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Second version of the economic model and the environmental model

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Executive summary

Aquaculture is a growing sector both in quantity and in terms of technologies and type of fish which is grow. However it is responsible for a series of impacts including climate change, eutrophication, fine particulate matter, toxicity, land use and resource scarcity. In this report the models developed adopted for the economic assessment and environmental assessment are described. The deliverable also describes the approach to use to calculate True Prices. First available results are presented to further illustrate what the models that are used will deliver. It is indicated which information is available at the time of writing and options for further data collection are given.

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Chapter 1: Introduction

Aquaculture is a growing sector both in quantity and in terms of technologies and type of fish which is grown (EC, 2019; FAO, 2018). Currently aquaculture provide 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 increased 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, 2018). 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, 2018). The impact related to climate change, eutrophication, pollution, resource use is related to the C, N, P cycle (Bohnes and Laurent, 2018; 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, environmentally friendly organic and conventional aquaculture to meet future challenges with respect to climate changes, 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 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 in 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 reports (D4.8) is the second deliverable in WP4 and outlines the main structure of the economic model and the environmental model, aiming for 75% of the data and technical relationships to be included. A list of missing information is included in chapter 5.

To this end, the following data is provided

- A brief overview of the characteristics of the models, based on Deliverable 4.7 (Chapter 2)
- A description of the economic model to be used in FutureEUAqua (Chapter 3)
- A description of the LCA methodology and outlook on the method for True Pricing (Chapter 4)
- An overview of data currently available for use, and data gaps (C evaluation of models, in light of the objectives of FutureEUAqua (Chapter 5)

This deliverable describes the models to be used. The LCA model has been used to compare the environmental impacts of conventional vs RAS salmon farming, and different feed formulations The results of this analysis are described in a scientific publications that is prepared for submission end of 2020..

Methodology

The following activities were undertaken in drafting this report

- Methodological development: based on the model description (see Deliverable 4.7) and the expertise of the study team, models for evaluating innovation on the economic and environmental merit are developed.
- Data collection. Consisting of the following activities:
    - Literature review
    - Use of experiences in earlier projects, most notable OrAqua
    - Interaction with consortium partners who have provided new data to complement data from literature. This data has been used in particular in the LCA.

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Chapter 2: Models to be used in FutureEUAqua

Based on the review of models against criteria for FutureEUAqua, we proposed in Deliverable 4.7 to adapt the excel based models to cater to the specific needs of this project.

Economic model

The proposed model for the economic analysis in FutureEUAqua is described in the following section, looking at model description and model design.

Model description

Model-name	**FutureEUAqua**
Year	2019-2022
Format	Excel
Species	Salmon Sea bass & sea bream Trout
Production systems	RAS IMTA FT
Data sources	Input from Aquavlan and OrAqua models to be updated using data from • Literature • STECF data • Expert consultation • FutureEUAqua Consortium partners working in WPs 1, 2, 4 and 6
Available to all consortium partners	YES

Model design

The model will consist of the following modules

- Input module: this describes the economic characteristics of current aquaculture practices, up to the farm-gate
- Value chain module: this describes the economic characteristics of the post farm-gate processes (processing, retail)
- Expertise module: In this module, the impact of the various innovations in aquaculture is defined. Both volume indexes as well as price indexes can be added to the relevant cost categories

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- True price module: the module defines the true prices of input parameters and costs made during production. This module can be toggled on/off, dependent on the analysis required.
- Calculation module
- Optimisation module: this module calculates the optimal combination of innovations
- Output module in table format, including indicators per kg cleaned fish at retail
- Output module in graphic form

Environmental Model and True Prices

Model description

Model-name	**FutureEUAqua LCA**
Year	2019-2022
Format	Excel
Species	Salmon Sea bass & sea bream Trout
Production systems	RAS IMTA FT
Data sources	Input from FARM or nutrient balance equations to be updated using data from • Literature • Data collected from fish farms • Expert consultation • FutureEUAqua Consortium partners working in WPs 1, 2, 4 and 6
Available to all consortium partners	YES, unless information is classified as confidential

The true price methodology will be applied to the systems analysed to assess in monetary terms the environmental impacts. The true price assessment is based on the monetary evaluation of environmental impacts, as discussed in previous literature (Pizzol et al., 2015) and presented in a recent report (de Adelhart Toorop et al., 2018). The impacts are evaluated with the LCA framework in agreement with the ISO standards (ISO 14040:2006 and ISO 14044:2006). The aim of the true price assessment is to show how the total costs including the hidden costs differ between the innovation value chain and the current practice for fish farming systems.

Model design

The model will consist of the following modules

- Input module: this describes the technical characteristics of the fish farming systems analyse
- Biogeochemical cycle modules: these will take into account the biogeochemical implications of the fish farming adopting the FARM/nutrient budget equations on the basis of the data availability
- Value chain module: this describes the characteristics of the post farm-gate processes (processing, retail)
- True price module: the module defines the true prices of input parameters and costs made during production. This model can be toggled on/off, dependent on the analysis required.
- Calculation module
- Optimisation module: this module calculates the optimal combination of innovations
- Output module in table format, including indicators per kg cleaned fish at retail

Linkages between the economic and environmental model

The link between the economic and environmental model is visualized below:

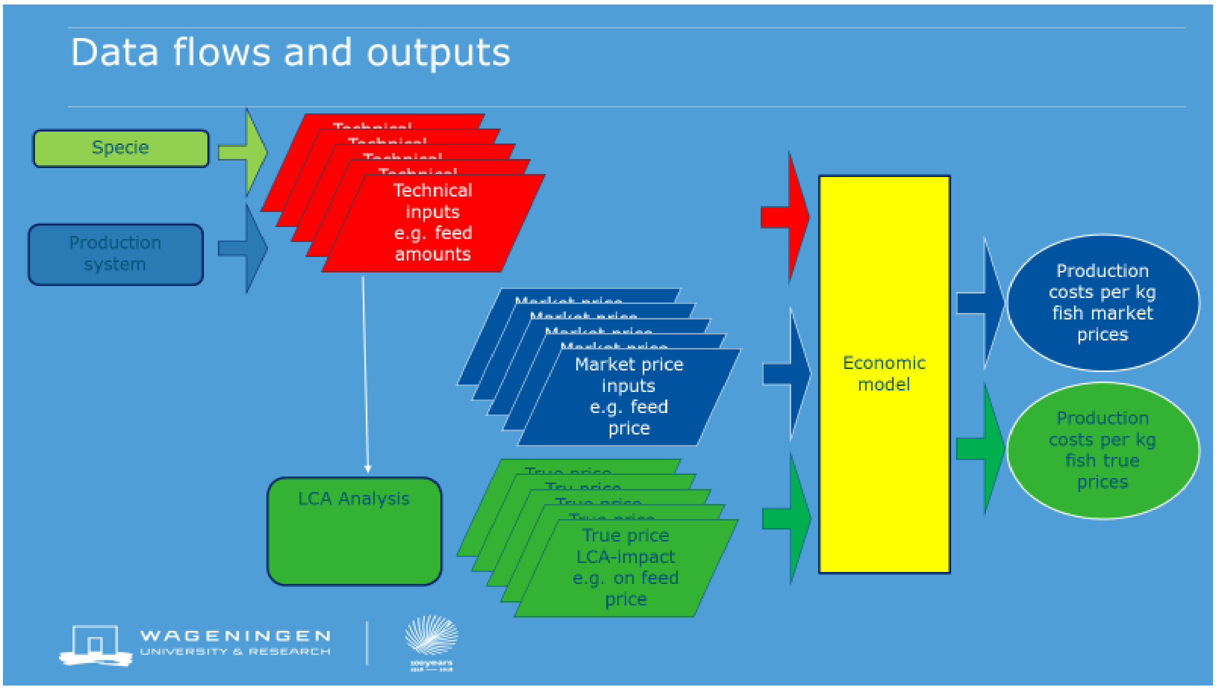

Figure 1: Links between economic and environmental model

In FutureEUAqua, the data collected on the technical inputs is used for two purposes: (1) the economic model and (2) the LCA. Additionally, data on market prices is input to the economic model. Results of the LCA are translated into true prices, this is the third type of input to the economic model.

These three inputs are brought together in the economic model to generate two types of output:

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1. Insight into the production costs per kg fish, for different species and production systems
2. Insight into the production costs in true prices, for different species and production systems

Chapter 3: Economic model

The purpose of the economic model module is to provide an overview of financial performance and business feasibility of conventional farming designs, against innovative alternatives that has the potential to provide additional environmental or social benefits. The key European aquaculture species examined by the economic model are salmon, trout and sea bass/bream. Table 1 below details the production systems that will be examined, by species, in the economic models of this project.

Table 1: Production systems by species assessed in the economic models of FutureEUAqua

Species	Production system	Year
Salmon	Conventional cage	2020
	Recirculating Aquaculture System (RAS)	2020
	Organic feed	*2020*
	Flow-through system	2021
	Integrated Multi-Trophic Aquaculture	2021
Sea bass/bream	Conventional cage	2020
	RAS	2020
	Organic feed	2021
Trout	Conventional tanks and raceways (incl. flow-through systems)	2021
	Organic feed	2021
	RAS	2021

Given data limitations (i.e. data availability), it is not yet clear which alternatives can be examined by the economic models in the post farm-gate (i.e. processing and retail) sectors. There may for example be possibilities for evaluation of bio-plastic packaging alternatives. However, this is heavily dependent on information available from partners, outputs from the other WPs and existing literature. Moreover, not all alternatives can be examined in the current year 2020. There are plans for the assessment of farming production systems for the species mentioned (see Table 1), as well as alternatives for the post farm-gate sectors in 2021.

Economic modelling

The economic models, based 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 assumption is not likely to hold in reality, as it will be evident with the Norwegian salmon example later in this report, 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 is intrinsic differences in production size even among key countries. For example, Norway's production capacity for Atlantic Salmon (*Salmo salar*) is more than 1000 times that of Ireland, who is the largest salmon producer in the EU-27. Therefore, the level of scale of production is incomparable even if data is available at farm level. This should be considered when comparing per unit metrics.

A number of financial metrics are used in the economic models, and they are summarised as the following:

- Turnover and total income
- Operating costs
- Capital costs
- Annual financial profit
- Return on Investment (ROI)
- Per unit metrics (e.g. turnover, farming cost and financial profit per kilogram of output)

The most basic metric for assessing the financial performance of a business enterprise is the **annual financial profit**, which is calculated as total income less expenses. Expenses include both operating costs for day-to-day activities of the farm, and capital costs of financing borrowings and depreciation. The latter is not a cash expense or outflow, but needs to be accounted for in the financial performance of a business as it captures the loss in value in the capital investment, which needs to be recovered and/or replaced over time. More specifically, annual financial profit is calculated as:

$$Financial\ profit_t = Income_t - Operating\ cost_t - Capital\ cost_t$$

Or

$$Financial\ profit_t = Income_t - Cash\ cost_t - Depreciation_t$$

where t is the time period, whether it is a calendar year or a financial year.

Here, the distinction should be made between turnover and income. Turnover is the revenue earned for the sale of production outputs, and this differs from total income which can include other sources of income such as work done for third parties, subsidies and other income. This is especially important when interpreting the per unit metrics. For example, turnover/kg output is essentially the farm-gate price received for the species farmed while the profit/kg output includes income other than revenue earned from the sale of production output.

The last per unit metric included here is farming cost/kg output, which reflects both operating costs and capital costs incurred in production divided by the total volume of output produced. At this point in time, no opportunity costs are included in the economic models (i.e. opportunity cost of capital or labour). As the models develop, especially alongside the environmental models there will be room to consider economic (i.e. inclusion of opportunity costs) and social (i.e. inclusion of environmental costs and true prices) in the per unit metrics.

The final metric that is considered in this report is the **Return on Investment (ROI)**, which measures the annual return as a percentage of initial capital investment. This is calculated as:

$$ROI_t(\%) = \frac{Capital\ gains_t + Net\ profit\ or\ dividend\ yield_t}{Captial\ investment_t} \times 100$$

For the purpose of this report, we do not assume that any capital investments are sold during the period of operation, so that the ROI simplifies to:

$$ROI_t(\%) = \frac{Net\ profit_t}{Captial\ investment_t} \times 100$$

The specific methods used in the calculation of financial performance for the individual species and technologies are described in their respective sections.

Data sources

The economic models in this report are built on data from a number of sources, including models developed in past projects and reports:

- OrAqua (funded by the EC, Grant no. 613547): examines the economics of organic aquaculture through costs and benefits analyses, at both the farm and chain level, within the context of EU markets
- AquaVlan (funded under the Interreg IVA program): details the various inputs and outputs from RAS farming for 4 different species – Yellowtail Kingfish, Omega perch, Freshwater cod and Pike perch – in assessing the economic, social and ecological aspects of RAS farming
- STECF data (produced under JRC of the EC, JRC114801): economic data for aquaculture sectors within EU Member States, containing unit and value information for different elements of production, and reported by DCF and EU-MAP guidelines
- Fiskeridirektoratet (Directorate of Fisheries, Norway): economic data for aquaculture sectors within Norway, financial information for different elements of production
- Bjorndal et al. 2018 (funded by The Norwegian Seafood Research Fund): analysis of the impacts of shifting Atlantic salmon production from traditional sea-based cages to land-based production. Contains both physical and economic assessment of production inputs needed
- Space@sea (funded under H2020 program, Grant no. 774253): looks at farming options at sea for mussels and sea bream that strays away from the conventional methods. The report provides an overview of financial performance for both conventional and alternative aquaculture practices.

As is with the methodology, the treatment of data and time frames for the individual species and technologies are described in their respective sections.

First results

Atlantic salmon

For salmon, the conventional method of farming using sea cages is examined against Recirculating Aquaculture System (RAS). In addition, the option of using organic feed is also considered, a practice that can be applied to either farming systems. However, for simplicity of the exercise, the organic feed model is only applied to the case of salmon farming in Ireland[1]. The adjustment ratios used in the economic model for organic feed is derived from the OrAqua project. The key areas of adjustments include the price premium, labour cost, premium on the price of feed, feed conversion ratio, growth rate and reduced density required within cages. The last two factors have direct impacts on the capital investment and ongoing capital cost (i.e. depreciation and financing) for a farm.

Table 2: Economics of conventional vs alternative farming for salmon, Ireland (IE) and Norway (NO)

	Conventional (IE)	**Organic (IE)**	**Conventional (NO)**	**RAS (NO)**
Income per enterprise				
Turnover	6,441,778	8,374,311	5,024,586	5,054,908
Subsidies	0	0	0	0
Other income	66,609	66,609	240,745	240,745
Total income	**6,508,387**	**8,440,921**	**5,265,332**	**5,295,654**
Operating costs per enterprise				
Wages and salaries	592,036	680,841	264,874	316,247
Imputed value of unpaid labour	0	0	0	0
Energy	94,657	94,657	0	480,000
Feed	1,928,706	2,538,660	1,447,625	1,586,879
Livestock	867,015	1,333,869	339,407	43,287
Repair and maintenance	391,583	391,583	0	151,848
Other operational costs	1,183,613	1,187,898	1,213,015	906,444
Total operating costs	**5,057,610**	**6,227,508**	**3,264,920**	**3,484,705**
Capital costs per enterprise				
Depreciation	147,577	378,402	200,598	807,824
Financial costs	84,064	215,549	18,263	198,930
Total capital costs	**231,641**	**593,951**	**218,861**	**1,006,754**
Net result per enterprise	**1,219,137**	**1,619,462**	**1,781,551**	**804,196**
Capital investment	5,753,547	14,752,685	2,545,783	10,853,510
Employment	**11**	**13**	**2**	**4**
Female FTE	1.4	1.4	0.2	0.5
Male FTE	10.0	11.4	1.6	3.2
Production				
Volume of production (tonnes)	1,000	1,000	1,000	1,000
Volume of feed (tonnes)	1,278	1,495	1,283	1,150

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[1] Salmon farming in Ireland can be considered as small to medium scale farming, while salmon farming in Norway represents (very) large scale farming.

Volume of livestock (tonnes)	40	62	64	43
Turnover/kg output	6.44	8.37	5.02	5.05
Farming cost/kg output	5.29	6.82	3.48	4.49
Profit/kg output	1.22	1.62	1.78	0.80

The economic model for RAS farming, on the other hand, sources its information from Bjorndal et al. (2018). This includes everything from capital investment required to operating expenses and units required. Limited by the research and data available for RAS farming of salmon to commercial size for other countries, and in turn smaller scales of production, thus the focus of the RAS model is only on Norway. While Norway lies outside of the EU-27, it is the world's largest producer of farmed salmon and the EU remains its biggest export market – e.g. Poland, Denmark, France, Netherlands, Spain and Italy (UN Comtrade, accessed 29 October 2020).

As discussed previously, there is huge disparity in the production capacity between Norwegian and Irish farms for Atlantic salmon. Therefore, in the interest of making comparable comparisons, the data for conventional cage farming was also extracted separately for Norway and Ireland. The Irish economic data for salmon cage farming was taken from the STECF database reported against DCF guidelines (STECF 2019)[2]. For Norwegian economic data for conventional cage farming, this was sourced from the Directorate of Fisheries in Norway (Fiskeridirektoratet). The Fiskeridirektoratet database has extensive financial and capital information on a large sample of existing salmon farms in Norway. Given the large differences in production capacity across the two countries, and also average production reported or assumed in the Fiskeridirektoratet and Bjorndal et al. (2018), all analyses in this study is standardised to 1000 tonnes for comparability purposes. The results are displayed in Table 2.

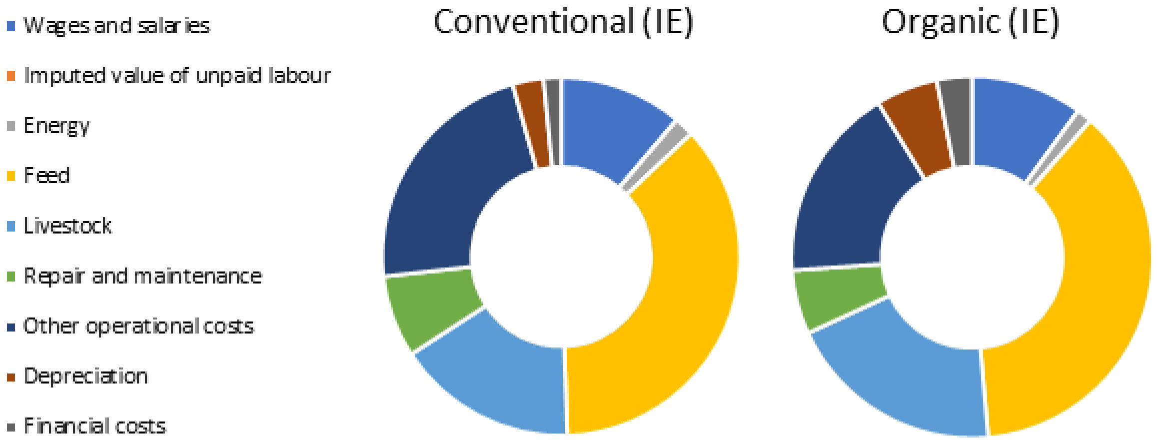

Figure 2: Breakdown of costs for conventional vs organic farming for salmon, Ireland (IE)

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[2] STECF (2019), Aquaculture economic data tables.xlsx (Version 1.0), accompanying Economic Report of the EU Aquaculture sector (STECF-18-19). Publications Office of the European Union, Luxembourg, 2018, ISBN978-92-79-79402-5, JRC114801, available online: https://stecf.jrc.ec.europa.eu/reports/economic

Looking at the results for Ireland (i.e. small to medium scale farming), the price premium generate for organic feed farming for salmon appears to be sufficient in offsetting the increases in the operating and capital costs (Table 2). The largest percentage increase in costs under the organic model is capital costs (i.e. depreciation and finance) which is a reflection of the more than doubling in capital investment required to maintain the necessary density to be organically certified (see Figure 2). The relative increases in livestock and feed are the next largest, owing higher price for feed, lower feed conversion and slower growth rate. The latter results in the need for higher number of smolts (i.e. livestock). It should be noted however, that the organic model does not consider costs related to organic treatment of lice for salmon (e.g. investments in sea lice skirts or snorkels, thermal treatment, flushers etc.), nor does it take into account the reduced value of salmon that require additional treatments which is especially the case with thermal or flushing treatments.

In contrast to the organic feed results, the net result per enterprise for salmon RAS farming is reduced compared to the conventional cage model. While the average farm will still make a financial profit, it is unlikely the case once opportunity costs of capital and labour are included. This is especially the case when considering the 5 fold increase in capital investment – opportunity cost of capital is the return that would have otherwise been generated if capital is placed in a similarly risked investment. The increase in ongoing capital cost is especially evident when looking at the change in cost composition (refer to Figure 3). The large increase in ongoing capital cost (i.e. depreciation and financing) is predominately resulting from the substantial investment needed for the construction of the RAS facility, noting that land does not depreciate. A breakdown of capital investment for both farming systems can be found in Table 3 and Table 4.

Out of the operating costs, the main sources of increase in expenses come from energy use and repairs and maintenance. This is not unexpected given that RAS farming requires high level of energy use, and potential repairs and maintenance to the building and equipment, as alluded to in the discussion on capital costs. However, it should be noted that the categories for energy, which also includes fuel usage by vessels servicing the offshore salmon cages, and repairs and maintenance are not explicitly detailed in the enterprise database by Fiskeridirektoratet (2019). Therefore, these are likely to be included in other operational costs.

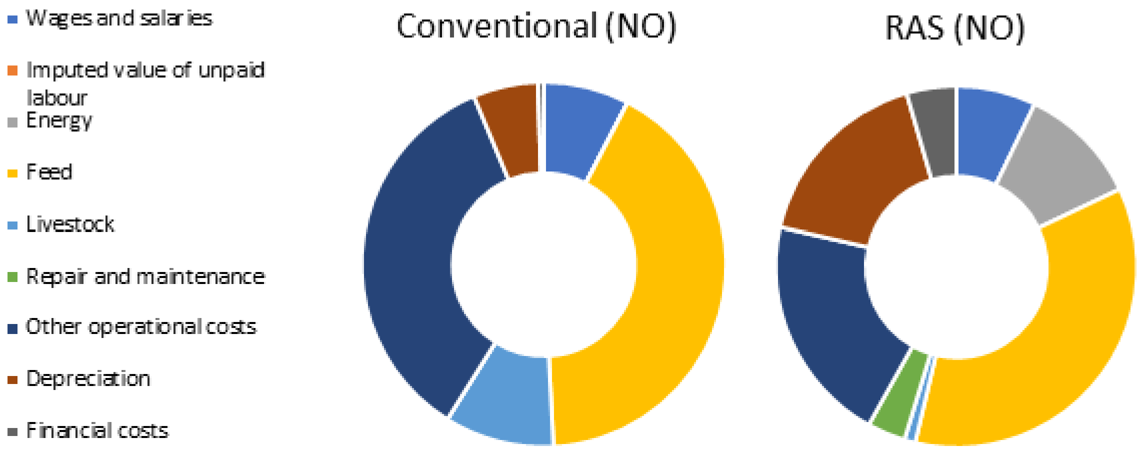

Figure 3: Breakdown of costs for conventional vs RAS farming for salmon, Norway (NO)

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Nevertheless, the key conclusion that can be drawn from both the Irish organic case and the Norwegian RAS farming case is that it is financially viable for farms to adopt the alternative systems explored. However, it is likely that more incentive is necessary to ensure economic profit (i.e. inclusive of opportunity costs of capital and labour) remains positive, especially for the Norwegian example.

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Table 3: Capital investment cost for salmon RAS farming, adapted from Bjorndal et al. (2018)

	Investment Amount	Lifetime	Annual Interest and Depreciation
Land (no depreciation)	**482,465**	**n.a.**	**19,299**
Build total:			
Building	2,853,667	20	209,978
Electrical installations	566,083	15	50,914
Secondary inst. (Ventilation etc.)	397,050	15	35,711
Concrete work (filter and fish tanks)	1,948,500	20	143,374
Total building	**5,765,300**		**439,977**
Water treatment and equipment:			
Water treatment	4,411,633	20	324,616
Other	194,112	10	23,932
Total water treatment and equipment	**4,605,745**		**348,548**
Total investment	**10,853,510**		**807,824**
Investment, EUR per kg live weight	10.9		0.8
Investment, EUR per m3 tank volume	1,447		108

Table 4: Capital investment cost for salmon cage farming, adapted from Fiskeridirektoratet (2019)

	2016	2017	2018	3 year average
Fixed assets:				
Intangible fixed assets	686,417	754,259	1,031,913	848,984
Land, buildings and other real property:	197,571	232,825	403,248	292,866
Plant and machinery	779,241	882,141	1,056,952	923,879
Operating equipment	61,544	79,391	54,885	63,942
Total tangible fixed assets	***1,038,357***	***1,194,357***	***1,515,085***	***1,280,687***
Financial fixed assets	386,904	462,645	404,638	416,113
Total fixed assets	**2,111,678**	**2,411,261**	**2,951,636**	**2,545,783**

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Sea bass/bream

The sea bream farming model is based on the business feasibility report for Space@sea (Jak et al. 2020). Data from the AquaVlan model**Error! Bookmark not defined.** is combined with STECF data for seabream cage system farming in Spain and trout RAS farming in Finland[2] to construct a likely cost structure for farming sea bream in a RAS facility. To ensure robustness, the final model is an amalgamation of two separate models that each seeks to individually estimate the expected financial performance of moving sea bream farming to RAS in Spain.

For the model using STECF data the cost structure of trout RAS farming in Finland was adapted to economic conditions for sea bream farming in Spain where possible due to the lack of data for RAS farming for most other aquatic animals to commercial size. An example for such adaption is labour cost where labour productivity (tonnes per employee) is derived from the Finnish data, but annual salary per employee is taken from the existing cage farming case in Spain. We take the Finnish data for trout based on the reasoning that at least it is also RAS so the energy usage and equipment maintenance could be reflective. Feed cost uses the combination of feed conversion from Finnish RAS data, due to the low feed loss within the enclosure, and feed price per kilogram specific to seabream farming from Spain. Livestock cost for juvenile seabream is purely sourced from Spanish data, as was other operational costs.

The AquaVlan model, on the other hand, contains individual cost components collected from literature review and expert consultations[3]. Therefore, the model is constructed using unit inputs multiplied by their associated cost per unit rather than an amalgamation of various datasets. For turnover, the price received for fresh sea bream in the AquaVlan model is based on the EUMOFA report for supply chain price transmission for sea bream in Italy (EUMOFA 2017)[4]. The results of the two models, the RAS adapted model from STECF data and the AquaVlan model, are comparable which provides some confidence in the estimates (refer to Table 5). The final model is then the average of these two models with the exception of capital investment, which is purely based on the AquaVlan model because it contained more detailed and transparent breakdown of capital investment information (see Annex 1). As is with the salmon results, all revenues and costs are standardised for a production volume of 1000 tonnes for comparability.

As illustrated in Table 5, the key difference in the cost structure between RAS and the conventional cage system for sea bream farming is labour, energy and feed. The cost of labour and energy are both considerably higher for RAS farming due to the intensity of both factors used in production. In contrast, feed cost is lower for the enclosed system compared to open cage farming. It should be noted that only financial costs are considered in this exercise, and there are likely to be potential environmental benefits from reduced excess feed runoffs in moving to RAS farming. Lastly, the capital investment and ongoing cost required for RAS farming system is expected to be relatively higher than that for the conventional cage system, including higher depreciation costs. A graphical illustration of the differences in cost composition between the two farming systems is provided in Figure 4.

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[4] EUMOFA (2017), Case study: Gilthead seabream in Italy – price structure in the supply chain, available online: https://www.eumofa.eu/documents/20178/107625/EN_Gilt-head+seabream+in+IT.pdf

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Table 5: Economics of cage vs RAS farming for seabream, based on the Space@sea project

	Conventional	**RAS adapted**	**AquaVlan**	**Average**
Income per enterprise				
Turnover	6,748,665	6,748,665	6,600,000	6,674,332
Subsidies	344,965	344,965	0	172,483
Other income	106,149	106,149	0	53,075
Total income	**7,199,779**	**7,199,779**	**6,600,000**	**6,899,889**
Operating costs per enterprise				
Wages and salaries	804,759	1,698,936	1,000,000	1,349,468
Imputed value of unpaid labour	1,975	4,169	0	0
Energy	75,319	993,915	1,019,979	1,006,947
Feed	3,103,544	1,386,873	1,568,789	1,477,831
Livestock	1,048,822	1,048,822	1,447,074	1,247,948
Repair and maintenance	86,160	200,741	176,910	188,826
Other operating costs	1,503,756	1,503,756	1,339,828	1,421,792
Total operating costs	**6,624,333**	**6,837,212**	**6,552,580**	**6,692,811**
Capital costs per enterprise				
Depreciation	254,982	1,386,206	829,018	829,018
Financial costs	150,348	599,807	198,179	198,179
Total capital costs	**405,330**	**1,986,014**	**1,027,197**	**1,027,197**
Net result per enterprise	**170,116**	**-1,623,446**	**-979,777**	**-1,120,009**
Capital investment	7,748,073	30,910,616	8,845,488	8,845,488
Employment	**27**	**57**	**20**	**39**
Female FTE	4	9	na	na
Male FTE	23	48	na	na
Production				
Volume of production (tonnes)	1,000	1,000	1,000	1,000
Volume of feed (tonnes)	2,473	1,105	1,250	1,178
Volume of livestock (tonnes)	22	22	31	26
Turnover/kg output	6.75	6.75	6.60	6.60
Farming cost/kg output	6.62	6.84	6.55	6.69
Profit/kg output	0.17	-1.62	-0.98	-1.12

While total farming cost (i.e. operating and ongoing capital cost) is not substantially different between the two aquaculture systems in relative terms – around 10% higher, €7 million compared to €7.7 million – the financial viability varies considerably. This is owing to the fact that the margins made for sea bream farming at the current time is very small and this has 2 likely explanations. The first is that the seabream market has a high degree of competition from large and specialised producing countries such as Greece and Spain, and for a relatively homogenous product the Bertrand economic model suggests price competition would leave price equal to marginal cost (i.e. very low or no profit margin). The second is that sea bream is traditionally purchased whole with little to no processing, and the limited room for value addition and development is likely to explain the stable retail/consumption price observed in Europe (EUMOFA market data, 2015-2020).

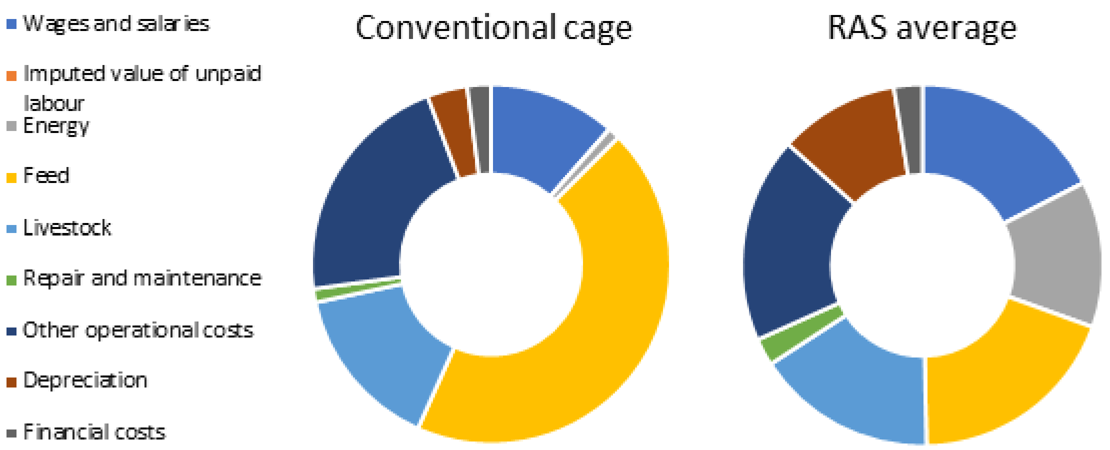

Figure 4: Breakdown of costs for cage vs RAS farming for seabream, based on the Space@sea project

Chapter 4: Environmental model and True Prices

Life cycle assessment

The methodology and models used for Life Cycle Assessment are further defined and have been applied to the case of salmon farming. The results of the latter exercise are reported in a draft scientific publication. Below, we first describe the generic approach to LCA to use in FutureEUAqua. After that, we describe how data for the salmon case was collected and processed.

Generic approach for FutureEUAqua

The LCA will be carried out with cradle to farm gate approach. The functional unit is 1 kg of living weight of fish at the fish farm (Besson et al. 2016; Abdou et al. 2017, 2018).The consequential LCA was undertaken with regards to the soybean present in the feed composition, to fish meal and fish oils, as these results as major issues for feed composition (Smetana et al. 2017, 2019; Bohnes et al. 2018; Li et al. 2020).

This LCA includes all the phase from the extraction of raw material extraction, their transport and processing, field cultivation of crop feed ingredients, their processing, fishing of marine ingredients, their transport and processing, all fish farming activities, fuel production and transport for all the fuel consumed during fish farming, the production and transport of materials used in fish farming, in agreement with previous LCA research (Aubin et al. 2009; Abdou et al. 2017, 2018).

A consequential LCA is carried out, based on marginal system and system expansions for 3 main feed ingredients (soybean meal, fish meal and fish oil) (Samuel-Fitwi et al. 2013; Bohnes and Laurent 2018)). The marginal system considered for the soybean produced in Brazil is the conventional fish feed meal, for fish meal is soybean produced in Brazil and for fish oil the rapeseed oil produced in Denmark. Despite strong critics on consequential LCA with regards agriculture (van der Werf et al. 2020), indirect land use change was accounted for on the basis of the methodology developed in the AgriFootprint database (Blonk 2017). ALCA and CLCA results will be presented separately following van der Werf et al. (2020) and Bohnes et al. (2018).

The Life cycle inventory data are processed adopting the impact assessment method proposed by the European Commission for the product environmental footprint of product (Fazio et al. 2018; Zampori and Pant 2019).

A contribution analysis will be carried out in agreement with the ISO standard for LCA (ISO 2006b, a). This was carried out to identify key processes which contribute most to the overall environmental impact of the fish farming systems assessed. Together with the contribution analysis, a sensitivity analysis to test the influence on 10% variation of fish to feed ratio and a 10 % change in the amount of juvenile salmon used in both cage and RAS systems (ISO 2006b, a; Bohnes and Laurent 2018). Indeed, in a recent review, it was reported that there is a high agreement among LCA studies that fish feed is a key driver for climate change, acidification and cumulative energy demand (Bohnes et al. 2018). This was carried out to critically analyse the results obtained from this LCA scenario assessment, as suggested by recent literature on fish farming and carried out ins some recent LCA of fish farming systems (Bohnes and Laurent 2018; Mendoza Beltran et al. 2018).

Application to salmon

The methodology outlined above is applied to evaluate four different scenarios for salmon fish farming: cage system with a conventional feed composition (C-C), cage system with low fish feed composition (C-LF), RAS system with conventional feed (RAS-C) and RAS systems with low fish feed composition (RAS-LF). All the systems are located in the West Norway region (Egersund and Ålesund area).

In the cage, RAS and juvenile systems, only material production was considered but not their assembly (Winther et al. 2020), water used for transport of fish and lice control fish was not considered, while only operation of the fishing boat used in the cage systems and only the climate change impact of krill production were included in the calculations, as this was the only data available for krill (Parker and Tyedmers 2012).The juvenile system provide post-smolt fish to the cage and RAS systems.

Data collection in the case of salmon

Life cycle inventory data (LCI) for the fish farming systems was taken from Winther et al. (2020) for both cage and RAS systems. Data contained in Winther et al. (2020) are based on a nationwide survey of fisheries and fish farming facilities in Norway. Data for the cage systems were reported here in table 1 which were used in the scenarios and integrated with background processes contained in SimaPro databases (SimaPro 9.0 2019). LCI data for the cage farming systems will be made available in the appendix of the manuscript to be submitted, as suggested in a recent review of LCA of fish farming (Bohnes et al. 2018). Variability ranges for each parameter where available were integrated in the life cycle inventory. It was assumed that all the materials used in the cage systems were transported by truck for 400 km, while the juvenile salmon and cleaner fish were transported for 292 km.

Life cycle inventory for RAS systems was taken from a series of different sources. The amount of material considered was calculated on the basis that the RAS system will last at least 10 years before being dismantled (Bjørndal et al. 2018). As for the cage systems also for the RAS systems, it was assumed that all the material were transported for a total of 400 km by truck, while fish and fish meal for 292 km and fuel used and sludge produced in the fish farming operations (excluding boat fuel) for 20 km (Table 2). As described in several sources, RAS systems have a filtering systems which reduce the amount of emissions from uneaten feed, provide oxygen and provide lice control (Terjesen et al. 2013; Bjørndal et al. 2018; Gorle et al. 2018; Winther et al. 2020).

The juvenile salmon farming was accounted mostly on the basis of previous publications (Bjørndal et al. 2018; Winther et al. 2020). Specific data for the farming were taken from Winther et al. (2020), while data regarding material use were taken from Bjørndal et al. (2018). It was also assumed that the same amount of juvenile would be used in the RAS and cage system to begin the post-smolt fish farming (Table 1).

Feed ingredient composition and processing

Feed ingredient composition was based on the current research carried out by NOFIMA diet expert as part of the FutureEUAqua project, as considered important for future LCA of fish farming system study (Bohnes et al. 2018). This life cycle inventory was built by eliciting expert knowledge and on the basis of

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substituting marine sources of marine ingredients with land based sources (Samuel-Fitwi et al. 2013; Li et al. 2020) (Table 3).. It was assumed that all the ingredients are transported for 10 km before from the harbour before reaching the feed processing facility which was assumed to be located in Bergen (Table 2) and that the fish feed was then transported by truck for 292 km which is the average distance between Bergen and two of the main fish farming areas in the West coast of Norway (Egersund and Ålesund area).

Life cycle inventory for each ingredient were taken from SimaPro contained databases (SimaPro 9.0 2019), with the exception of fish meal, algal biomass meal, insect meal and micronutrient. Fish meal is composed of the of following fish having a Norwegian origin: 51% by product herring (Clupea sp), 25% Norway pout (Trisopterus esmarkii Nilsson); 18% sprat (Sprattus sp); 6% blue whiting (Micromesistius poutassou Risso). The LCI for herring fish was used to account for the by-product herring (Winther et al. 2020), while Norway pout was assumed as cod to account for the Norway pout fishing. LCI for sprat and herring were taken from previous literature (Winther et al. 2020), while process data for blue whiting was based on purse seiner fishing (Winther et al. 2020). Data for fish meal ingredient processing were taken from available processes in Simapro (SimaPro 9.0 2019). Fish feed processing data were obtained directly from the producer (Table 3). The LCI for the herring fish production, sprat and purse seiner fishing was made available in the appendix.

The insect meal processing data were accounted for on the basis of literature (Smetana et al. 2019), considering that the insects are grown on manure. Transport assumptions were described in table 2. The algal biomass meal was based on the heterotrophic algae detail provided in a recent research study (Smetana et al. 2017). The life cycle inventory for algal biomass was then adapted to consider US production following the assumptions shown in table 2. Data for krill production was taken for literature (Parker and Tyedmers 2012), it was assumed that krill landed directly in Bergen harbour.

It must be noted that growing insects on manure would not be authorized for commercialization in the food chain in the EU now. Insects farmed for human consumption or feed are considered 'farmed animals' and the feeding of farmed animals with manure is prohibited under General Food Law Regulation (EC) No 178/2002.[5]

As limited data are available in literature (Bohnes et al. 2018), micronutrients were grouped in vitamins and minerals, phosphorous which was accounted as phosphate, amminoacids and other micronutrients (including pigments and cholesterol). For vitamins, minerals and amminoacids, data reported by Winther et al. (2020) were used, for phosphate data on phosphate fertiliser production was used among the processes present in SimaPro (SimaPro 9.0 2019), while for the other micronutrients climate change data from Adom et al. (2013). For all the micronutrients with the exclusion of phosphorous only climate impact data was utilized, thus excluding other impacts.

Nutrient loss, C, N, P cycles in the case of salmon

Nutrient loss in cage systems was accounted following Abdou et al. (2017, 2018) as a difference between nutrient contained in the feed and nutrient uptake for both N and P. P and N content of the salmon tissue were taken from literature (Wang et al. 2013), while ammonia emissions were calculated in

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[5] https://ipiff.org/insects-eu-legislation/

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agreement with the Intergovernmental panel on climate change on the basis of the N content of the fish feed (Ogle et al. 2019b), as carried out in previous research (Pelletier et al. 2009). Nutrient loss for the RAS systems was estimated using data collected by several authors across RAS system companies in Norway (Aas and Åsgård 2019), which reported a release of N of 0.036 kg kg-1 of fresh fish and of P 0.007 kg kg-1 of fresh fish. The same coefficient used in the RAS systems were also applied for the juvenile salmon systems. Carbon dioxide production due to respiration was accounted in both cases using data from literature on the basis of the carbon content of the feed (Wang et al. 2013). It was assumed that 40% of the carbon content was lost as CO_2 during respiration, all the N was released as ammonia and P as phosphate, due to anaerobic conditions (Schlegel 1993). Indirect N_2O emissions due to the N released in the water was accounted adopting the most recent Intergovernmental Panel for Climate Change methodology (IPCC) (Ogle et al. 2019b).

For each of the crop based ingredient due to land management was carried out using IPCC Tier 1 emissions factors to account to soil C dynamics and N_2O emissions due to the soil organic matter degradation, in agreement with De Klein et al. (2006) and Ogle et al. (2019b, a). This methodological choice was undertaken considering the objectives of the assessment and available data (ISO 2006a, b; Goglio et al. 2015, 2018). Data for yield were taken from FAOSTAT and a 30-years average yield was considered for the country of origin of each feed ingredient (FAOSTAT 2019). This approach was adopted for all the crops and processed crops present in the feed meal composition with the exception of soybean lecithin. The physical allocation factors used in the SimaPro processes were also employed to account for field emissions from cultivation (SimaPro 9.0 2019).

True Prices

True pricing entails the calculation of true prices and the facilitation of paying true prices as an instrument of the remediation of harm to people and communities. It is argued that true pricing increases transparency, enables individual action to support sustainable economic activity, and contributes to an efficient transition towards a sustainable and inclusive economy, one that does not breach human rights, labour rights or environmental rights.

Significant interest has gone out to the principles and methods for True Pricing, yet the number of scientific publications is still low. Based on experiences in earlier projects (Groot Ruiz et al 2018) and a review of reports and literature, a methodology suitable for FutureEUAqua is described below.

WP4 of FutureEUAqua will assess the economic and environmental performance of different production systems and innovations in the aquaculture value chain. The objective of True Pricing in FutureEUAqua is to be able to know how the costs of production relate to environmental impacts. Various methods can be used to calculate True Prices of food products, some of which are out of scope for FutureEUAqua. Methods such as *consumer revealed preferences* are criticized and require more time and resources then available in this project.

Alternatively, we propose to use the shadow price methodology. Shadow prices are "estimated prices for something that is not normally priced in the market or sold in the market. It is often used in cost-benefit accounting to value intangible assets but can also be used to reveal the true price of a money market share, or by economists to put a price tag on externalities." The Dutch institute CE Delft calculated shadow prices for a large amount of substances in 2017 and in 2018, for the Netherlands and the EU28 respectively (CE Delft, 2017, 2018). The prices have been calculated for the year 2015. The prices have been calculated for a lot of impact categories and is therefore easier than finding specific studies for each impact category. Alternatively, the OECD has estimated shadow prices for pollution in a selection of its member countries.[6]

Using one method for all categories also ensures a coherent approach and perspective in the process of calculating these prices, whereas using different methods has the disadvantage that each of the studies has/could have a different perspective and has thus made different choices which would make our pricing inconsistent. These “readymade” prices are the result of research by different organisations and will have to be evaluated in relation to the FutureEUAqua project. This takes some work and the process required is describe below.

Stepwise approach for calculating True Prices

To calculate the True Price the products developed in FutureEUAqua, using the shadow price methodology, the following steps will be taken.

1. Prepare an overview of relevant environmental impacts, based on the findings of the LCA
2. Check relevant data bases for latest data on shadow prices.
3. Since the prices are for earlier years (e.g. 2015) these will have to be adjusted for inflation, and purchasing power parity for the countries concerned.
4. Use the tables with shadow prices to calculate the ‘costs of pollution’ (see example below)
5. Calculate True Prices by adding the costs of pollution to the costs of production.
6. Reflect and discuss the reliability of the findings and data used. Relevant considerations include local environmental conditions and seasonality.

Discussion

There is a difference between environmental prices and true prices: environmental prices are aimed at pricing the impact of “biological” emissions/pollution, true prices also look at the costs of non-biological emissions, e.g. child labour. Sometimes the terms are used interchangeably. In the context of FutureEUAqua, we assume that environmental impacts are most relevant and the social costs of production are not considered.

Note that the True Price calculation can only be conducted for products evaluated within FutureEUAqua. No comparison can be made to products not evaluated in FutureEUAqua (for example true prices of aquaculture salmon with meat). For the latter, no data is available.

The findings of the True Price calculation should be carefully framed. True Prices are an indication of possible costs. The discussion on the value of True Pricing will include aspects of (un)certainty and discuss how the findings of the True Price calculation can be used.

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[6] https://www.oecd-ilibrary.org/docserver/5jxvd5rnjnxs-en.pdf?expires=1603718080&id=id&accname=oid006406&checksum=0083BD3121CD3F410425C2970C86D8DF

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Chapter 5: Next steps and list of missing information

In the next years of FutureEUAqua, the study team will continue to collect data, in cooperation with the consortium partners. Various options are open for further analysis. The comparison of different production systems is central to this task and data on IMTA systems is not yet available. This will be discussed together with WP4 partners and the project coordinator.

Data needed for the environmental evaluation of sea bream and trout farming is not yet available to the study team.

The following tables 6 and 7 visualise the status of data collection for the different production systems and species.

Table 6: Status of data collection for different production systems

	Economic data	Environmental model and True Prices
RAS	🟩	🟩
IMTA	🟥 No data available yet	🟥 No data available yet. Data from literature could be used as alternative.
FT	🟩	🟩

Green: data available, orange: data from literature available, red: no data

Table 7: Status of data collection for different species

	Economic data	Environmental model and True Prices
Salmon	🟩	🟩
Sea bass/bream	🟧	🟥

Green: data available, orange: data from literature available, red: no data

As it has been highlighted in recent review, key to the impact of fish farming is fish feed (Bohnes et al., 2018). Thus an assessment of different fish diet could be carried out depending on partners diet data availability to better establish diet and environment interaction.

The data used in the modeling could be complemented with full value chain assessment for the salmon farming depending on data availability from partners and on the basis of literature. This can include the evaluation of different processing or packaging options (e.g. bioplastics) if data on such innovations is available.

Data so far is based on other sources and an effort will be made to approach companies to obtain potential primary data in collaboration with partners. The validation of the model will be undertaken with the data collected from partners and literature.

All findings of the economic assessment, the LCA and the True Price calculation will be reported in Deliverable 4.9 “Final version of the economic model and the environmental model”, to be delivered in Month 44 of the project.

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Annex 1: Capital investment cost for sea bream RAS farming, from the Space@sea project

Capital breakdown	Unit	Quantity	Price (€)/unit	Value
Tanks				
Tank area	m^2	5,682	68	386,353
Biofilter material	m^2/m^3	150	200	30,000
Piping	m^3.h	13,635	15	204,528
Drums	m^3.h	13,635	60	818,110
Pumps	m^3.h	13,635	35	477,231
Oxygen reactor	m^3.h	13,635	20	272,703
Oxygen dose regulator	m^3.h	13,635	10	136,352
Total power (recirc:rest = 0.4)	kW	1,082	400	432,862
Building				
Building	m^2	16,233	200	3,246,667
- Ground preparation	m^2	16,233	5	81,167
- Heating	m^2	16,233	15	243,500
- Ventilation	m^2	16,233	5	81,167
- Lighting	m^2	16,233	15	243,500
- Electra	kW	1,082	400	432,862
Other initial set up costs				
- Permits	#	1	1,361	1,361
- Hook up electra	#	1	2,269	2,269
- Hook up gas	#	1	1,361	1,361
- Hook up water	#	1	1,000	1,000
- Hook up waste system	#	1	2,269	2,269
Other costs				
Emergency power aggregate	kW	1,082	400	432,862
Measurement and control	m^3	6,818	15	102,270
Alarm	Piece	1	2,269	2,269
Septic tank	ton/Y	243	100	24,316
Feeding equipment	m^3	1,250	15	18,750
Weighing equipment	piece	1	4000	4,000
Sorting equipment	piece	1	4000	4,000
Cooler/freezer	piece	1	2,000	2,000
High pressure cleaner	piece	1	1,000	1,000
Office	piece	1	5,000	5,000

Extraordinary costs	%	15	7,691,729	1,153,759
Total capital investment				**8,845,488**