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Deliverable D4.7:

First version of the environmental and economic model

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Executive summary

Aquaculture is growing sector both in quantity and in terms of technologies and type of fish which is grow. Currently aquaculture provide 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 methodology adopted for the economic assessment and environmental assessment is outlined. This constitutes the basis for the first version of the economic model and the environmental model, which is looking at format and parameter definition, methodology description, and listing of requirements for technical relationships.

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

Among the economic model assessed the FARM and OrAqua are the models that are selected based on best score against the criteria set as part of this review. Instead for the environmental assessment, the FARM model together with nutrient budget equations resulted as the optimal solution for the environmental assessment. Both assessments will be also based on primary data from fish farmers and data taken from literature. The environmental assessment will be complemented with the true price assessment. The monetarization of the impact is carried out using data available in literature.

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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 rising development and important 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 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. seaweed 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 (D4.7) is the first deliverable in WP4 and outlines the economic model and the environmental model, looking at format and parameter definition, methodology description, and listing of requirements for technical relationships.

To this end, the following steps are taken

- A concise overview of economic models used for economic evaluation of aquaculture (Chapter 2)
- A concise overview of environmental models and approaches used (Chapter 3)
- An evaluation of models, in light of the objectives of FutureEUAqua (Chapter 4)
- A proposal for the models to be used in FutureEUAqua (Chapter 5)

Methodology

The following activities were undertaken in drafting this report

- A review of scientific literature, looking specifically for models used in economic and environmental assessment. For the environmental assessment, key word employed included "C cycle", "life cycle assessment", "fish farming", "shellfish", "model", "N cycle", "IMTA", "environmental impact assessment". The papers were then screened for pertinence to the topic. Key criteria for the review were the level of applicability in terms of data requirements and expertise and the level of accuracy in agreement with previous research in the life cycle assessment field (Goglio et al., 2015). In addition to the former criteria, it was also considered particularly relevant whether the methodological approach has been used before in life cycle assessment of fish farming systems and the relevance for the research which will be conducted as part of the FutureEUAqua project. Further another criteria is whether the model have been used for cage systems, closed systems and IMTA.
- Review of past and present FP7 and H2020 projects and project presentation of Horizon 2020 projects.
- Consultation with experts

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Chapter 2: Overview of economic models

OrAqua

One aim of the FP7 project OrAqua (funded by the EC, Grant no. 613547) was to improve understanding of the economics of organic aquaculture production and the competitive position of organic aquaculture products in EU markets. OrAqua built on former studies on farm economics for organic aquaculture and contained extensive calculations on organic aquaculture. Costs and benefits analyses was performed for the farm and chain and how these affect the competitiveness of European organic aquaculture.

The assessment of farm economics in this report is based on the estimated differences regarding costs between organic and conventional aquaculture. Economic farm data for conventional aquaculture are available from several sources: the STECF database for most species, the Fiskeridirektoratet Norge (www.fiskeridirektoratet.no) provides data for and from the Norwegian salmon production, Turkovski and Lirski published the profitability of the Polish carp sector and the Landesfishereiverband Brandenburg provides a model for the carp production in Germany. For the three most important producing countries for each specie (as far as data are available), the transition from conventional to organic aquaculture is simulated. The needed price- and quantity indices are quantified by three kinds of information sources: literature, expert knowledge and workshop results.

A characterization of the OrAqua models is provided below”

Model-name	OrAqua
Year	2014
Format	Excel
Species	Carp Salmon Sea bass & sea bream Trout
Production systems	Dependent on species
Data sources	STECF data Expert consultation
Available to the WP4 partners	YES

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Aquavlan

The main goal of the Interreg IVA project AquaVlan was to lay the foundation for an economic, social and ecological sustainable aquaculture sector in the border region of Flanders and The Dutch province of Zeeland. In this region, the production, processing and trade in fish, shellfish and salty vegetables are an important sector for the economy and food supply. From the consumer's point of view, the economy and the history of the region, it is of key importance that this sector develops further into a sustainable sector, strongly relying on regional expertise and market perspectives

Model-name	**Aquavlan**
Year	2012
Format	Excel
Species	Yellowtail kingfish (Seriola lalandi) Omega perch (Scortum barcoo) Freshwater cod (Lata lata) Pike perch (Lucioperca lucioperca)
Production systems	RAS
Data sources	Literature Expert input Calculations
Available to the WP4 partners	YES

FARM

The FARM modelling determines the sustainable level of production for farms, improving profitability and environmental stewardship. framework applies a physical and biogeochemical model, bivalve/finfish growth models, and screening models for determining aquaculture production and eutrophication assessment. FARM determines the optimal carrying capacity (the greatest sustainable yield of market-sized animals within a given time period). The FARM model also calculates profit optimisation using marginal analysis and can be used for the valuation of nitrogen credits. (https://www.longline.co.uk/site/products/aquaculture/farm/)

Model-name	**FARM**
Year	2019
Format	Software Program
Species	Various fish (including Salmon, trout, seabream, seabass and tilapia), bivalves, shrimp, algae
Production systems	RAS

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	IMTA Open water
Data sources	Mixed sources
Available to the WP4 partners	Limited, only after paying subscription fee

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Chapter 3: Overview of environmental models

The environmental models and methodology to assess fish farming systems were grouped in 4 groups: Environmental risk assessment models, dispersion models, ecological models and nutrient balance equations. Finally among the model reviewed there is also the FARM model which was previously described in the above section.

Environmental assessment models

The environmental assessment models were developed and used by the regulatory authorities to authorize the development of fish farming in a certain sea areas. Several environmental risk assessment models were discussed: DEPOMOD, Ancylus-MOM, CAPOT. Other general characteristics of the environmental risk assessment model includes high accuracy in stream dynamics, large data requirement (daily and monthly data), they consider sedimentation ("Ancylus," 2019; Cromey et al., 2002; Telfer et al., n.d.). Further, they have been mostly developed for cage systems and open waters. Carbon losses outside the systems have been estimated on the basis of the detritus main transport ("Ancylus," 2019; Cromey et al., 2002; Telfer et al., n.d.).

DEPOMOD is used by the Scottish Environmental Protection Agency for the authorisation of fish farming. It is based on deposition and dispersion model (Cromey et al., 2002). It requires species specific data to be run and it has been used in finfish farming (Cromey et al., 2002).

In agreement with the previous model, Ancylus-MOM (Modelling-On growing fish farms-Monitoring) is also used by Directorate of Fisheries as part of the site selection process for salmon and trout farms in Norway (Lundebeye, 2013). Ancylus-MOM is at the same time a monitoring and a modelling tool which is web-based. It composed of four sub-model: fish, dispersion sediment and water quality ("Ancylus," 2019). The data requirements are very detailed as to run the model, species specific data are necessary. In this model the water biogeochemistry is very limited. It has been used mostly in finfish farming ("Ancylus," 2019).

The last model selected is the CAPOT model which has been developed as GIS (Geographical Information Systems) excel tool by the University of Stirling in Scotland (Telfer et al., n.d.). It is a model able to simulate the dispersion of solids and the sedimentation. The CAPOT model is based on a fish sub-model, a dispersion sub-model, a sediment sub-model and a water quality sub-model. It requires large data requirement in particular hydrologic data. It has been used for finfish farming worldwide (Telfer et al., n.d.).

Dispersion models

The dispersion models mostly consider the dispersion of solids and their redeposition (BIM, 2008; Jusup et al., 2009, 2007). These type of models have been mostly used in open-field fish farming systems and requires complex hydrogeological variables (BIM, 2008; Jusup et al., 2009, 2007). Some accounts for C, N and P loss on the basis of the organic material decomposed (BIM, 2008; Jusup et al., 2009, 2007).

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The KK3B model is a three-dimensional particle tracking model that can be used to predict the benthic carbon loading from fish farms which can only be used for local scale assessment. It requires benthimetric data to be run. The biogeochemistry has been included in the model by integrating a steady state model (Jusup et al., 2009, 2007).

Together with KK3D, also the UISCE model consider biogeochemical and hydrodynamics models and it is mostly used for environmental assessment of aquaculture and shellfish. It was developed by the Bord Iascagh Mhara, the agency of the Irish state with responsibility for developing the Irish marine fishing and aquaculture industries (BIM, 2008). UISCE is combined with ARCGIS to provide geospatialised results (BIM, 2008).

Ecological models

Among the many ecological models applied to marine biology, several have been retained as potential models for a life cycle assessment of fish farming: MIKE3-ECOL, Ecowin 2000, AIM, FVCOM-ERSEM, Shell-SIM, EcoPath. Common characteristics of this models are that they consider different trophic level, they have been used for IMTA systems. They also account for sedimentation and water flow, together with the C, N and P cycle. However these models still have large data requirements (Christensen and Pauly, 1992; Ferreira et al., 2012b; Foreman et al., 2015; Kluger et al., 2016; MIKE, 2019; Petihakis et al., 2012; Tsagaraki et al., 2011).

The MIKE model is developed by DHI and it is a commercial model which has been used for IMTA systems. As mentioned earlier, it considers the biogeochemical cycles, sedimentation and the water flow (MIKE, 2019). Differently from the former model, ECOWIN is an ecological model developed using an object-oriented approach which can be used for nutrient loading and aquaculture assessment scenario it is not appropriate for farm scale assessment (Ferreira et al., 2012b).

In contrast with the previous models, the AIM (Aquaculture Integrated Model) model is based on a generic model coupled with a 3D hydrodynamic model. It considers relations between organism. The computational requirements are quite high for the AIM model and they are dependent on the resolution (Baretta et al., 1995; Petihakis et al., 2012; Tsagaraki et al., 2011). Instead the FVCOM-ERSEM combines a biogeochemical model with a 3D hydrographical model. It has similar characteristics to the AIM model and similar challenges, e.g. high computational requirements (Foreman et al., 2015).

Differently from the previous models, ShellSIM and EcoPath mostly concentrate on shellfish farm systems assessment (Christensen and Pauly, 1992; Kluger et al., 2016; SHELLSIM, 2019). Both models are based on a dynamic energy balance and it concentrate on the shellfish growth, estimating the nutrient release in the water. It is not freely available and small fee should be paid to use it. Another disadvantage is that it requires daily data for growth conditions (Christensen and Pauly, 1992; Kluger et al., 2016; SHELLSIM, 2019).

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Nutrient balance equations

The mass balance equations have been used by several authors in the field of life cycle assessment of fish farming with different systems (Abdou et al., 2018, 2018; Aubin et al., 2019, 2018, 2009). The nutrient balance equations such as FARM, EcoPath (Ferreira et al., 2015, 2012a; Mendoza Beltran et al., 2018). At the moment there are nutrient equations capable of estimating C, N, P cycle. This methodological approach is cost effective and has low data requirement (Abdou et al., 2017; Aubin et al., 2019, 2018).

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Chapter 4: Evaluation of models in the light of the objectives of FutureEUAqua

In FutureEUAqua Task 4.3 is concerned with the economic profitability and environmental impact of production systems. The task description is provided in the text box below.

In this task the economic and environmental impact of the innovations, as described in the work packages WP1, WP2 and WP4, will be evaluated, on the level of the complete value chain, from feed production to consumption. For a proper comparison we will express all relevant indicators per kg cleaned fish at retail.

The economic and environmental analyses will conclude with the calculation of the integration of the innovations in the value chain into monetary value by true pricing. True pricing means that the external environmental, economic and social impacts are expressed in euros on top of the market price. The price for each issue is determined by the costs to reverse or compensate its negative effects. Comparing the true prices of the innovations to the true price of current production methods will provide insight into possible trade-offs between different sustainability topics, and hence a valuable instrument for decision making by industry and governmental institutes. Innovators will gain more insight into the sustainability improvement potential of the technologies they are developing and can better decide which technologies need to be further developed and promoted.

Subtask 4.3.1. Economic profitability. This task aims in particular at the effects caused by innovations regarding production and use of alternative feed ingredients and by-products (such as seaweeds), use of different breeds, use of production in different systems (RAS, IMTA, FT) as well as innovations in packaging. To evaluate the economic effects of introducing the innovations, a simulation model will be constructed, using the output from WP1, WP2, WP4 and WP6. Using a simulation model, the input variables can be varied and effects on profitability and the underlying cost- and revenue items can be calculated.

The model will work out the optimal combination of the innovations in genetics, feed and system and provides the economic cost-benefit analysis of the innovations compared to current value chain, categorized by the discerned fractions in the value chain. Next to the more quantitative effects, the quality of the products will be evaluated, using relevant quality indicators such as taste, consistency, appearance and shelf live. The model will get specific input from genetics (WP1), feed (WP2), systems (WP4) and their effects on the quality indicators (WP6). From the participating industry partners the relation between the quality indicators and the production costs during the different phases in the chain will be obtained.

Subtask 4.3.2: Environmental impact. The environmental effects of the innovations in the value chain will be assessed using a Life Cycle Assessment (LCA; ISO14040/14044: 2006). The LCA will cover the relevant categories of environmental impact as defined by end-point analysis (contribution of each impact category to the three endpoint categories human health, ecosystems and resources), such as climate change, fine particulate matter, toxicity, land use and resource scarcity.

Based on this task description the following requirements for the models are formulated:

1. Evaluate economic and environmental impacts of innovations at the level of complete value chain
2. Evaluate effects of the following innovations on economic profitability
    a. Innovation in production
    b. Use of alternative feed ingredients and by-products
    c. Use of different breeds
    d. Use of production in different systems (RAS, IMTA, FT)
    e. Innovations in packaging
3. Be able to incorporate true pricing in the economic assessment
4. Vary input variables and calculate effects on profitability and underlying cost- and revenue items

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5. Calculate optimal combination of innovation
6. Evaluate effects of changes in quality on economic performance

The performance of identified models against these criteria is presented in table below

Table 1: Performance of identified models against criteria

		Economic models		**Economic/ Environmental models**	**Environmental models**			
		OrAqua	*Aquavlan*	*FARM*	*Enviromental risk assessement models*	*Dispersion models*	*Ecological models*	*Mass balance equations*
1	Value chain perspective	Some data on consumer prices available	Limited to "farm level"	Limited to "farm level"	Limited to "farm level"	Limited to "farm level"	Limited to "farm level"	Limited to "farm level"
2	Effect of innovations	Possibly after adapting the model	Not included	Yes	Yes	Yes	Yes	Yes
3	True Pricing	Not included	Not included	Not included	No	No	No	No
4	Vary input and calculate effects	Yes, not in detail	Yes, in detail	Yes, in detail	Yes, in detail	Yes, in detail	Yes, in detail	Yes in details
5	Calculate optimal combination	No	No	No	No	No	No	No
6	Changes in quality of product	Not included	Not included	Not included	Not included	Not included	Not included	Not included

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Chapter 5: Proposal for models to be used in FutureEUAqua

Based on the review of models against criteria for FutureEUAqua, we propose to adapt the excel based models to cater to the specific needs of this project. Although the FARM model does cover the species and production systems concerned, the poor availability to the consortium (only after paying high fees) and the absence of a method to deal with true prices render it less useful.

Economic model

The proposed model for the economic analysis in FutureEUAqua is described in the following section, looking at model description, 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 the WP4 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)

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- 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
- 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 model: 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/R
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 the WP4 partners	YES

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

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assessment is to show how the total costs including the hidden costs differ between the innovative value chain and the current practice for fish farming systems.

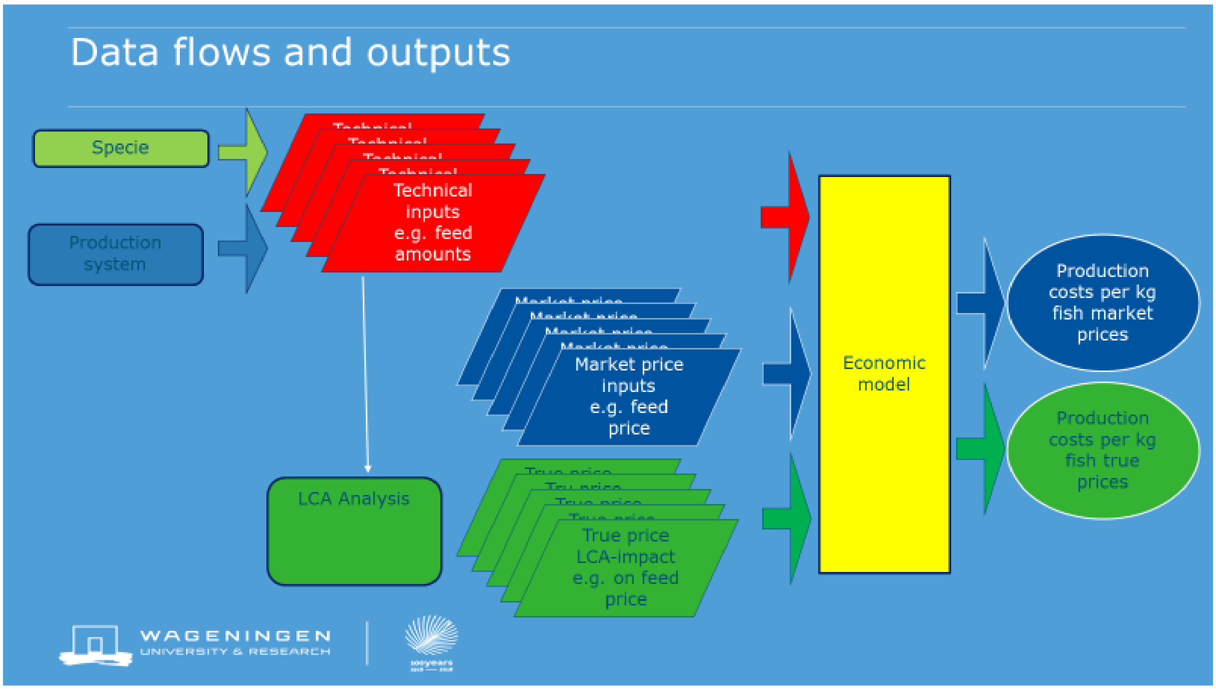
Model design

The model will consist of the following modules

- Input module: this describes the technical characteristics of the fish farming systems analyse
- Biogeochemical cycle modules: this 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 model: 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:



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.

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

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

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