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ECO-FORMULATION OF FISH FEEDS:

A promising efficient solution to limit aquaculture impacts on the environment. Application to rainbow trout

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

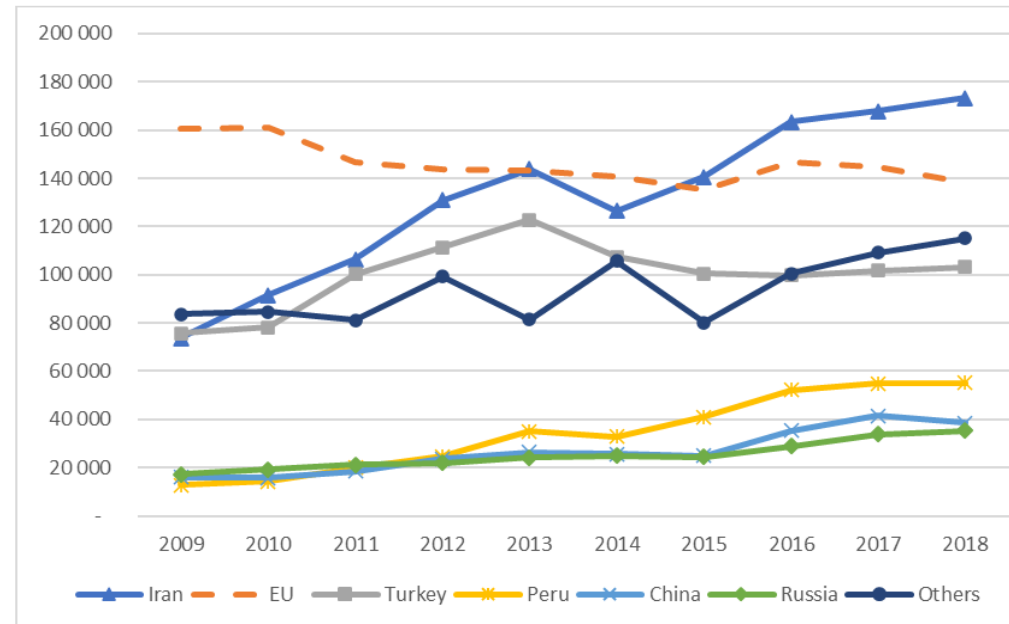
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➤ Rainbow trout production

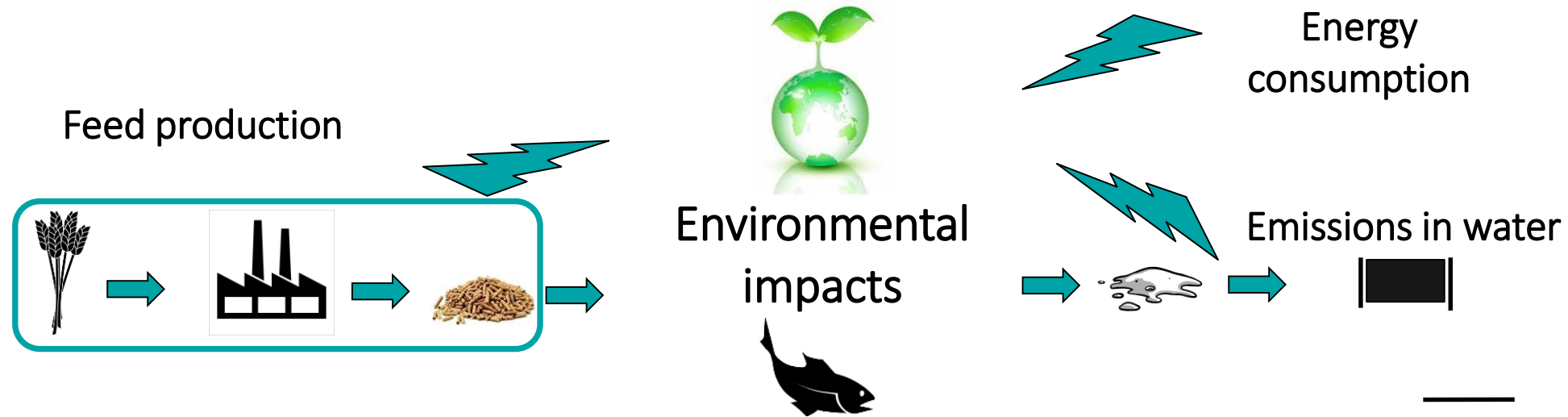


FAO, 2018

- ✓ 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

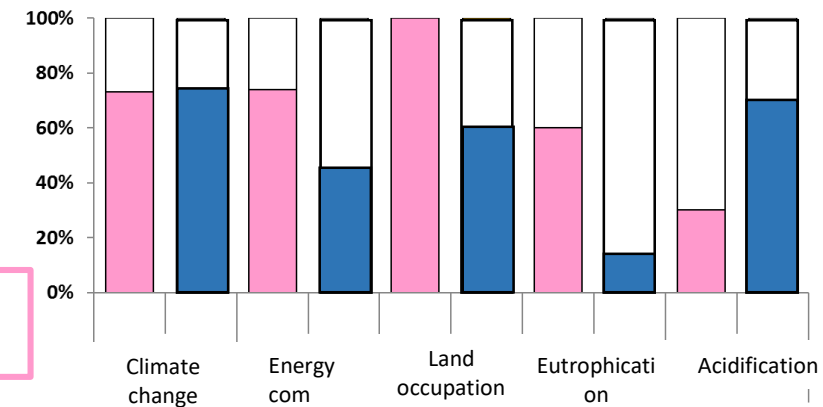
➤ Environmental impacts of aquaculture



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



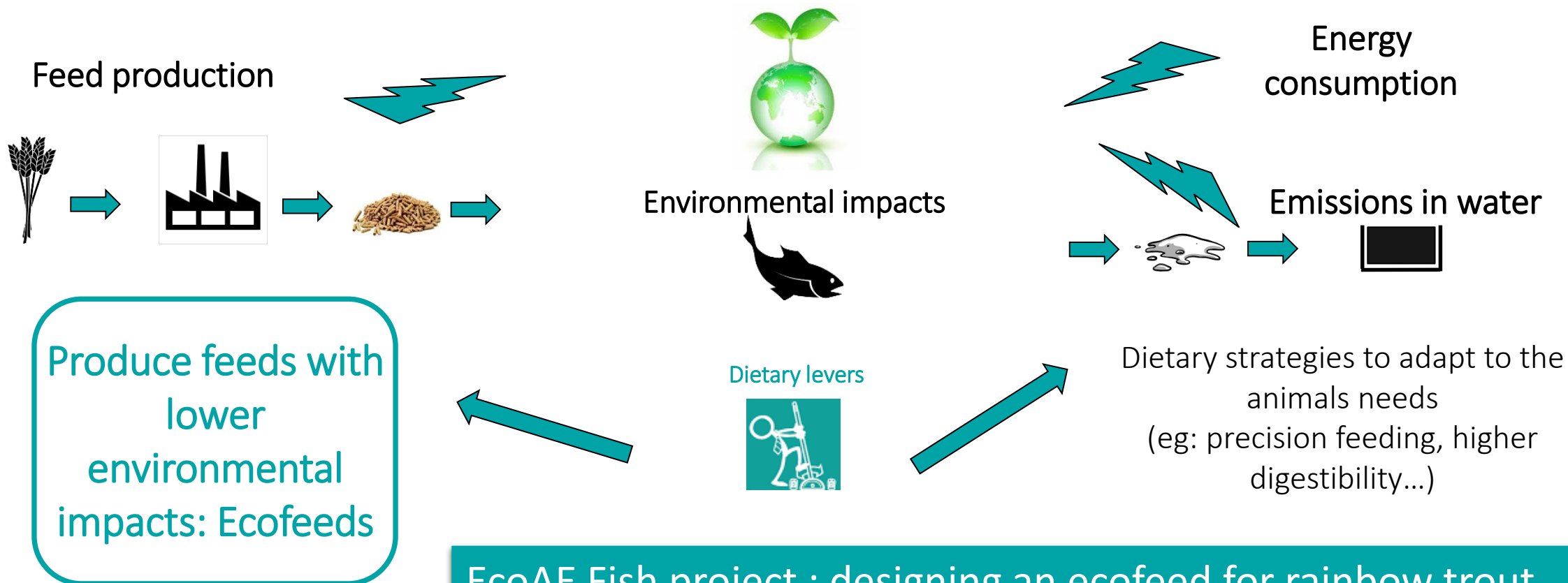
Basset-Mens &
van der Werf, 2005
Dourmad et al. 2014



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

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

➤ Environmental impacts of aquaculture



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

Eco-feed

Least-cost formulation

Cost of raw materials and nutritional requirements



Traditional feed

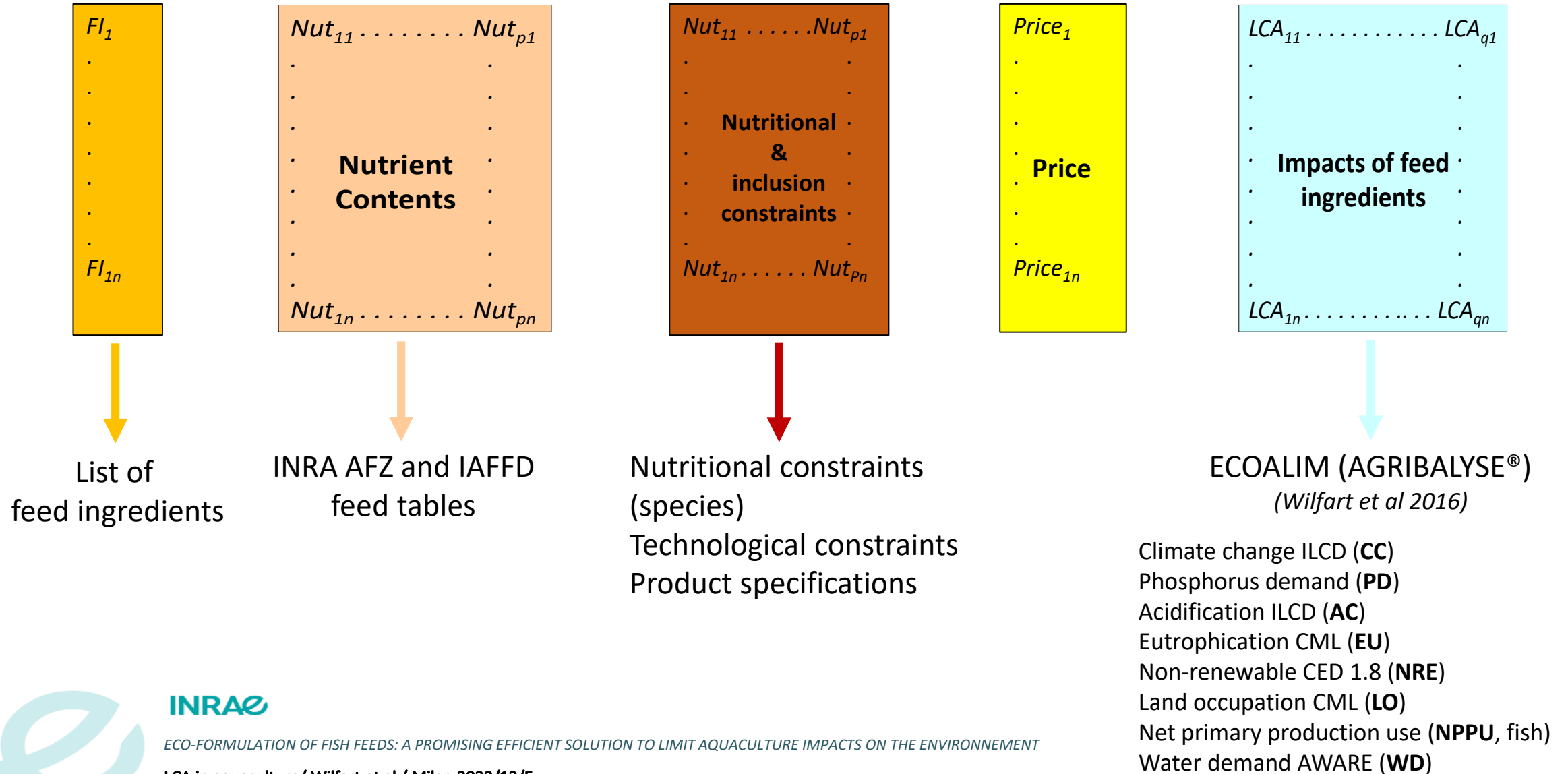


➔ Feed with less environmental impact and controlled cost

➔ Lower cost feed



➤ Feed Formulation matrix



➤ Multi-objective formulation algorithm

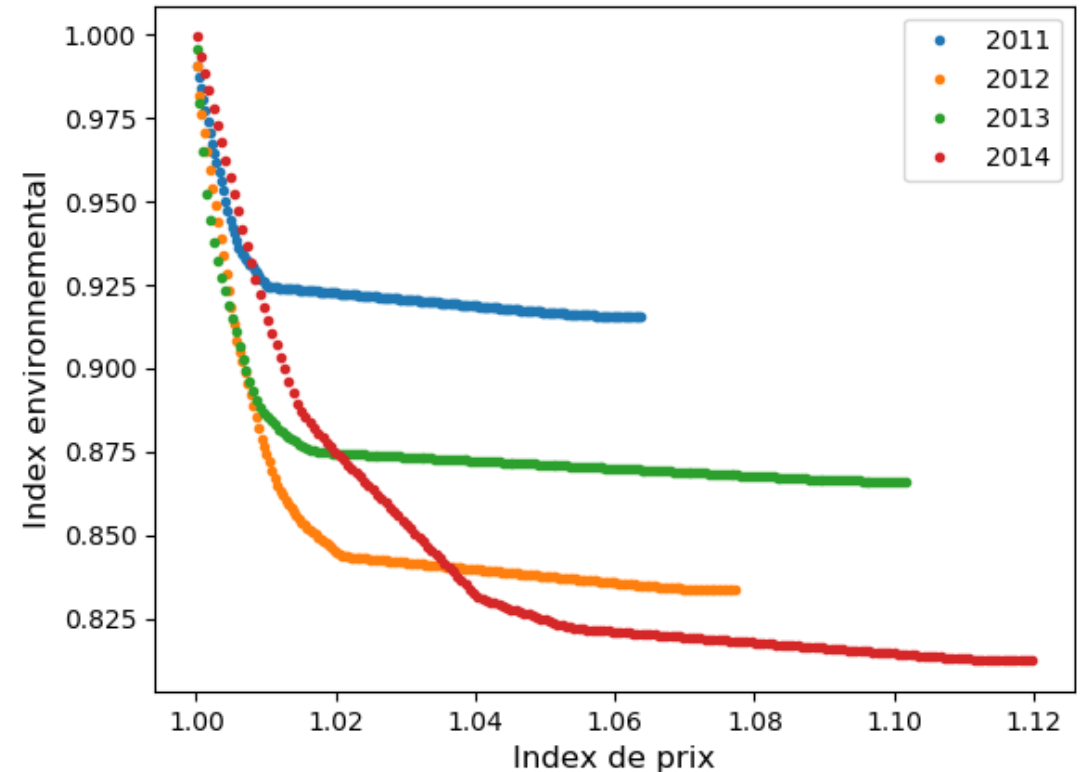
$$f(x) = \sum_{i \in I} \text{coef}_i \frac{\text{Impact}_i^t x - \text{Min}_i}{\text{Ref}_{\text{impact}_i} - \text{Min}_i}$$

$$c^t x \leq \epsilon \quad \epsilon = \{\text{Ref}_{\text{prix}}, \dots, \text{Max}_{\text{prix}}\}$$

$$\text{Impact}_i^t x \leq 1.05 \times \text{Ref}_{\text{impact}_i}$$

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

$i = [\text{CC}, \text{AC}, \text{EU}, \text{NRE}, \text{LO}, \text{PD}, \text{NPPU}, \text{WD}]$



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	-45 %
Fish oil	6.53	3.61	
Gluten meal	8.50	-	
Oilseed meal	16 raw materials	23 raw materials	
Poultry meal (blood, feather)		19.58	
Oilseed oil	1276.9 €/t	1171.5 €/t	-8 %
Guar meal/Soy lecithin	-	2.97/5.76	
Pea protein concentrate	25.01	20.00	
Premix and additives	4.35	4.4	

➤ 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 ² year)	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 , $^{\circ}C$)
- ✓ Calculation of growth performance parameters



NuMÉA, Donzacq experimental facilities

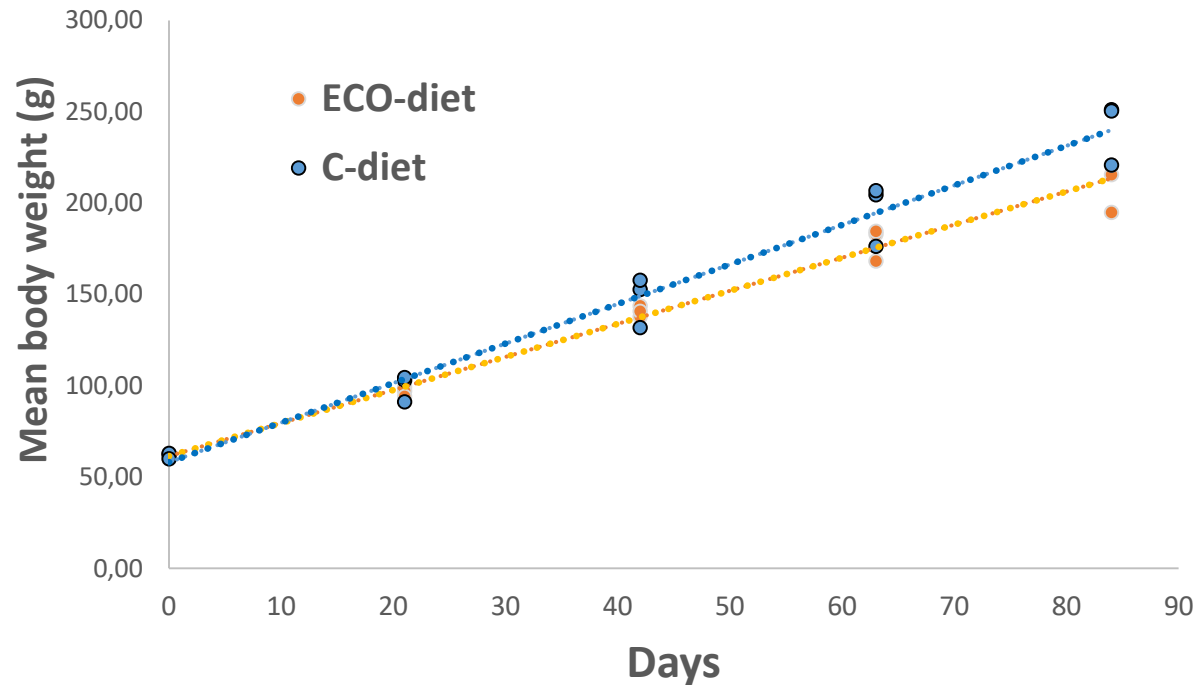
➤ In vivo performance of the Eco-diet

	C-diet		ECO-diet		P-value
	Mean	SD	Mean	SD	
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		P-value
	Mean	SD	Mean	SD	
ADC (%)					
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

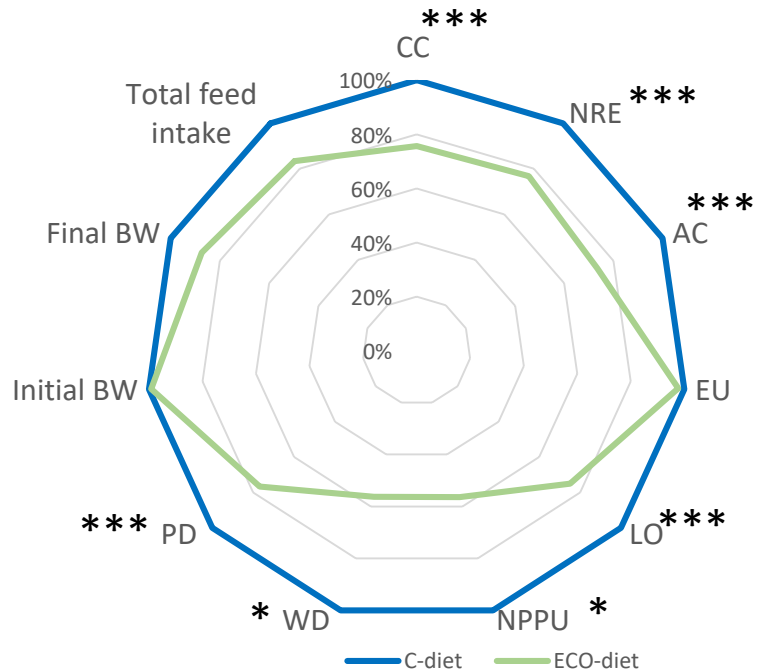
- Good growth performance
- No significant difference after 84 days ($p=0.07$) but to be confirmed over a longer rearing period
- No difference in body composition

➤ 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



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

CC = climate change (kg CO₂eq); NRE = non-renewable and fossil energy demand (MJ); AC = acidification (molH⁺eq); EU = eutrophication (kg PO₄-eq); LO = land occupation (m².y); NPPU = net primary production use (kg C); WD = water demande (m³); PD = phosphorus demand (g P)

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 !

- ✓ 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 tendency 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 !

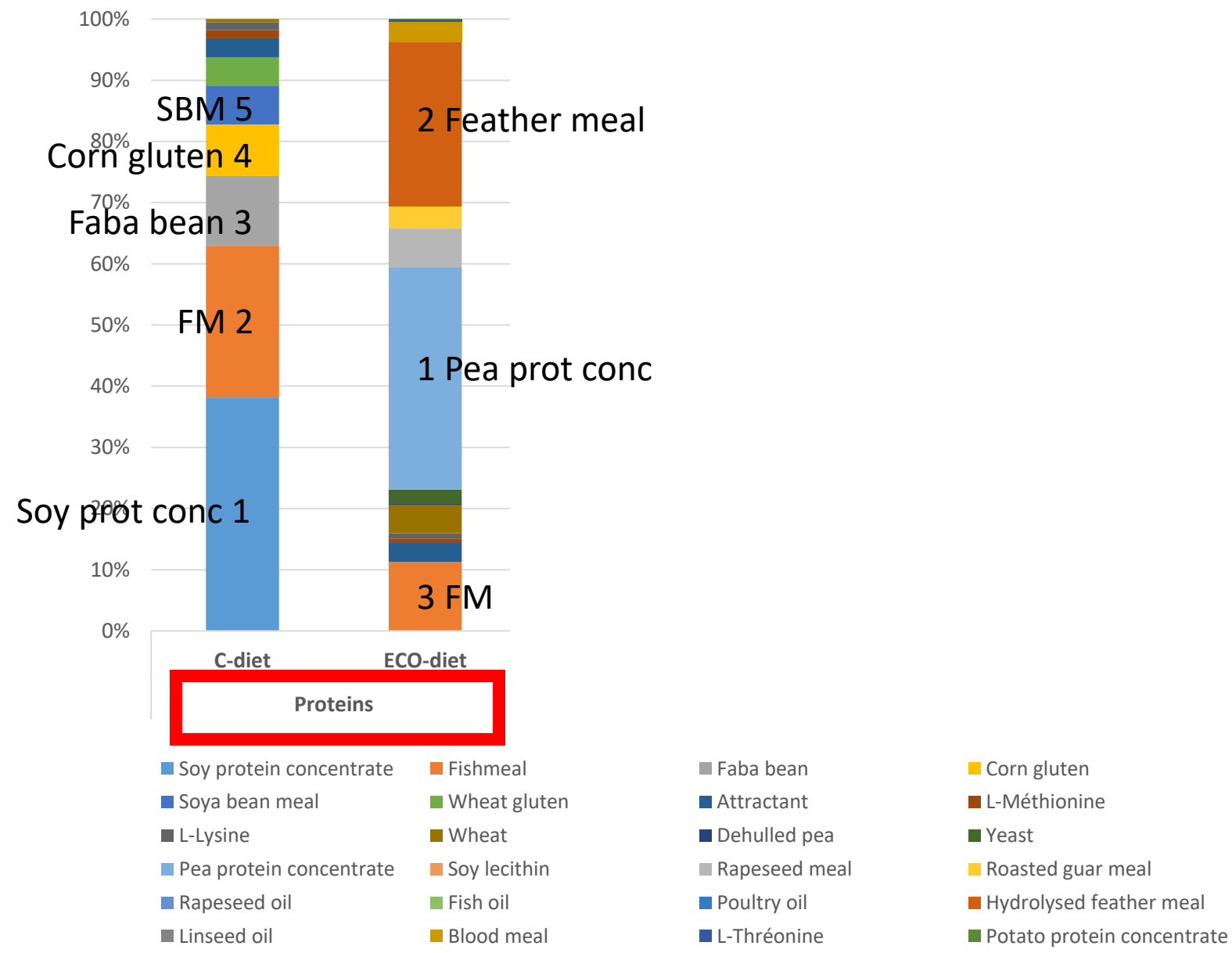
aurelie.wilfart@inrae.fr

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

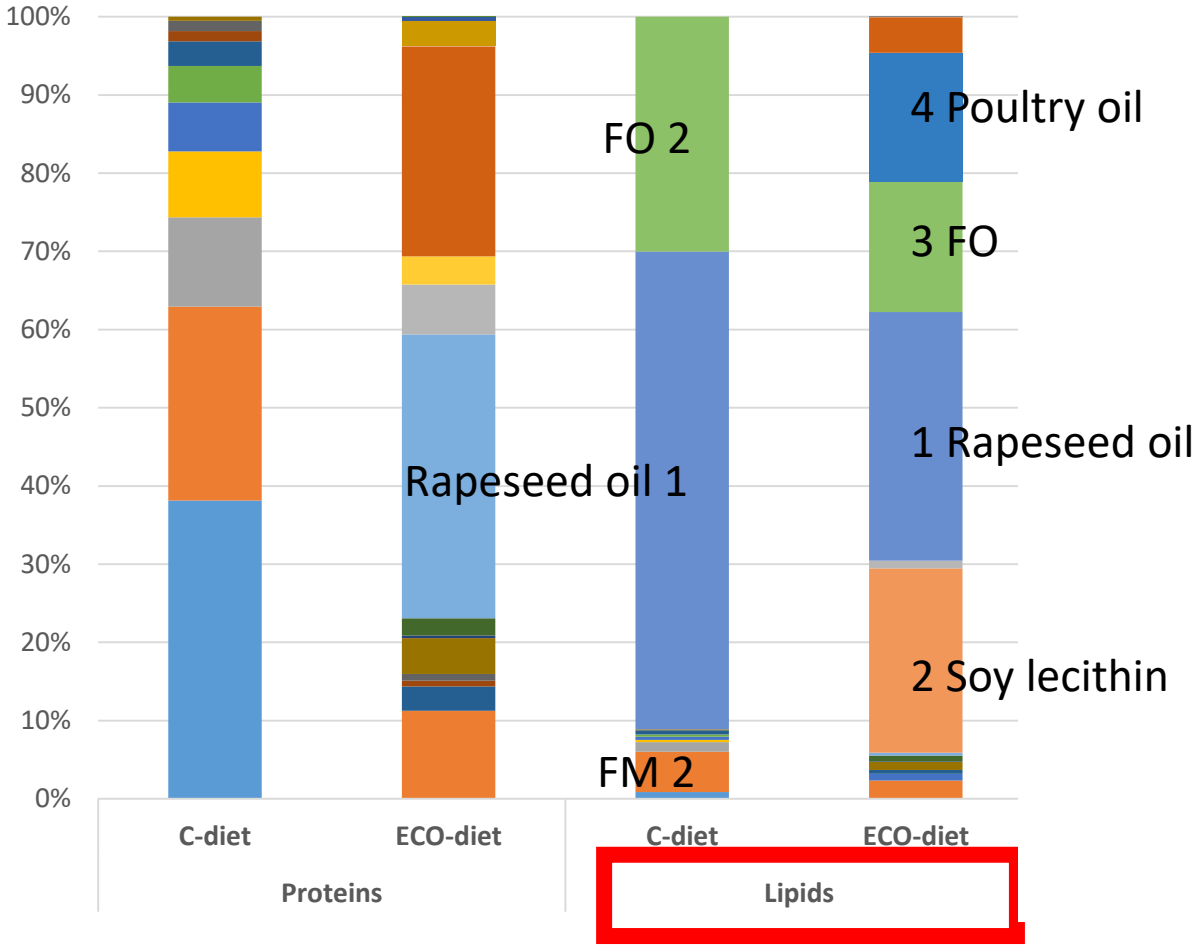
The screenshot shows the website interface for the ECOALIM data base, which provides LCA data on feedstuffs for animal feed. The website includes a header with the logo 'AMT élevages & environnement' and a navigation menu. Below the header, there is a welcome message and a list of partners including ifip, INRA, ARVALIS, Terres Inovia, ITAVI, and FEEDSIN Avenir. The main content area displays a table with the following columns: Feedstuffs, Percentage, Average date / subcategory, Country of production for the raw feedstuff, Country of transformation for the feedstuff, Atmospheric consumption (kg N), CED L & non renewable (kg CO2e), Climate change (kg CO2e), Acidification (kg SO2e), Eutrophication (kg PO4e), Land occupation (kg CO2e), and Land use change (kg CO2e). The table lists various feedstuffs such as 'Maïs humide (Région Nord)' and 'Maïs humide (Région Sud)' with their respective LCA impact values.

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



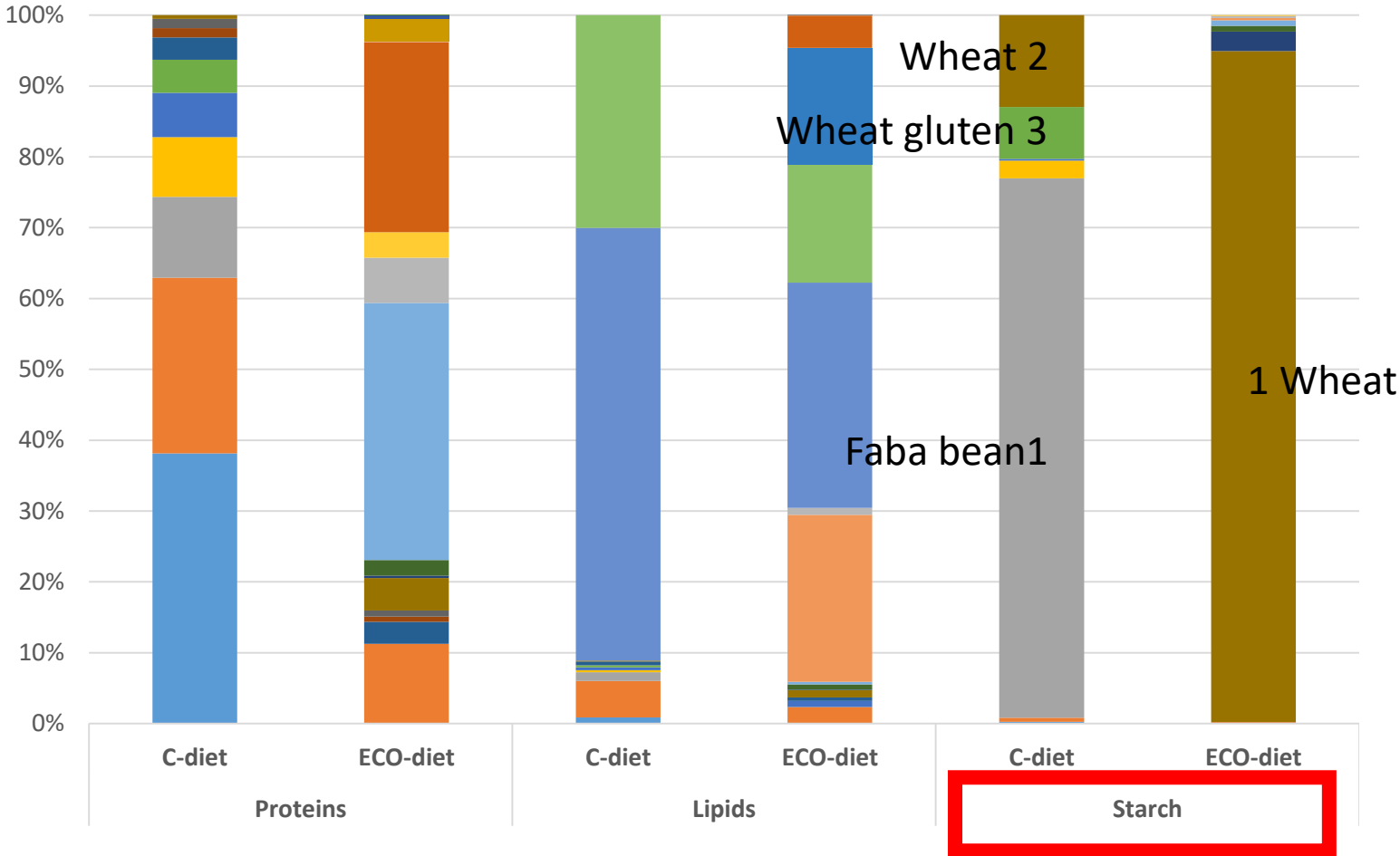
Contribution of feed ingredients to protein, lipid and starch content



- 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



Contribution of feed ingredients to protein, lipid and starch content



- Soy protein concentrate
- Fishmeal
- Faba bean
- Corn gluten
- Soya bean meal
- Wheat gluten
- Attractant
- L-Méthionine
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- Dehulled pea
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- Hydrolysed feather meal
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- Potato protein concentrate

