LCA of aquafeed: introduction to ecoformulation. Application to rainbow trout

Aurélie Wilfart, Florence Garcia-Launay, Frédéric Terrier, Espoir Soudé, Pierre Aguirre, Sandrine Skiba-Cassy

ECO-FORMULATION OF FISH FEEDS: A promising efficient solution to limit aquaculture impacts on the environment. Application to rainbow trout

Aurélie Wilfart[1], Florence Garcia-Launay[2], Frederic Terrier[3], Espoir Soudé[3], Pierre Aguirre[3], Sandrine Skiba-Cassy[3]

1INRAE, Institut Agro, SAS, 35000 Rennes, France

2INRAE, Institut Agro, PEGASE, 35590 Saint-Gilles, France

3INRAE, Univ. Pau & Pays Adour, E2S UPPA, NUMEA, 64310 Saint Pée-sur-Nivelle, France.

Life cycle Assessment of in aquaculture
University of Milan December 5th 2022

ECO-FORMULATION OF FISH FEEDS:
A promising solution or crazy idea of mathematicians ?

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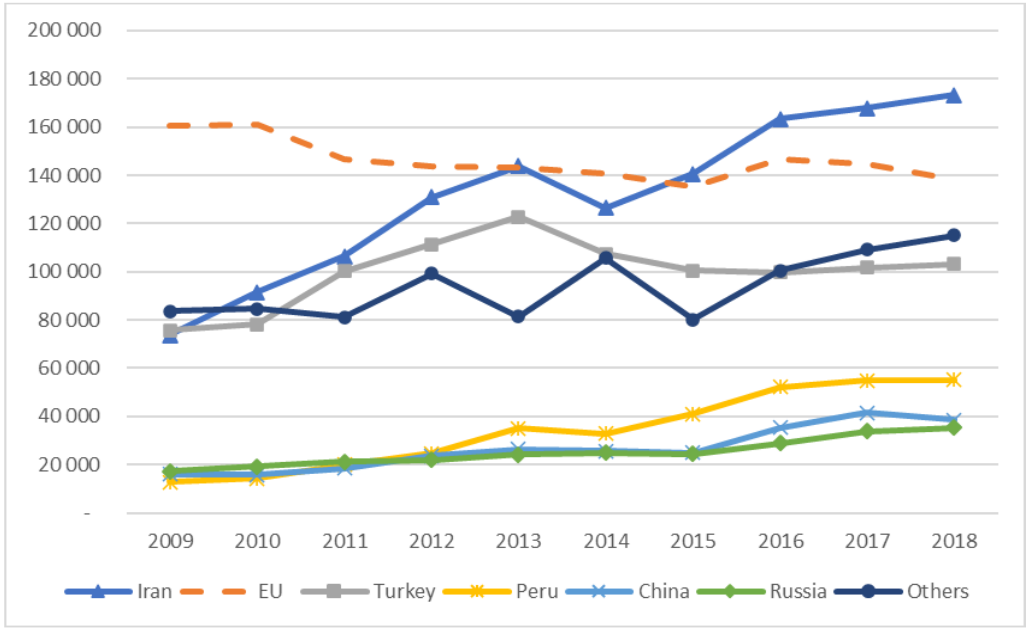
Rainbow trout production

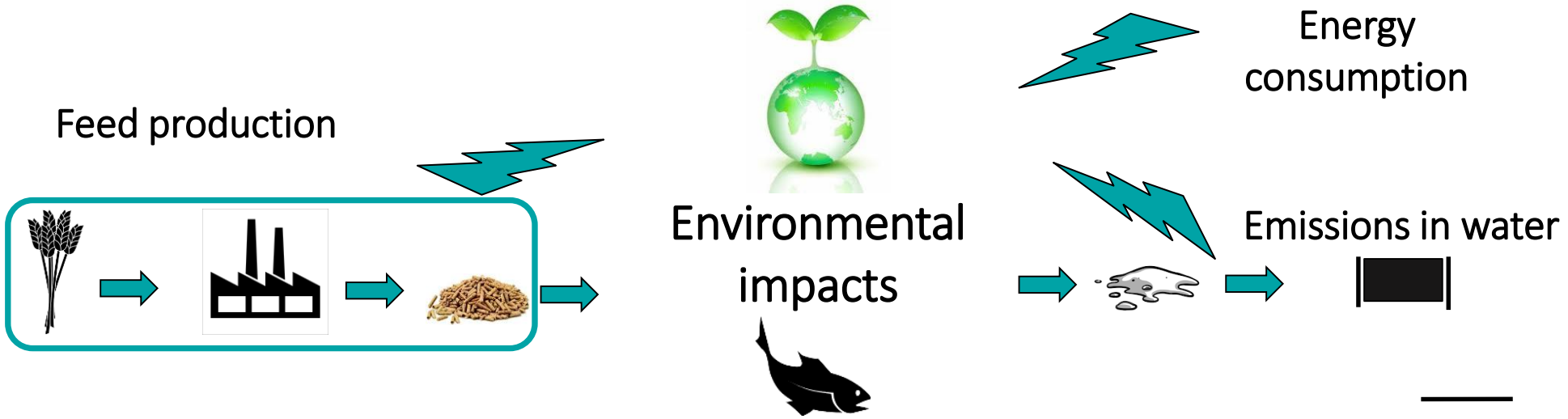


FAO, 2018

- ✓ Leading freshwater farmed species in Europe (156,000 t)
- ✓ Mainly for portion size-fish (200-300 gr)
- ✓ Almost all rainbow trout on the EU market comes from aquaculture

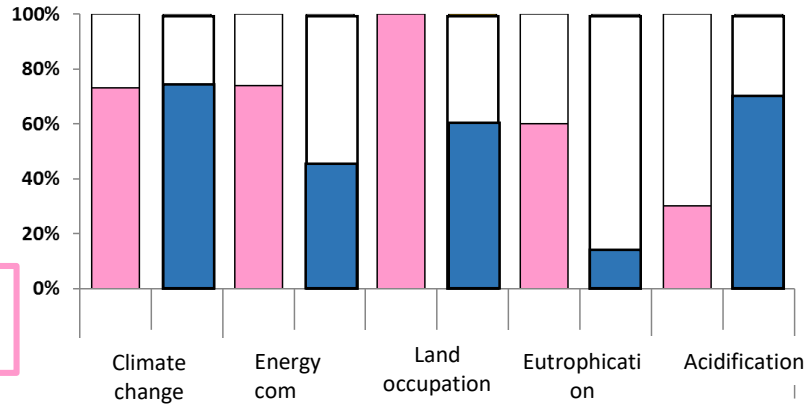
EUMOFA, 2021

Environmental impacts of aquaculture



- ✓ 65-95% of the environmental impacts (Wilfart et al, 2018)
- ✓ 60-75 % of production cost (Hoffman et al, 1997)

Basset-Mens & van der Werf, 2005
Dourmad et al. 2014



Feed contribution to LCA impacts for 1 kg of life weight at farm gate

Aubin et al., 2009
Boissy et al., 2011
Wilfart et al, 2013,

Environmental impacts of aquaculture

Produce feeds with lower environmental impacts: Ecofeeds

Dietary levers

Dietary strategies to adapt to the animals needs
(eg: precision feeding, higher digestibility…)

EcoAE Fish project : designing an ecofeed for rainbow trout and test its digestibility, the consequences on animal growth performances and its environmental impacts

EcoFeed: multi-objective formulation concept

- ✓ Formulate : combine feed ingredients into feed by using linear programming to meet user-defined animal requirements with an objective to optimize

EcoFeed: multi-objective formulation concept

Eco-formulation

Multi-objective formulation

Environmental impacts of raw materials

Least-cost formulation

Cost of raw materials and nutritional requirements

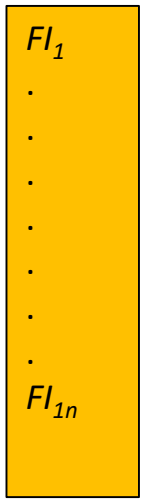
Traditional feed

Eco-feed

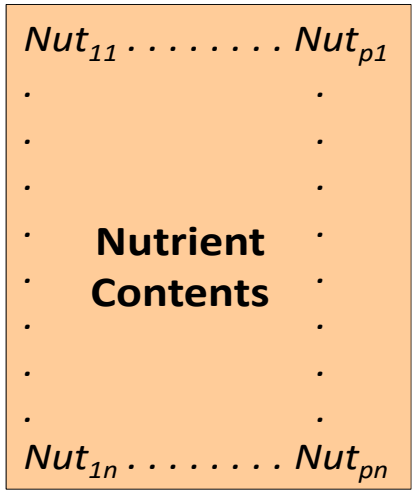
Feed with less environmental impact and controlled cost

Lower cost feed

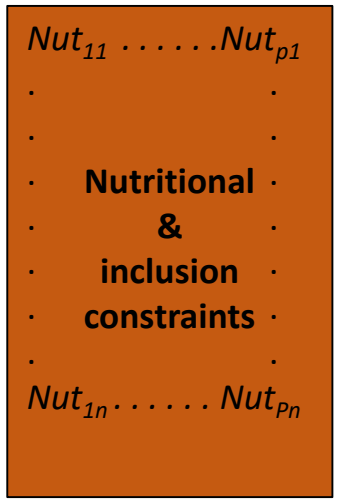
Feed Formulation matrix



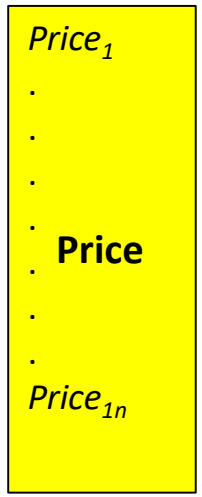
List of feed ingredients

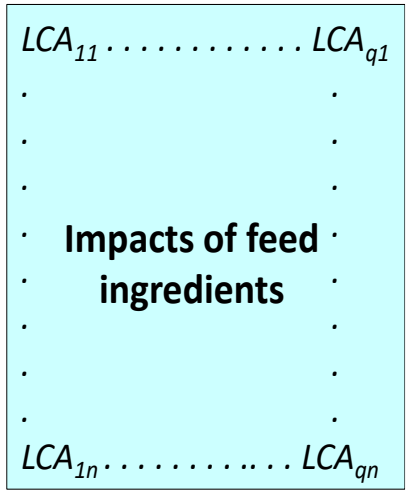


INRA AFZ and IAFFD feed tables



Nutritional constraints (species)
Technological constraints
Product specifications





ECOALIM (AGRIBALYSE®)
(Wilfart et al 2016)

Climate change ILCD (**CC**)
Phosphorus demand (**PD**)
Acidification ILCD (**AC**)
Eutrophication CML (**EU**)
Non-renewable CED 1.8 (**NRE**)
Land occupation CML (**LO**)
Net primary production use (**NPPU**, fish)
Water demand AWARE (**WD**)

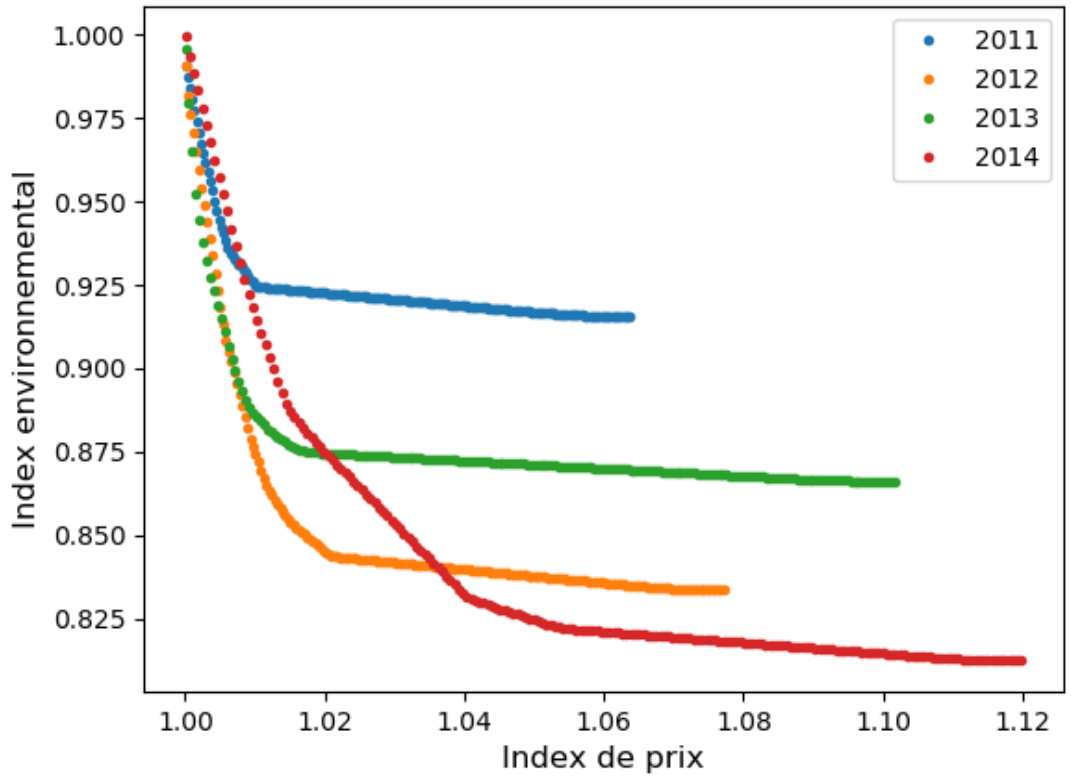
➢ Multi-objective formulation algorithm

$$f(x) = \sum_{i \in I} coef_i \frac{Impact_i{}^t x - Min_i}{Ref_{impact_i} - Min_i}$$

$$c^t x \leq \epsilon \qquad \epsilon = \{Ref_{prix}, \dots, Max_{prix}\}$$

$$Impact_i{}^t x \leq 1.05 \times Ref_{impact_i}$$

$$\begin{pmatrix} q_{min} \\ n_{min} \\ 1 \end{pmatrix} \leq \begin{pmatrix} Q \\ N \\ 1^t \end{pmatrix} x \leq \begin{pmatrix} q_{max} \\ n_{max} \\ 1 \end{pmatrix}$$



i = [CC, AC, EU, NRE, LO, PD, NPPU, WD]

Trade-off economy/environment

Feed formulas : ingredients

2 different formulations approaches

- ✓ **Commercial formulation** in accordance with practices in commercial farms (**C-diet**)
- ✓ **Ecodiet** with MO-formulation considering feed cost and environmental impacts (**ECO-diet**)

Major ingredients (%)	C-diet	ECO-diet
Wheat	**2.00**	**17.31**
Fababean	17.01	-
Fish meal	**16.01**	**7.24**
Fish oil	**6.53**	**3.61**
Gluten meal	8.50	-
Oilseed meal		
Poultry meal (blood, feather)		
Oilseed oil	**1276.9 €/t**	**1171.5 €/t**
Guar meal/Soy lecithin	-	2.97/5.76
Pea protein concentrate	25.01	20.00
Premix and additives	4.35	4.4

-45 %

16 raw materials

23 raw materials

-8 %

Feed formulas: chemical composition and environmental impacts

Chemical composition	C-diet	ECO-diet	
Dry matter (g/kg)	966.4	973.4	
Crude protein (g/kg)	473.7	476.7	
Crude lipid (g/kg)	237.0	237.9	
Starch (g/kg)	91.5	**111.1**	
GE (kJ/g DM)	25.7	24.6	
Environmental impacts /kg of feed)			
Climate change (kg CO_2-eq)	**1.387**	**0.751**	**- 46 %**
Non renewable energy (MJ)	**14.851**	**8.547**	**- 57 %**
Acidification (molc H^+-eq)	0.017	0.012	
Eutrophication (kg PO_4^{3-}-eq)	0.007	0.00458	
NPPU (kg C)	**21.593**	**12.150**	**- 44 %**
Land occupation (m^2year)	1.625	1.240	
Water demand (m^3)	**10.321**	**5.759**	**- 44 %**
Phosphorus demand (kg P)	0.007	0.00556	

Consequences on the formula: take home message

- Reduction >50% of fishmeal and fish oil
- Elimination of soybean meal and soybean protein concentrate
- Introduction of new yeast ingredients such as yeast
- Reduction of feed cost (8%)

But :

- Increase in the number of ingredients (16 → 23)
- Significant use of animal by-products : hydrolysed feather protein, poultry blood meal, poultry oil
- Introduction of raw materials in very small quantities: 0.02% linseed oil, 0.01% potato protein concentrate

➢ Digestibility and growth trials

- ✓ Triplicate groups of 27 fish (initial BW 60 g) per diet
- ✓ 84 d of experiment (Growth) – 21 d (digestibility)
- ✓ C-diet or Ecodiet
- ✓ Feeding ad libitum twice a day
- ✓ Biomass weighing every 21 days
- ✓ Total quantity of feed distributed
- ✓ Control of physico-chemical parameters (O_2, N-NH_4, °C)
- ✓ Calculation of growth performance parameters

NuMéA, Donzacq experimental facilities

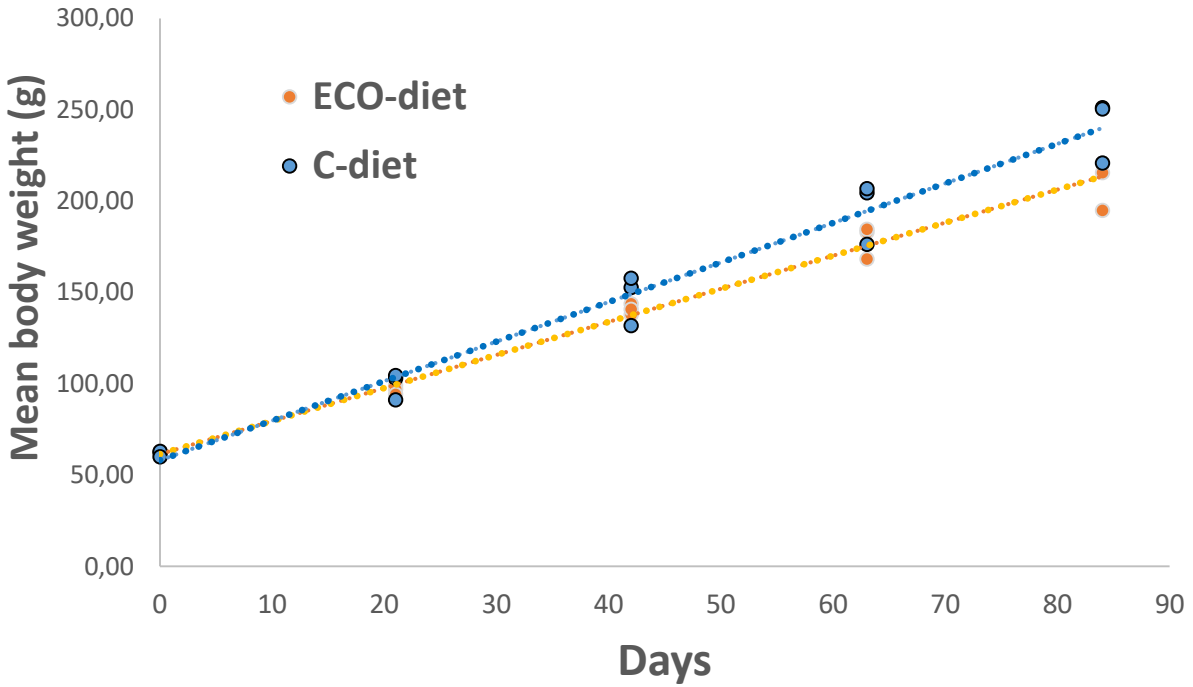
In vivo performance of the Eco-diet

	C-diet		ECO-diet		
	Mean	SD	Mean	SD	P-value
Initial BW, g	61.73	1.54	61.23	1.54	0.71
Final BW, g	240.74	17.32	210.37	13.72	0.08
SGR, %	1.62	0.06	1.47	0.08	0.07
DFI, g kg^{-1} day^{-1}	16.17	0.03	15.03	0.02	0.009
FCR	1.15	0.02	1.15	0.05	0.93

	C-diet		ECO-diet		
ADC (%)	Mean	SD	Mean	SD	P-value
Protein	91.69	0.23	91.01	0.17	0.08
Lipid	95.56	0.27	93.99	0.08	0.0003
Starch	92.51	0.48	97.66	0.32	0.0003
Energy	89.07	0.34	87.27	0.29	0.02
Ash	44.93	1.36	38.81	0.3	0.04

- No effect on body composition, final BW, nutrient retention and nutrient gain except for protein
- Energy and lipid gain are lower with ECO diet
- ECO-Diet significantly affected daily feed intake

In vivo performance of the Eco-diet



IMPORTANT

Eco-feed consumption does not affect animal performance

- Good growth performance
- No significant difference after 84 days (p=0.07) but to be confirmed over a longer rearing period
- No difference in body composition

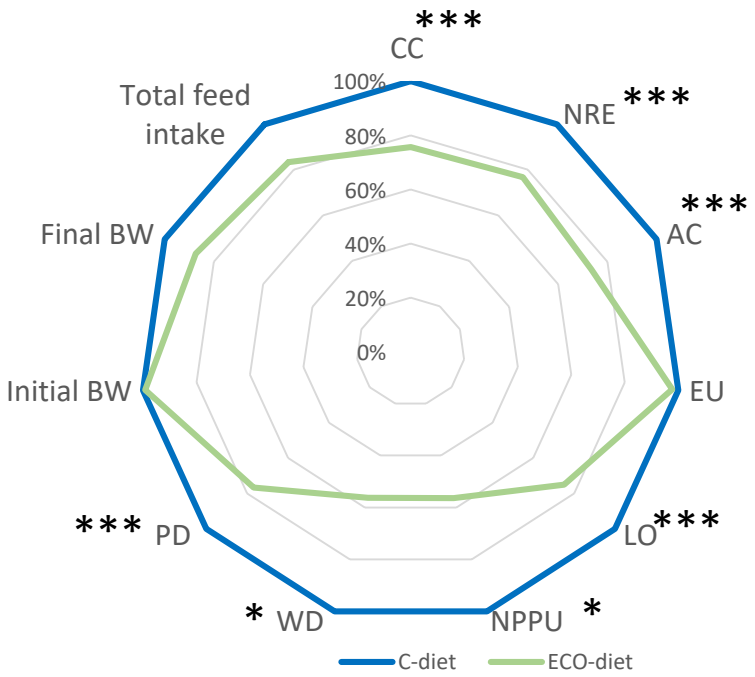
➢ LCA methodology

- ✓ LCA was conducted for each tank according to tank performance and feed consumption. Electricity and water consumption for feed production were measured directly on the experimental feed facility

- ✓ The functional units and the main components considered in LCA model were:
  - ✓ One kg of feed at factory gate, including resources and emissions to the production of feed and transportation to plant (ECOALIM dataset, Wilfart et al 2016)
  - ✓ One kg of live body weight gain at the end of experiment which included the uses of resources (oxygen, energy, water) and emissions during the experiment.

- ✓ The impacts considered were climate change (CC), acidification (AC) obtained by ILCD method, eutrophication (EU by CML IA) and non renewable energy demand (NRE by CED v1.08), water demand (WD by AWARE) as implemented in Simapro® v8.3.0.0 and net primary production use (NPPU, Papytryphon et al 2004) and phosphorus demand (Wilfart et al 2016)
- ✓ Background data base : Agribalyse 3.0 including ECOALIM dataset (Wilfart et al, 2016)for agricultural machineries, Ecoinvent v3.8

LCA results at the end of the experiment



* P< 0.05, **P<0.01, ***P<0.001.

Per kg of BW gain, Eco diet reduced all the impact except for EU.

Major reduction for NPPU and WD (44 %)
Others impacts are reduced by about 25 %

The reduction at « farm » level is smaller than that observed at the feed level

IMPORTANT

Ecodiet: It works !

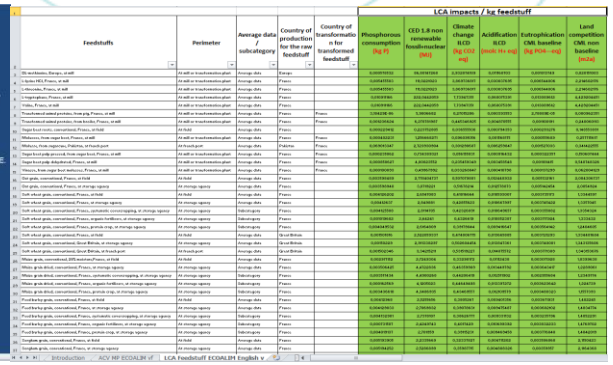
CC = climate change (kg CO2eq); NRE = non-renewable and fossil energy demand (MJ); AC = acidification (molcH+eq); EU = eutrophication (kg PO43-eq); LO = land occupation (m^2.y); NPPU = net primary production use (kg C); WD = water demande (m3); PD = phosphorus demand (g P)

- ✓ By formulating with environmental impacts, it is possible to reduce the environmental impacts of trout feed
- ✓ ECO diet use more raw materials than a commercial diet
- ✓ To compensate the substitution of fishmeal and fish oil, more animal co-products are needed in the ECO diet
- ✓ Despite a tendancy to reduce growth, ECO diet reduce significantly environmental impacts per kg of BW gain
- ✓ The interest of the multi-objectives formulation has to be validated for longer rearing times and on other fish species

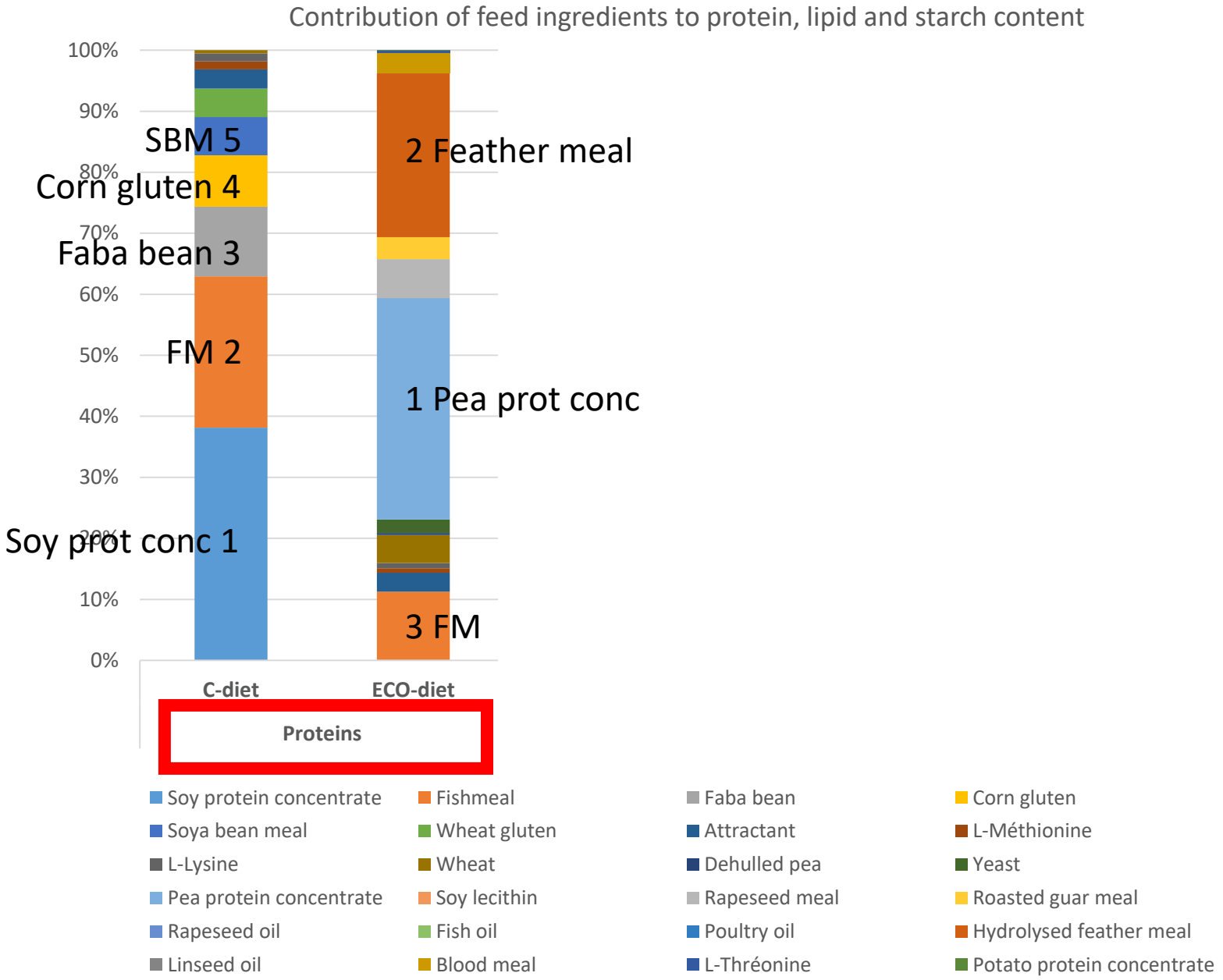
Thank you for your attention !

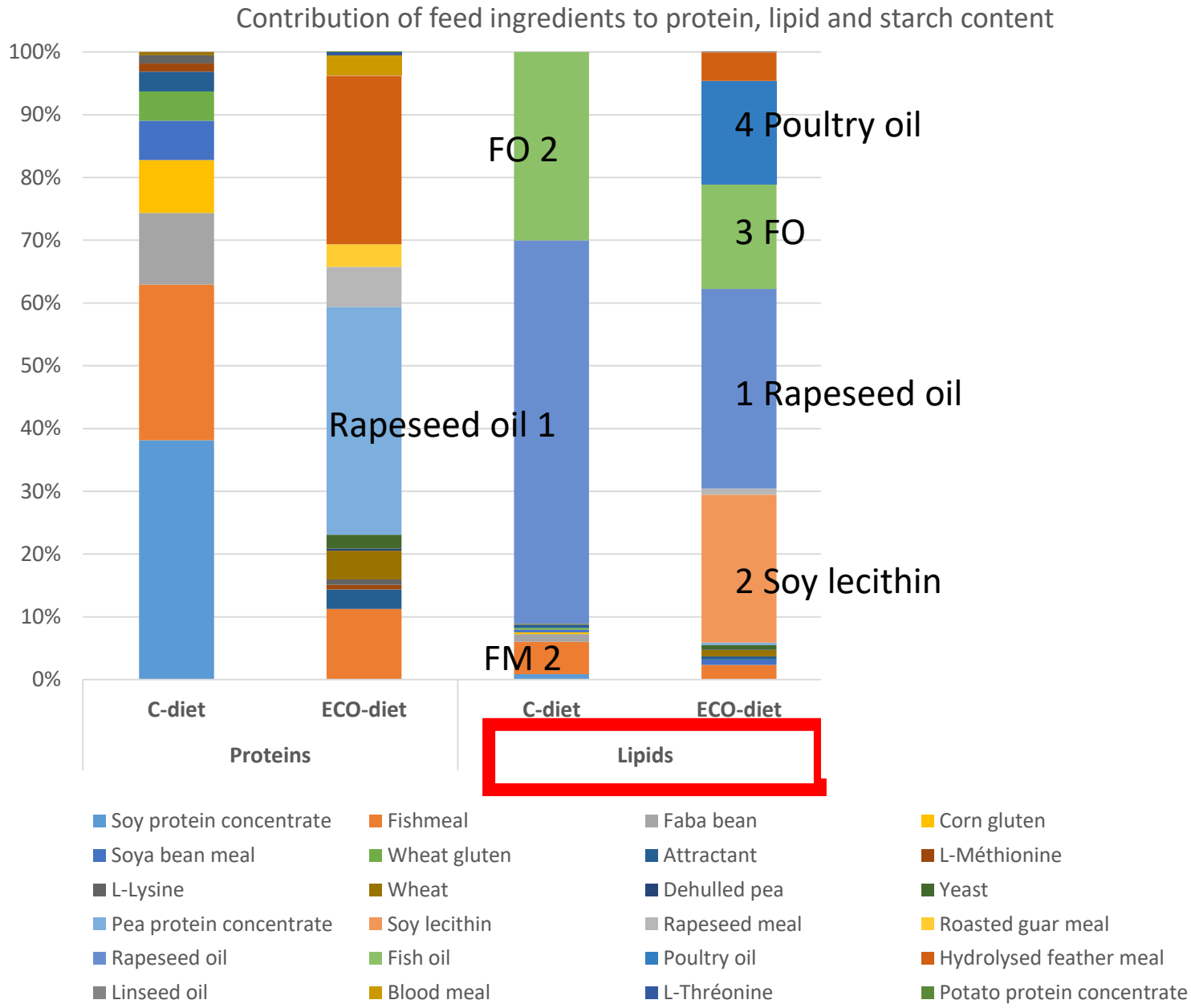
aurelie.wilfart@inrae.fr

https://www6.inrae.fr/ecoalim_eng/



Want to know more ? Read our article in *Aquaculture*
https://doi.org/10.1016/j.aquaculture.2022.738826


Contribution of feed ingredients to protein, lipid and starch content
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
SBM 5
Corn gluten 4
Faba bean 3
FM 2
Soy prot conc 1
2 Feather meal
1 Pea prot conc
3 FM
C-diet
ECO-diet
Proteins
Soy protein concentrate
Fishmeal
Faba bean
Corn gluten
Soya bean meal
Wheat gluten
Attractant
L-Méthionine
L-Lysine
Wheat
Dehulled pea
Yeast
Pea protein concentrate
Soy lecithin
Rapeseed meal
Roasted guar meal
Rapeseed oil
Fish oil
Poultry oil
Hydrolysed feather meal
Linseed oil
Blood meal
L-Thréonine
Potato protein concentrate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FO 2
FM 2
4 Poultry oil
3 FO
1 Rapeseed oil
2 Soy lecithin
C-diet
ECO-diet
C-diet
ECO-diet
Proteins
Lipids
Soy protein concentrate
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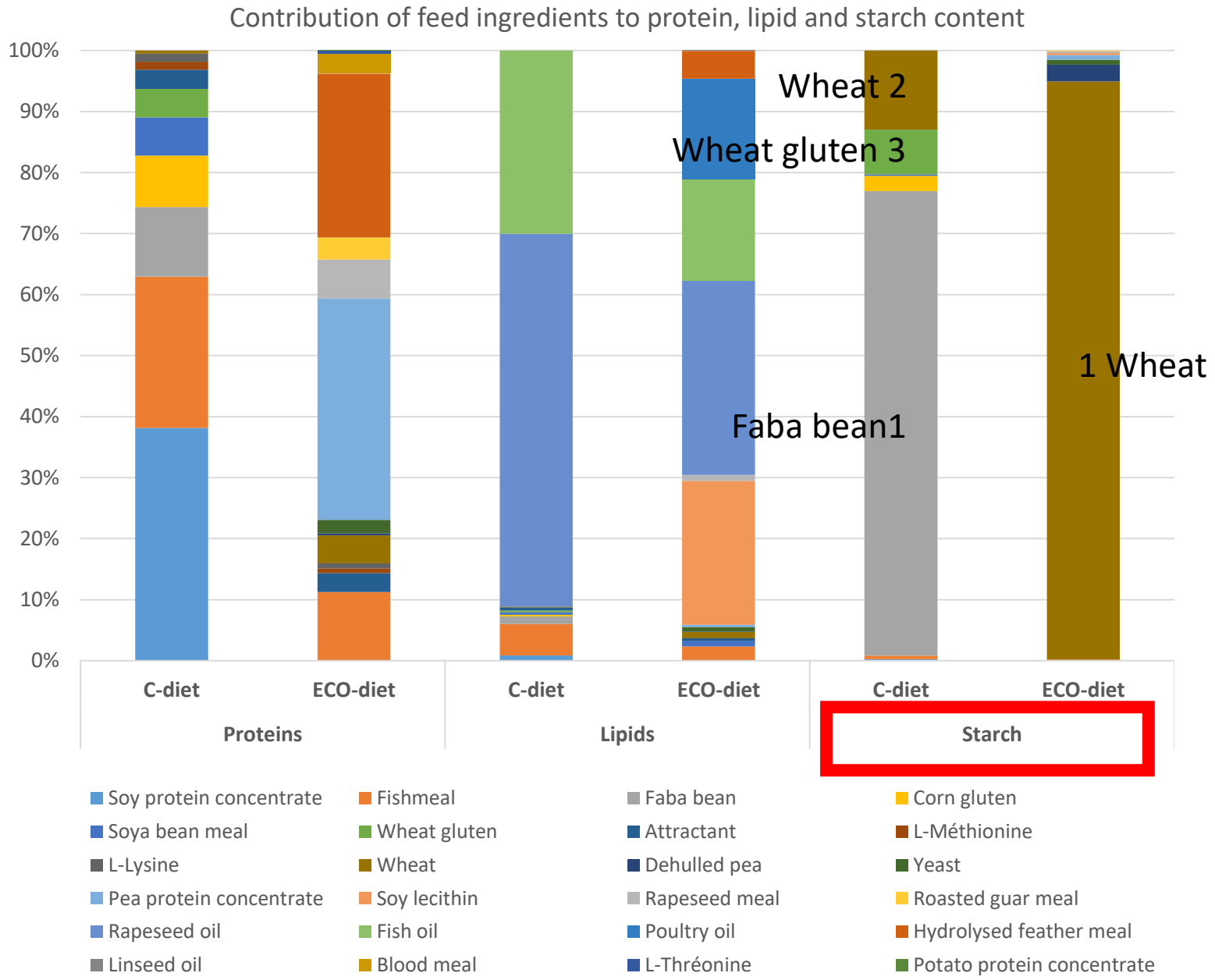
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C-diet
ECO-diet
C-diet
ECO-diet
Proteins
Lipids
Starch
Soy protein concentrate
Fishmeal
Faba bean
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