris paribus). Thus, for example, it is not assumed that higher costs of production can be passed on to retail and/or consumers

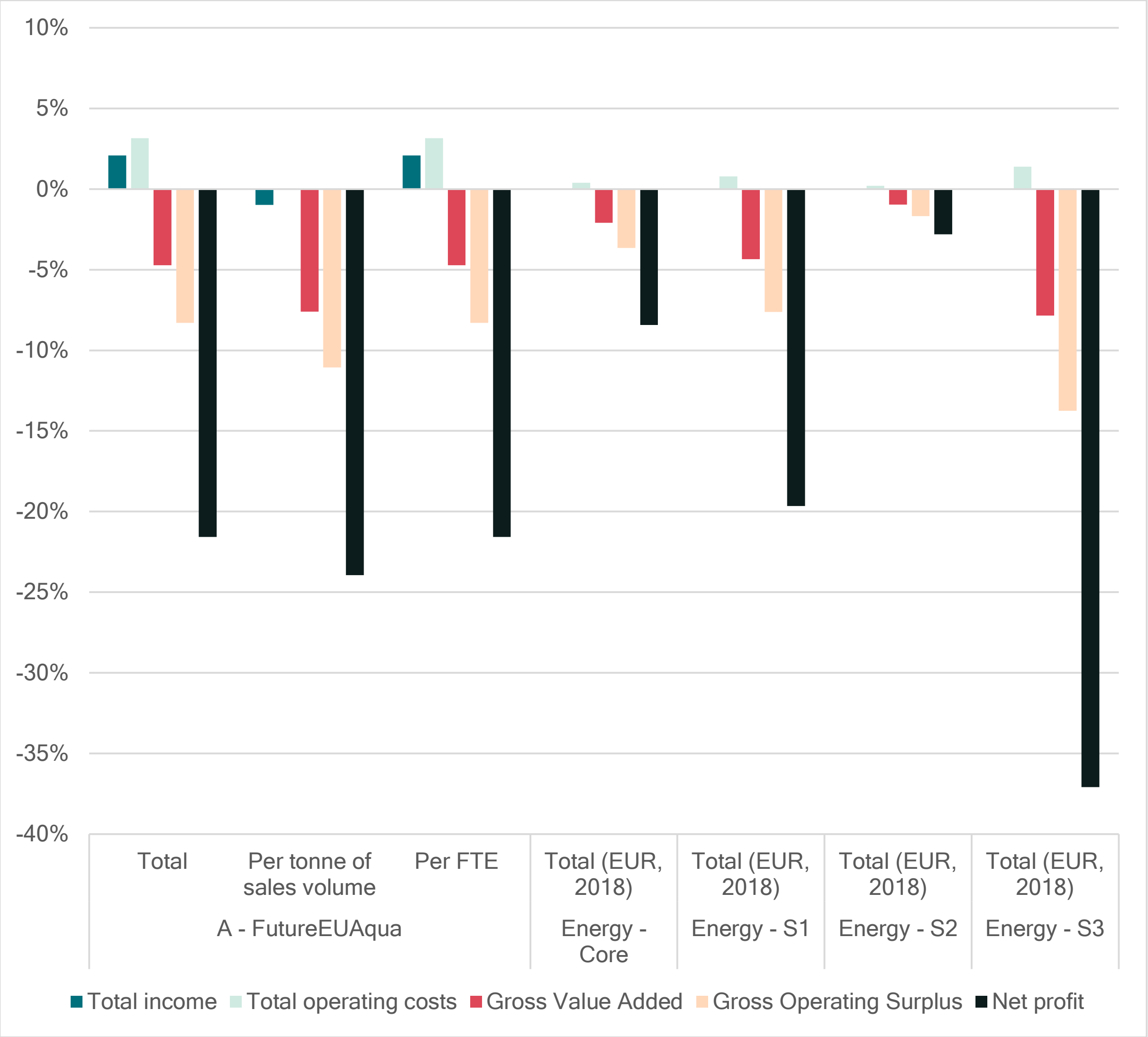
Table 7 Summarization of the analysis results (Italy)

Scenario	Result	Total income	Total operating costs	Gross Value Added	Gross Operating Surplus	Net profit
A - FutureEUAqua	Total	0%	0%	-1%	-2%	-6%
	Per tonne of sales volume	0%	3%	-19%	-30%	-93%
	Per FTE	7%	15%	-35%	-62%	-206%
Energy - Core	Total (EUR, 2018)	0%	2%	-2%	-2%	-3%
	Per tonne of sales volume (EUR, 2018)	0%	2%	-2%	-2%	-3%
	Per FTE (EUR, 2018)	0%	2%	-2%	-2%	-3%
Energy - S1	Total (EUR, 2018)	0%	3%	-4%	-5%	-6%
	Per tonne of sales volume (EUR, 2018)	0%	3%	-4%	-5%	-6%
	Per FTE (EUR, 2018)	0%	3%	-4%	-5%	-6%
Energy - S2	Total (EUR, 2018)	0%	1%	0%	-1%	-1%
	Per tonne of sales volume (EUR, 2018)	0%	1%	0%	-1%	-1%
	Per FTE (EUR, 2018)	0%	1%	0%	-1%	-1%
Energy - S3	Total (EUR, 2018)	0%	2%	-3%	-3%	-4%
	Per tonne of sales volume (EUR, 2018)	0%	2%	-3%	-3%	-4%
	Per FTE (EUR, 2018)	0%	2%	-3%	-3%	-4%
C - Salary	Total	0%	0%	0%	-1%	-2%
	Per tonne of sales volume	0%	1%	2%	-6%	-28%
	Per FTE	0%	3%	6%	-19%	-85%

D - Price Down	Total	-2%	0%	-10%	-18%	-53%
	Per tonne of sales volume	-20%	0%	-127%	-222%	-641%
	Per FTE	-62%	0%	-384%	-672%	-1939%
E - Price Up	Total	2%	0%	11%	19%	53%
	Per tonne of sales volume	20%	0%	131%	229%	641%
	Per FTE	62%	0%	396%	693%	1939%

Figure 15 visualises the impact of changes in cost of feed input, distinguishing between total change, change per tonne of sales volume and per FTE, and the impact of various changes in the energy costs (Energy-core, Energy – S1, Energy – S2, energy – S3).

Figure 15 Visualisation of the impact of changes in cost of feed input (Italy)



Trout recirculation systems in Denmark

Table 8 below summarizes the results of the analysis, looking into the effect of changes in input parameters on total operating costs, gross value added, gross operating surplus and net profit for trout recirculation systems in Denmark. All results are under the assumption that all other parameters remain equal (ceteris paribus). Thus, for example, it is not assumed that higher costs of production can be passed on to retail and/or consumers.

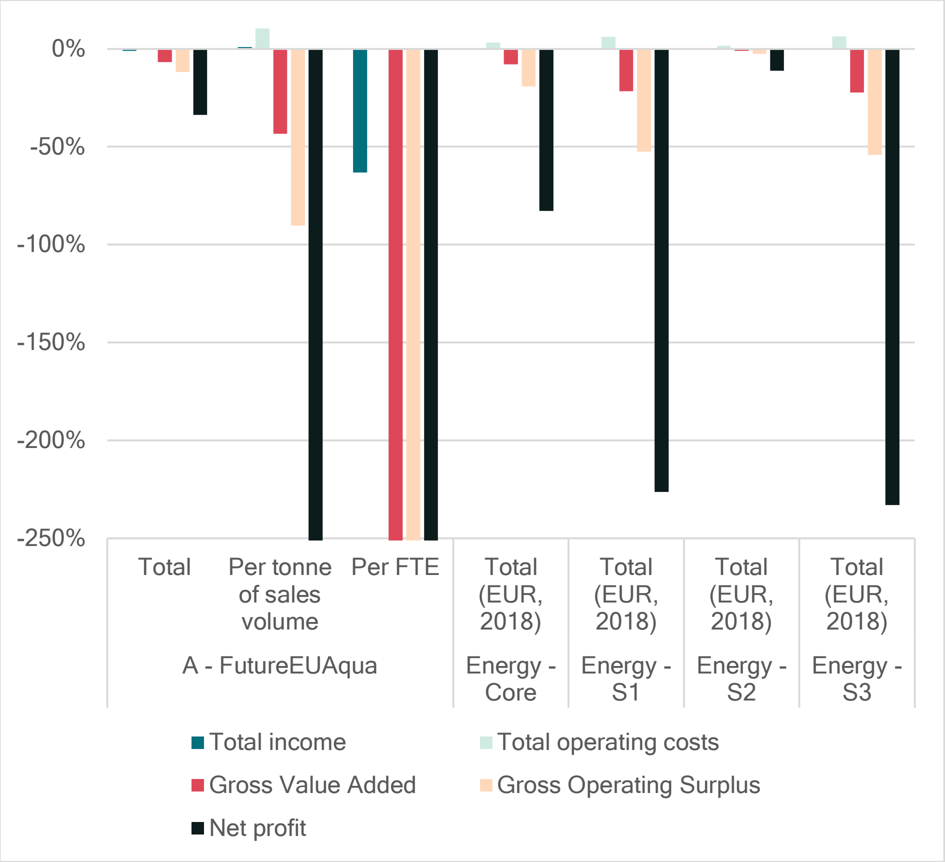
Table 8 Results of analysis for trout recirculation systems in Denmark

Scenario	Result	Total income	Total operating costs	Gross Value Added	Gross Operating Surplus	Net profit
A - FutureEUAqua	Total	-1%	0%	-7%	-12%	-34%
	Per tonne of sales volume	1%	11%	-44%	-90%	-278%
	Per FTE	-63%	0%	-374%	-655%	-1859%
Energy - Core	Total (EUR, 2018)	0%	3%	-8%	-19%	-83%
	Per tonne of sales volume (EUR, 2018)	0%	3%	-8%	-19%	-83%
	Per FTE (EUR, 2018)	0%	3%	-8%	-19%	-83%
Energy - S1	Total (EUR, 2018)	0%	6%	-22%	-53%	-226%
	Per tonne of sales volume (EUR, 2018)	0%	6%	-22%	-53%	-226%
	Per FTE (EUR, 2018)	0%	6%	-22%	-53%	-226%
Energy - S2	Total (EUR, 2018)	0%	2%	-1%	-3%	-11%
	Per tonne of sales volume (EUR, 2018)	0%	2%	-1%	-3%	-11%
	Per FTE (EUR, 2018)	0%	2%	-1%	-3%	-11%
Energy - S3	Total (EUR, 2018)	0%	6%	-22%	-54%	-233%
	Per tonne of sales volume (EUR, 2018)	0%	6%	-22%	-54%	-233%
	Per FTE (EUR, 2018)	0%	6%	-22%	-54%	-233%
C - Salary	Total	0%	0%	0%	0%	0%
	Per tonne of sales volume	0%	1%	3%	0%	0%
	Per FTE	0%	5%	26%	-1%	-2%

D - Price Down	Total	-1%	0%	-7%	-12%	-34%
	Per tonne of sales volume	-8%	0%	-47%	-82%	-232%
	Per FTE	-64%	0%	-379%	-664%	-1886%
E - Price Up	Total	1%	0%	8%	14%	39%
	Per tonne of sales volume	8%	0%	53%	93%	264%
	Per FTE	64%	0%	432%	756%	2147%

Figure 16 visualises the impact of changes in cost of feed input, distinguishing between total change, change per tonne of sales volume and per FTE, and the impact of various changes in the energy costs (Energy-core, Energy – S1, Energy – S2, energy – S3).

Figure 16 Visualisation of the impact of changes in cost of feed input (Denmark)



Comparison of energy price shock across the various scenarios

Under the all-thing-equal assumption (ceteris paribus), large change in energy costs have small impacts on operating costs yet larger impact on net profit. Not all production systems are impacted equally. Size of impacts depends on size of shock, baseline profitability, energy intensity of operations. Summarizing the impact of changes in energy costs on the four scenarios, the following observations are made. Trout Recirculation Systems in Denmark (S4) experiences the biggest impacts, being substantial due to weak baseline profitability, high energy costs as % total, larger energy price shock. Ireland Salmon Cages (S1) is second in terms of impacts, witnessing a small increase in operating costs, much larger impact on net profit, yet on average industry could still be profitable. Greek Seabass & Seabream Cages (S2) comes third in terms of impacts, with small impact on profitability. A significant electricity spike may imply larger impact. In all tests industry remains profitable. Least affected is Italy Seabass & Seabream Cages (S3) where significantly smaller impacts are observed, compared to other case studies, energy price spike is lower, baseline profitability is stronger, energy as a % of total costs are lower.

Results of True Pricing

The True Price calculations for conventional and algae-insect feed

The following tables show the result of the True Price calculations for conventional and algae-insect feed, as well as comparing them. The LCA results underlying this analyses are presented in Goglio et al 2022, reporting on work done in FutureEUAqua (see Figure 1 on the integration of work done).

The following impact categories were left out of the calculation, lacking reliable values:

- Acidification, terrestrial and freshwater
- Eutrophication, terrestrial

Three other impact categories are left out of the calculations because the units used in the LCA do not correspond to the units in True Prices literature. The conversion of data is questionable; there is no scientifically sound method for this. They include:

- Resource use, energy carriers
- Resource use, mineral and metals
- Eutrophication freshwater

The calculations using the remaining impact categories are summarized in Table 9 below.

Table 9 Indicative True Price calculations

Impact category	CC (in €)	AI (in €)	AI *minus* CC (in €)	% change	% change total contribution
Climate change	0.44	0.68	0.24	56%	36%
Eutrophication marine	0.11	0.55	0.44	397%	64%

True Price Gap	0.55	1.23	0.68	124%	100%
Market Price	7.65	7.65			
True Price	8.20	8.88			

The results show that the True Price of 1kg of salmon ex-farm is €0.55 higher than the market prices, mostly due to the costs of the contribution to climate change. For algae-insect feed, the True Price gap (the price difference between the market price and the True Price) is higher: €1.23. This is in line with the conclusion of the LCA that showed that algae-insect feed has a higher environmental impact than conventional feed. Here it should be said that LCA methodology comes with assumptions and setting boundaries (see LCA chapter).

Disclaimer on True Price calculations

The methodology for True Prices calculations is still under development. The objective of this task was **not** to present a definitive number on the True Price of salmon, with conventional or algae-insect feed. Instead, the calculations were carried out to learn about the methodology and its application to aquaculture.

The True Price calculations are limited due to the following factors:

- LCA units are not well aligned with data available in True Price literature. This means conversion should be done for a more complete calculation. Reliable conversion factors are not available.
- Local conditions vary. The True Price calculations assume that emissions have the same negative impact and the same remediation costs for different places. This is not realistic.
- There are not many good values available to assess the costs of environmental impacts stemming from aquaculture.

Bearing in mind these limitations, the True Prices calculations presented should be considered indicative, meant to stimulate a discussion on the value and methodology for True Price accounting. Numbers presented should not be used for the purpose of marketing or substantiating claims on environmental impacts.

Recommendations and conclusions

The environmental and economic models, as well True pricing, was used to evaluate the impact of FutureEUAqua innovations. For the environmental model, LCA was used, a well-developed and standardized methodology. For the economics, a tailored excel based model was developed, drawing upon data from STECF. True Pricing was done using a newly developed approach, building on earlier experiences. While all three methods rely on setting of system boundaries and making assumptions, there is a disparity in the level of standardization in these kind of assessment.

Looking into the results, in relation to the environmental model, we conclude that the (partial) substitution of marine- and terrestrial animal co-product ingredients by plant based ingredients resulted in a higher environmental impact for almost all of the impact categories analyzed. The production of feed ingredients has the largest contribution to all of the impact categories analyzed. Optimizing the feed ingredient production practices (e.g. cultivation of crops, production of animals) and to a lesser extend sourcing locally (if no adverse effects on impacts during the production), can contribute to a lower environmental impact of the studied feeds.

From an economic perspective, the shift to plant-based ingredients is expected to result in higher costs of production. The economic model can also help to put such expected changes in perspective. The economic modelling exercise was performed in a time when concerns about energy prices dominated the public and political agenda. The question how higher costs of production due to the plant-based feed compare to higher costs of energy differ per sector. For energy-intensive aquaculture practices such as RAS energy prices hike has much bigger impact. For low energy intense practices such as seabream and seabass, higher feed prices have a bigger impact.

The economic modelling also shows that innovations that can increase the price of produce have the biggest positive impact on the business-case of aquaculture. At the time of writing, the eventual impact of innovations in such as marketing seafood and innovative packaging on price cannot be estimated reliably.

The developed True Price approach shows that the innovative feed have a higher True Price than conventional feed. This directly stems from the higher environmental impact. Acknowledging the limitations of this methodology, we also observe that the True Price would be in the order of 10%. higher

Does this all mean that the innovations in feed tested for are not valuable innovations? We argue it is too early to come to this conclusions for the following reasons:

- The results of LCA methodology are dependent on the system boundaries and the selection of impact categories. In this case, the impact of fisheries (for conventional feed) on the marine ecosystem and fish stock are not included in the assessment, yet this is where plant-based feed can have a positive impact.
- Better insight into the effect of novel feeds on FCR is needed. A better FCR or better animal can offset higher feed costs for the new feeds. While first results are promising, no statistically significant results can be presented now (see FutureEUAqua deliverable 2.3).
- Similarly, other benefits of novel feeds can offset higher costs.
- The results of the True Price calculations are indicative and should not be used as more than food for thought on developing a proper methodology.

Recommendations for further development

This reflection leads us to the following main recommendations for further development:

- Methodological development is needed if True Price is to be used in communicating the differences in environmental impact of various products.
- Methodological development is also needed to include the impact of fisheries on fish-stocks in LCA.

- The impact of novel feeds and FCR and animal health is crucial and needs to be understood better.

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