Life Cycle Assessment in aquaculture

The workshop, organized in the framework of the PRIMA project SIMTAP (https://www.simtap.eu/), is supported by the "Piano di supporto alla ricerca" of Departament of Environmental Science and Policy of University of Milan.

Mon **Dec 5**, 2022

Via Celoria 2, Room **C03**,

University of Milan

Link for registration (both in presence & online):
https://forms.gle/LM6S4KHUJSKZdGsG7

L'evento partecipa al programma di formazione professionale continua dei Dottori Agronomi e dei Dottori Forestali per 0,333 CFP con riferimento al Regolamento CONAF n. 3/2013

A&Q Provider presso il Consiglio Nazionale dei Tecnologi Alimentari - Prot. n° 53/2014 - ha accreditato l'iniziativa per il rilascio di 2 CFP ai Tecnologi Alimentari iscritti all'Albo

Schedule

Introduction: background and issues of aquaculture

14.00-14.20 Interventions in aquaculture to promote food security
Patrick Henriksson - Stockholm Resilience Centre

14.20-14.40 Circularity in aquaculture – the role of LCA
Killian Chary - Wageningen University

14.40-15.00 The Simtap project
Alberto Pardossi – University of Pisa

LCA application towards more circular aquaculture

15.00-15.20 Insect for aquafeed
Laura Gasco - University of Turin,

15.20-15.40 LCA of aquafeed: introduction to ecoformulation. Application to rainbow trout
Aurélie Wilfart – INRAE

15.40-16.00 BREAK

16.00-16.20 Environmental performance and ecosystem services of shellfish farming: LCA and carbon sequestration potential
Arianna Martini – CREA

16.20-16.40 LCA of Aquaponics
Daniele Brigolin – University IUAV of Venice

16.40-17.00 LCA in SIMTAP project
Joel Aubin & Michele Zoli – INRAE & University of Milan

General discussion: how to better eco-design circular aquaculture? Technics and assessment method needs

Organized by: Jacopo BACENETTI - jacopo.bacenetti@unimi.it & Claudia STELLINI - claudia.stellini@unimi.it

Interventions in Aquaculture to Promote Food Security 05 December 2022

Patrik JG Henriksson

One Earth

Gold Standard for the Global Goals
1 ton of CO_2 offset

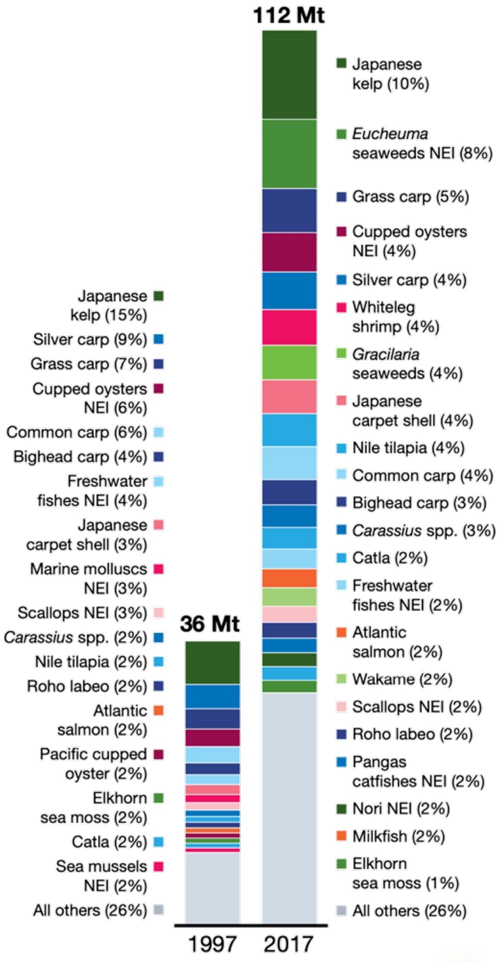
CellPress

Perspective

Interventions for improving the productivity and environmental performance of global aquaculture for future food security

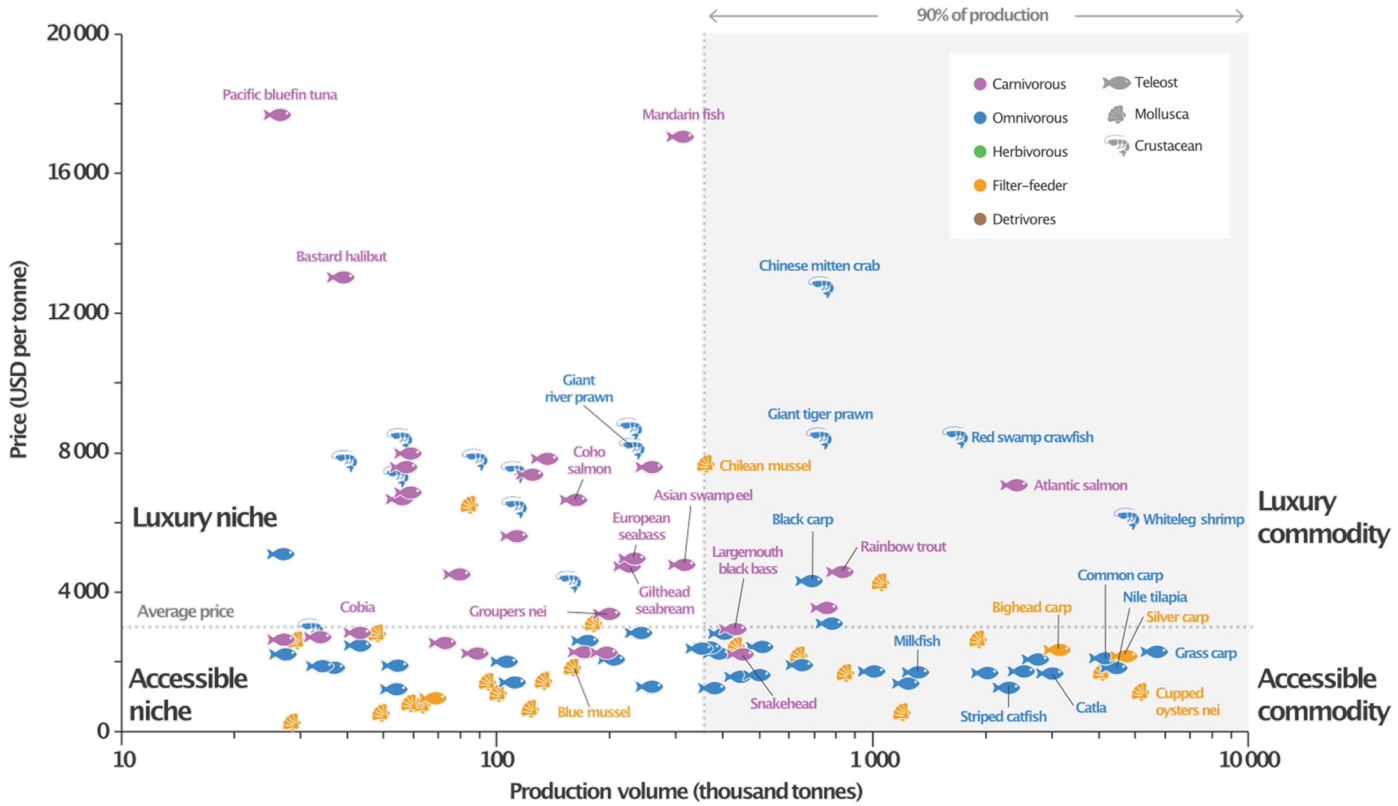
Patrik John Gustav Henriksson,[1,2,3,*] Max Troell,[1,3] Lauren Katherine Banks,[2,4] Ben Belton,[2,5] Malcolm Charles Macrae Beveridge,[6] Dane Harold Klinger,[7,8] Nathan Pelletier,[9] Michael John Phillips,[2] and Nhuong Tran[2]

SeaWin Sustainable Seafood · FORMAS · The Beijer Institute of Ecological Economics · Kungl. Vetenskaps Akademien · Stockholm Resilience Centre Sustainability Science for Biosphere Stewardship · Stockholm University · WorldFish



Naylor et al. 2021

Aquaculture volumes and prices



From: Henriksson et al. 2021

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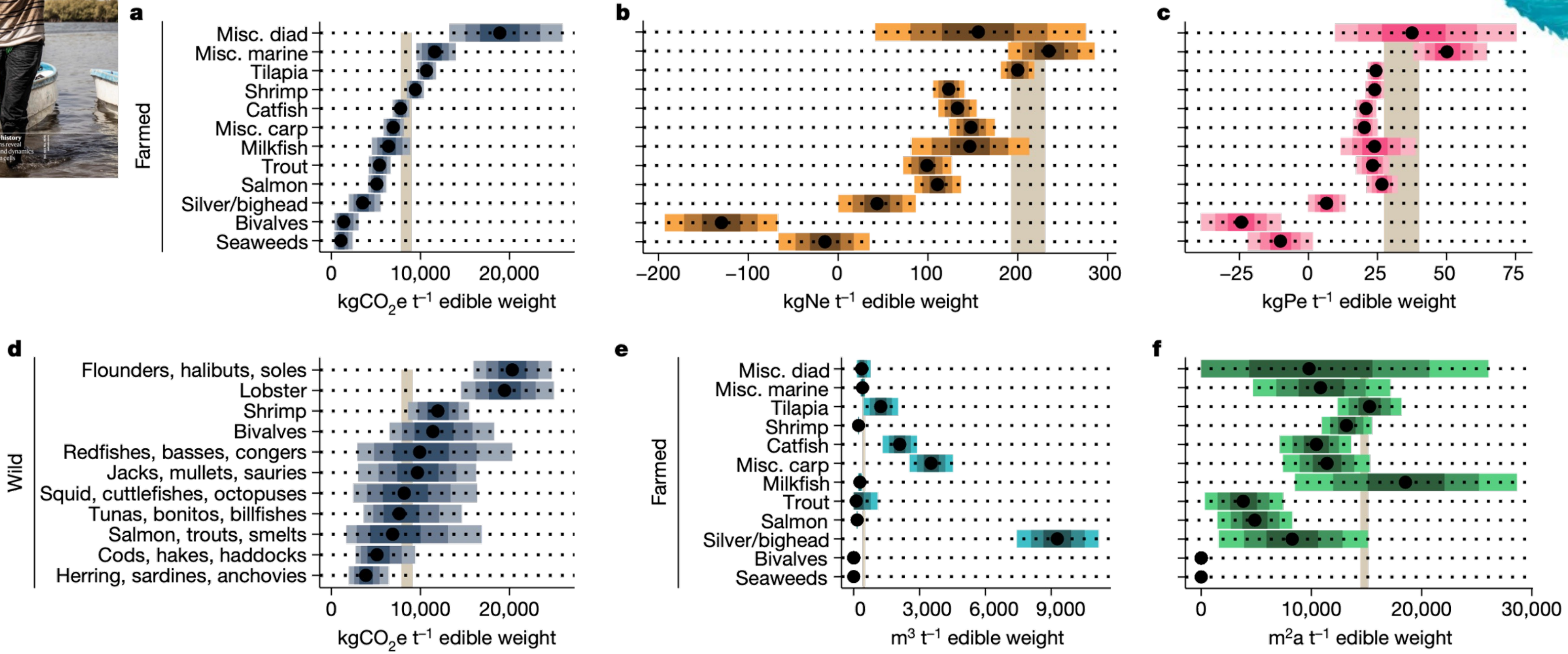
Environmental performance of blue foods



From: Gephart et al. 2021

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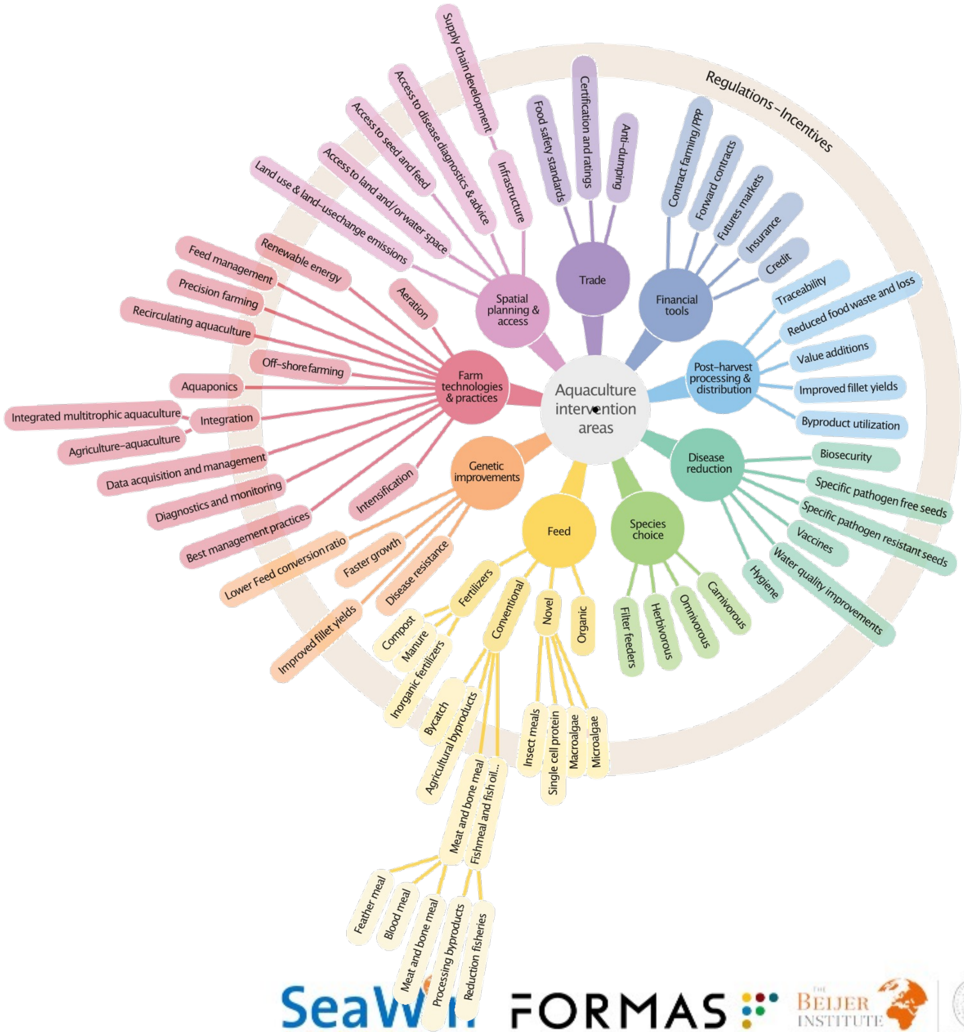

From: Henriksson et al. 2021

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Species choice

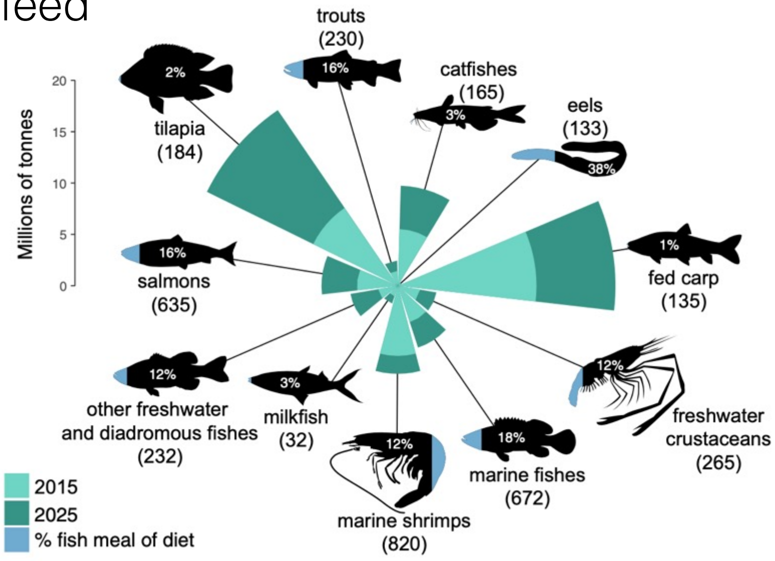
Species choice

Physiology

- Carnivorous species need higher quality feed resources
- Edible part varies by species and culture
- Tolerance to disease, oxygen levels, water quality, etc.

Consumers are selective

- Desire bone-free portion sized fillets
- Bivalves have limited acceptance
- Macroalgae only consumed in limited quantities, e.g. Misu soup, sushi, etc.



From: Hua et al. 2019

Feeds

Feeds

- Feeds often make up over 90% of environmental impacts
- Many feed resources result in deforestation, e.g. soybeans from Brazil
- Many resouces compete with food availability, e.g. fishmeal, maize, and wheat
- Novel ingredients are many, but volumes limited and prices high
  - Fish byproduct meals
  - Insect meals
  - Microbes
  - Etc.

		Protein content	Environmental sustainability	Consumer acceptance	Feasibility
Fishery and aqua-culture by-products		+	+	+	+
Insect meals		+	+	+	+
Microbial biomass	Bacteria and dry bio-floc	+	+	+	−
	Yeast	+	+	+	−
	Microalgae	+	+	+	−
Macroalgae		−	+	+	+
Food wastes		−	+	−	−

From: Hua et al. 2019

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Farm technologies and practices

Farm technologies and practices

Ponds

- Require land
- Risk for spread of disease

Net pens in lakes or the ocean

- Release of eutrophying agents.
- Risk for spread of disease and escapees

Recirculating aquaculture systems (RAS)

- Expensive to establish and operate
- Energy intensive

Off-shore

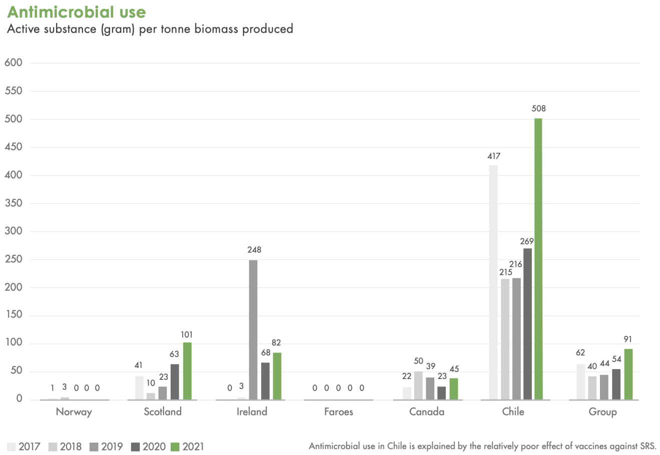
- Expensive
- Reliant on high quality feed resources

Spatial planning & access

Disease reduction

Spatial planning & Access & Disease reduction

- Consequences related to land use and land-use change
- Consider carrying capacities
- Access to optimal farming locations
- Limit spread of disease
- Biosecurity



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Genetic improvements

Genetic improvements

- Only 10% of global aquaculture improved via selective breeding programs
- Large potential to improve yields and increase disease resistance.
- Hard to select for more than one trait
- Trade-off between species diversity and investments in genetic improvement programs

From: Henriksson et al. 2021

Table 1. Potential genetic gains from selective breeding of a selection of aquatic species

Trait	Genetic gain per generation	Order, family, genus, or genus and species
Appearance[69]	4%–46%	*Mytilus galloprovincialis*
Growth rate[69]	12.7% (2.3%–42%)	*Oreochromis*, Cyprinidae, Salmonidae, Perciformes, Siluriformes, Penaeidae, Palaemonidae, Astacoidea, Bivalvia
Disease resistance[69]	6.3%–19%	*Oreochromis*, Salmonidae, *Litopenaeus vannamei*, Palaemonidae,
Reproductivity[69]	3.3%–11.7%	*Oreochromis*, Siluriformes, Salmonidae
Edible yield[69,73]	0.15%–1.7%	*Oreochromis*, Bivalvia

Post-harvest processing and distribution

Value-addition

- Can increase acceptance for many species
- Can increase the edible yield
- Makes seafood more accessible to consumers
- Improved expiry dates

Reduce food waste

- FAO estimates that 35% of all seafood is not consumed
- In the U.S., food loss and waste can be up to 50%


Gäddnigiri toppad med shisokrasse och rostad purjolök, svartmunnad smörbult med tångkaviar och friterad vitmossa, maki på mört med morot, vårlök och dill.

Trade

Financial tools

Regulation, Trade & Financial tools

Trade

- Certification standards only cover a small portion of global aquaculture
- Traceability, 30% of traded seafood is mislabelled
- Blockchain and DNA barcoding

Financial tools

- Smallholder farmers can often not benefit from improved seed, feed, and diagnostics
- Insurance and cooperatives

Regulations

- Drafting efficient public regulations is difficultly and needs to be enforced

Conclusions

- Blue foods have variable environmental footprints, but still suffer from large performance gaps
- Freshwater finfish aquaculture will most likely continue to dominate global production, but has had limited gains from improvement interventions
- Focusing on a few species might result in larger advancements in the short-term, but will erode the sector's resilience in the long-term

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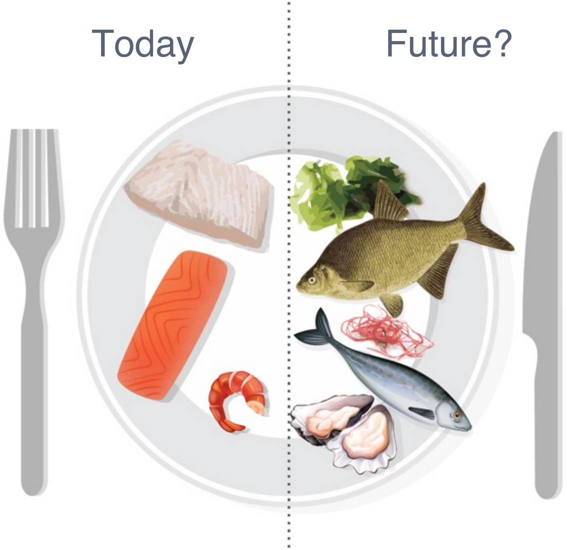
Thank you! Questions?



More material:

https://www.seawin.earth/
https://bluefood.earth/

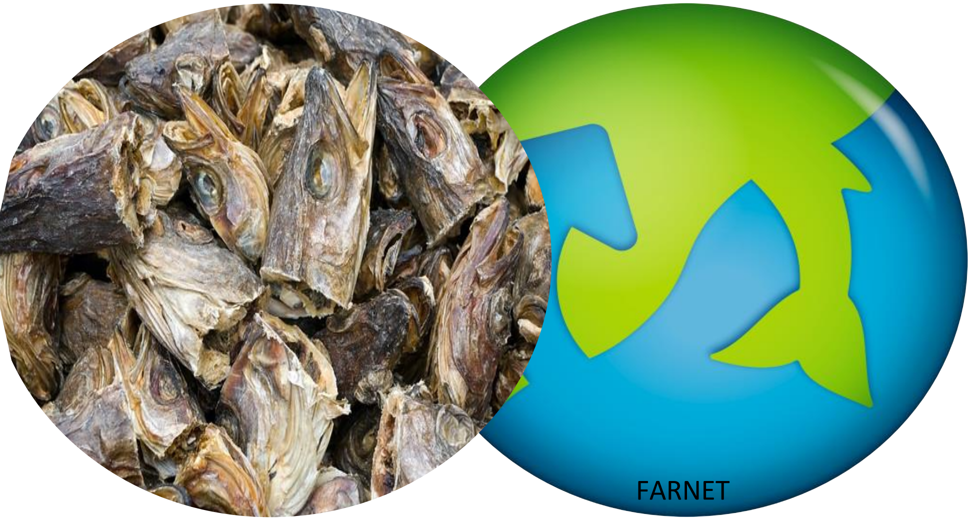
https://doi.org/10.1016/j.oneear.2021.08.009
https://www.nature.com/articles/s41586-021-04331-3

Patrik Henriksson email: patrik.henriksson@beijer.kva.se

Circularity in aquaculture – the role of LCA –

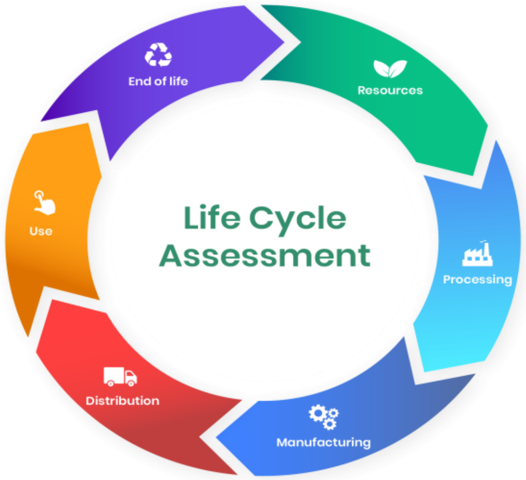
Killian Chary

Aquaculture and Fisheries group, Department of Animal Sciences, Wageningen University & Research



- SIMTAP workshop –

- 05/12/22 -



Introduction and context

- Food production is the main drive causing environmental change

- Circular economy (CE) as a tool for more sustainability

- A package of concepts originating from industrial ecology

- Recently adapted for systems that rely on biomass (food, energy, etc.)


nature food
PERSPECTIVE
https://doi.org/10.1038/s43016-021-00340-7
Check for updates

Principles, drivers and opportunities of a circular bioeconomy

Abigail Muscat[1], Evelien M. de Olde[1], Raimon Ripoll-Bosch[1], Hannah H. E. Van Zanten[2], Tamara A. P. Metze[3], Catrien J. A. M. Termeer[3], Martin K. van Ittersum[4] and Imke J. M. de Boer[1]

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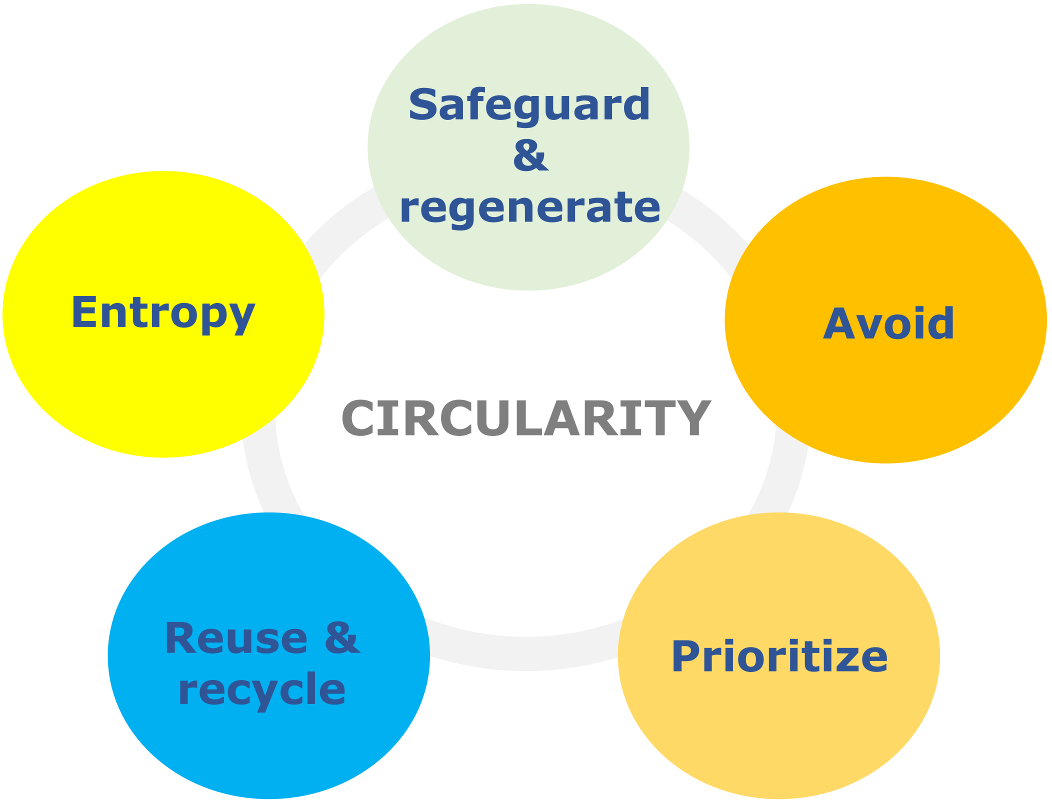
Objectives of the presentation



Adapted from Muscat et al. 2021

1. Presentation of the principles applied to aquaculture

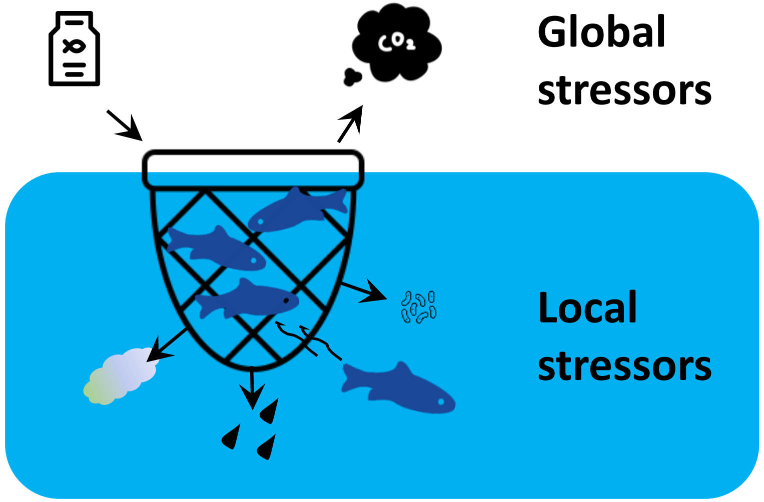
2. LCA developments to further implement circularity principles

Circularity principles in aquaculture

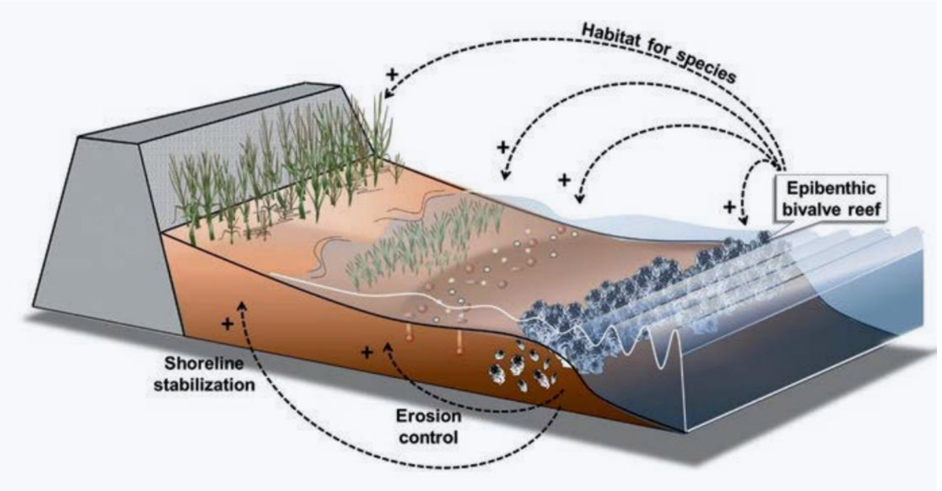
Killian, Chary, Anne-Jo van Riel, Ramon Filgueira, Aurélie Wilfart, Souhil Harchaoui, Abigail Muscat, Marc Verdegem, Max Troell, Patrik Henriksson, Imke de Boer, Geert Wiegertjes

P1: Safeguarding and regenerating the health of aquaecosystems

- Manage aquaculture in the context of ecosystem(s) **carrying capacities**
  - Local ecosystems
  - Distant (global) ecosystems



- Practices/systems that
  - enhance **ecosystem services** (e.g. extractive species.)
  - improve **resilience** (e.g. robust species)
  - preserve **biodiversity** (e.g. ponds)



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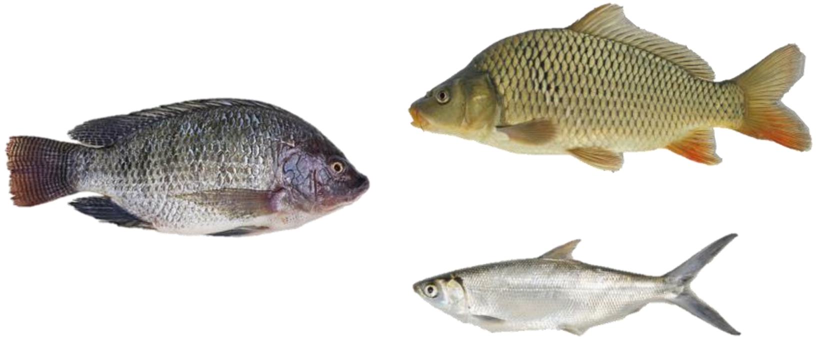
P2: Avoiding the production of non-essential products

- Focus on most essential species (and avoid others)

  - **Nutrient richness and health benefits**
    - (Proteins)
    - PUFAs
    - Micronutrients

  - **Food security**
    - Low-cost products
    - Large volumes
    - Nutrient-scarce regions



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P2: Avoiding the waste of essential ones

- Reduce losses and waste
  - Reduce **mortality** at farm scale
  - Avoid **contamination** at other stages

Farm
- Harvest and handling
- Misuse of veterinary drugs
- Mortality
- Escapes

Processing and storage
- Poor processing methods & equipments
- Delays in processing
- Poor hygiene conditions
- Cold chain

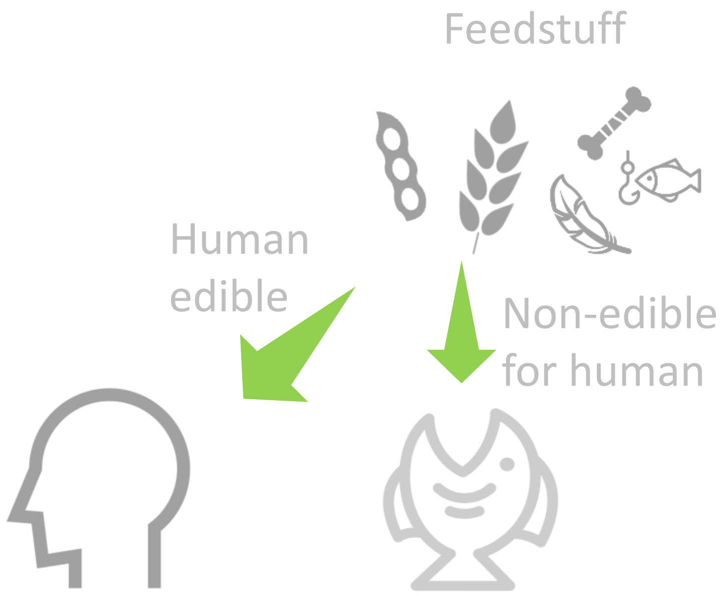
Wholesale and Retail
- Lack of buyers
- Damage to packaging
- Delays in selling
- Error in labelling

Consumption
- Consumer confusion
- Overbuying
- Discards

Waste treatment
- Absence or inadequate collect of waste

P3: Prioritizing biomass streams for basic human needs

- Limited resources: Lands, freshwater, fossil energy
- Hierarchy of use: Food > Feed > Industry > Energy
- Avoid **direct feed-food competition**
  - Do not use human edible feedstuff in aquafeeds
    - E.g. maize, wheat, whole fish (FM/FO)
  - Use non-food competing feedstuff
    - E.g. Insects, food waste, microbial biomass, etc.



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P3: Prioritizing biomass streams for basic human needs

- Avoid **indirect feed-food competition**
  - Use resources to produce food and not feed
  - Allocate resources to the most efficient food production systems (planning)

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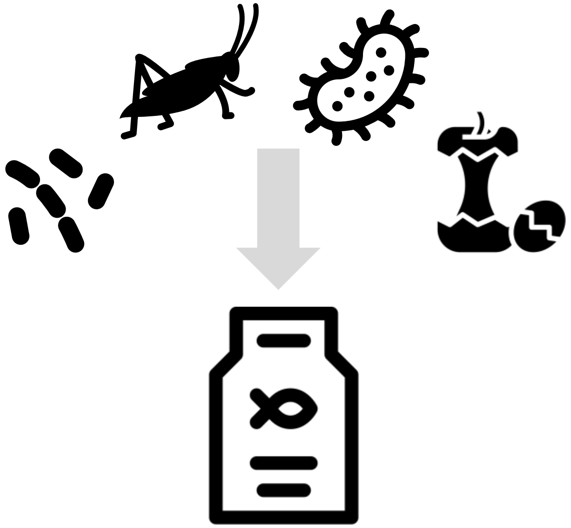
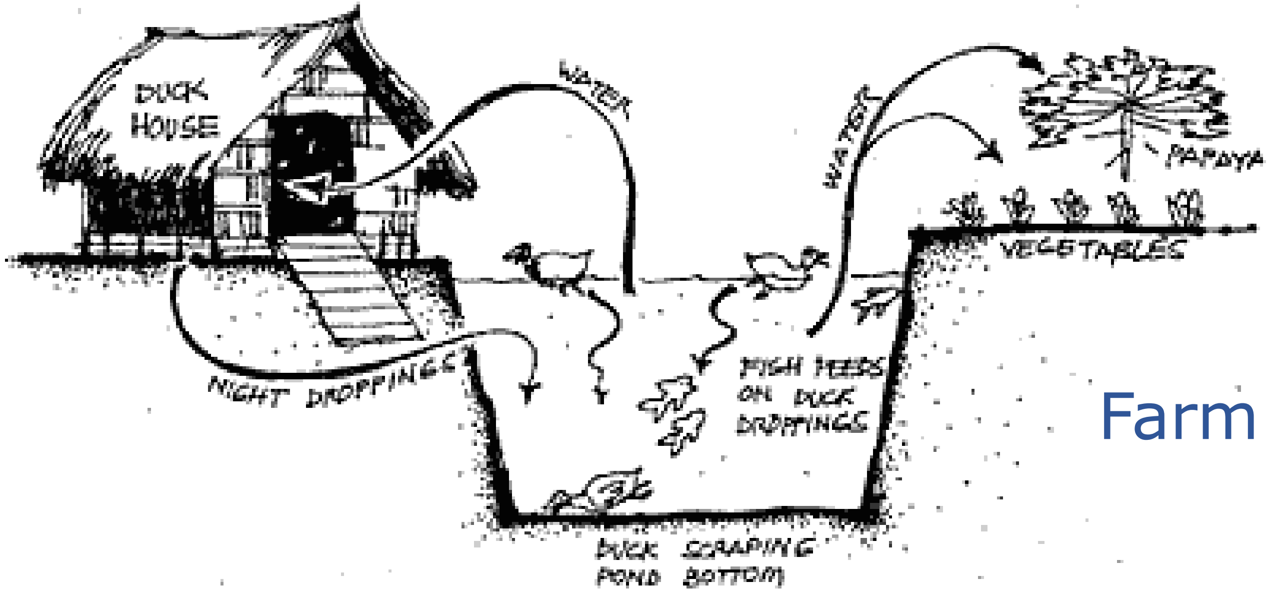
P4: Recycling by-products of agro and aquaecosystems

- Use **aquaculture systems as a sink**:
  - Feed based on leftovers
  - Integrated production systems



Feed stage



Farm stage

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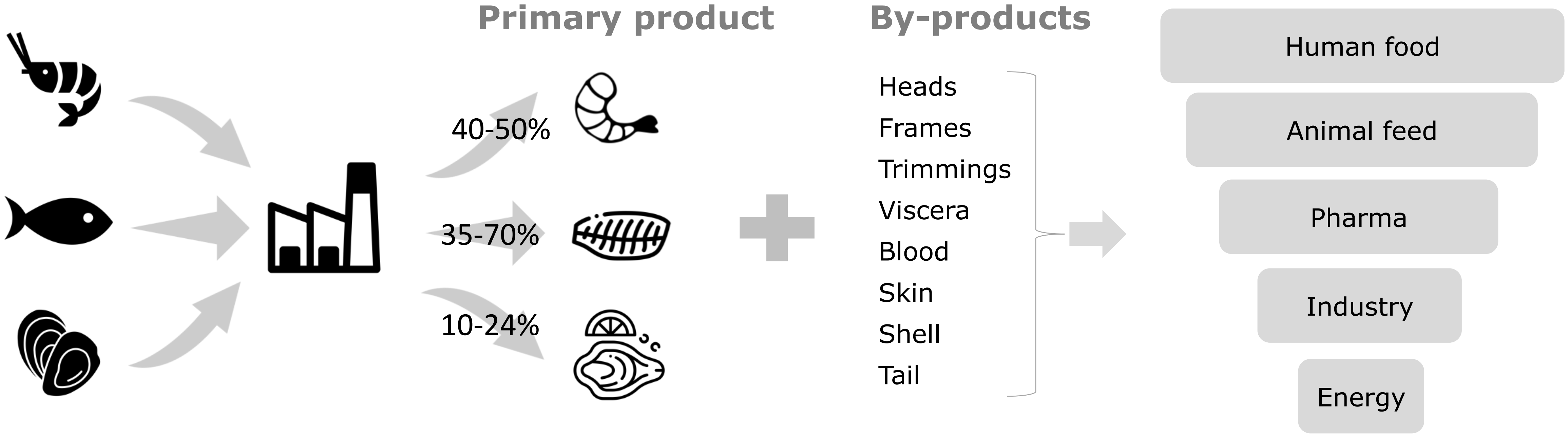
P4: Recycling by-products of agro and aquaecosystems

- **Recycle** aquaculture **by-products**:
  - Processing by-products
  - Use food recovery hierarchy



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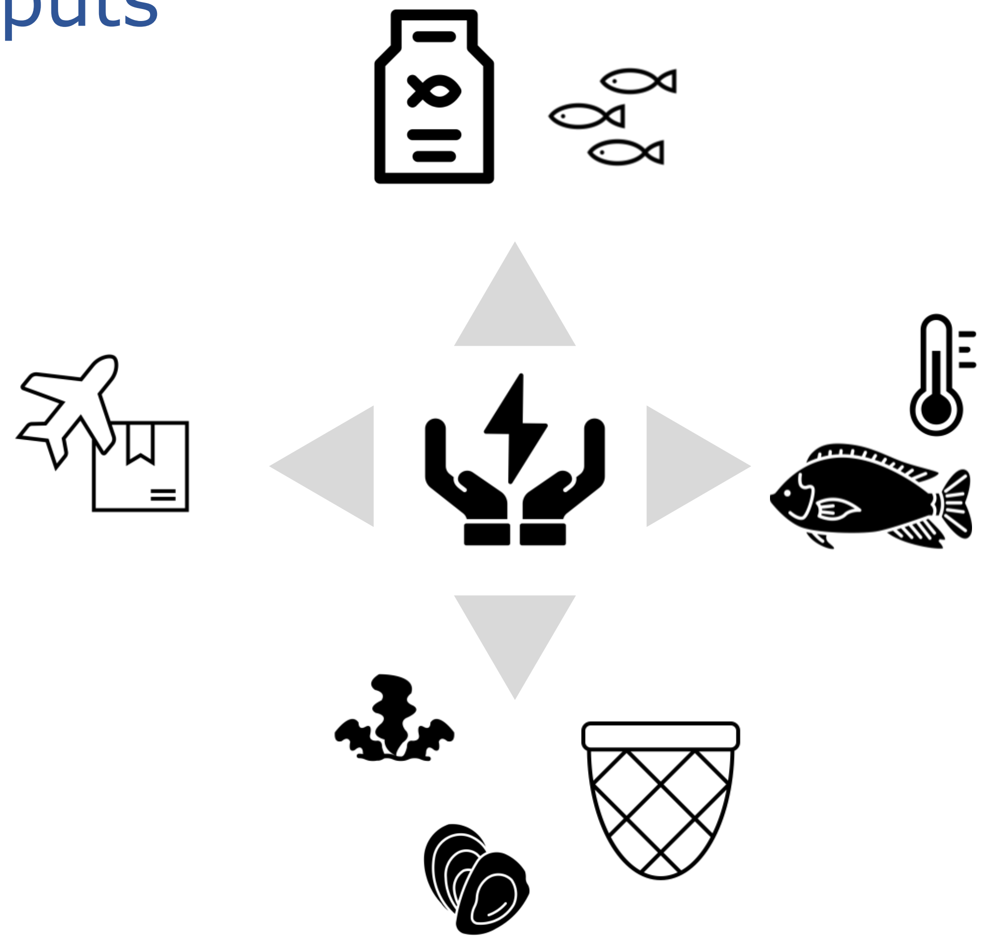
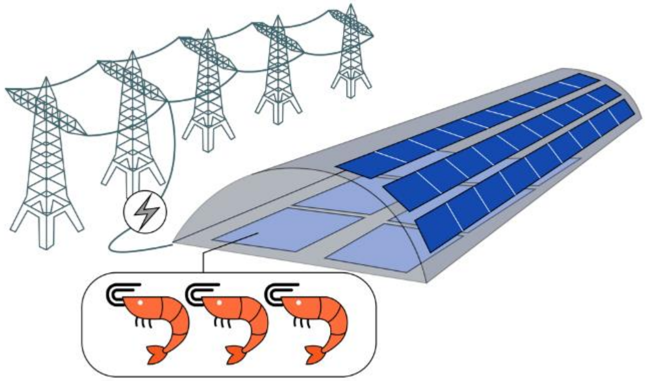
P5: Minimizing overall energy use

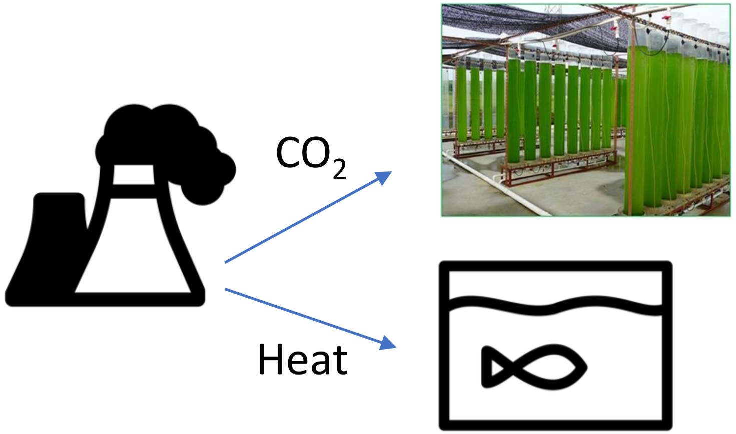
- Efficient use of energy-intensive inputs
- Avoid energy-intensive processes
- Energy efficient species
- Energy efficient systems
- Location vs species requirements



P5: Using (efficiently) renewables and low-carbon energy



- Better use of solar energy
  - Aquavoltaics
  - Polyculture
  - Integrated systems
- Eco-industrial symbiosis and dual use:
  - Multi-use platform
  - Waste heat from industries



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LCA developments to support circularity principles

Circular economy and LCA literature

The International Journal of Life Cycle Assessment (2021) 26:215–220
https://doi.org/10.1007/s11367-020-01856-z
LIFE CYCLE SUSTAINABILITY ASSESSMENT

Check for updates

Using life cycle assessment to achieve a circular economy

Claudia Peña[1] · Bárbara Civit[2] · Alejandro Gallego-Schmid[3] · Angela Druckman[4] · Armando Caldeira- Pires[5] · Bo Weidema[6] · Eric Mieras[7] · Feng Wang[8] · Jim Fava[9] · Llorenç Milà i Canals[8] · Mauro Cordella[10] · Peter Arbuckle[11] · Sonia Valdivia[12] · Sophie Fallaha[13] · Wladmir Motta[14]

Contents lists available at ScienceDirect
Sustainable Production and Consumption
ELSEVIER
journal homepage: www.elsevier.com/locate/spc

Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy.

Steve Harris[a,*], Michael Martin[a,b], Derek Diener[c]

The International Journal of Life Cycle Assessment
https://doi.org/10.1007/s11367-020-01810-z
LCI METHODOLOGY AND DATABASES

Check for updates

Is mainstream LCA linear?

Reinout Heijungs[1,2]

Int J Life Cycle Assess (2017) 22:832–837
DOI 10.1007/s11367-017-1267-1
CrossMark
CONFERENCE REPORT

How can LCA support the circular economy?—63rd discussion forum on life cycle assessment, Zurich, Switzerland, November 30, 2016

Melanie Haupt[1] · Mischa Zschokke[2]

sustainability
MDPI

Review

Sustainable Agri-Food Processes and Circular Economy Pathways in a Life Cycle Perspective: State of the Art of Applicative Research

Teodora Stillitano, Emanuele Spada, Nathalie Iofrida *, Giacomo Falcone and Anna Irene De Luca

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A suitable method to assess performances of CE strategies

- Quantification of emissions, material losses, use of natural resources

- Compare env. performances of different end-of-life options

- Identify environmental trade-offs between impacts (particularly with energy)

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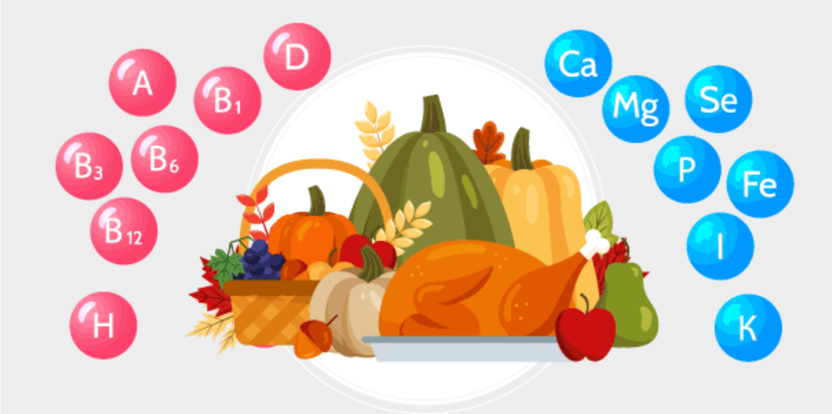
Support selection of most essential foods

- Env. performances are generally calculated per **kg of (edible) protein** (or ton wet weight)

- **PUFAs and micronutrients** content make aquatic food essentials (compared to other ASF)

- Toward **nutritional LCAs** (McLaren et al. 2021)
  - Alternative functional units
  - Weight nutrients based on availability
  - Other solutions



Incorporate feed-food competition issues

- Results expressed per **gross** unit (not net) of food/nutrients produced

- Animals are not necessarily **net producers of nutrients** (FCR, feed composition, edible yields, etc.)

- Env. impacts per **net unit of food produced**
  - Allocation methods?
  - New impact categories?
  - Functional unit?

Assessing performances at broader scale

- Impacts are often calculated from **cradle to farm** gate, = performances at farm-scale
- Some CE strategies can imply alternative land uses
- In this case, env. performances should be evaluated at a broader scale, e.g. **at territory scale**
- Territorial LCAs ? (Loiseau et al. 2018)

Conclusion

- LCA can help implementing circularity principles
- Other tools should be used and combined with LCA
- Methodological developments needed
- More complete view of env. erformance of aquatic foods

Thank you!

Contact information

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References

- Loiseau, E., Aissani, L., Le Féon, S., Laurent, F., Cerceau, J., Sala, S., and Roux, P. 2018. Territorial Life Cycle Assessment (LCA): What exactly is it about? A proposal towards using a common terminology and a research agenda. Journal of Cleaner Production, 176: 474–485.
- McLaren, S., Berardy, A., Henderson, A., Holden, N., Huppertz, T., Jolliet, O., De Camillis, C., *et al.* 2021. Integration of environment and nutrition in life cycle assessment of food items: opportunities and challenges. Rome. 161 pp. https://www.fao.org/documents/card/en/c/cb8054en/.
- Muscat, A., de Olde, E. M., Ripoll-Bosch, R., Van Zanten, H. H. E., Metze, T. A. P., Termeer, C. J. A. M., van Ittersum, M. K., *et al.* 2021. Principles, drivers and opportunities of a circular bioeconomy. Nature Food 2021 2:8, 2: 561–566. Nature Publishing Group. https://www.nature.com/articles/s43016-021-00340-7.

Department of Agriculture, Food and Environment
University of Pisa
180 Anniversary 1840-2020

Workshop “Life Cycle Schedule Assessment in aquaculture”
Milan, 5th December 2022

“The SIMTAP project”

Alberto Pardossi - University of Pisa

[*alberto.pardossi@unipi.it*]

The PRIMA programme is supported under Horizon 2020, the European Union’s Framework Programme for Research and Innovation

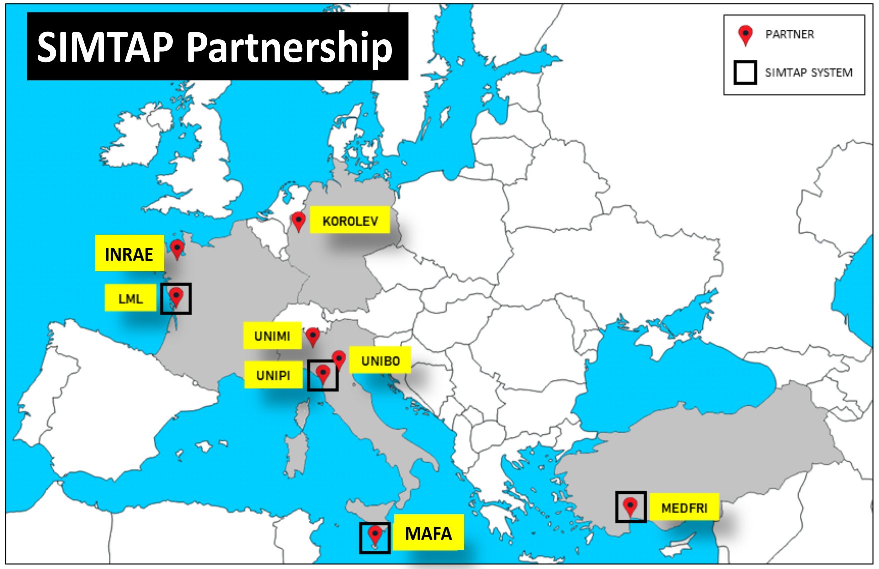
European Commission

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

SIMTAP: Self-sufficient Integrated Multi-Trophic AquaPonic systems for improving food production sustainability and brackish water use and recycling.

The partnership

1. **UNIPI**: University of Pisa (ITALY); PI/TL: Alberto Pardossi and Carlo Bibbiani.
2. **UNIBO**: University of Bologna (ITALY), TL: Daniele Torreggiani.
3. **UNIMI**: Università di Milano (ITALY); TL: Jacopo Bacenetti.
4. **INRAE**: INRAE-Agrocampus, SAS Sol Agro et hydrosystème Spatialisation, Rennes (FRANCE); TL: Joel Aubin.
5. **LML**: Lycée de la Mer et du Littoral, Bourcefranc le Chapus (FRANCE); TL:. Vincent Gayet.
6. **MEDFRI**: Mediterranean Fisheries Research Production and Training Institute, Antalya (TURKEY); TL: Mehmet Ali Turan Koçer.
7. **MAFA**: Ministry for Agriculture, Fisheries and Animal Rights, Agriculture Directorate Marsa (MALTA); TL: Iman Busuttil.
8. **KOROLEV**: Korolev GmbH, Bonn (GERMANY); TL: Rainer Linke.



www.simtap.eu

SIMTAP project: goals and workplan.

Main goals:

- to assess the performance of four SIMTAP prototypes built in France, Italy, Turkey, and Malta
- to identify the main drawbacks and obstacles to the application of the SIMTAP concept to saltwater aquaponics
- to assess the sustainability of SIMTAP through LCA, LCC, EA etc.

Kickoff: 1 June 2019
Expected end: 31 May 2022 (M36)
Extended end: 31 May 2023 (M48)

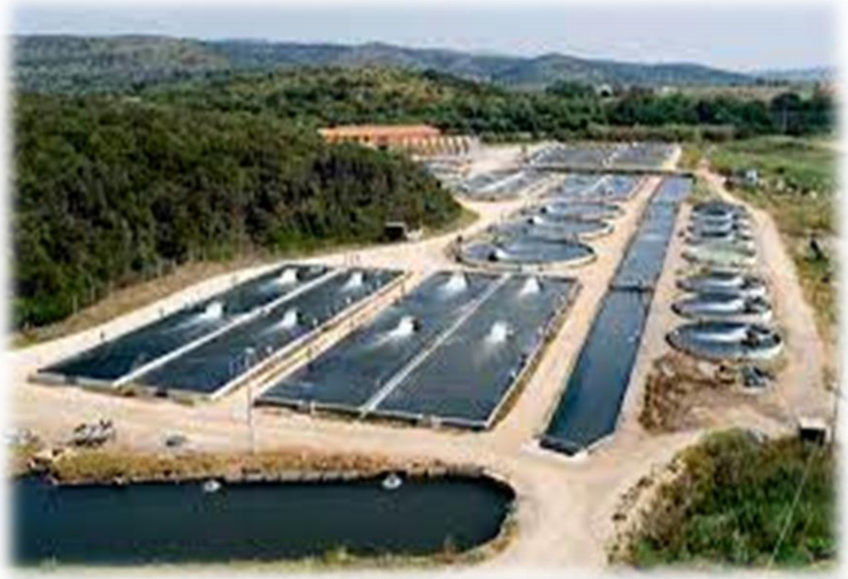
Workpackages:

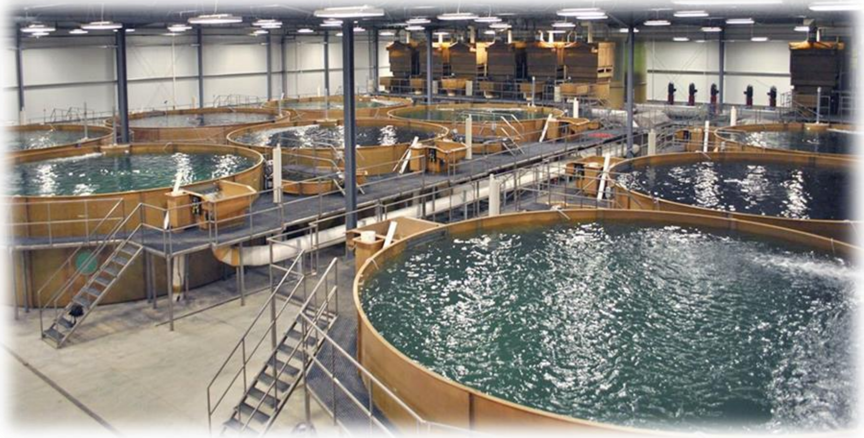
WP No	WP title	WP leader
0	SIMTAP coordination and management	UNIPI
1	Ecosystem based approach for SIMTAP	UNIPI
2	Implementation and test of SIMTAP	MEDFRI
3	Integration of SIMTAP in current hydroponic systems to enhance market transferability and sustainability	UNIBO
4	Assessing the quality of the food end-products	UNIPI
5	Economic and environmental sustainability assessment	INRAE
6	SIMTAP recommendations and guidelines	UNIMI
7	Communication, dissemination and exploitation	UNIBO

SIMTAP: expected benefits.

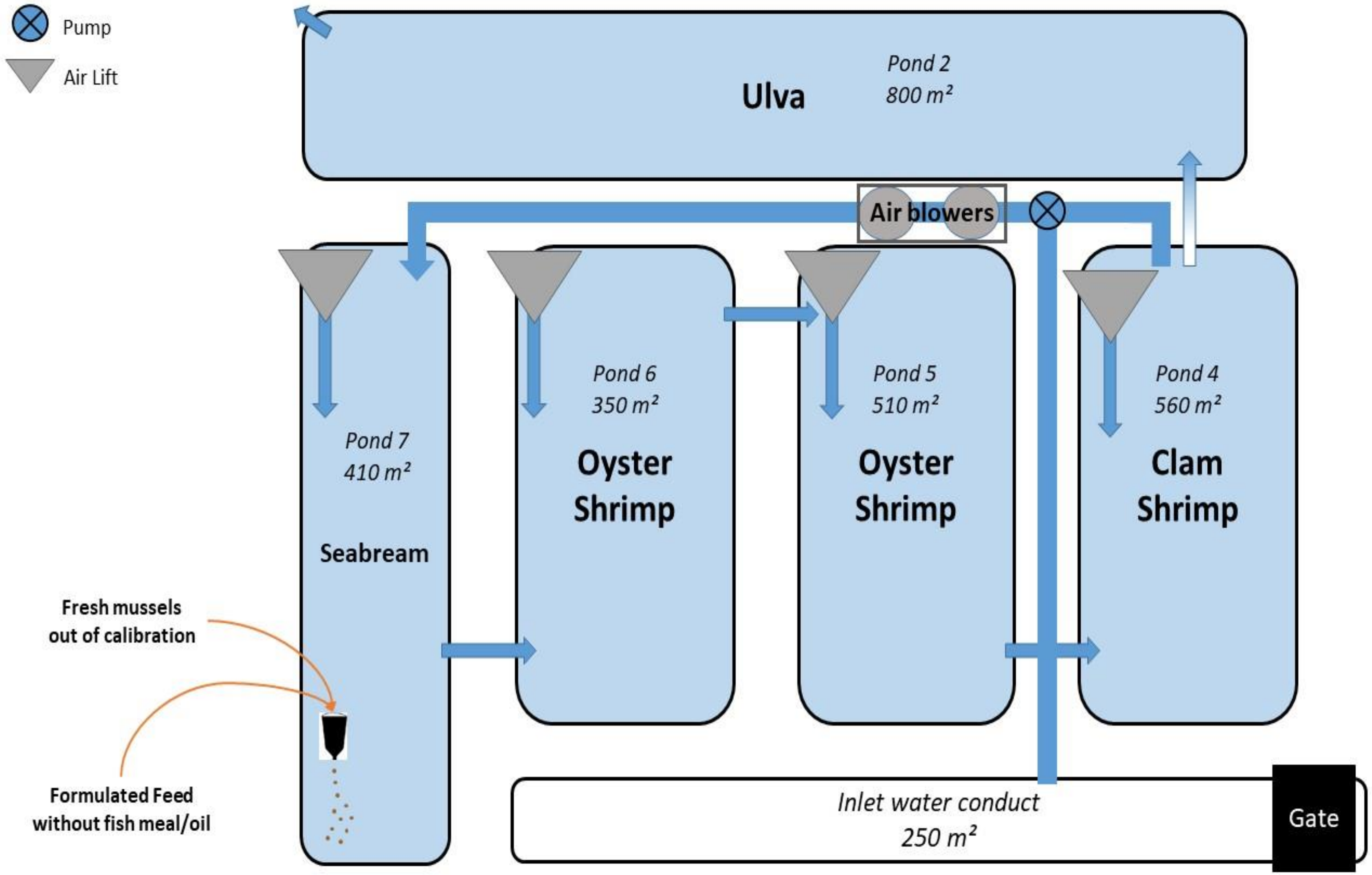
- ❑ Lower use of commercial fish feed based on fish meal and fish oil in land-based aquaculture
- ❑ Reduced water use and contamination
- ❑ Re-use of greenhouse effluents.

versus





SIMTAP in France



RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

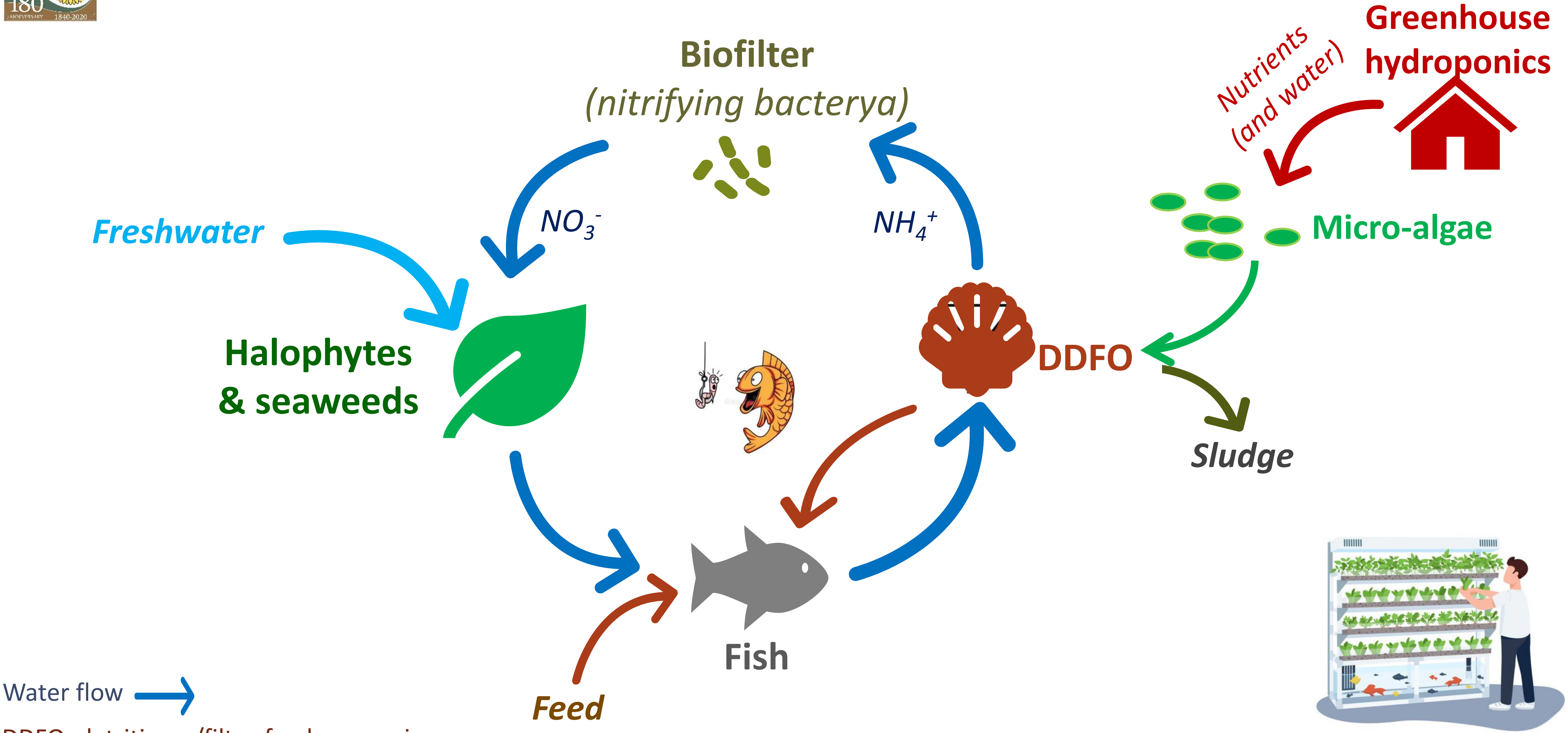
INRAE

Lycée de la mer et du littoral
BOURCEFRANC LE CHAPUS

SIMTAP

SIMTAP in France

SIMTAP in Italy



DDFO: detritivore/filter-feeder organisms

SIMTAP in Italy

Sections:

A: fish (2.5 m^3; 3.5 m^2)

B: DFFO (4.0 m^3; 9.0 m^2)

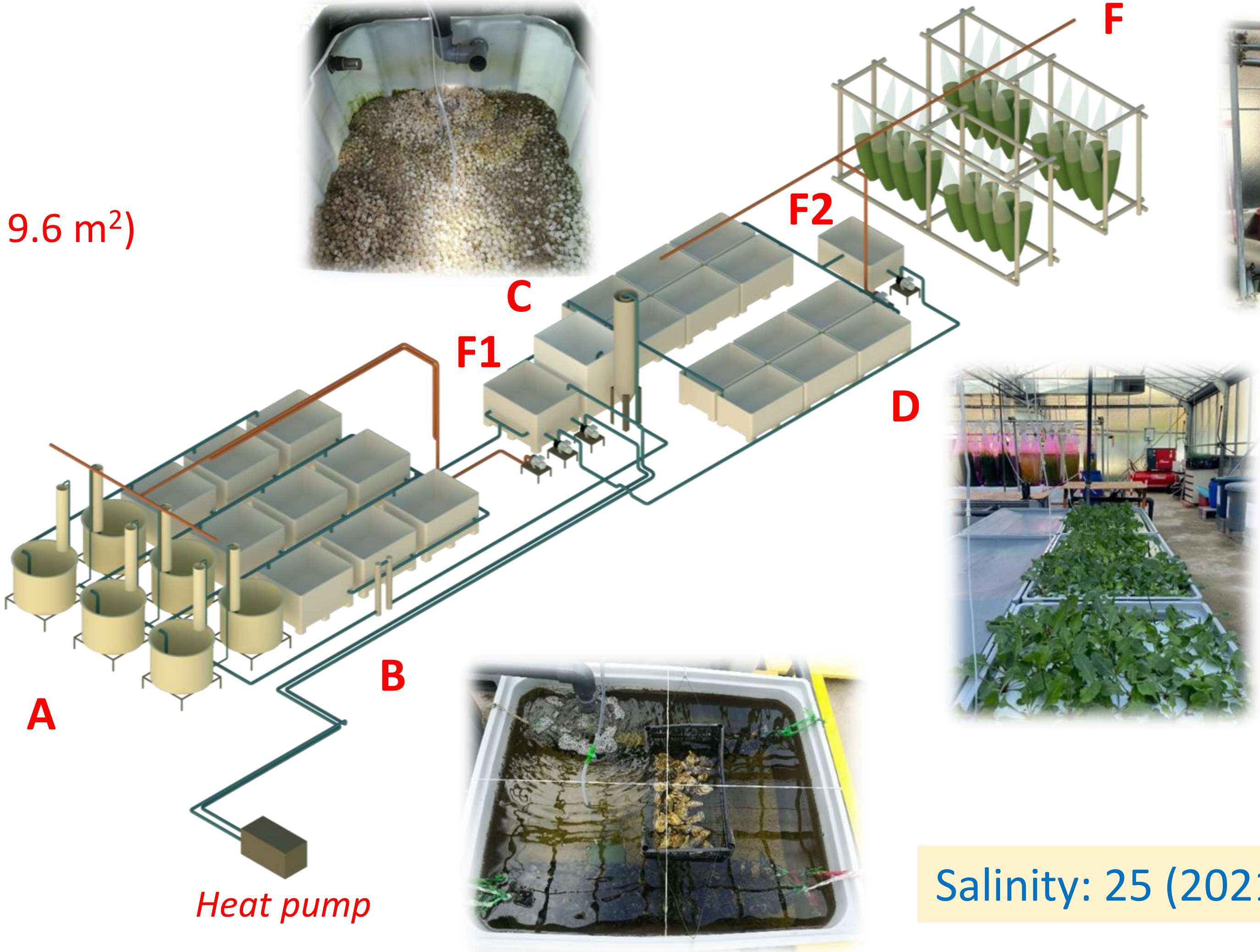
C: biofilter (0.5 m^3)

D: halophytes & seaweeds (4.5 m^3 ; 9.6 m^2)

F: sumps (0.5 m^3)

G: (100-L) photobioreactors

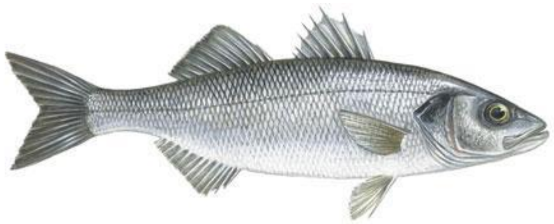
A+B+C+D+E: 12.5 m^3; 22.1 m^2)



Salinity: 25 (2021) or 10 (2022) ppt

SIMTAP: Fish & crops.

European sea bass
(*Dicentrachus labrax*)



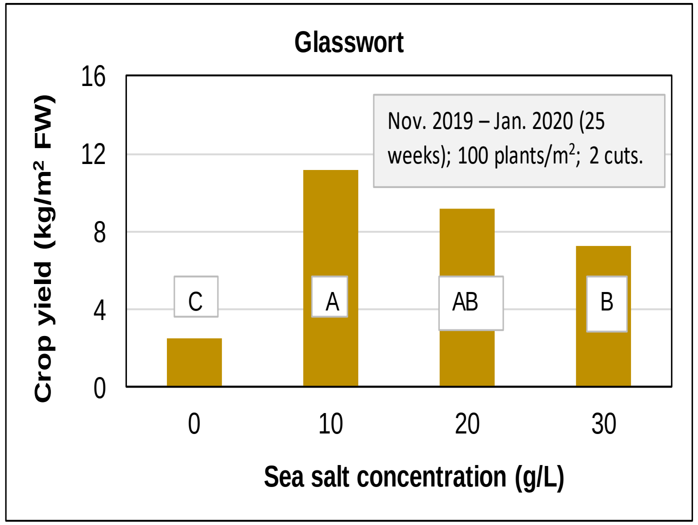
Gilthead seabream
(*Sparus aurata*)

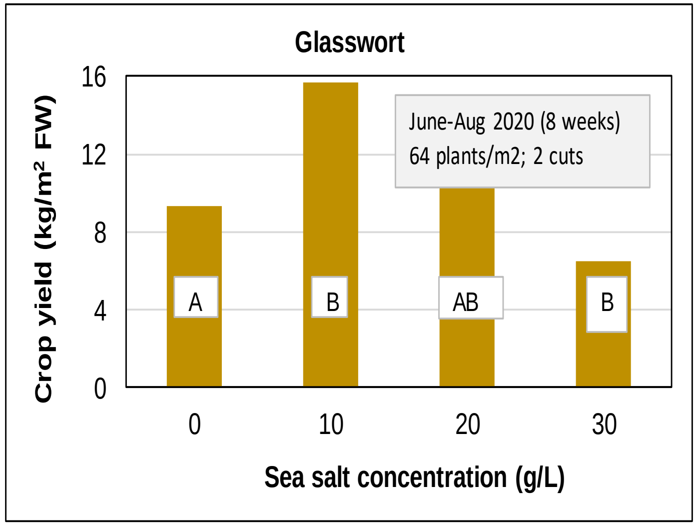
15.00 €/kg

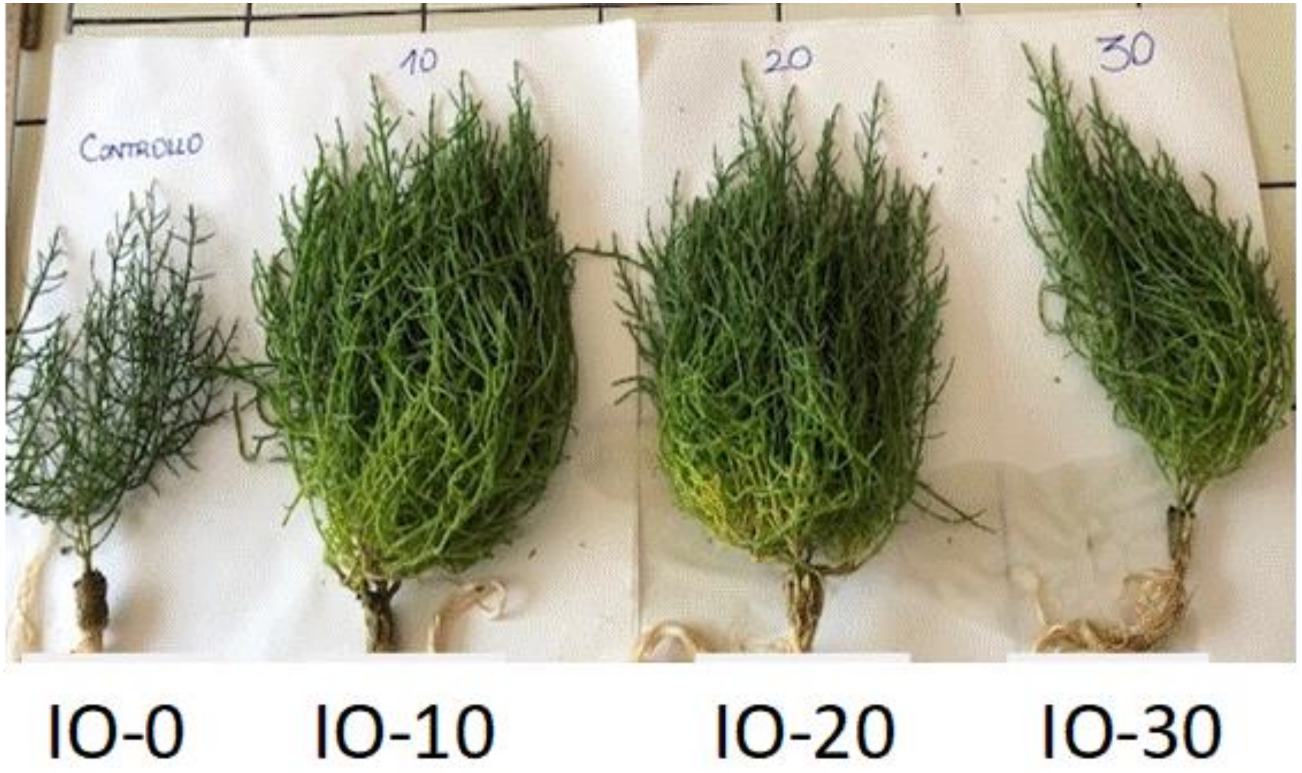
9.90 €/kg

Salicornia europaea L.

SIMTAP crop plants: *Salicornia europaea*.

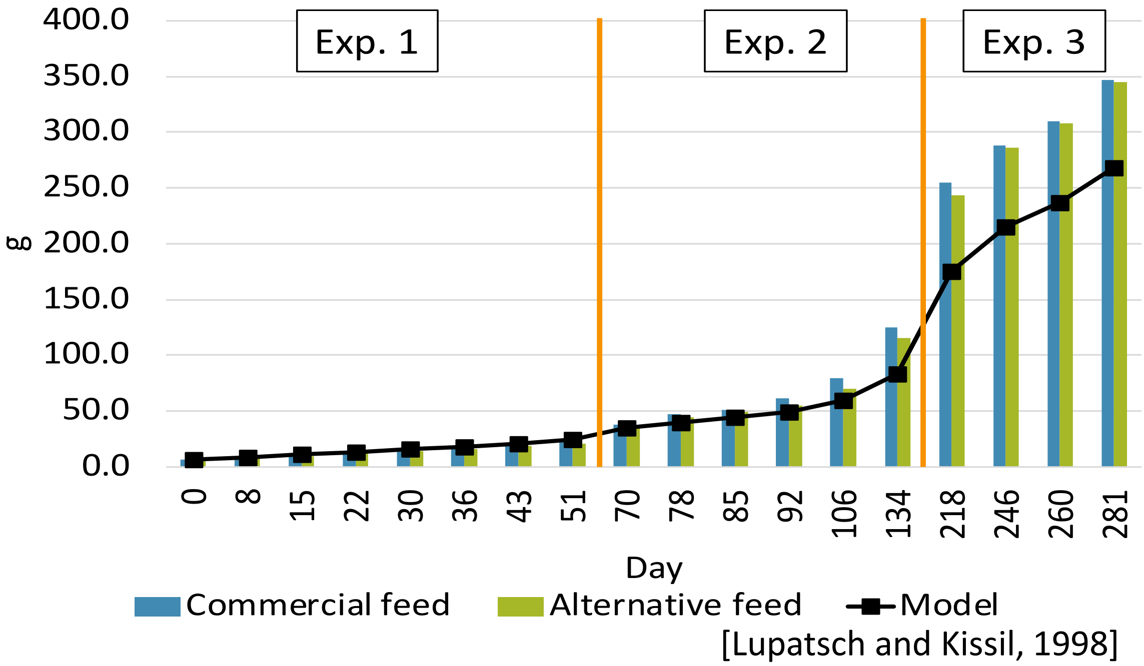






Crop yield (fresh shoots) in *Salicornia europaea* (glasswort) in closed-loop hydroponic system under greenhouse in different seasons and with different concentration of synthetic sea salt Instant Ocean™ in the nutrient solution. Mean values (n=3) keyed by the same letter are not significantly different according to Tukey test ($p<0.05$).

Feeding experiments with Gilthead seabream (*Sparus aurata*) – Pisa, 2021



Experiment	Commercial feed [g]	Alternative feed [g]*	Rearing density [kg/m³]
Exp. 1	23.6 ± 0.4 (n=632)	20.8 ± 3.9 (n=615)	10.9
Exp. 2	125.2 ± 15.0 (n=161)	115.4 ± 12.6 (n=161)	15.2
Exp. 3	346.8 ± 41.0 (n=83)	344.4 ± 39.7 (n=128)	35.0

Initial weight [g]	Final weight [g]	Duration [days]	Weight gain [g/day]	System
6.8	**345.7**	**281**	**1.2**	**SIMTAP**
0.4	450.0	274	1.6	RAS[1]
2.4	474.6	420	1.1	Sea cages (Black sea) [2]
11.0	307.3	480	0.6	Sea cages (Tyrrenian sea) [3]

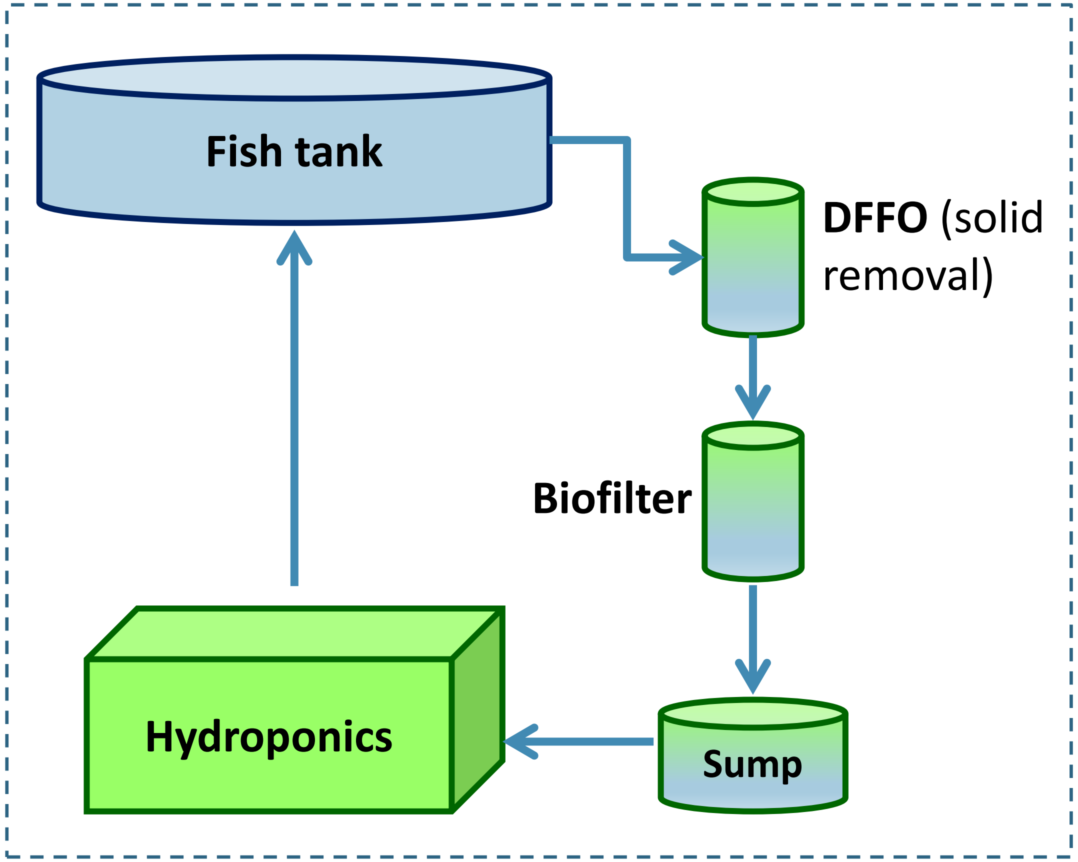
References: [1] Tal et al., 2009; [2] Kaya Öztürk et al., 2020; [3] Di Marco et al., 2017

SIMTAP: pros and cons.

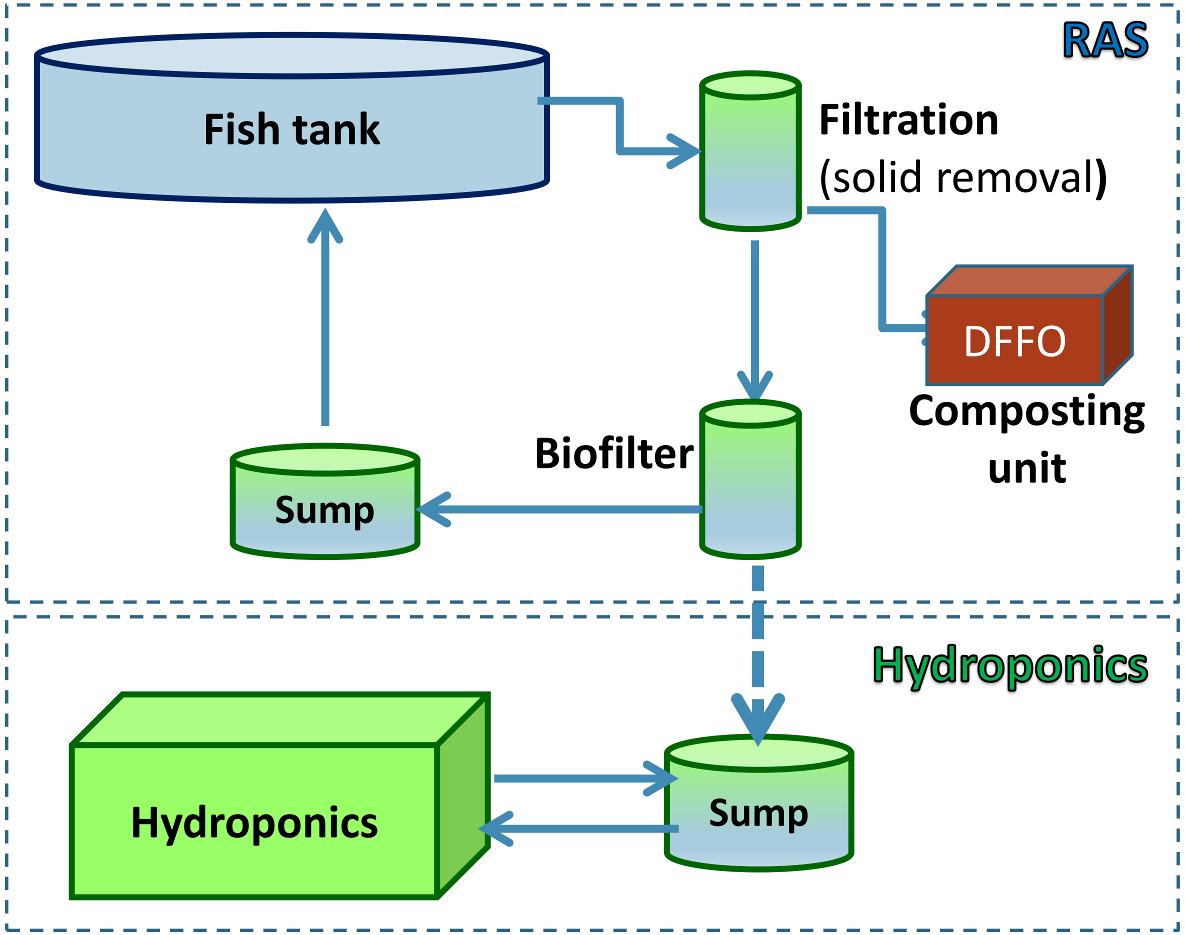
- ✓ Fish can reach market size in 10 months with alternative feed consisting of only DDFOs.
- ✓ Native polychaete worm *H. diversicolor* showed good adaptation to SIMTAP (25 ppt).
- ✓ Salicornia is a good candidate crop; it grows well and fast in spring-summer but much more slowly in winter.
- ✓ Culture of bivalves was unsuccessful.
- ✓ Lower water salinity (<5 ppt) increases the list of candidate crops but makes it more difficult the maintenance of high-quality water environment in a system without mechanical filtration.

Conclusions

Coupled SIMTAP



De-coupled SIMTAP



THANK YOU VERY MUCH

The PRIMA programme is supported under Horizon 2020, the European Union’s Framework Programme for Research and Innovation

INSECT FOR AQUAFEED

LAURA GASCO

UNIVERSITÀ DI TORINO

DISAFA
Università degli studi di Torino

SIMTAP

PRIMA
IN THE MEDITERRANEAN AREA

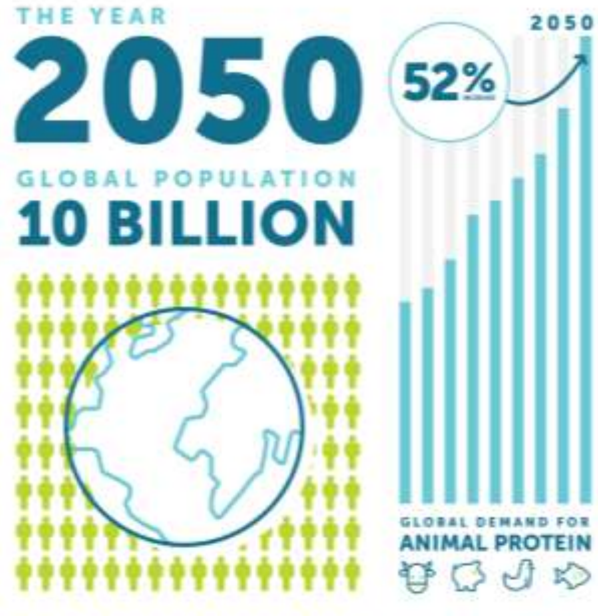
DiSAA
DIPARTIMENTO di SCIENZE AGRARIE e AMBIENTALI

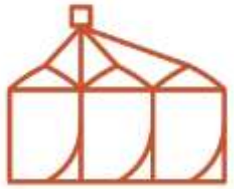
ASSOCIAZIONE RETE ITALIANA LCA

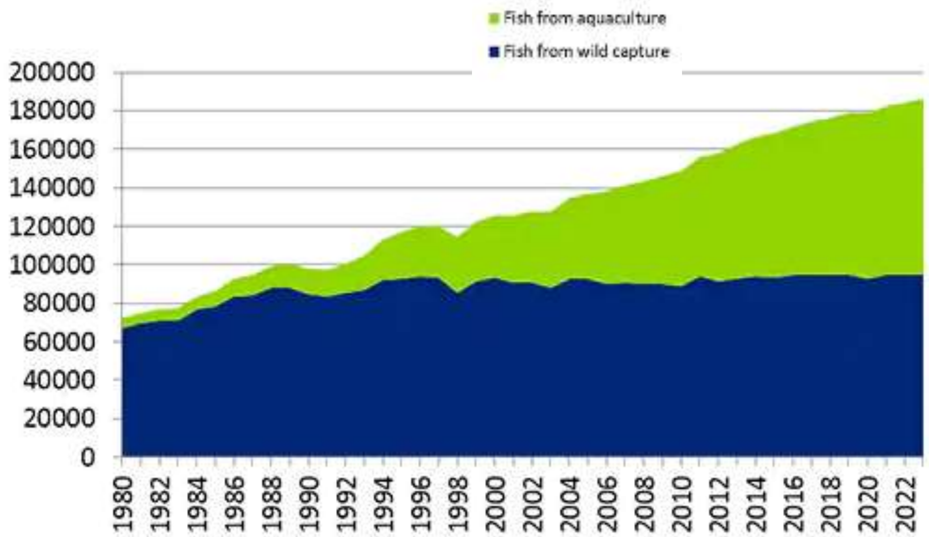
WHY AND HOW INSECTS?

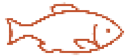
- Population, aquaculture growth & sustainable ingredients
- Nutritional value
- Bioconversion
- Impact
- Bioactive compounds
- Circular economy
- Aquafeed applications

POPULATION, AQUACULTURE GROWTH & SUSTAINABLE INGREDIENTS









51.4 mt

FEEDS

Ingredients (proteins) shortage

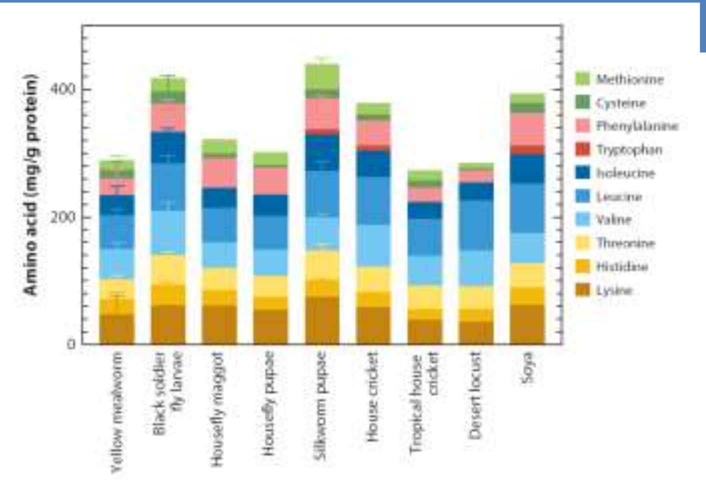
INSECTS

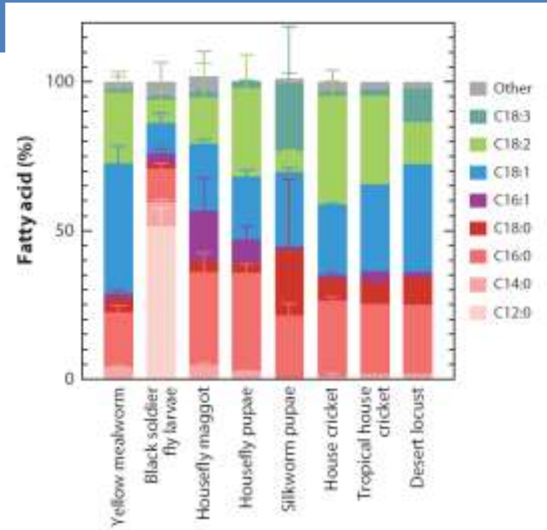
=

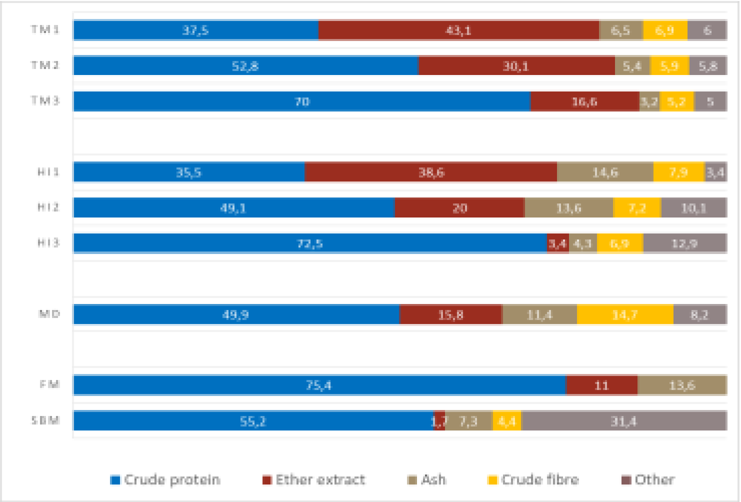
new & sustainable ingredients

NUTRITIONAL VALUE

- Proteins (EAA)
- Lipids (FA)
- Vitamins
- Minerals







- specie
- stage
- substrate
- process

Hawkey et al., 2021. Annu. Rev. Anim. Biosci. 9, 333-354

BIOCONVERSION

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Current Opinion in
Green and Sustainable Chemistry

From waste to feed: A review of recent knowledge on insects as producers of protein and fat for animal feeds

Laura Gasco[1], Irene Biancarosa[2,3] and Nina S. Liland[3]

IMPACT

- Low (no) water & soil use
- Low GHG emissions
- FCR
- Rapid growth
- Controlled mass production
- Natural diet

- T°
- Substrates

Resources, Conservation & Recycling 144 (2019) 285–296

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Sustainable use of *Hermetia illucens* insect biomass for feed and food: Attributional and consequential life cycle assessment

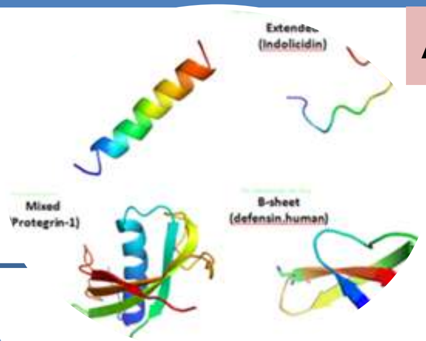
Sergiy Smetana[a], Eric Schmitt[b], Alexander Mathys[c,*]

Upscaling of insect production (improved efficiency of feed conversion and processing) reduced environmental impact making *H. illucens* biomass competitive to feed protein sources. Further application of non-utilized side-streams or alternative sources of energy for processing will result in a more beneficial source of proteins than most known alternatives. However, the availability of non-utilized side-streams, usable for the insect production is a key factor which would determine the further development of the insect industry. The environmental impact of insect production additionally would depend on substitution of non-utilized biomass treatment, alternative utilization options and their geographic distribution. The consequential LCA indicated that transforming organic residuals into *H. illucens* biomass could result in lower environmental impacts if composting or anaerobic digestion (as a waste treatment technology) is avoided.

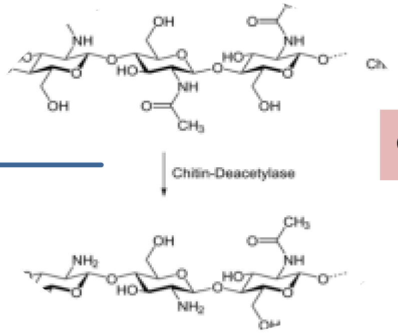
non-utilized side-streams = key factor

legislation

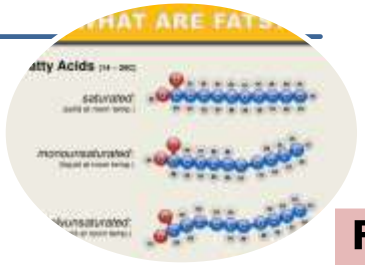
BIOACTIVE COMPOUNDS



AMP



Chitin



Fatty acids

Bioactive compounds

- antimicrobial effects
- antioxidant effects
- immune system stimulation
- microbiota modulation

Antimicrobial resistance
=
biggest threats to global health, food security and development

“natural” biomolecules

animal feeds

Journal of Insects as Food and Feed, 2021; 7(5): 715-741

SPECIAL ISSUE: *Advancement of insects as food and feed in a circular economy*

Wageningen Academic Publishers

Beyond the protein concept: health aspects of using edible insects on animals

L. Gasco[1*], A. Józefiak[2] and M. Henry[3]

Immunostimulation

TM

Fish & Shellfish Immunology 69 (2017) 59–66

Contents lists available at ScienceDirect

Fish & Shellfish Immunology

journal homepage: www.elsevier.com/locate/fsi

ELSEVIER

Full length article

Effects of dietary *Tenebrio molitor* meal on the growth performance, immune response and disease resistance of yellow catfish (*Pelteobagrus fulvidraco*)

TM: 0%, 9%, 18%, 27%

in fish fed 18% TM

- decrease in plasma MDA content + increase in plasma SOD activity
- increase in plasma
  - lysozyme activity
  - IgM levels
- up-regulation of immune related genes (MHC II, IL-1, CypA, Img, HE)

- increase of survival rate after **challenged** with ***Edwardsiella ictaluri***

TM could **improve immune response & bacterial resistance**

Su et al., 2017. Fish & Shellfish immunology, 69:59-66

Antibacterial effect

TM

Article

Replacement of Fish Meal by Defatted Yellow Mealworm (*Tenebrio molitor*) Larvae in Diet Improves Growth Performance and Disease Resistance in Red Seabream (*Pargus major*)

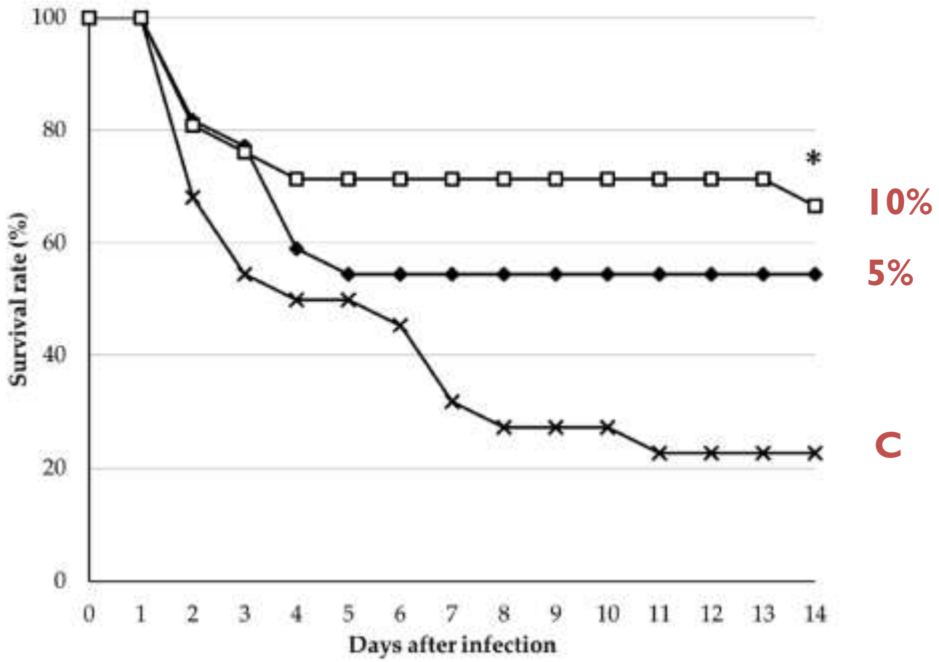
growth trial

25 – 40 – 65% TM

increased performances

challenge test

5 – 10% TM



increased protection against Erdwardsiella tarda

TM chitin or AMP or other bioactive compounds?

Ido et al., 2019. Animals, 9, 100

Microbiota modulation

BSF

inclusion: 0% - 10% - 20% - 30%

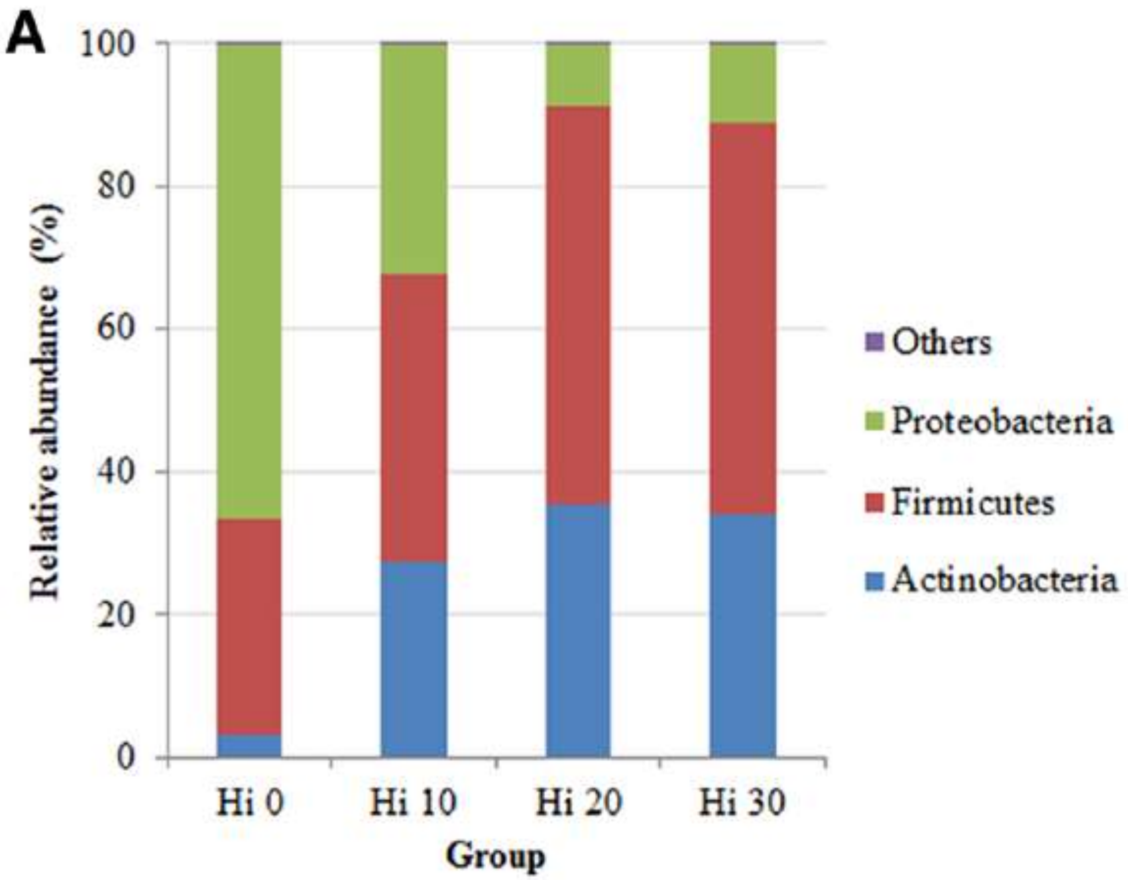
Rev Fish Biol Fisheries (2019) 29:465–486
https://doi.org/10.1007/s11160-019-09558-y

ORIGINAL RESEARCH

Rainbow trout (*Oncorhynchus mykiss*) gut microbiota is modulated by insect meal from *Hermetia illucens* prepupae in the diet

Genciana Terova · Simona Rimoldi · Chiara Ascione · Elisabetta Gini · Chiara Ceccotti · Laura Gasco

Actinobacteria, Firmicutes & Proteobacteria



- increasing microbiota diversity & richness
- increasing lactic acid- & butyrate- producing bacteria

→ contribute to the global fish health

Terova et al, 2019. Rev. Fish Biol Fisheries, 29, 465-486

Microbiota modulation

Weththasinghe *et al. Animal Microbiome* (2022) 4:9
https://doi.org/10.1186/s42523-021-00161-w

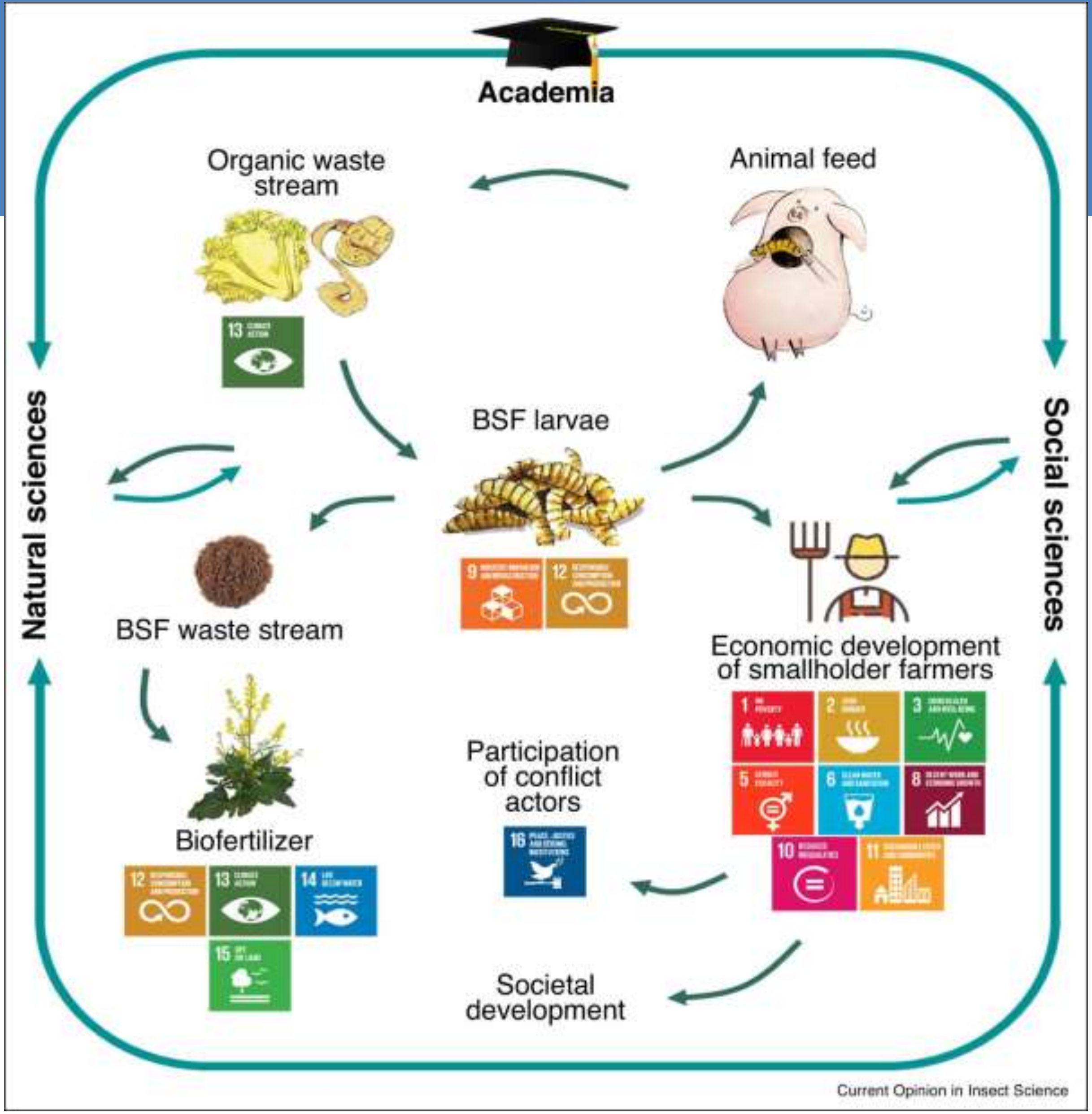
Animal Microbiome

RESEARCH ARTICLE Open Access

Modulation of Atlantic salmon (*Salmo salar*) gut microbiota composition and predicted metabolic capacity by feeding diets with processed black soldier fly (*Hermetia illucens*) larvae meals and fractions

Pabodha Weththasinghe[1*], Sérgio D. C. Rocha[1], Ove Øyås[1,2], Leidy Lagos[1], Jon Ø. Hansen[1], Liv T. Mydland[1] and Margareth Øverland[1*]

CIRCULAR ECONOMY



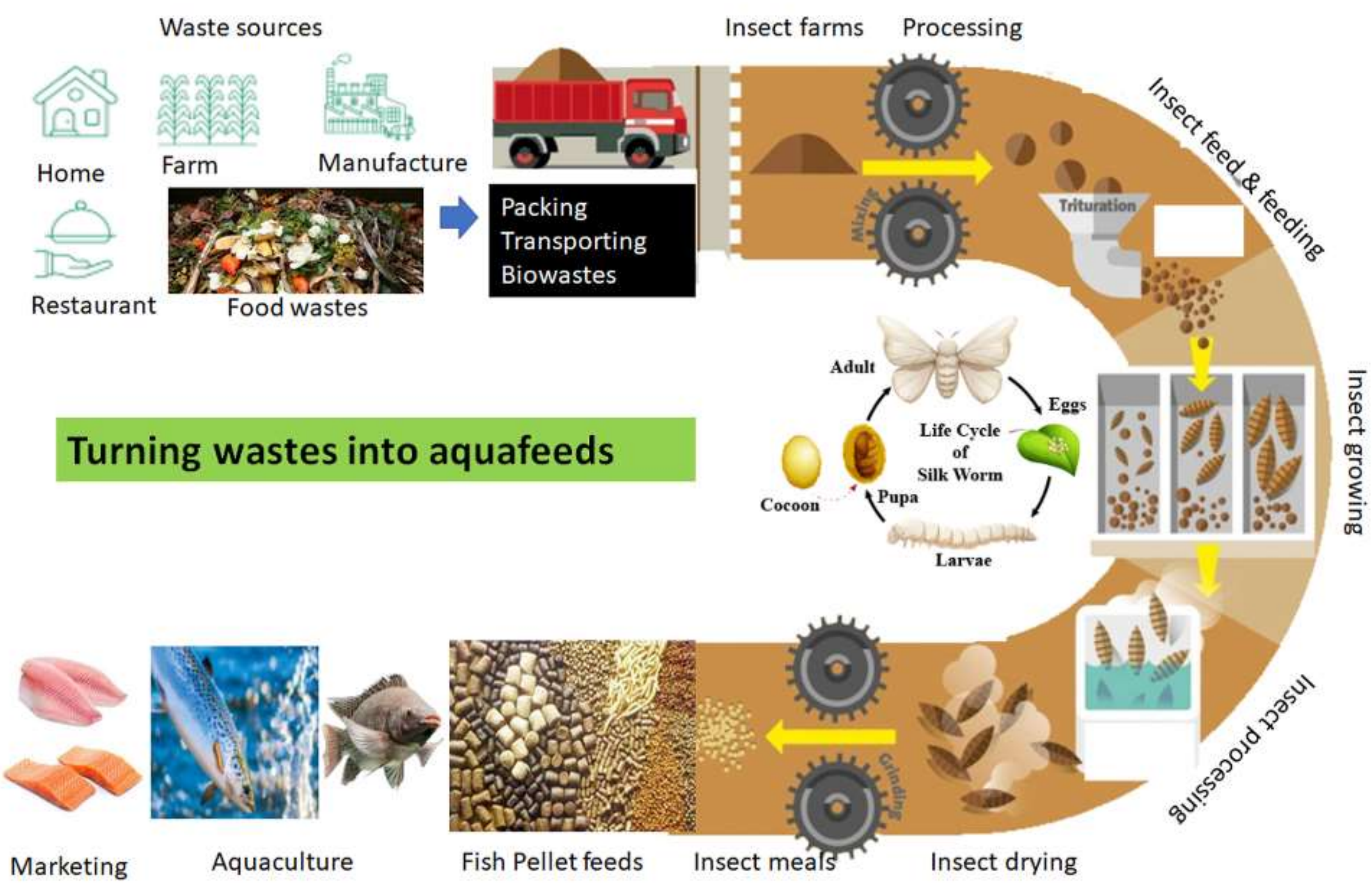


Fig. 2. Turning wastes into proteins using insects to produce insect meals to replace fishmeal in aquafeeds for fish culture.

Alfiko et al., 2021. https://doi.org/10.1016/j.aaf.2021.10.004

AQUAFEED APPLICATIONS

Received: 16 November 2021 | Revised: 4 February 2022 | Accepted: 7 February 2022
DOI: 10.1111/raq.12666

REVIEWS IN Aquaculture

REVIEW

Systematic review and meta-analysis of production performance of aquaculture species fed dietary insect meals

Hung Quang Tran[1] | Tram Thi Nguyen[1] | Markéta Prokešová[1] | Tatyana Gebauer[1] | Hien Van Doan[2,3] | Vlastimil Stejskal[1]

Aquaculture 530 (2021) 735732

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

A meta-analysis of the effects of replacing fish meals with insect meals on growth performance of fish

Katheline Hua[a,b,*]

- authorized species [Reg (EU) 2017/893 + Reg (EU) 1925/2021]
- insect-derived products used (full fat – defatted meals / oils)
- target conventional protein source: FM
- inclusion *vs* substitution
- N-P conversion factor
- digestibility
- impact on product quality & consumer

Weththasinghe *et al. Animal Microbiome* (2022) 4:9
https://doi.org/10.1186/s42523-021-00161-w
Animal Microbiome

RESEARCH ARTICLE **Open Access**

Modulation of Atlantic salmon (*Salmo salar*) gut microbiota composition and predicted metabolic capacity by feeding diets with processed black soldier fly (*Hermetia illucens*) larvae meals and fractions

Pabodha Weththasinghe[1*], Sérgio D. C. Rocha[1], Ove Øyås[1,2], Leidy Lagos[1], Jon Ø. Hansen[1], Liv T. Mydland[1] and Margareth Øverland[1*]

KeAi
CHINESE ROOTS GLOBAL IMPACT
Contents lists available at ScienceDirect
Aquaculture and Fisheries
journal homepage: www.keaipublishing.com/en/journals/aquaculture-and-fisheries

Insects as a feed ingredient for fish culture: Status and trends

Yuzer Alfiko[a,1], Dizhi Xie[b,1], Retno Tri Astuti[c,1], Joey Wong[d,1,*], Le Wang[e,**]

ELSEVIER

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Check for updates

Effect of feeding with insect meal diet on the fatty acid compositions of sea bream (*Sparus aurata*), tench (*Tinca tinca*) and rainbow trout (*Oncorhynchus mykiss*) fillets

Dmitri Fabrikov [a], Fernando G. Barroso [a,*], Mª. José Sánchez-Muros [a], Mª. Carmen Hidalgo [b], Gabriel Cardenete [b], Cristina Tomás-Almenar [c], Federico Melenchón [c], Jose Luis Guil-Guerrero [d]

Consumer attitude and acceptance toward fish fed with insects: a focus on the new generations

L. Baldi, T. Mancuso, M. Peri, L. Gasco, M.T. Trentinaglia

*Corresponding author: laura.gasco@unito.it

Journal of Insects as Food and Feed: 8 (11)- Pages: 1249 - 1263

OPEN ACCESS

https://doi.org/10.3920/JIFF2021.0109

laura.gasco@unito.it

Animal SCIENCE

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.

INRAE

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 ?

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

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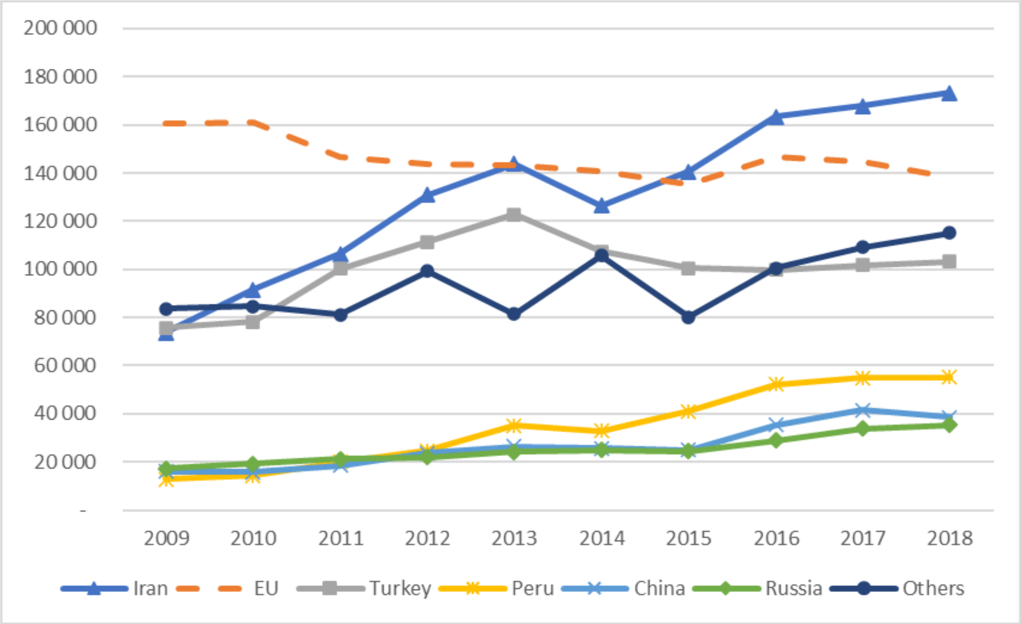
INRAE

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

Rainbow trout production

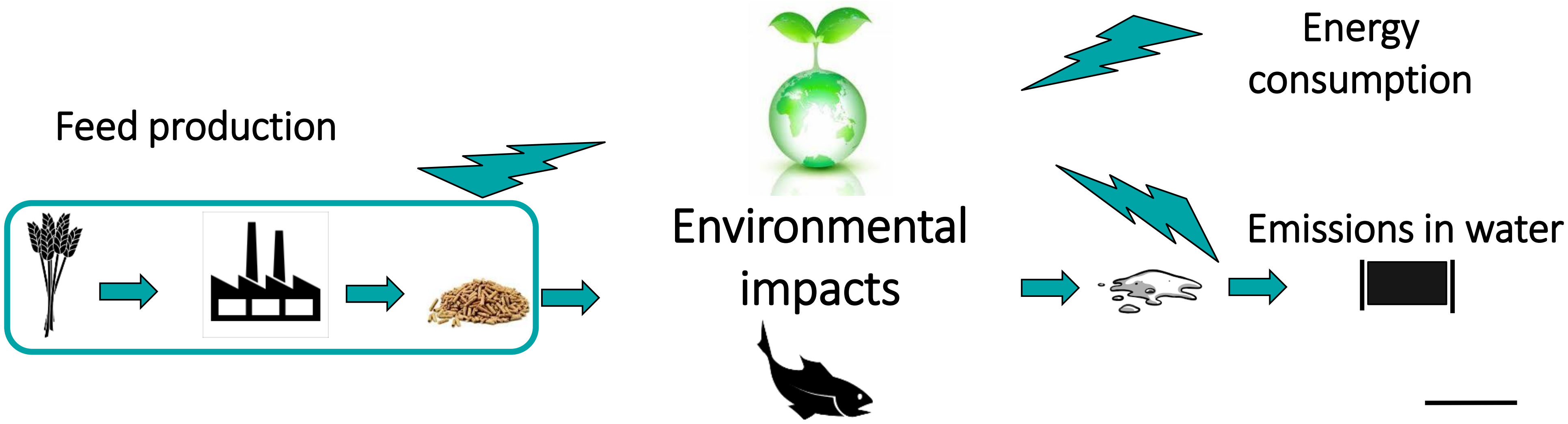


FAO, 2018

- ✓ 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

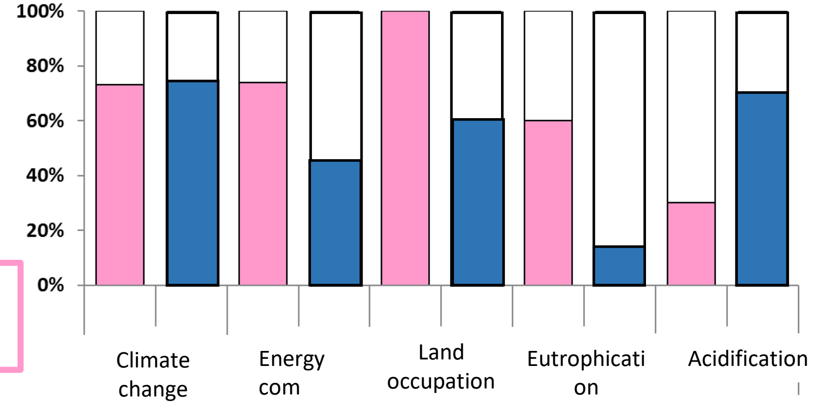
EUMOFA, 2021

➢ Environmental impacts of aquaculture



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

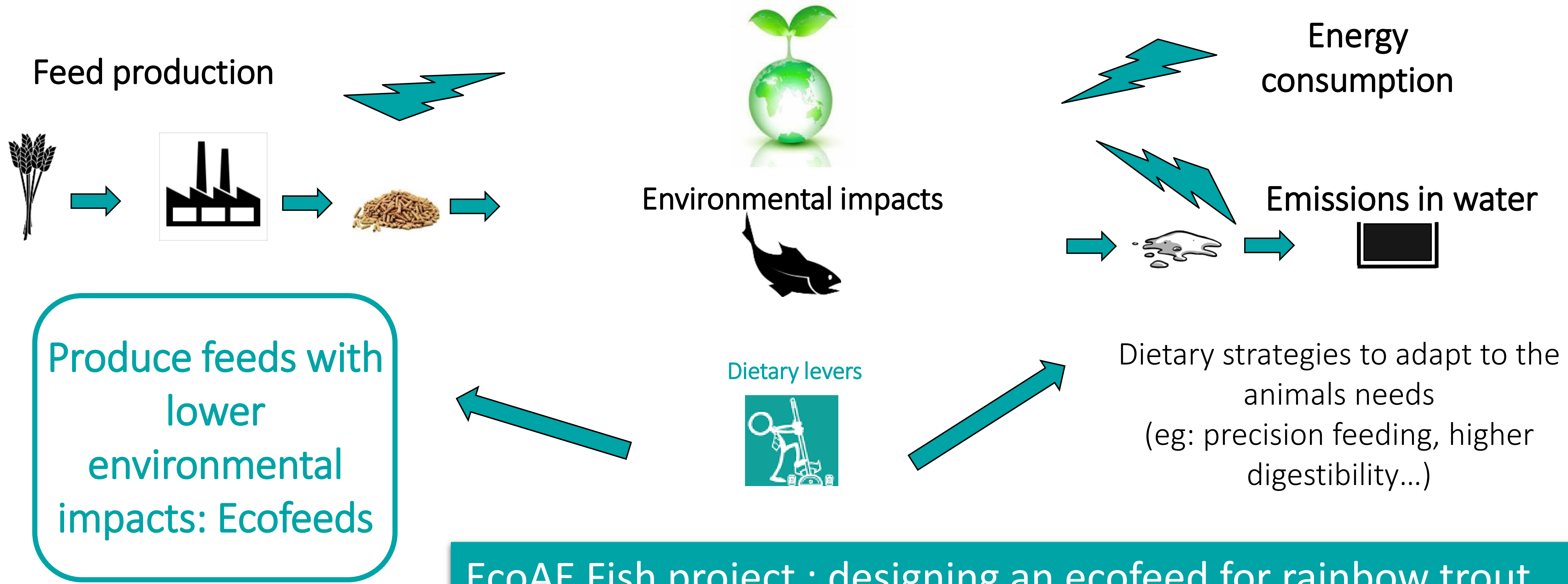
Basset-Mens & van der Werf, 2005
Dourmad et al. 2014



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

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

FI_1 … FI_{1n}	Nut_{11} … Nut_{p1} … Nut_{1n} … Nut_{pn}	Nut_{11} … Nut_{p1} … Nut_{1n} … Nut_{Pn}	$Price_1$ … $Price_{1n}$	LCA_{11} … LCA_{q1} … LCA_{1n} … LCA_{qn}
	Nutrient Contents	**Nutritional & inclusion constraints**	**Price**	**Impacts of feed ingredients**
↓ 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

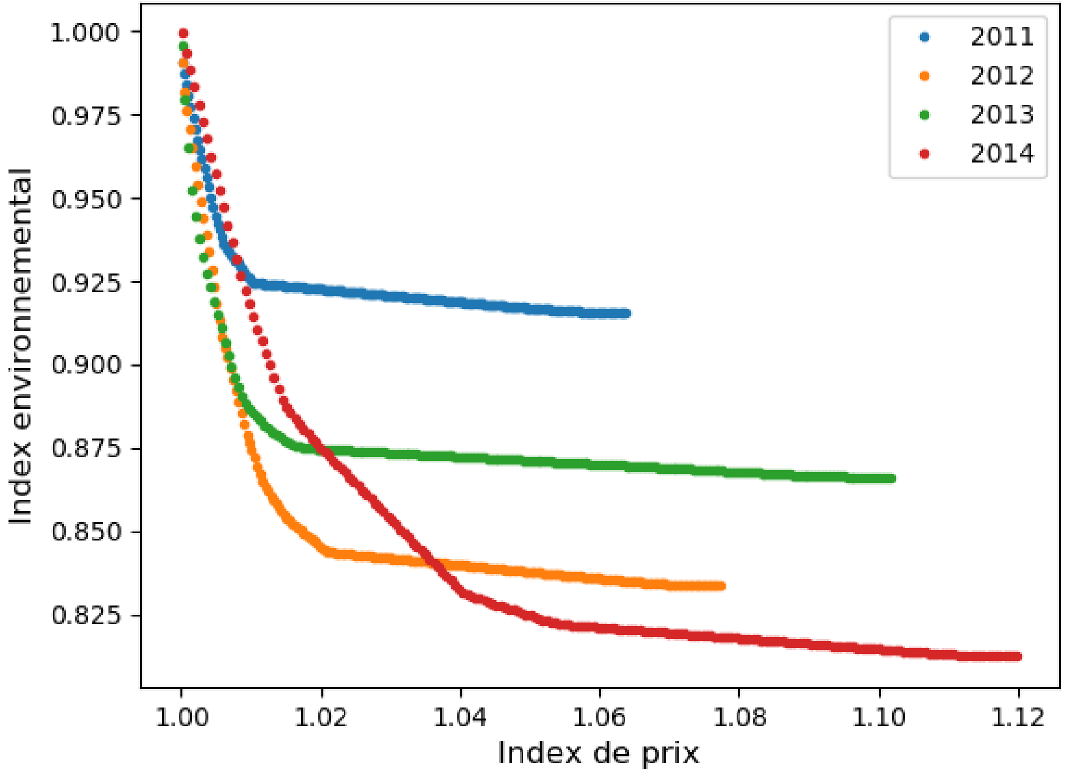
$$f(x) = \sum_{i \in I} coef_i \frac{Impact_i{}^t x - Min_i}{Ref_{impact_i} - Min_i}$$

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

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

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

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	[illegible])	7[illegible]
Poultry meal (blood, feather)	[illegible]	[illegible]
Oilseed oil	[illegible]	[illegible]
Guar meal/Soy lecithin	-	2.97/5.76
Pea protein concentrate	25.01	20.00
Premix and additives	4.35	4.4

Fish meal + Fish oil: **-45 %**

16 raw materials (C-diet) — **23 raw materials** (ECO-diet)

1276.9 €/t (C-diet) — **1171.5 €/t** (ECO-diet) — **-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

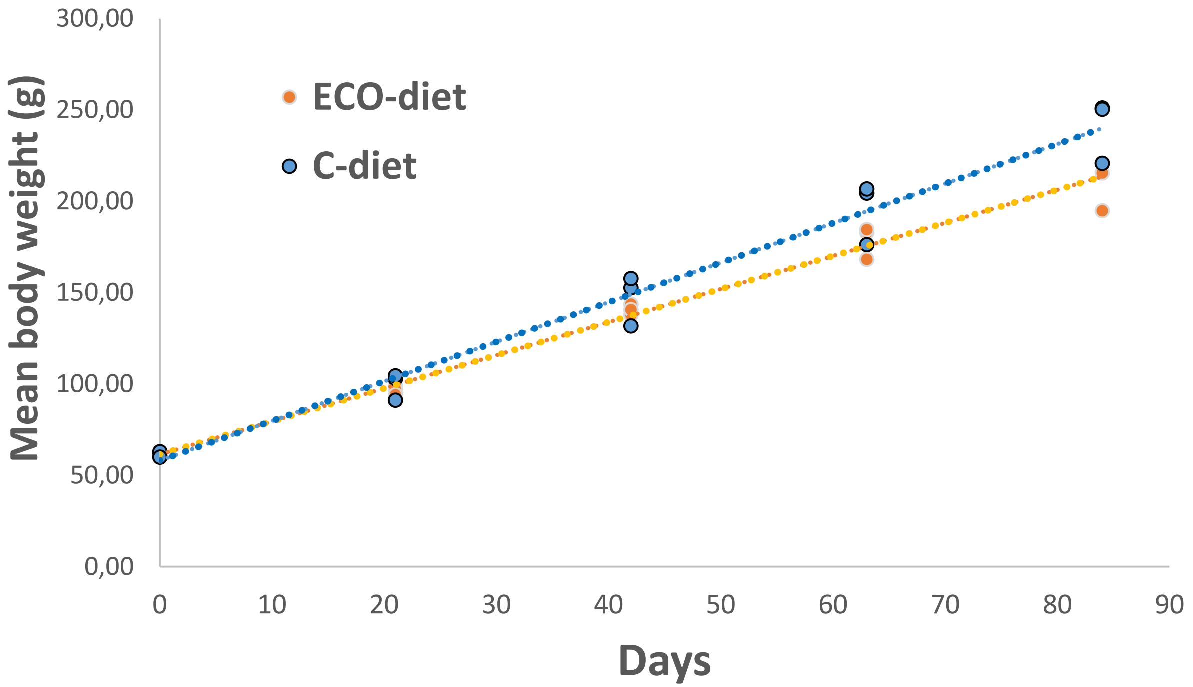
➢ In vivo performance of the Eco-diet

	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

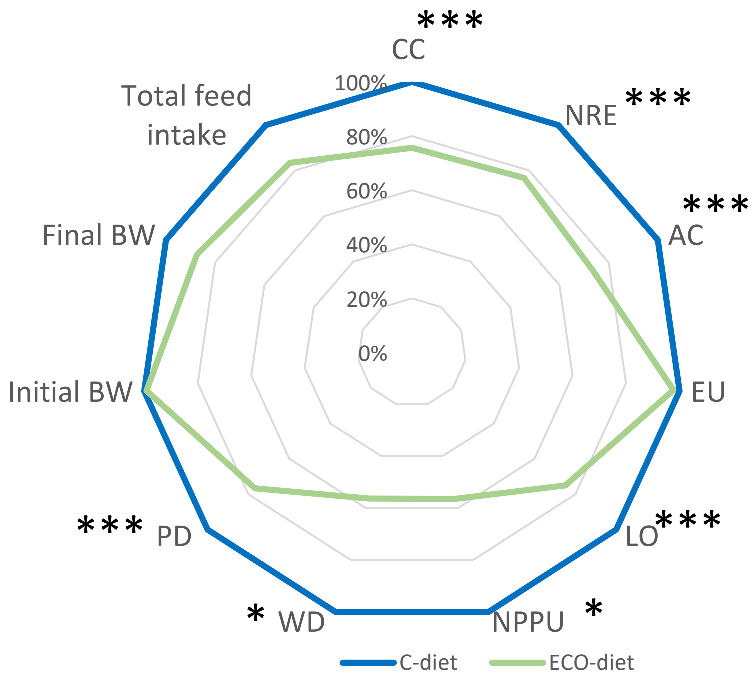
Eco-feed consumption does not affect animal performance

- 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

Ecodiet: It works !

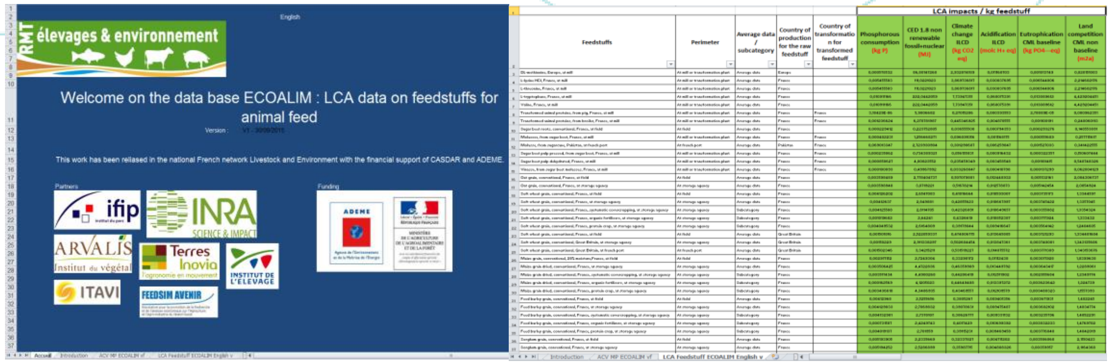
CC = climate change (kg CO2eq); NRE = non-renewable and fossil energy demand (MJ); AC = acidification (molcH+eq); EU = eutrophication (kg PO43-eq); LO = land occupation (m².y); NPPU = net primary production use (kg C); WD = water demande (m3); PD = phosphorus demand (g P)

- ✓ 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

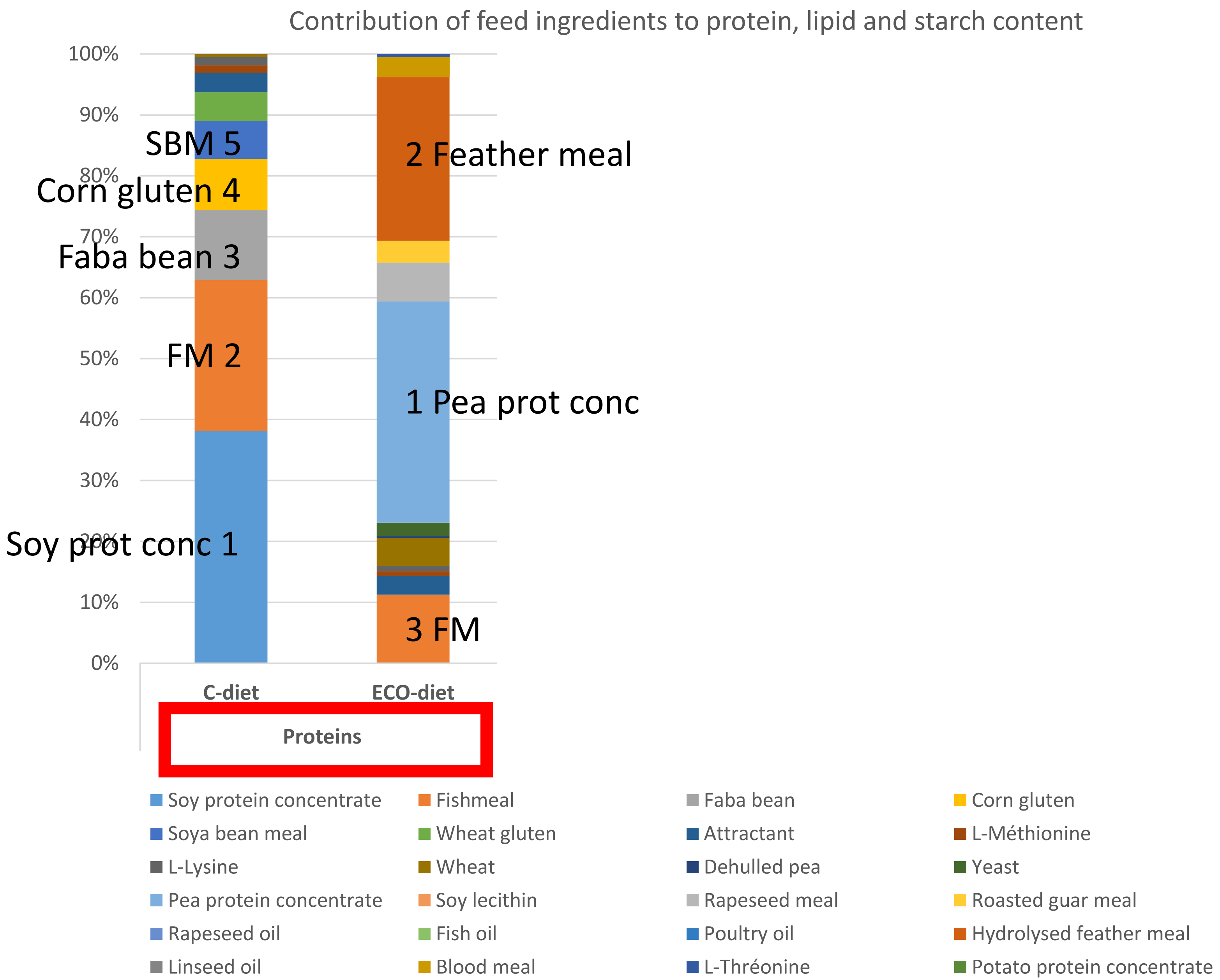
Thank you for your attention !

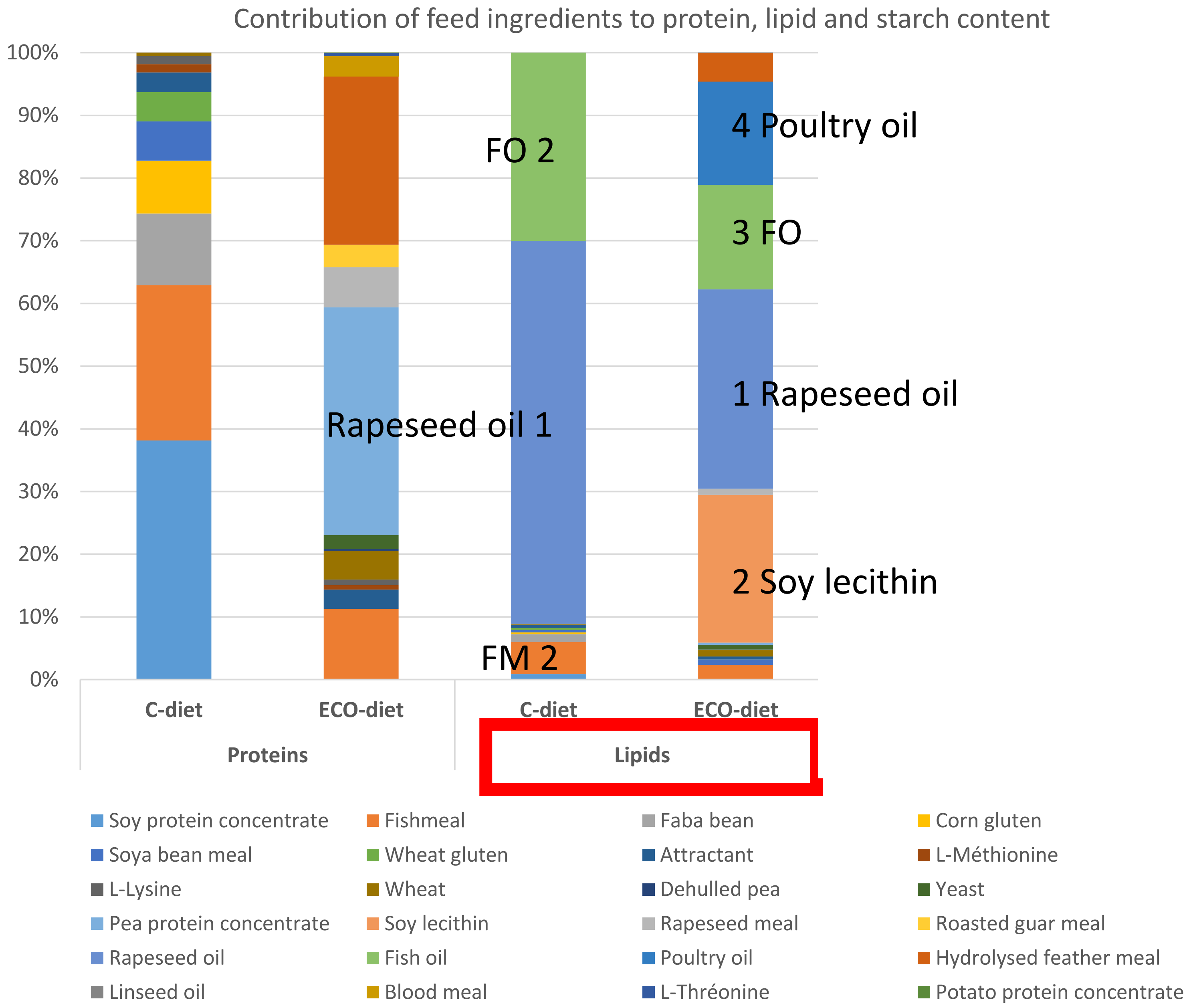
aurelie.wilfart@inrae.fr

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


Contribution of feed ingredients to protein, lipid and starch content
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70%
60%
50%
40%
30%
20%
10%
0%
FO 2
4 Poultry oil
3 FO
Rapeseed oil 1
1 Rapeseed oil
2 Soy lecithin
FM 2
C-diet
ECO-diet
C-diet
ECO-diet
Proteins
Lipids
Soy protein concentrate
Fishmeal
Faba bean
Corn gluten
Soya bean meal
Wheat gluten
Attractant
L-Méthionine
L-Lysine
Wheat
Dehulled pea
Yeast
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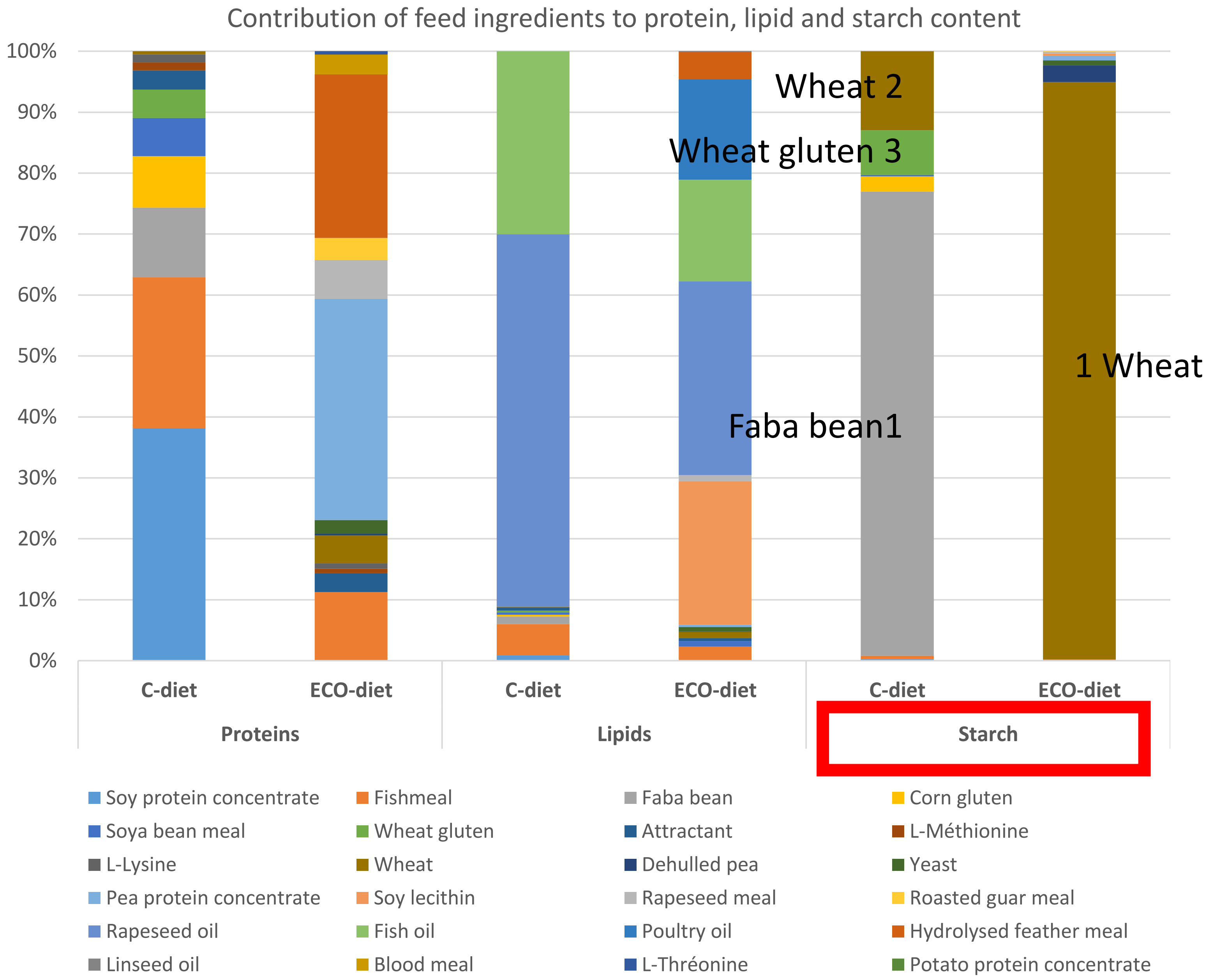
Linseed oil
Blood meal
L-Thréonine
Potato protein concentrate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0%
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Wheat gluten 3
1 Wheat
Faba bean1
C-diet
ECO-diet
C-diet
ECO-diet
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Proteins
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Rapeseed meal
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Potato protein concentrate

UNIVERSITÀ DEGLI STUDI DI MILANO

DiSAA DIPARTIMENTO di SCIENZE AGRARIE e AMBIENTALI

Agrifood LCA Lab

crea Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria

mipaaf ministero delle politiche agricole alimentari e forestali

LCA and shellfish farming

- case study of organic Manila clam aquaculture

Arianna Martini

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Milan, 5th December 2022 – Workshop - Life Cycle Assessment in Aquaculture

Low-impact aquaculture: a sector with high growth potential

SUSTAINABLE DEVELOPMENT GOALS

Sustainable food system (SFS)
deliver food security and nutrition for all in a **sustainable** way

- **Ecological transition** towards food systems having **zero or positive impacts** and that can provide multiple **ecosystem services**
- Quantification of the **positive** and **negative** environmental **impacts** of food supply chains

Shellfish aquaculture → well-established ecosystem services

Supporting services
Services necessary for the production of other ecosystem services

- restoration of degraded seabed habitats, increase biodiversity at all trophic levels
- play a role in the storage and cycle of fundamental nutrients in aquatic environments

Provisioning services
products obtained from ecosystems

- provision of high-quality animal proteins and omega-3 PUFA
- shells as construction materials, fertilisers

Regulating services
Benefits obtained from the regulation of ecosystem processes

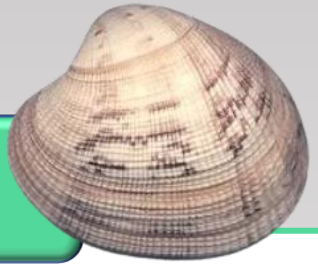
- mitigation of the effects of eutrophication
- Reduced rates of shoreline and bed erosion

Cultural services
Non-material benefits obtained from ecosystems

- Education, tourism, seafood festivals and symbolic and spiritual benefits

van der Schatte Olivier et al., 2020

Manila clam aquaculture



Ruditapes philippinarum

Manila clam aquaculture gives the opportunity to describe an important European food supply chain and inform future management plans

- In the EU, *R. philippinarum* is an economically important sector
- Italy is the leader MS for Manila clam production (24,453 tonnes in 2020, > 95% of EU production, 36% of Italian aquaculture production value)
- Faster growth rate than *R. decussatus*, tolerance to salinity and temperature variations and eutrophication

CLIMATE CHANGE

OVEREXPLOITATION

HABITAT DEGRADATION

LACK OF AVAILABLE NATURAL SEED

DECLINE IN MANILA CLAM PRODUCTION

RELIANCE ON HATCHERIES to guarantee seed provisioning to on-growing clam facilities

Despite the relevance of Manila clam farming in Italy, there is only one clam hatchery

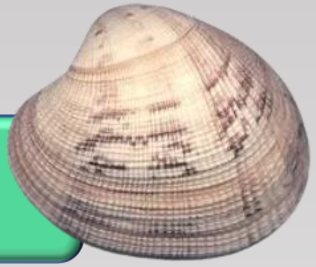
Producing certified and controlled Manila clam seed could be an opportunity for the development of ORGANIC clam aquaculture

The start of organic Italian clam production was allowed by the establishment of the first certified hatchery in 2017

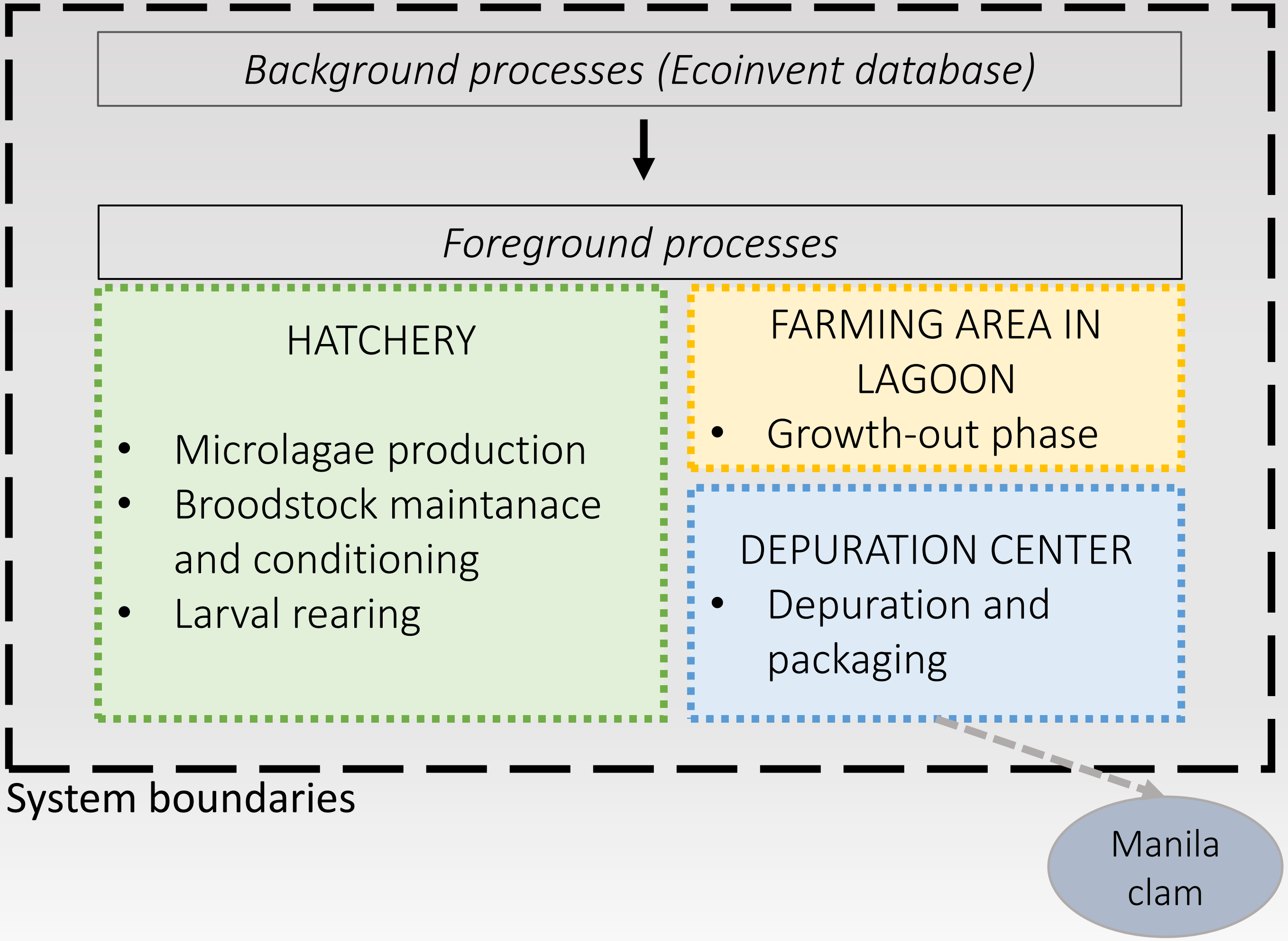
From 2015 to 2018 the production increased from 20 to 291 tonnes

BUT just one hatchery unit is not sufficient to provide spat for all the on-growing national facilities and seed is almost all imported from USA and other EU MS

LCA of organic Manila clam aquaculture

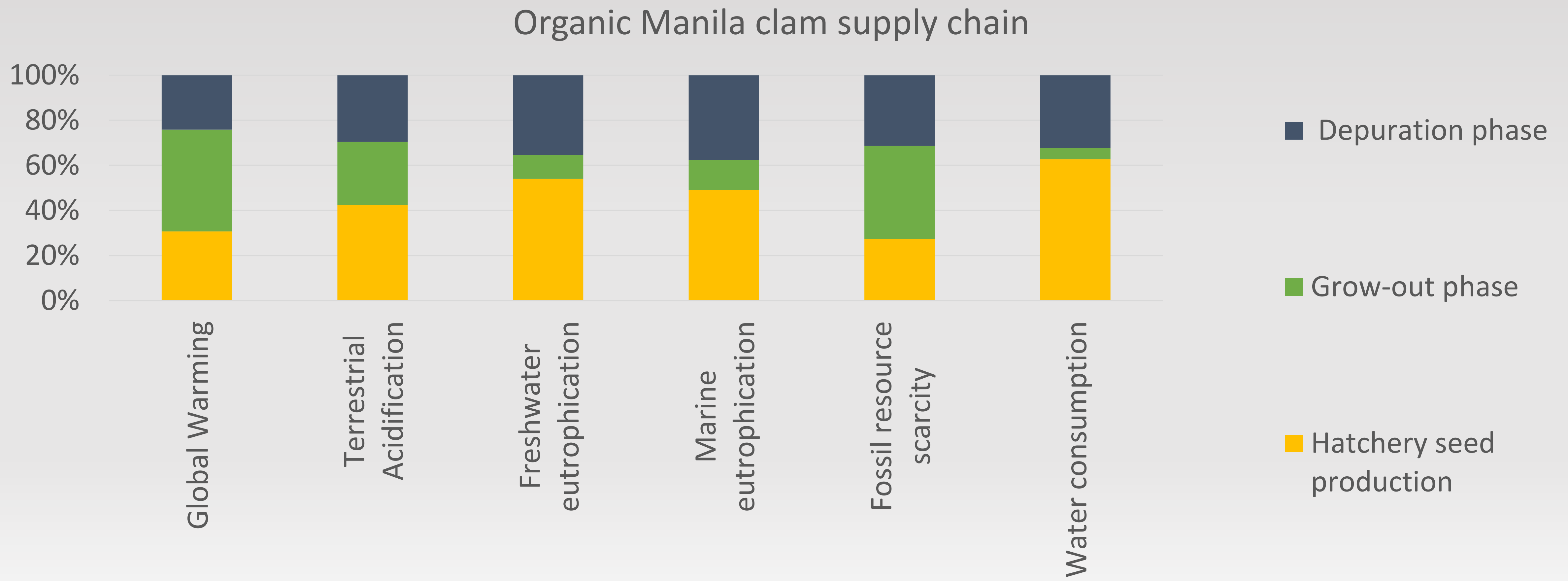


- **Case study**: organic Manila clam supply chain in the North Adriatic Sea – the three phases are carried out in a restricted area (Goro, Emilia-Romagna)
- Assessment of the **environmental performance,** identification and quantification of major sources of impacts
- Life Cycle Assessment (LCA) (**cradle-to-gate analysis**)
- Impact Assessment method: **ReCiPe 2016 Midpoint** (H) V1.04
- Functional Unit: **1 kg** of packed organic clam
- Software: Simapro 9.1.0.7



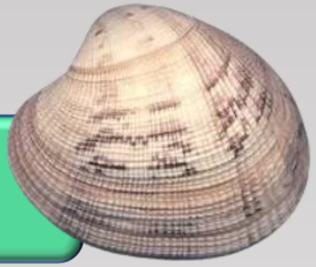
LCA of organic Manila clam aquaculture

CONTRIBUTION ANALYSIS (preliminary results)



Results are referred to the functional unit: **1 kg** of packed organic clam

LCA of organic Manila clam aquaculture



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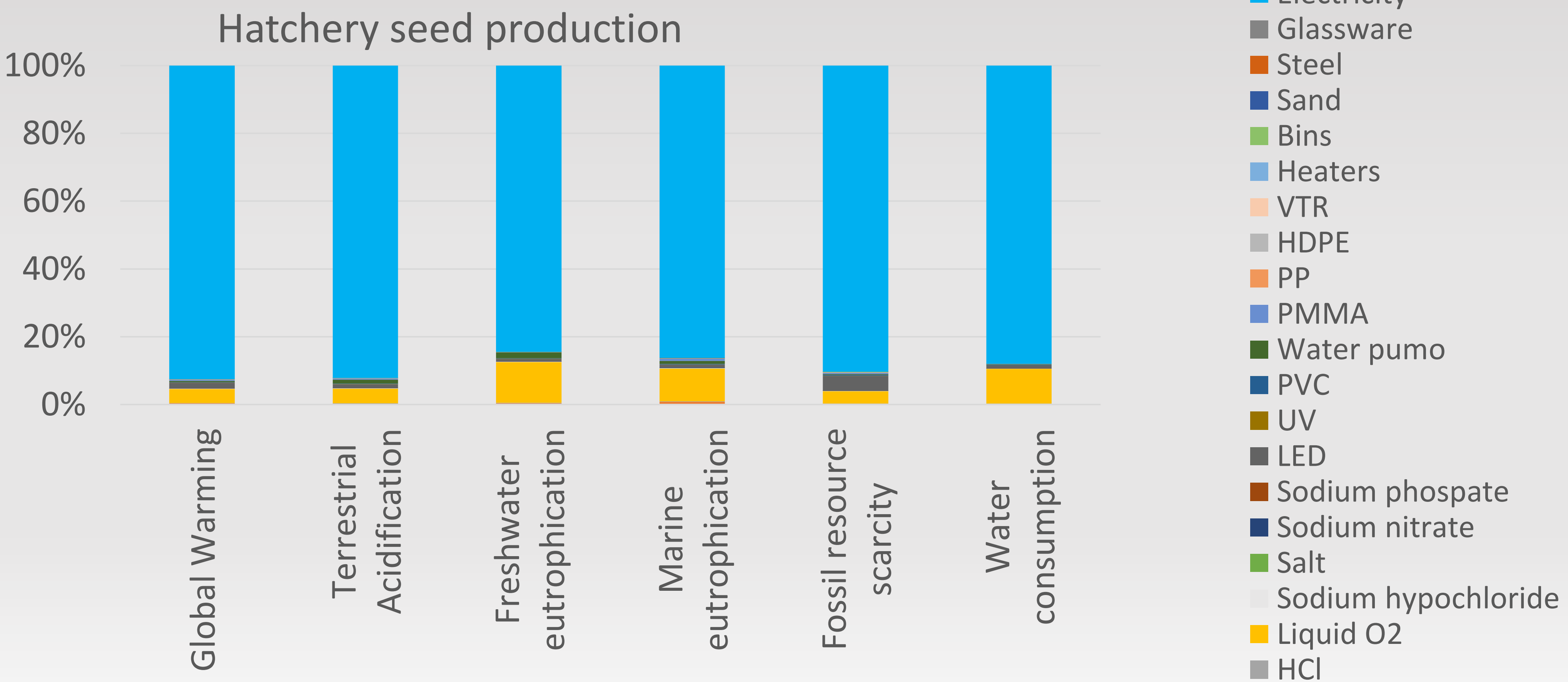

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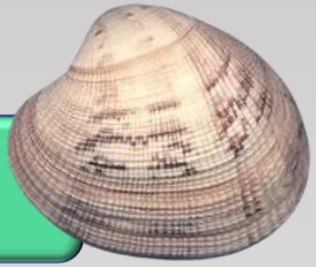
LCA of organic Manila clam aquaculture



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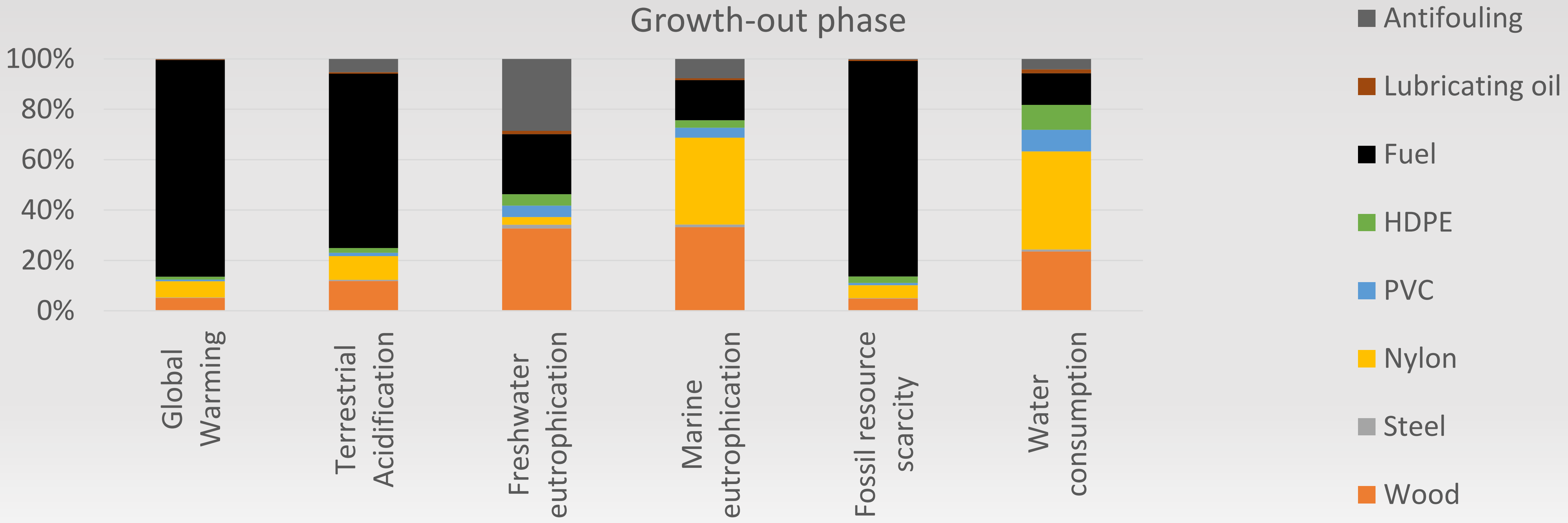

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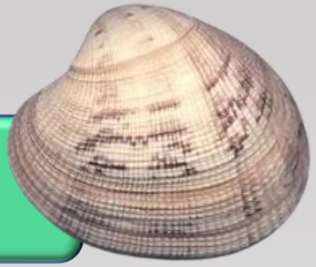

LCA of organic Manila clam aquaculture

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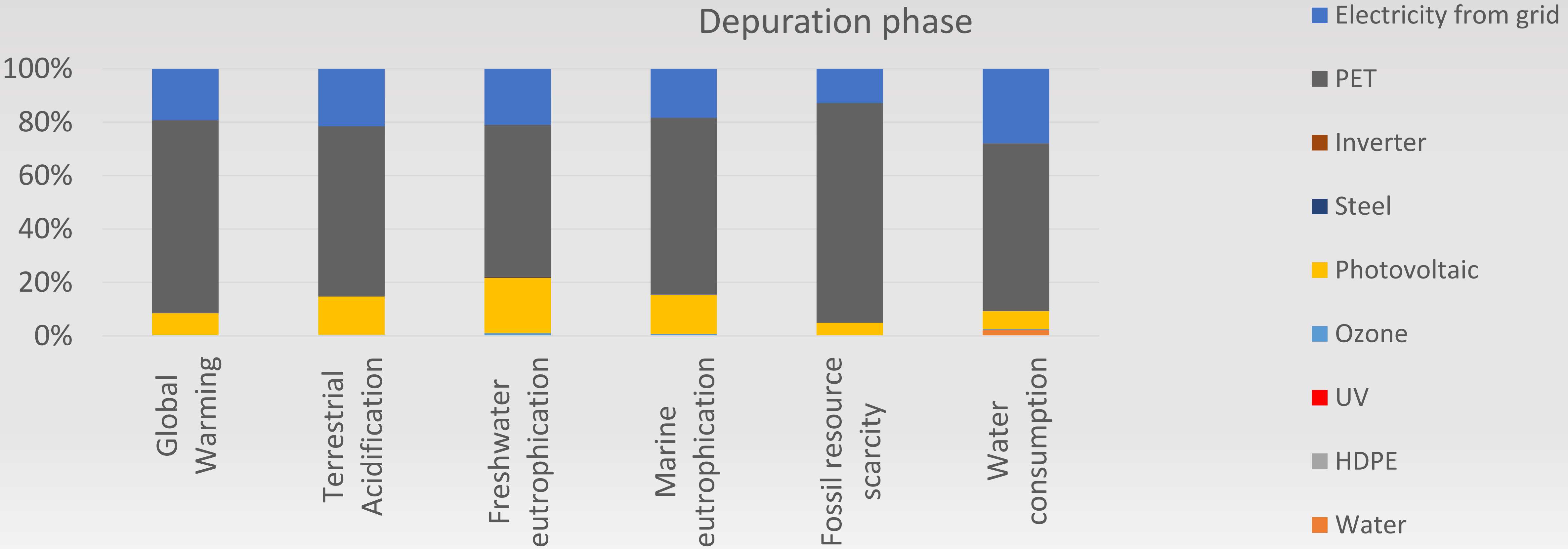


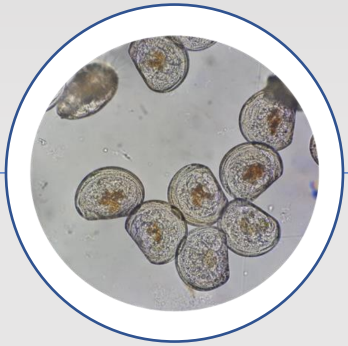
Results are referred to the functional unit: **1 kg** of packed organic clam

Main results

An organic clam supply chain carried out entirely in a restricted area has rather modest environmental impacts

The three production phases differently contribute to the different midpoint impact categories selected

HATCHERY

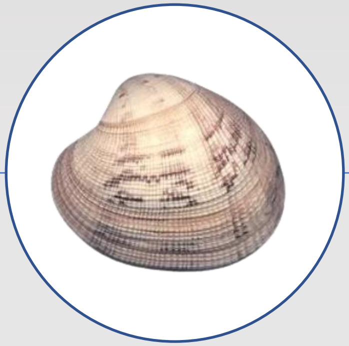


>40% contribution

a. TERRESTRIAL ACIDIFICATION
b. FRESHWATER AND MARINE EUTROPHICATION
c. WATER CONSUMPTION

Major contributor: **ELECTRICITY**

GROW-OUT



>40% contribution

a. GLOBAL WARMING
b. FOSSIL RESOURCE SCARCITY

Major contributor: **FUEL**
Other contributors: **NYLON** and **WOOD**

DEPURATION

<40% contribution

a. ALL IMPACT CATEGORIES

Major contributor: **PLASTIC**
ELECTRICITY from photovoltaic plant

Conclusions

- The increasing gap between **natural seed availability** and **demand needs** to be faced

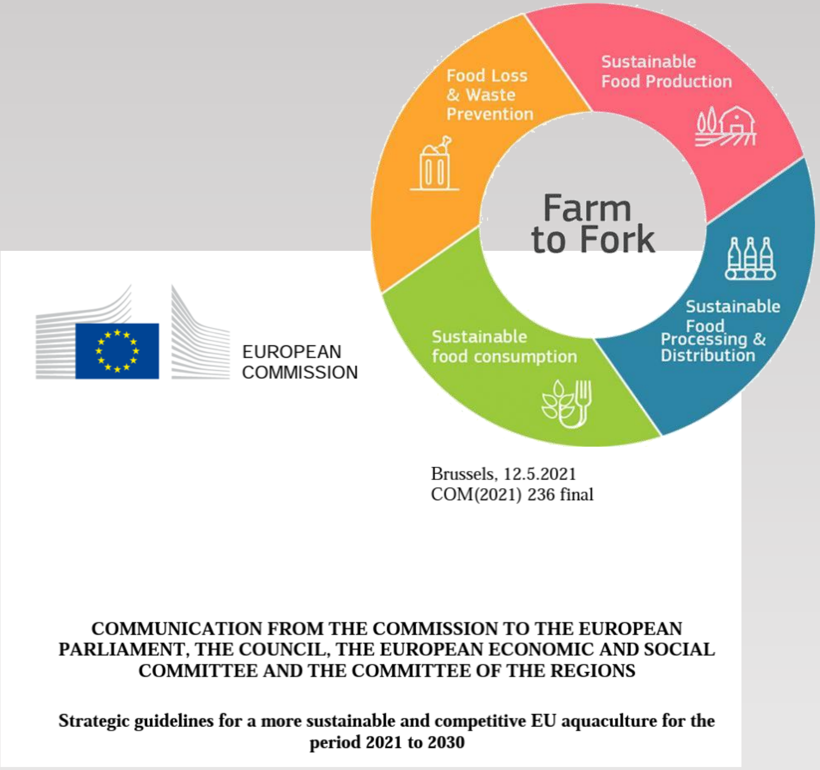
- The build up of a **national network of clam hatcheries** should be the answer

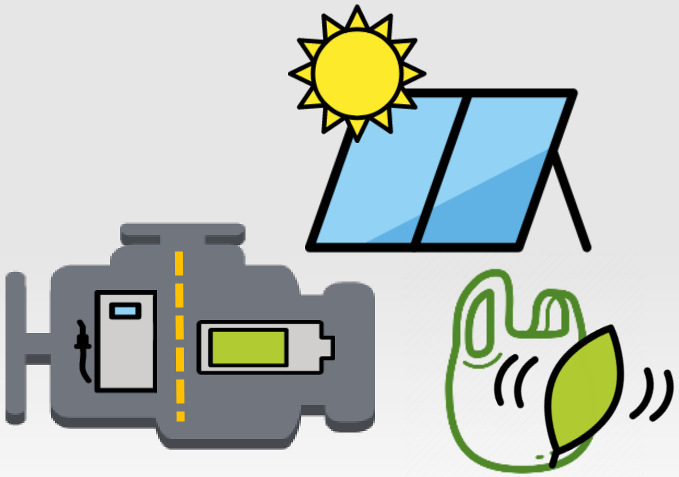
- It should **reduce the impact of seed transfer** from other countries, but its environmental impact should be assessed

- It should also give the opportunity for the **development of the organic clam farming**, as requested by the EU Strategic Guidelines

- **Mitigation strategies** must be implemented in clam farming to reduce impacts in the three different phases:

  1. the impact of electricity and fuel use
  2. The impact of plastic materials





Thanks for your attention

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LCA of aquaponics

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Università Iuav di Venezia

Life Cycle Assessment in Aquaculture workshop – SIMTAP project – Milano 5/12/2022

Outline

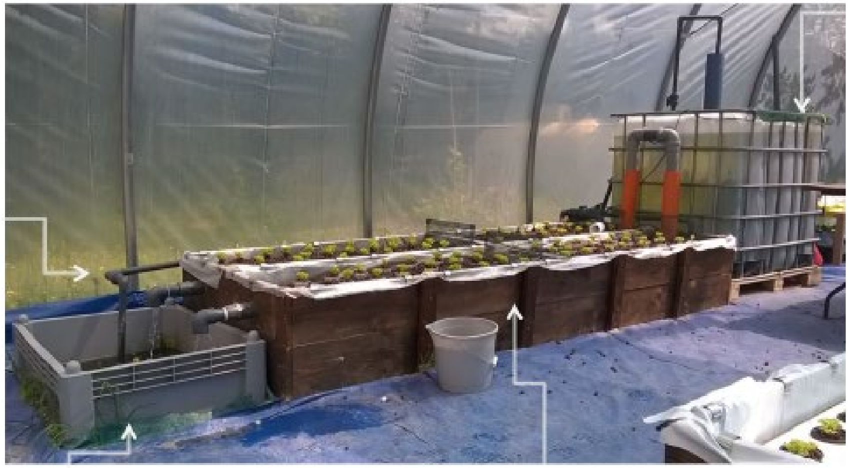
Approaching LCA of aquaponics (methodology)

Comparing results from 4 different systems

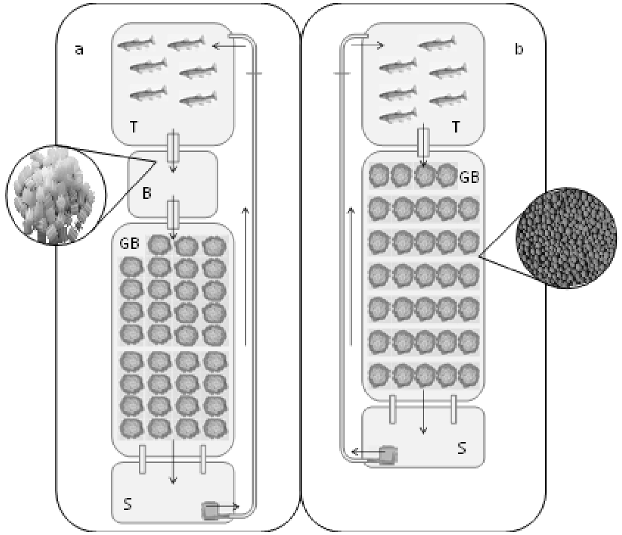
Limitations and future perspectives

Università Iuav di Venezia

BlueFarm



Upper view scheme of the aquaponic system: RAFT (a) and MFBS (b). T: tank; B: biofilter; P: water pump S: sump tank, GB: grow bed.



Fish tanks 2 m^3

Growth beds 10 m^2

No temp. control

Tabella 1. Riporta i risultati della produzione di pesce e lattughe di un ciclo della durata di un mese

	DWC		MFB	
	t_0	t_f	t_0	t_f
Mortalità pesce (morti/mese)	6 morti (1.71%)		5 morti (1.42%)	
Peso medio pesci (g)	27.82 ± 8.88	35.18 ± 8.84	28.01 ± 9.04	35.36 ± 9.62
Lunghezza media pesci (cm)	11.10 ± 1.28	12.28 ± 1.53	11.35 ± 1.81	12.63 ± 1.33
Biomassa totale di pesce (kg)	9.74	12.10	9.80	12.20
FCR	1.21		1.26	
Peso medio lattuga (g)	4.81 ± 0.56	180.25 ± 39.29	4.82 ± 0.64	158.80 ± 46.93
Biomassa totale lattughe (kg)	0.43	16.22	0.43	14.29
Produzione lattughe (kg·m^{-2})	5.4		4.76	

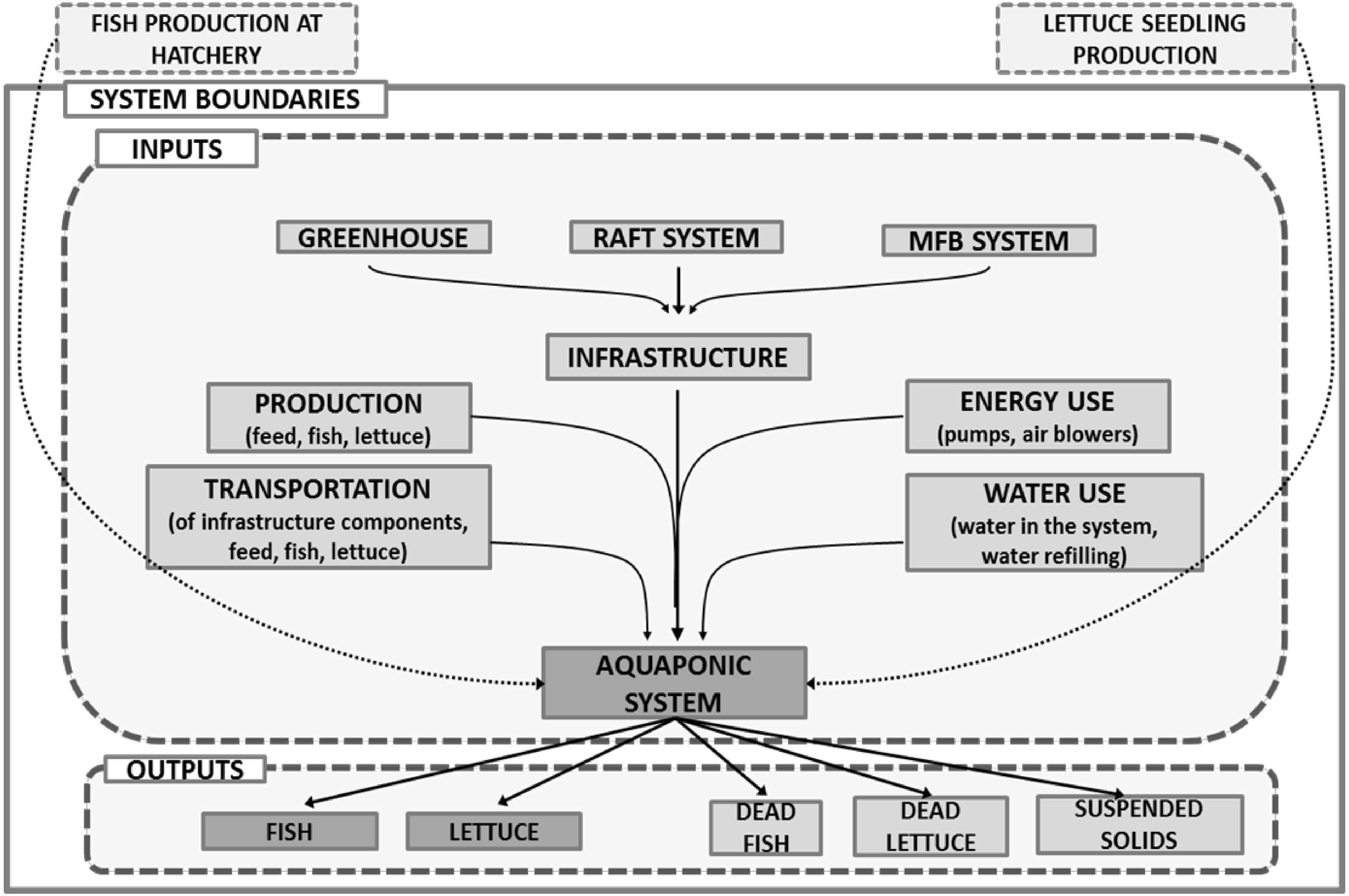
- All primary data with respect to building materials and transportation;
- Primary data with respect to system functioning;
- LIMITATION: time span of monitoring during functioning (only 1 year project duration)

Università Ca'Foscari Venezia

WWF OASI

FONDO SOCIALE EUROPEO

Buondaries and FU



FU “1 kg of lettuce produced by the aquaponic system”

allocation to lettuce: 73.18%;
allocation to tench = 26.82%

Building the inventory: LCA main inputs and outputs for the aquaponic system.

Consumptions	
Water (m^3)	1.69
Electricity (kWh)	7.8
Fish feed (kg)	36.71
Truck (t/km)	53.9
Car (km)	750.6
Outputs	
Lettuce (*Lactuca sativa*) (kg)	60.93
Tench (*Tinca tinca*) (kg)	22.19
Nitrogen (Emission in the soil) (kg)	0.043
Phosphorous (Emission in the soil) (kg)	0.01
Nitrogen (Emission in the water) (kg)	0.77
Phosphorous (Emission in the water) (kg)	0.16

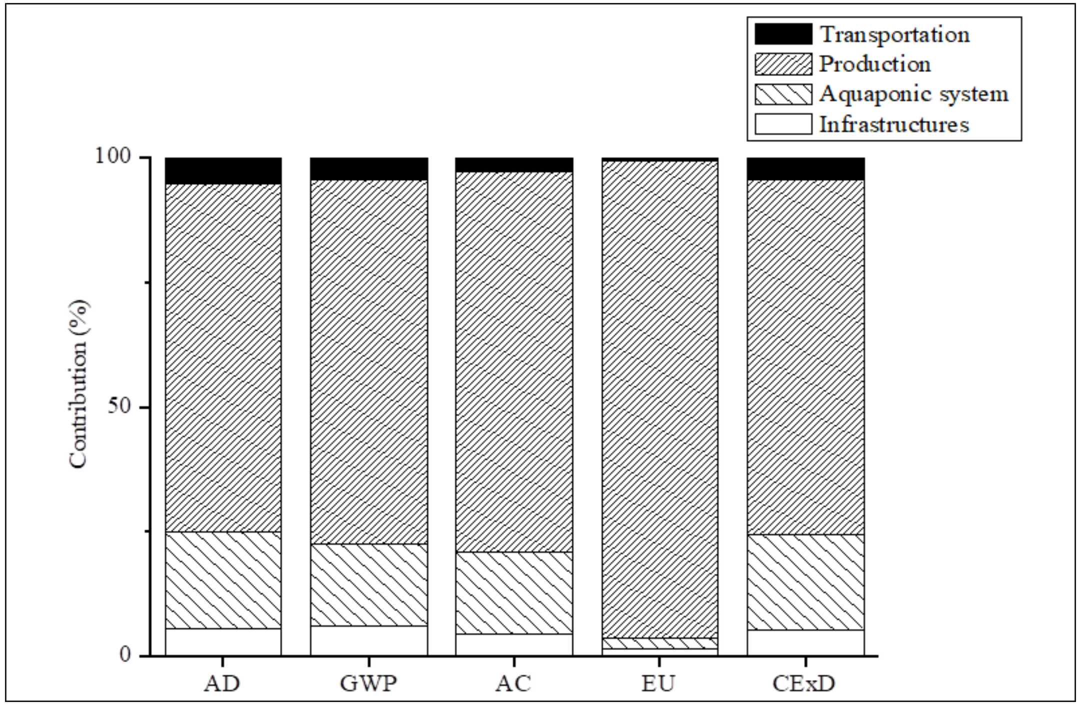
MATERIALS (kg)	
Greenhouse	
Iron (pipes, small items)	272.85
Nylon (tarpaulin, strips)	46.74
PE (tarpaulin, small items)	5.94
Aluminium (small items)	0.92
Aquaponic unit - RAFT	
PVC (tanks, pump, pipes, small items)	43.54
PE (tank, pots, bacterial carriers)	118.14
PS (floating units)	0.36
Tinder wood (grow bed)	27.98
Expanded clay (substrate)	27.06
Perlite (substrate)	1.2
Aquaponic unit - MFB	
PVC (tanks, pump, pipes, small items)	26.18
PE (tank, tubes, net, small items)	64.63
Tinder wood (grow bed)	27.98
Expanded clay (substrate)	568.26

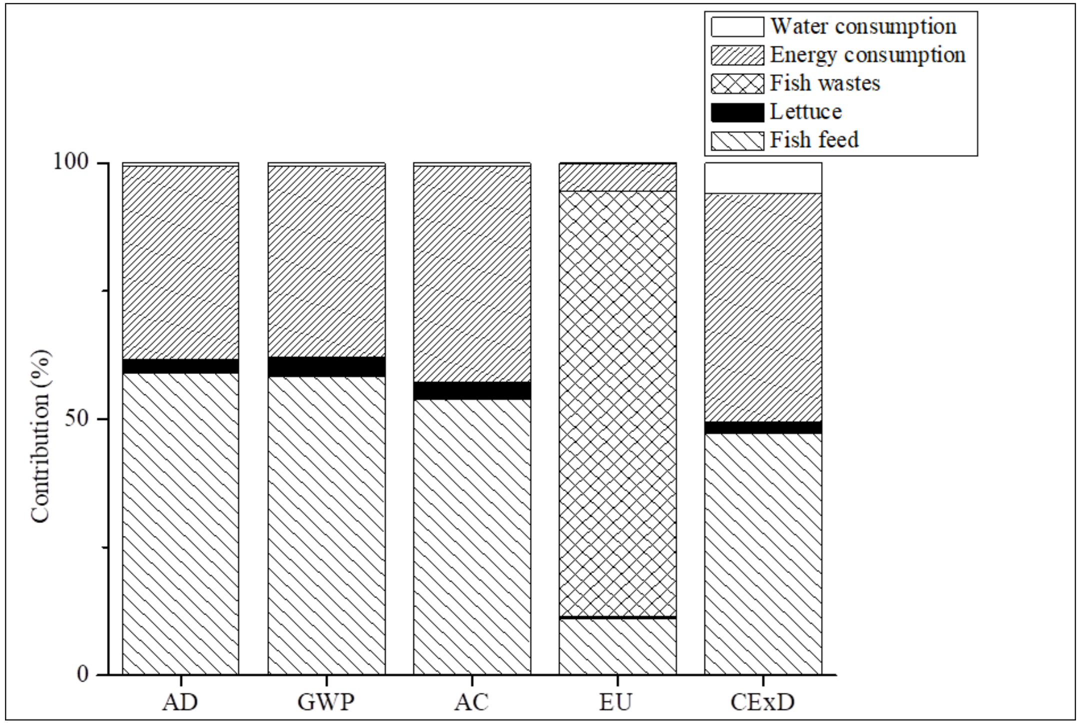
LCIA

METHOD	IMPACT CATEGORY	UNIT	
CML-IA (Version 3.01/World 2000)	Abiotic Depletion (AD)	MJ	
	Global Warming Potential 100a (GWP)	kg CO_2 eq	
	Acidification (AC)	kg SO_2 eq	
	Eutrophication (EU)	kg PO_4^{3-} eq	
Cumulative Exergy Demand V1.03	Cumulative Exergy Demand	MJ	
Boulay et al 2011 (v1.01)	Water scarcity - WSI	m^3	*
Life Cycle Costing	Cost	Euro	

Processes characterizing the system were aggregated in 4 macro-categories

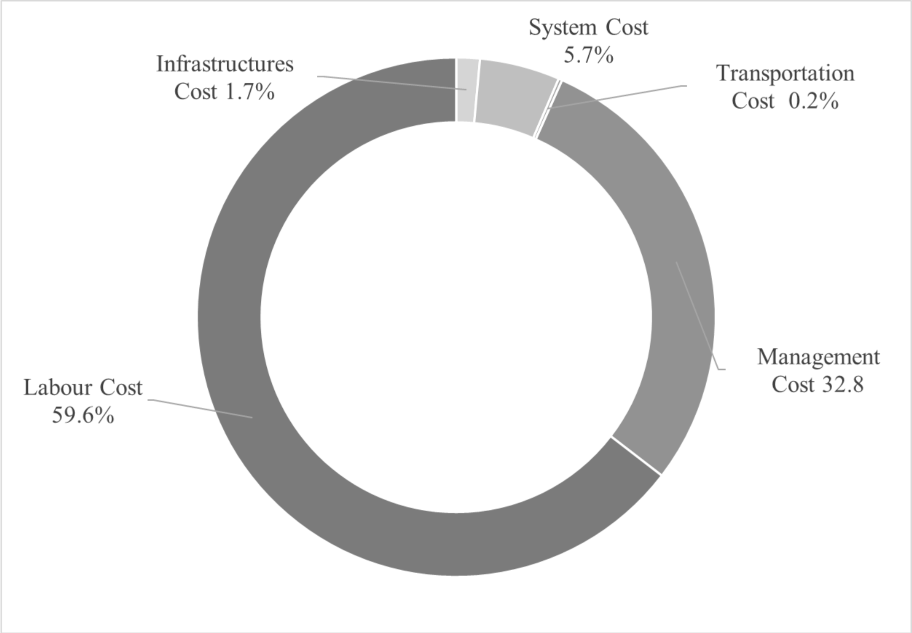
* Not considered in all the applications presented here



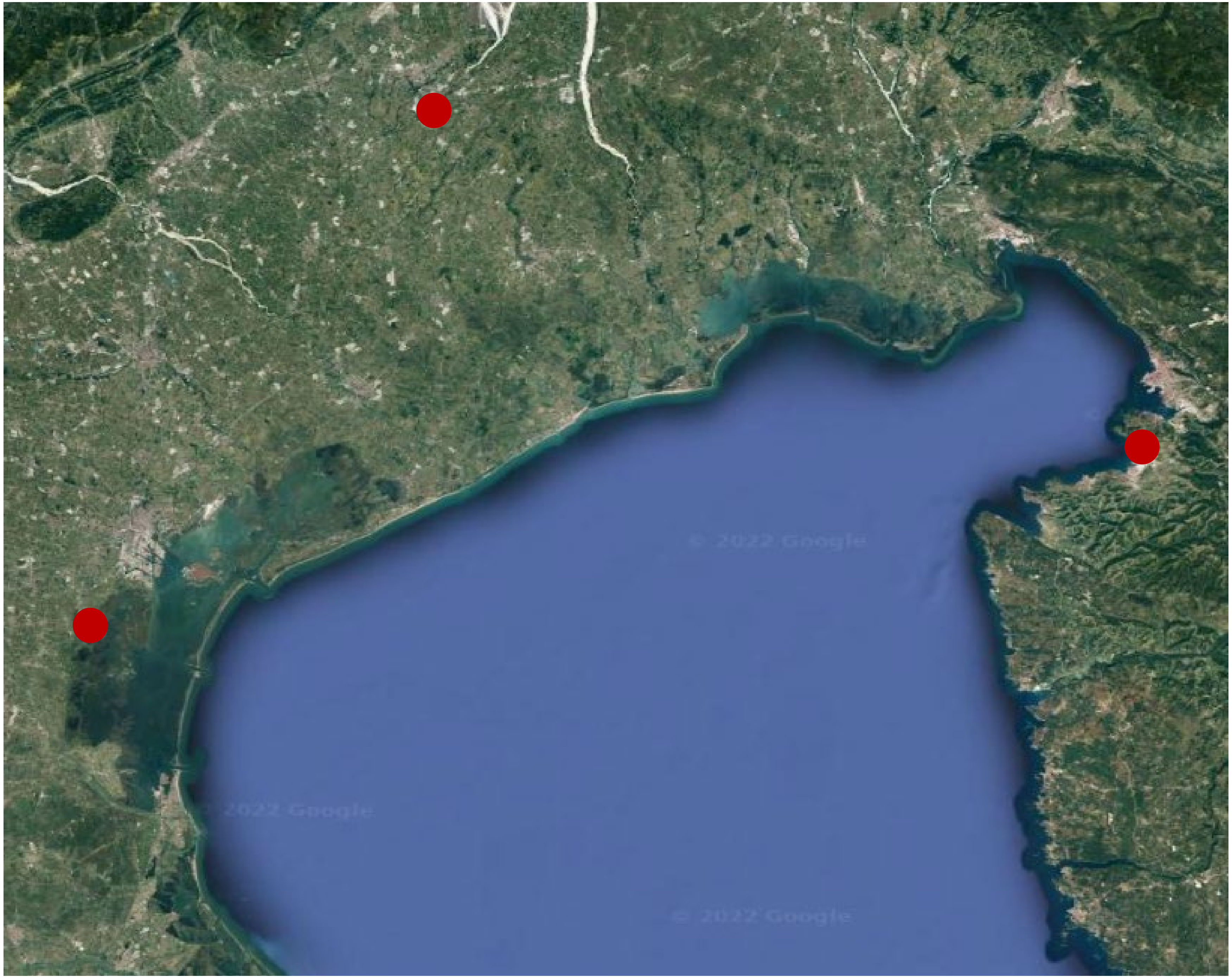


From May 2017 to July 2017, no mortality was recorded for plants and 60.9 kg of lettuce were harvested. During this period, fish were fed with a total of 36.7 kg of feed, resulting in a 22.2 kg increase in biomass, with a calculated Feed Conversion Ratio (FCR) of 1.65. The recorded tench mortality was 1.5% on a weight basis.

LCC analysis estimates a total cost of 7.38 euro to produce 1 kg of lettuce in the aquaponic pilot system.



Differences in design?? (farmed species, infrastructure, tech level)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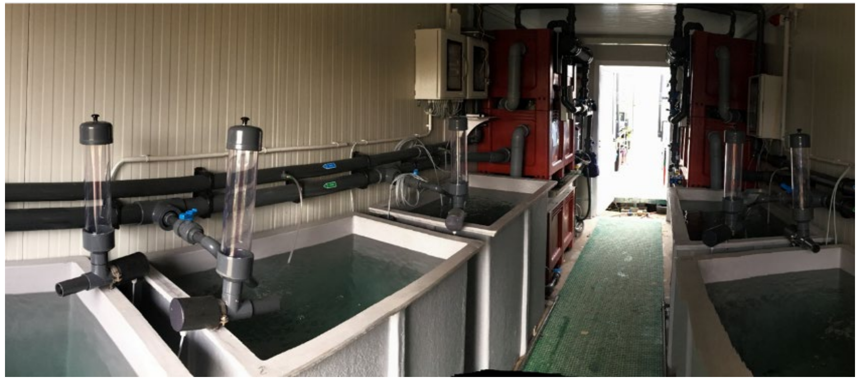
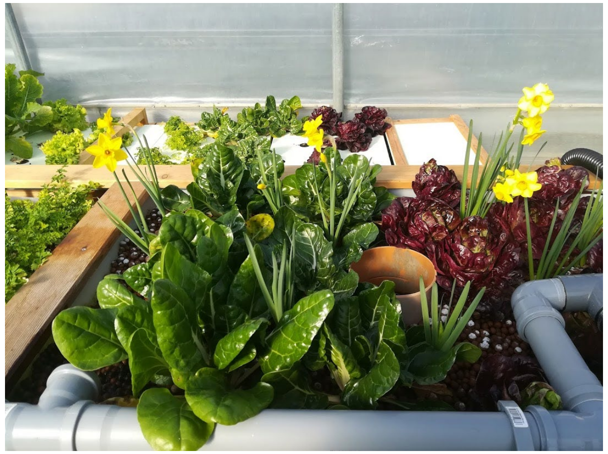
Porcia (Agroittica Friulana)



Koper (KZ-Agraria)



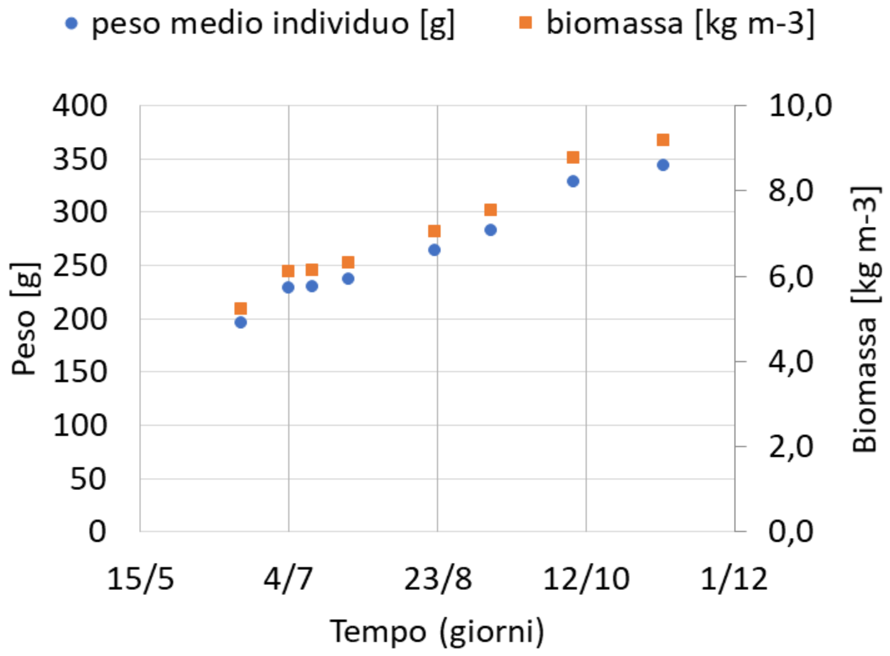
\+ tech → - tech

	Porcia	Koper
Infrastructure	6+6 m containers	Existing greenhouse
cultivation system	DWC; MFB; NFT	DWC; MFB; NFT
Number of production lines	2	1
Fish tanks volume	3.6 m^3	Fish tanks 2 m^3
Growth beds surface	10 m^2	10m^2
Fish species	Striped bass Tench	Common carp Perch
Solids removal	Sand filter	Mechanical filter (vortex)
Temperature control	Heating and cooling	No

Porcia	Koper
Lettuce	Lettuce
Basil	Basil
Barbatelle di vite – grape roots	Cauliflower
Green zucchini	Radicchio
Cucumber	
Cauliflower	
Red chard	
Red turnip	
Fennel	
Chicory	
Radicchio	
Coriander	
Mint	

Growth cycle stabilized and monitored for LCA purpose for approximately 6 months

Example, striped bass + lettuce in Porcia

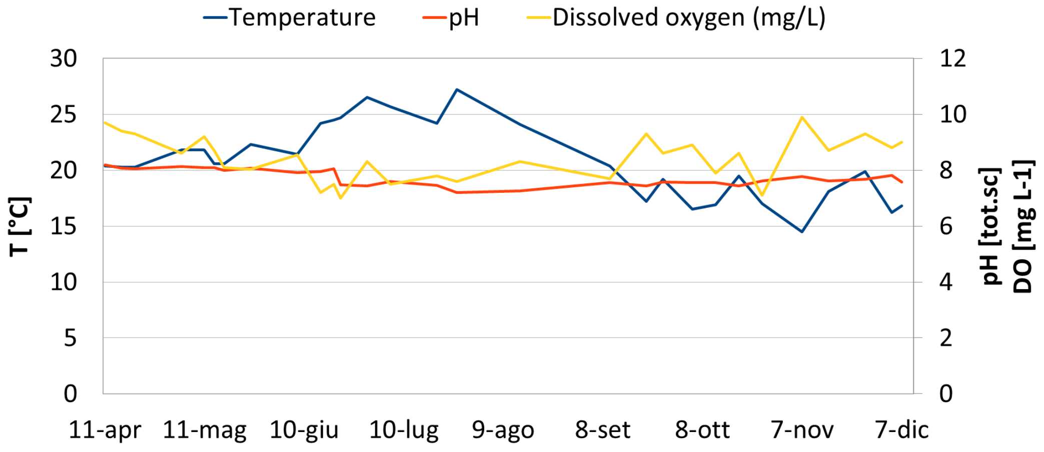


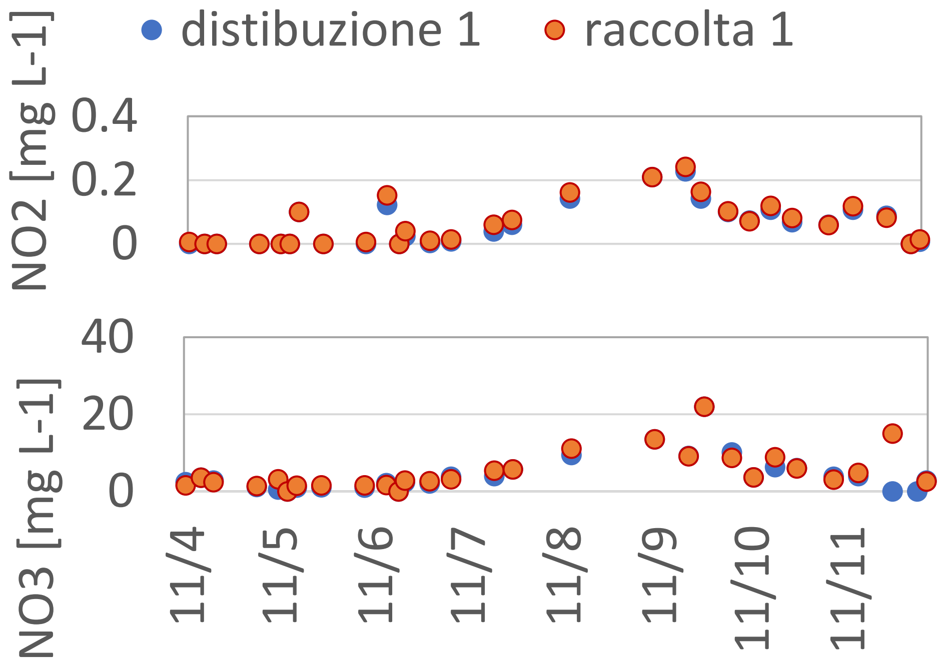
Overall good conditions – no mortality

Plants ok

Low Fe

High energy demand for conditioning





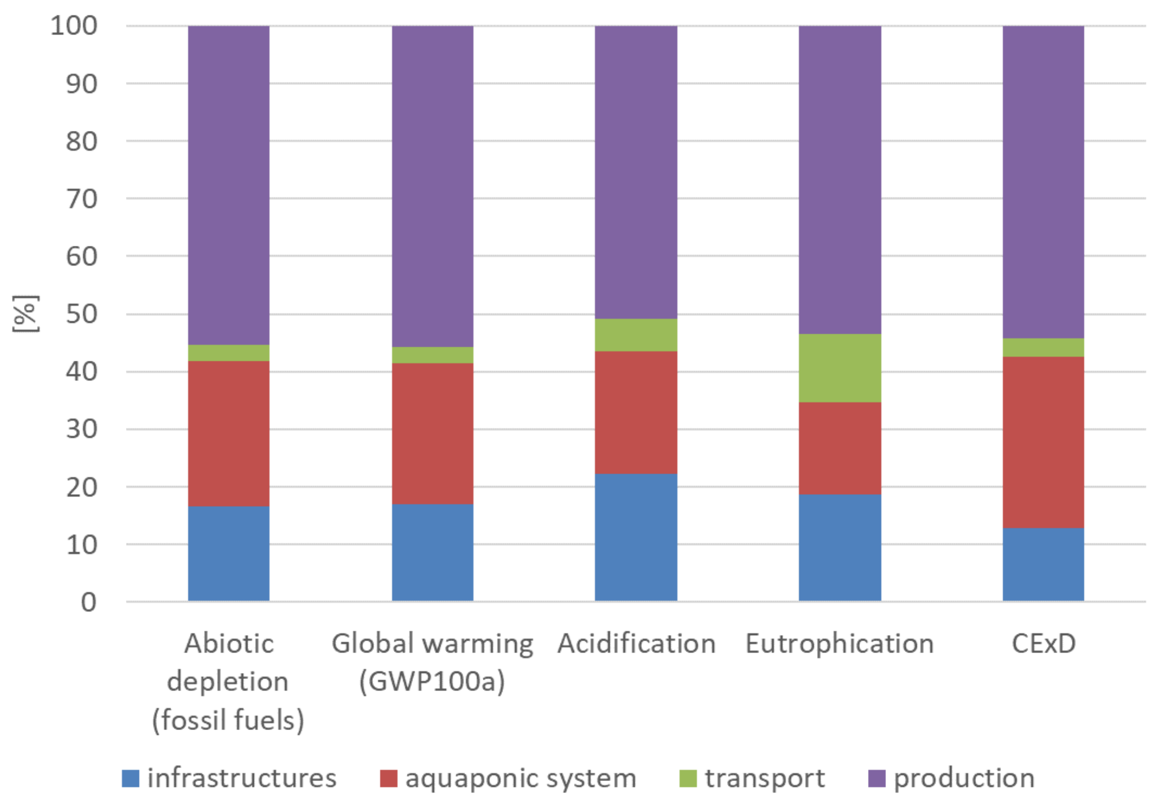
Additional variables monitored:

Ca^{2+}	Mg^{2+}	Carb.	Cl^{-}	K^{+}	SO_4^{2-}	Fe^{2+}	PO4

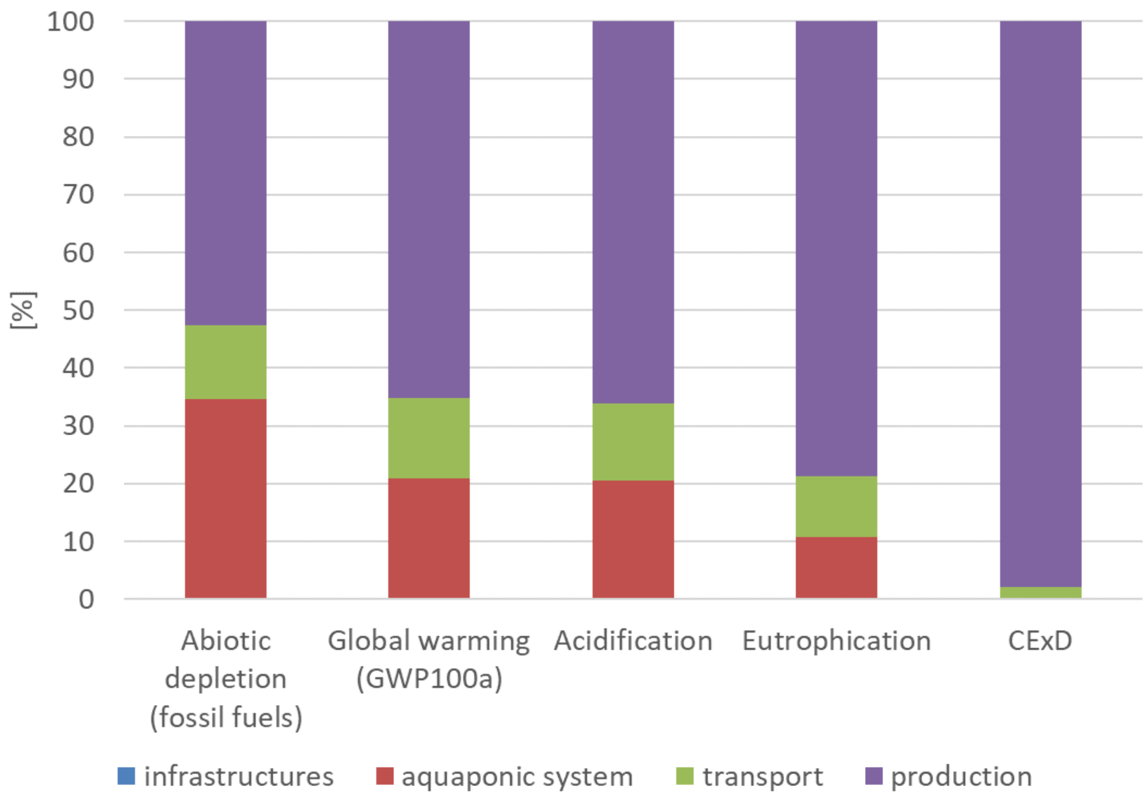
C:N:P sludge	Solids – suspended/sedimented

INTERREG ITALIA-SLOVENIJA BLUEGRASS — UNIONE EUROPEA EVROPSKA UNIJA

Porcia – Striped bass

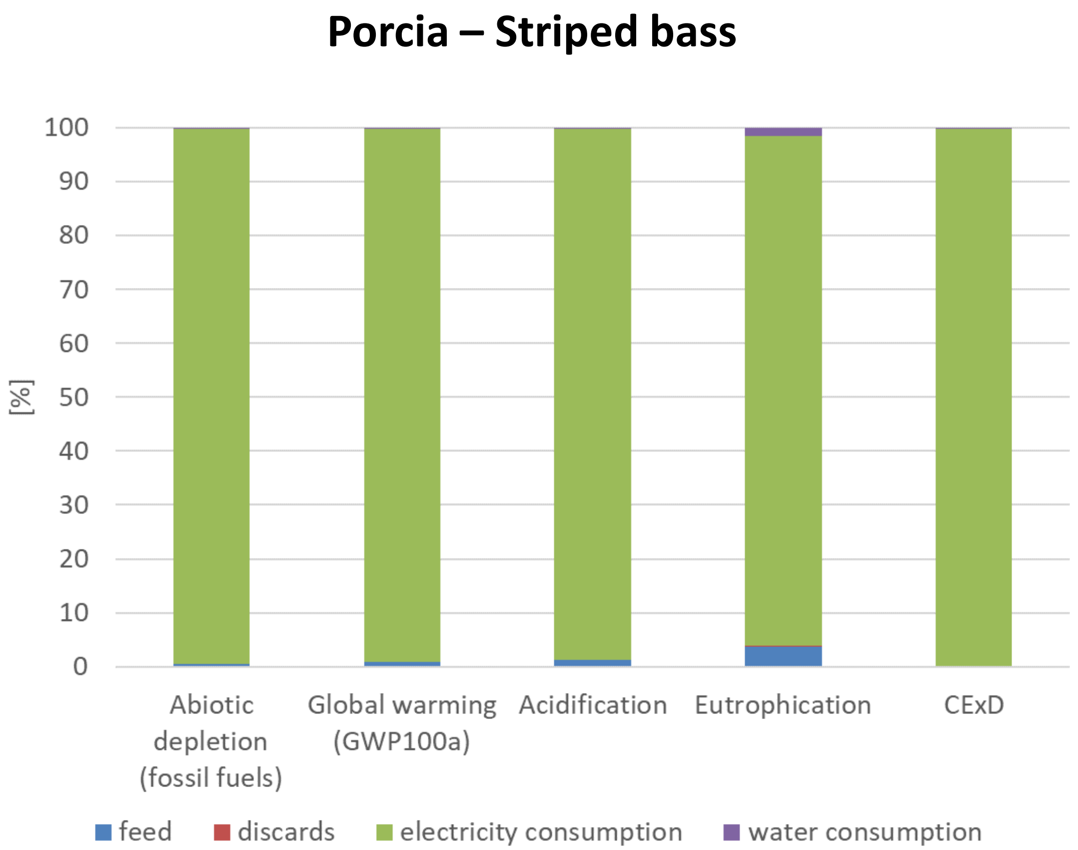


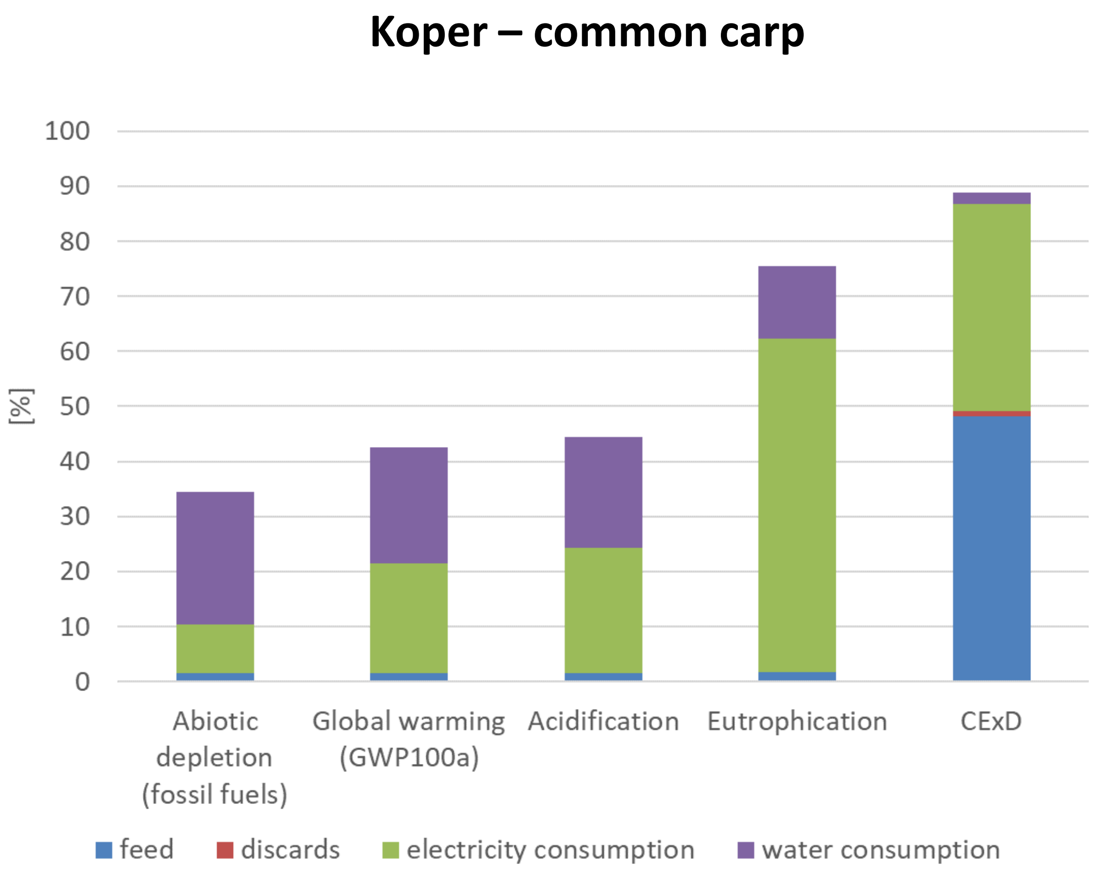
Koper – common carp



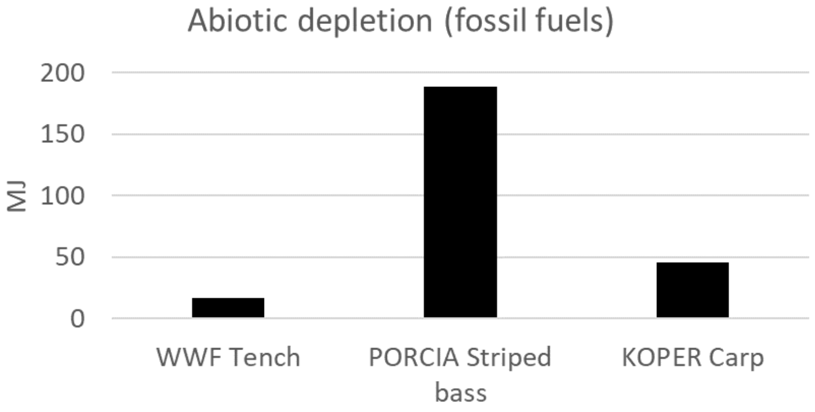
Duration of the production cycle
Stability of farming conditions
Life span of infrastructures and aquaponic system
Estimated cost of 1 kg of lettuce: **€ 4.06** Koper; **€ 12.8** Porcia !!

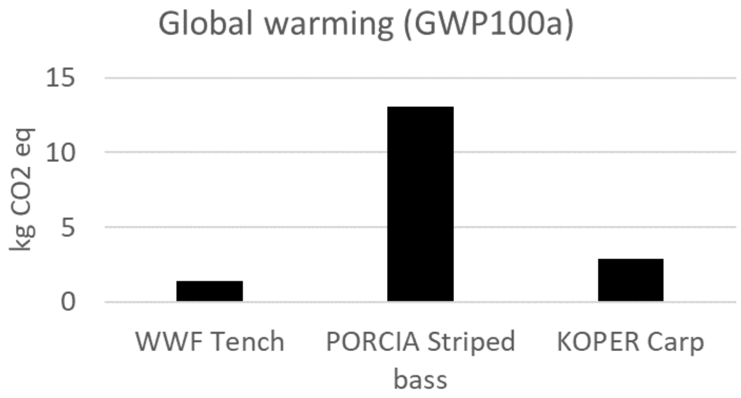
Production

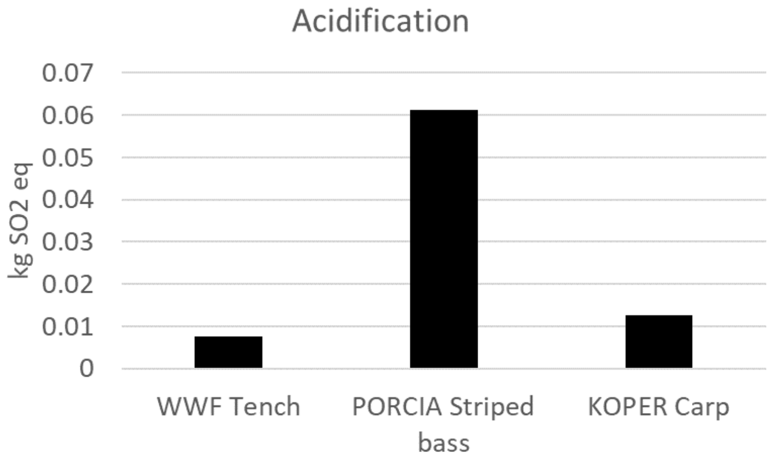

Porcia – Striped bass
100
90
80
70
60
50
40
30
20
10
0
[%]
Abiotic depletion (fossil fuels)
Global warming (GWP100a)
Acidification
Eutrophication
CExD
feed
discards
electricity consumption
water consumption

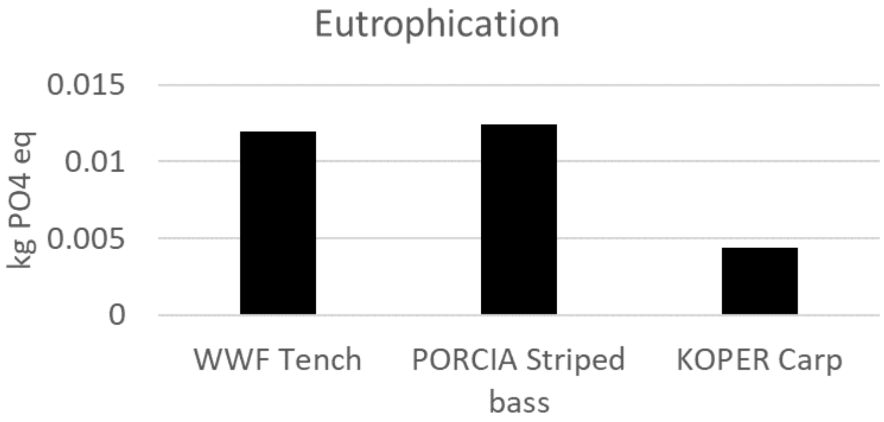

Koper – common carp
100
90
80
70
60
50
40
30
20
10
0
[%]
Abiotic depletion (fossil fuels)
Global warming (GWP100a)
Acidification
Eutrophication
CExD
feed
discards
electricity consumption
water consumption

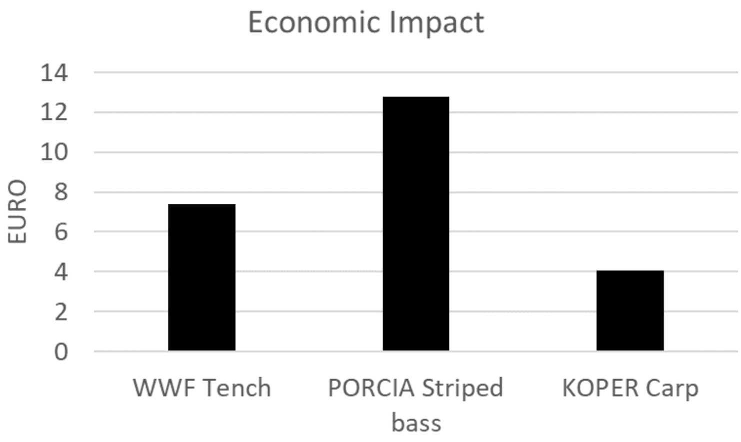
Comparing absolute values

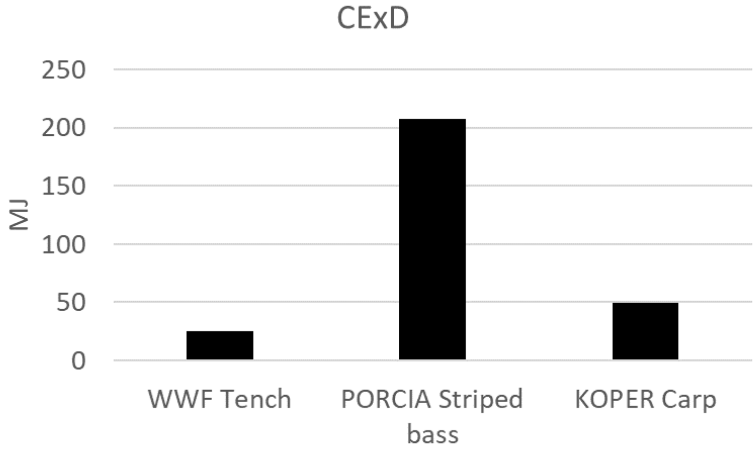




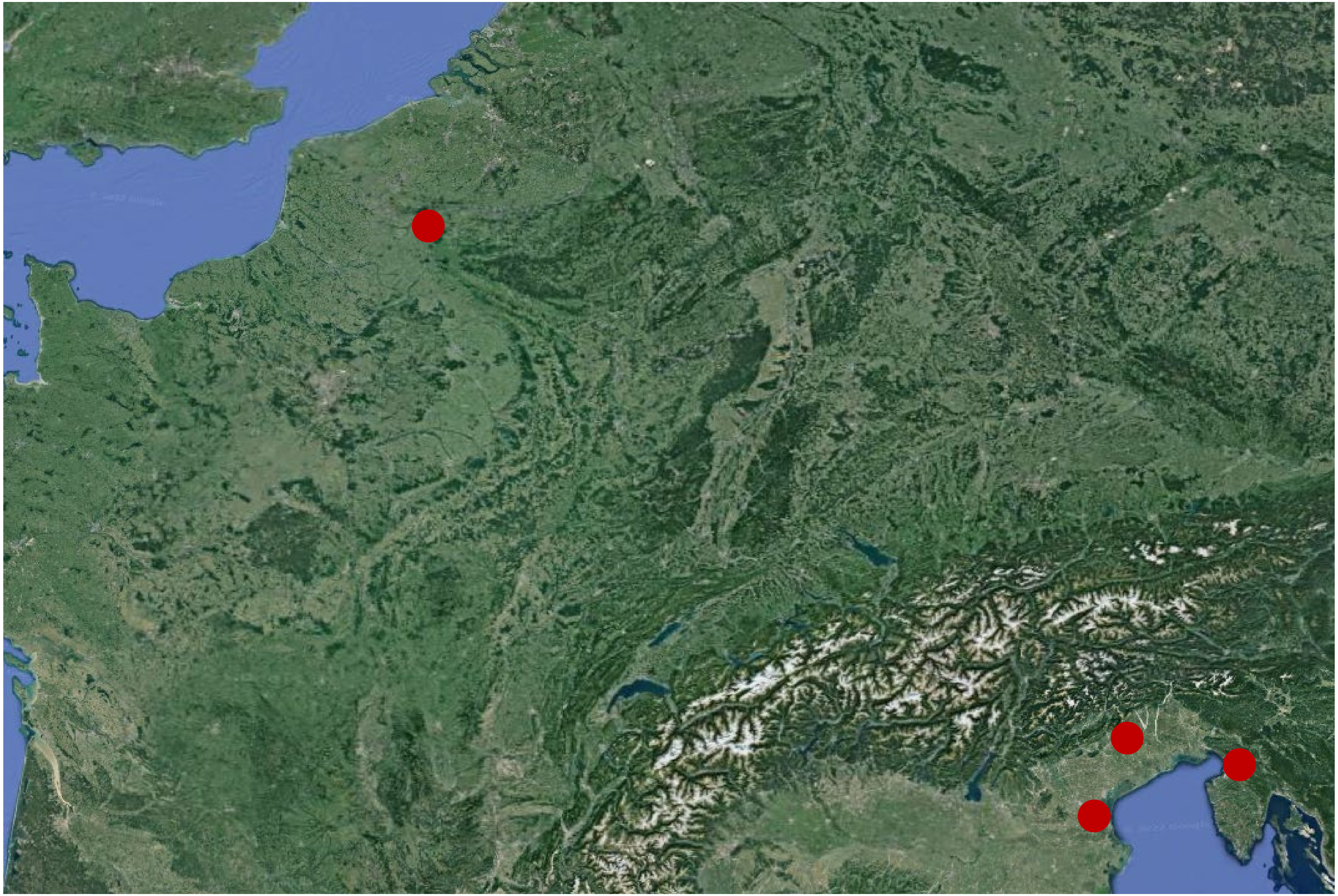








what about stability of the production in the longer term ??



Perciponie

Développement de la perciculture en aquaponie

BlueFarm

UNIVERSITÉ DE LORRAINE INRAE laboratoire agronomie et environnement UR AFPA UNITÉ DE RECHERCHE ANIMAL & FONCTIONNALITÉS DES PRODUITS ANIMAUX

LIÈGE université

CERER PISCICULTURE ASBL

htw saar

Interreg EUROPEAN UNION
Grande Région | Großregion
Perciponie
Fonds européen de développement régional | Europäischer Fonds für regionale Entwicklung

FAGE Filière Aquacole Du Grand-Est

Pays des Condruses Groupe d'Action Locale

COMMUNE DE MARCHIN

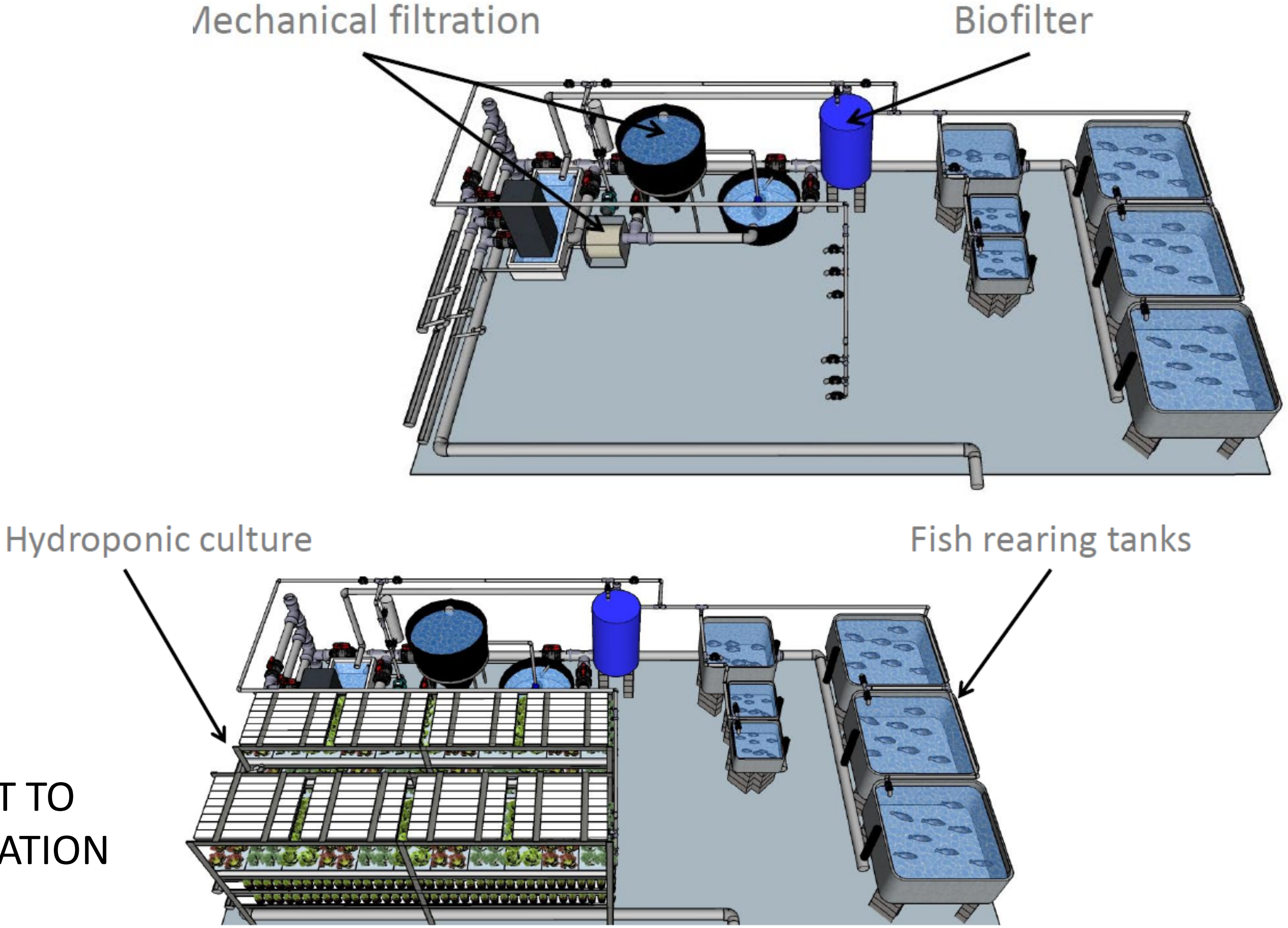
SEAWATER

LUXINNOVATION TRUSTED PARTNER FOR BUSINESS

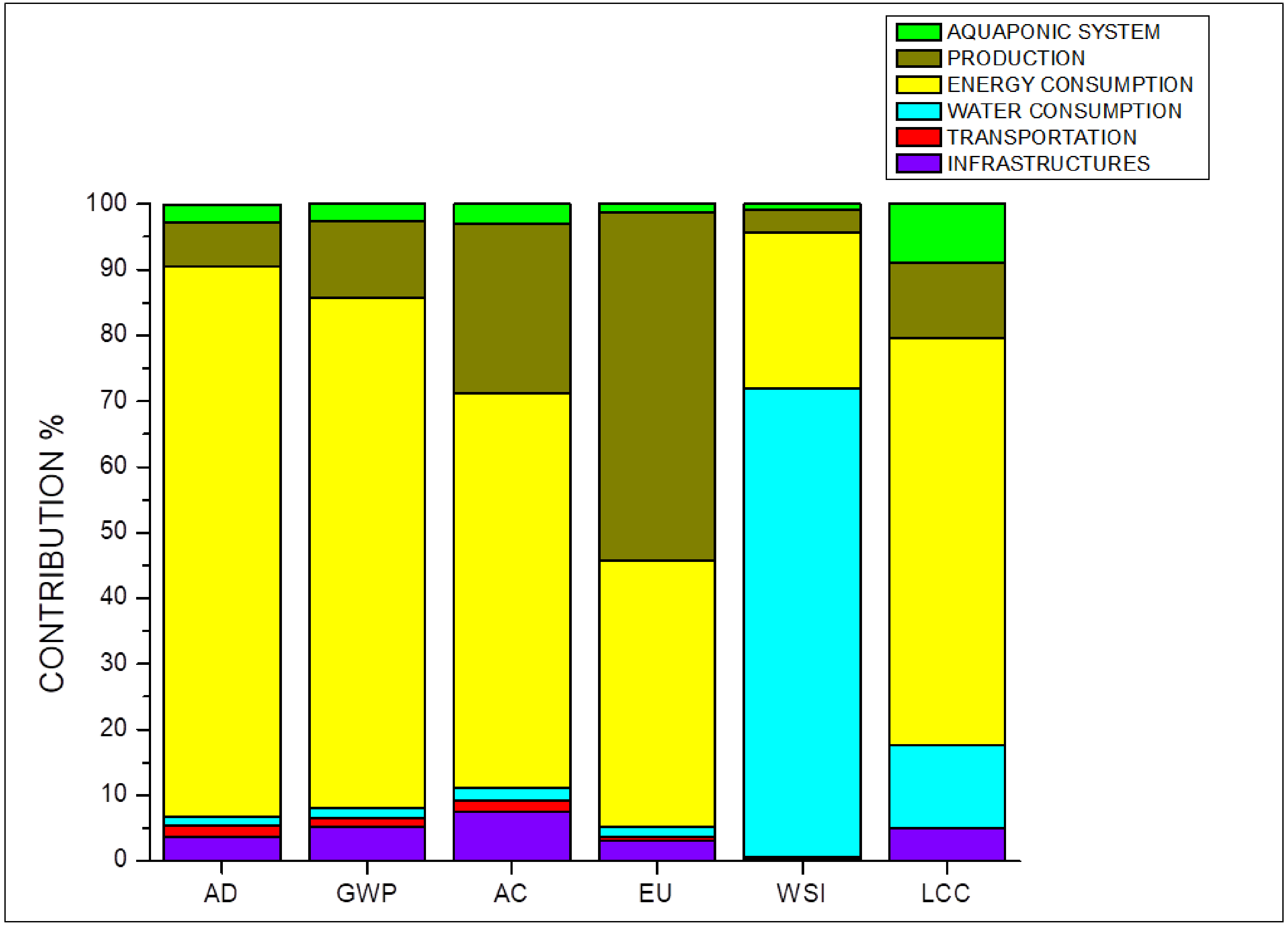
FEDER UNION EUROPEENNE
Wallonie
LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

CERER AQUAPONIC SYSTEM

- LOCATION: STREE, BELGIUM
- INDOOR SYSTEM
- FISH TANKS TOTAL VOLUME: 6.4 m^3
- GROW BEDS TOTAL SURFACE: 50 m^2
- IN OPERATION SINCE 2019
- DETAILED PRIMARY DATA WITH RESPECT TO BUILDING MATERIALS AND TRANSPORTATION
- PRIMARY DATA FOR SYSTEM FUNCTIONING (>1 YEAR BOTH FOR TILAPIA AND PIKEPERCH) annual production 211-553 kg fish, 1194-1680 kg vegetables



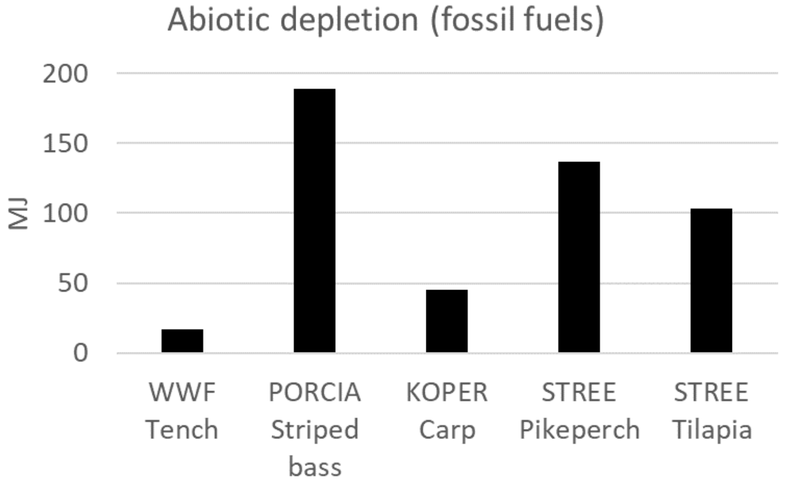
BlueFarm CERER PISCICULTURE ASBL Interreg Grande Région | Großregion Perciponie
Fonds européen de développement régional | Europäischer Fonds für regionale Entwicklung

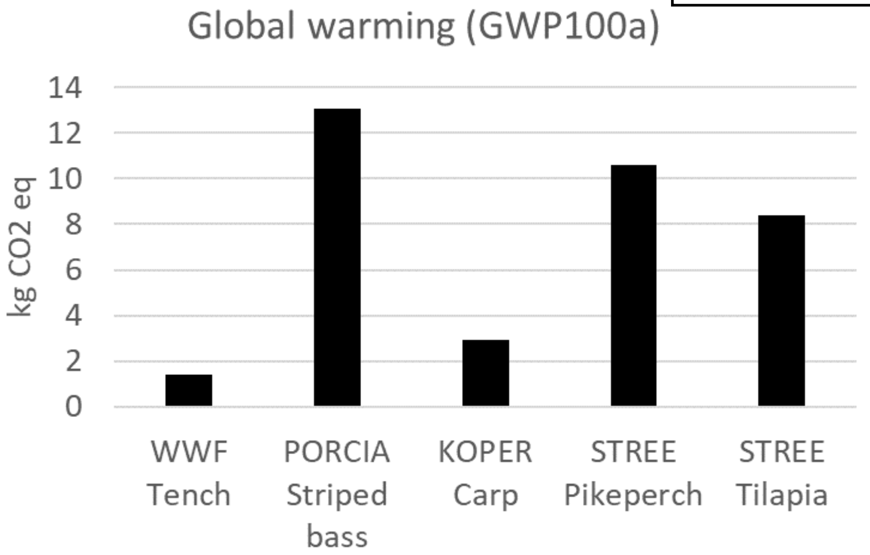


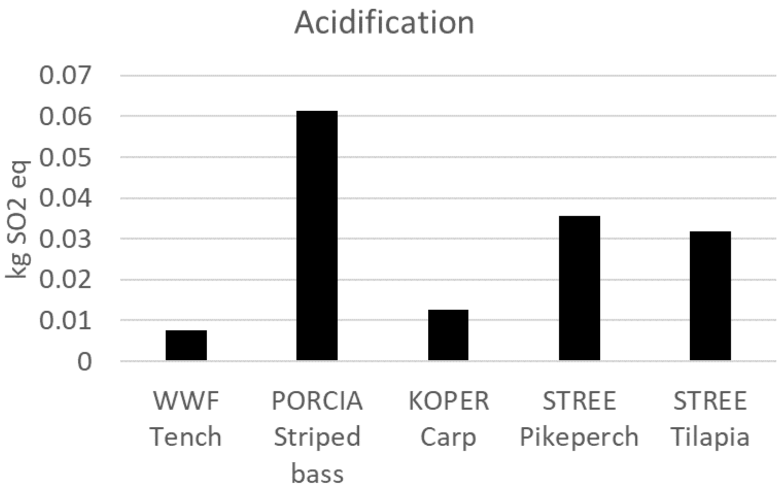
Aggregated differently; energy consumption highly relevant; comparison between different production models in the same system; Estimated cost of 1 kg of lettuce: € 14.35 Pikeperch; € 9.65 Tilapia

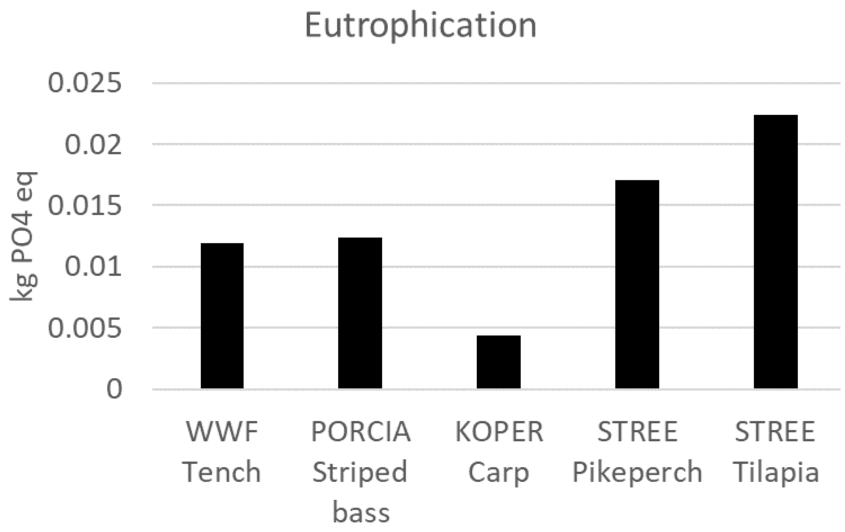
Comparing absolute values

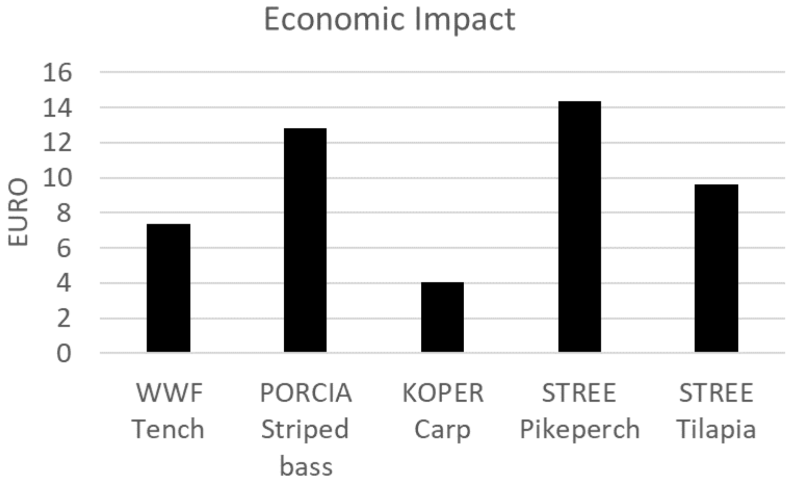
WWFT: 26.82F; 73.18V
PSB: 12.8F; 87.2V
KOPC: 9.8F; 90.2V
SP: 14.95F; 85.05V
ST: 24.76F; 75.24V

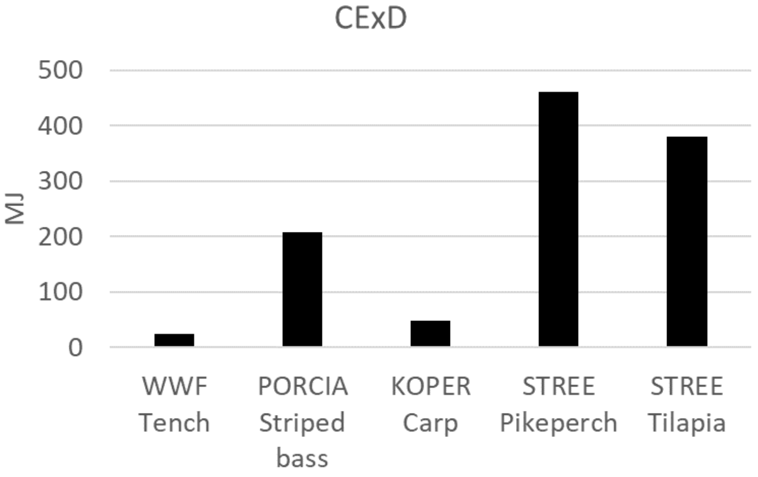








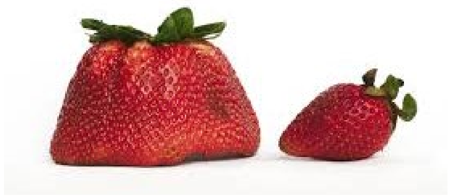




A classification of aquaponics according to different design principles.

Design goal	Categories
Objective or main stakeholder	Commercial crop production Household sufficiency Education Social enterprise Greening and decoration
Size	L large (>1000 m^2) M medium (200–1000 m^2) S small (50–200 m^2) XS very small (5–50 m^2) XXS micro systems (<5 m^2)

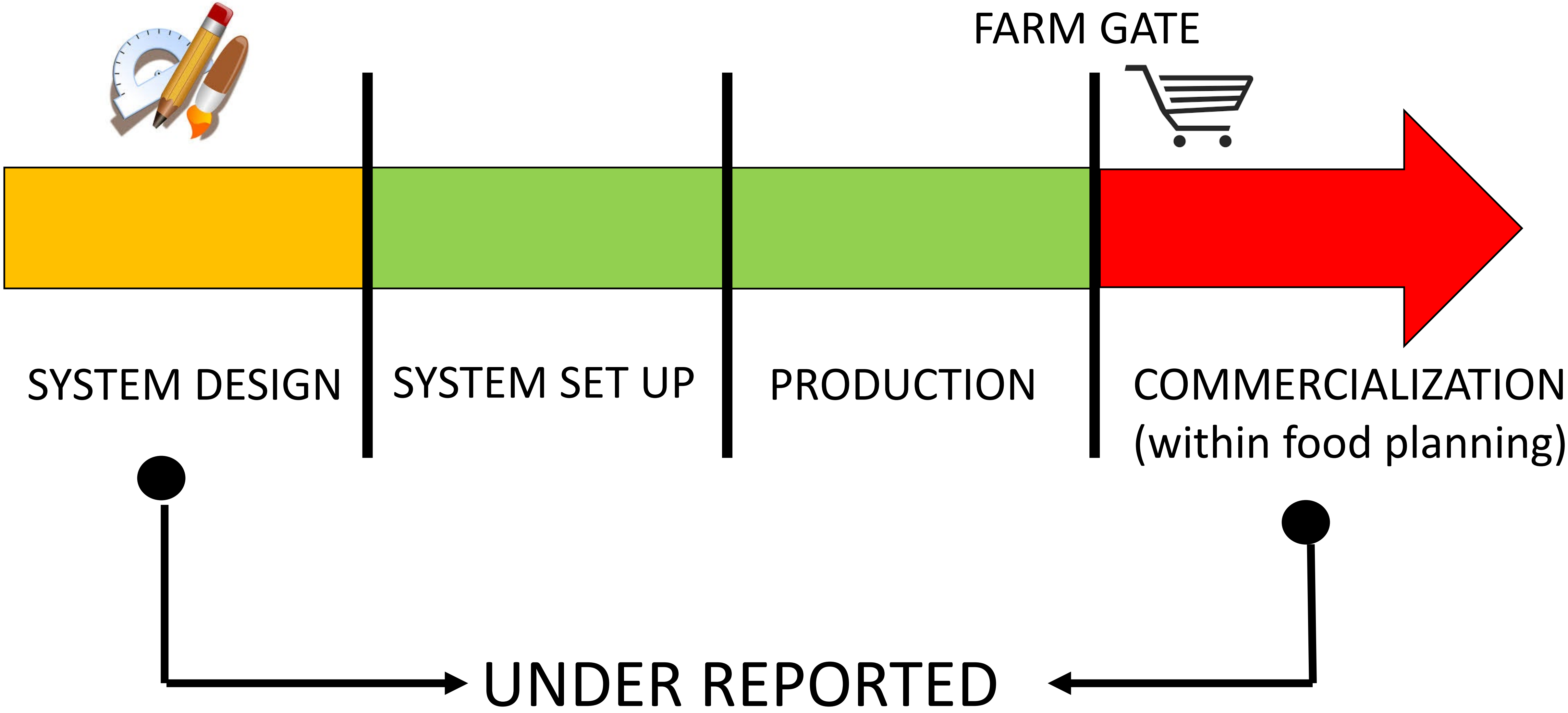
Maucieri et al., 2018. Journal of Cleaner Production 172: 3119-3127



Mostly, LCA studies has been performed on XXS or XS aquaponics systems

Scaling issues and difficulties to extend the results…

LCA and the different steps of the process



Concluding remarks

- Possibility to cross-compare systems is good (methodology issues; no «one size fits all» sistem);
- Importance of system «stability» for LCA (operational over a wide time frame);
- Low tech vs High tech and seasonality;
- Scaling of analysis to support larger systems design;
- Assessing sustainability by comparing aquaponics vs other production methods?
- Extending the set of assessment methods and/or impact categories?
- Screening LCA supporting system design and businness plan;
- Aquaponics in cities and LCA role in supporting urban food planning.

Thank you! (dbrigolin@iuav.it)

Special thanks to Andrea Alberto Forchino, Roberto Pastres, Elio Cannarsa, Vincent Gennotte

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Environmental assessment of circular systems: Questions and results of LCA application in SIMTAP

Joël Aubin (INRAE), Michele Zoli (UniMi)
Jacopo Bacenetti, Lorenzo Rossi, Carlo Bibbiani, Baldassare Fronte, Aurélie Wilfart, Christophe Jaeger, Mehmet-Ali Koçer, Huseyin Sevgili, et al.

The PRIMA programme is supported under Horizon 2020, the European Union's Framework Programme for Research and Innovation

European Commission

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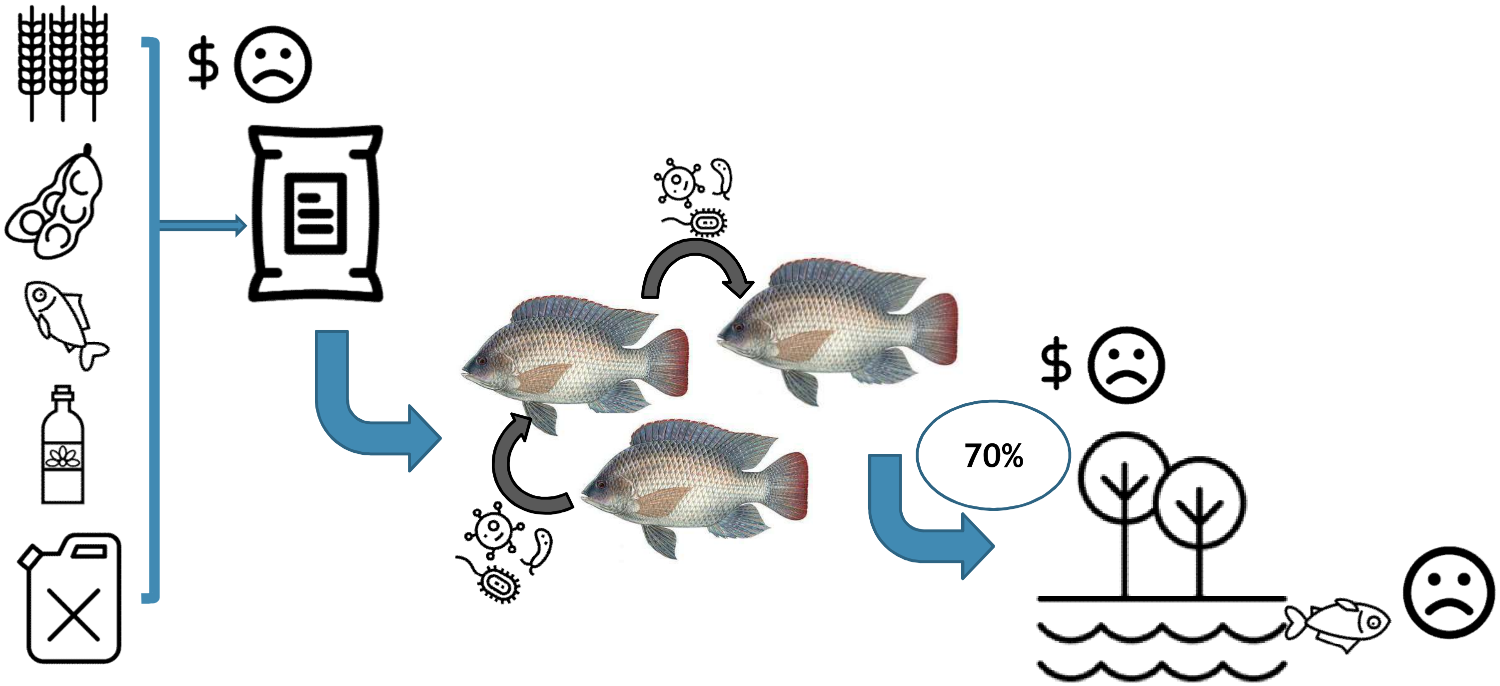
Modern linear aquaculture



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Guide the change

Proposing new circular aquaculture systems seems a good approach to solve the nutrient loss hot spot.

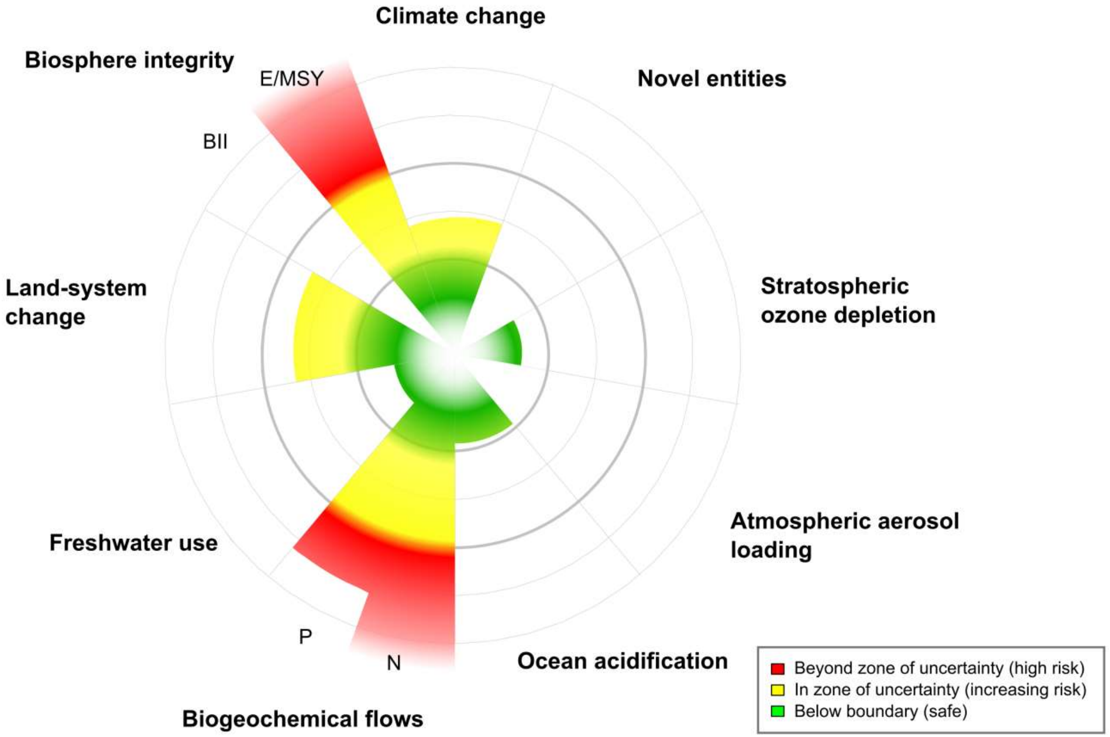
How can we be sure that we will not induce environmental impact transfers?

How can we be sure that the environmental gains are superior to the costs?

In SIMTAP project :

- **Life Cycle Assessment**

- Multicriteria decision analysis - Dexi



Steffen et al. (2015)

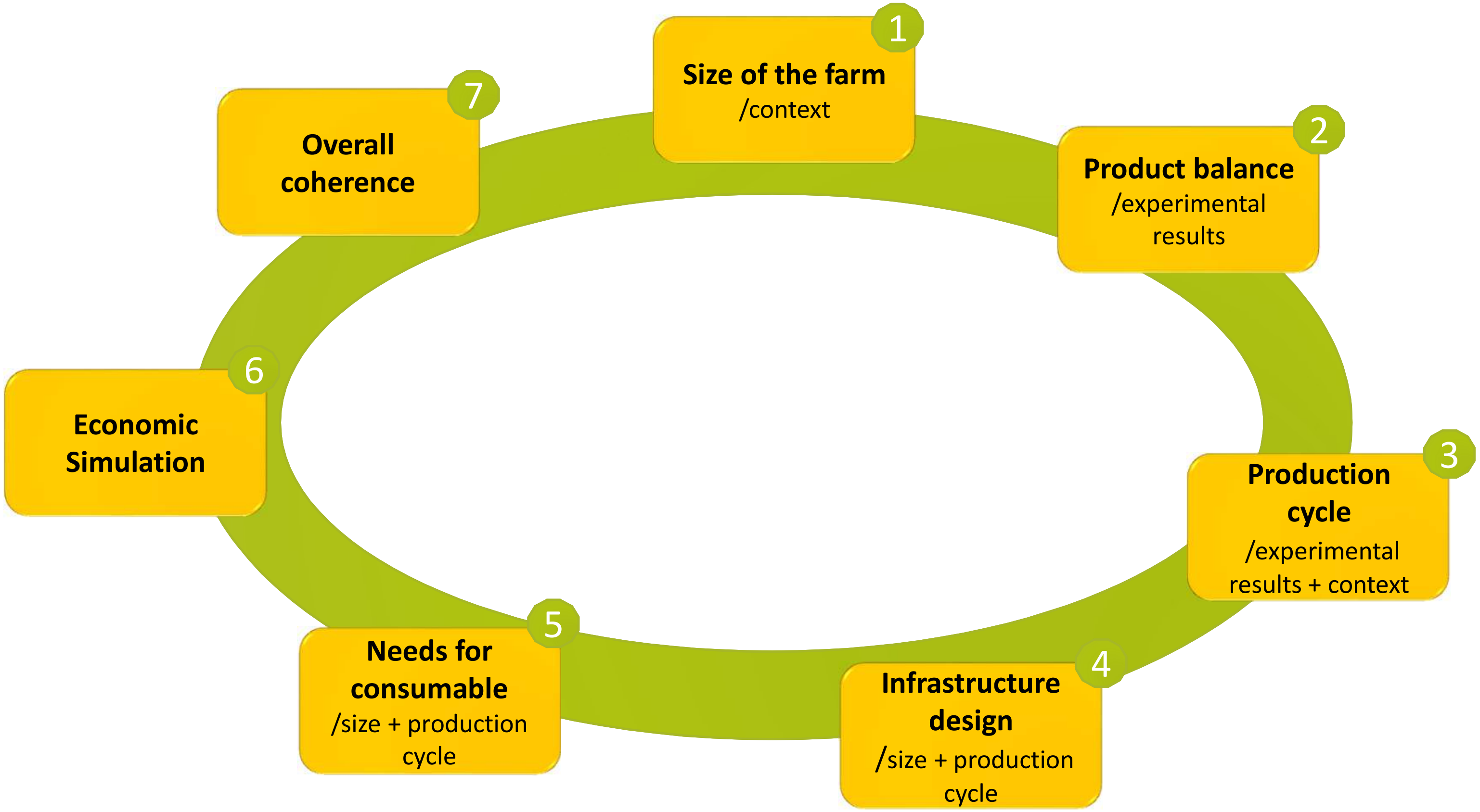
LCA application in experimental framework

… rises several questions:

- How to propose an upscaling of experimental results to an economic scale?
- As there is no reference value in LCA, how to conduct a fair comparision with reference systems?
- What is the most appropriate functional unit for multiple-outputs systems?
- …

=> solutions used in SIMTAP project

A framework to guide upscaling



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Choosing the adequate reference

- Choosing a reference system in the same area (climate, economic, social and physical contexts)
- Producing the same main target species
- Reflecting the conventional practices

- Illustration : the Italian SIMTAP and references case studies

- Comparison on the basis of 2 functional units agregating the different products in a single function:
  - Feeding people: kCal
  - Earning money: 1000 € turnover

Reference systems

Offhsore plants

Italian commercial farm
Turkish commercial farm

Primary data: feed composition and consumption; quantity of “seeded” fry; energy consumption (electricity, fuel for boat fleet management); mortality; oxygen consumption; productive yield.

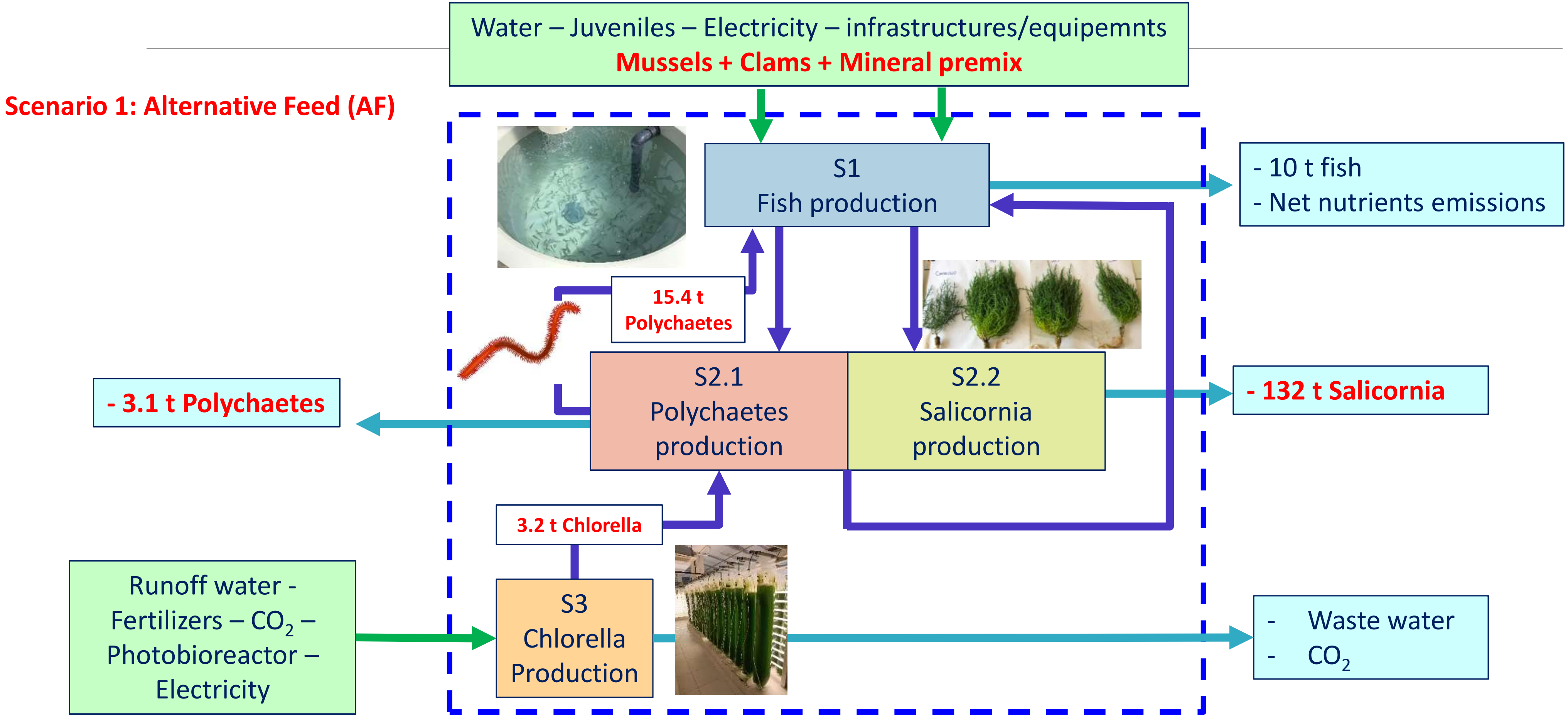
Secondary data: nutrient emissions by fish metabolism (mass balance, solid and dissolved N&P estimated based on: i) amount supplied by feed and amount assimilated; ii) digestibility of feed components, iii) not ingested feed, iv) fish mortality, v) fry composition) & Emissions due to fuel combustion.

Mix of primary and secondary data for sea cage (energy and materials consumption for manufacturing, lifespan, diesel for maintenance), pump, fishing vessel and equipment.

Inland plant

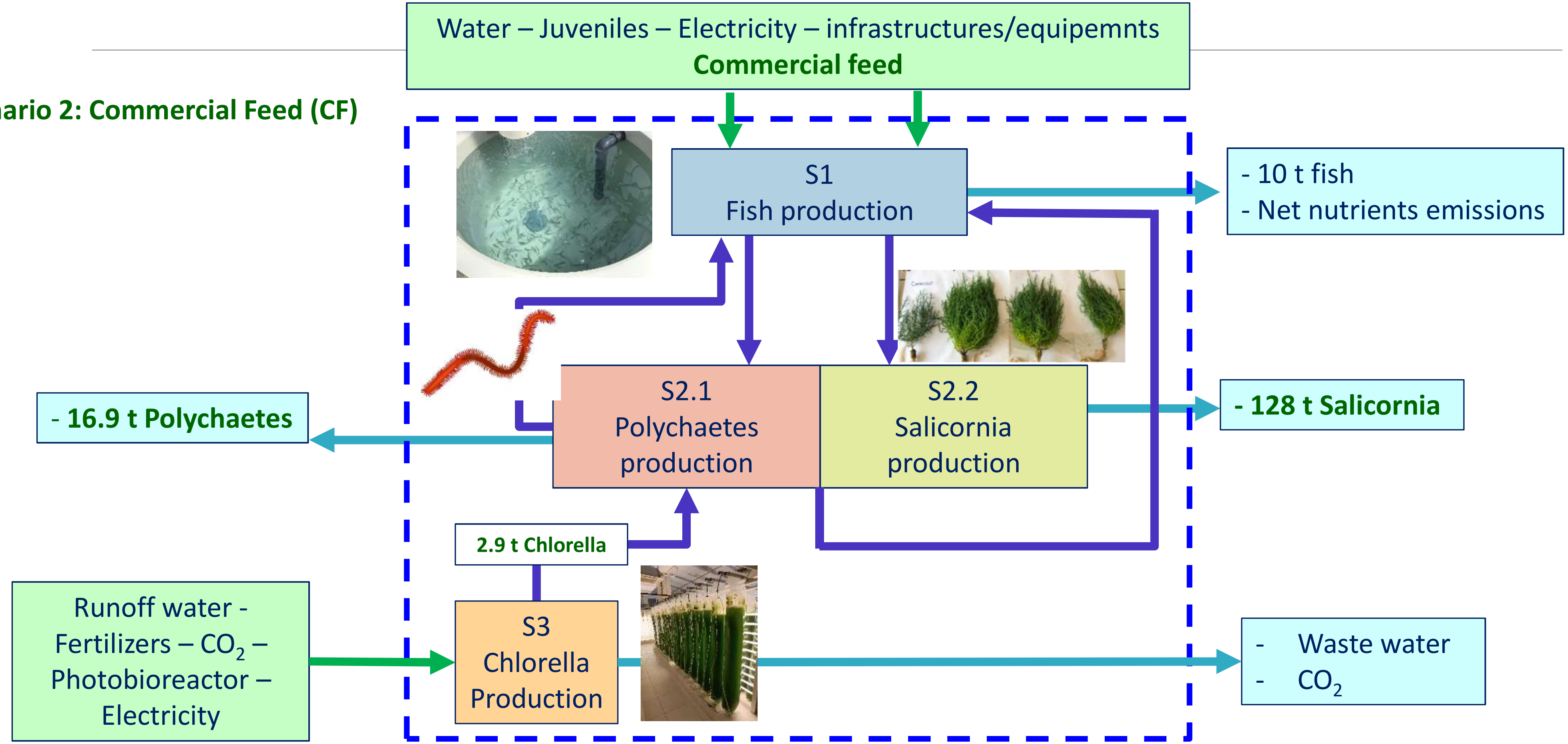
Italian commercial farm

SIMTAP System



SIMTAP System

Scenario 2: Commercial Feed (CF)



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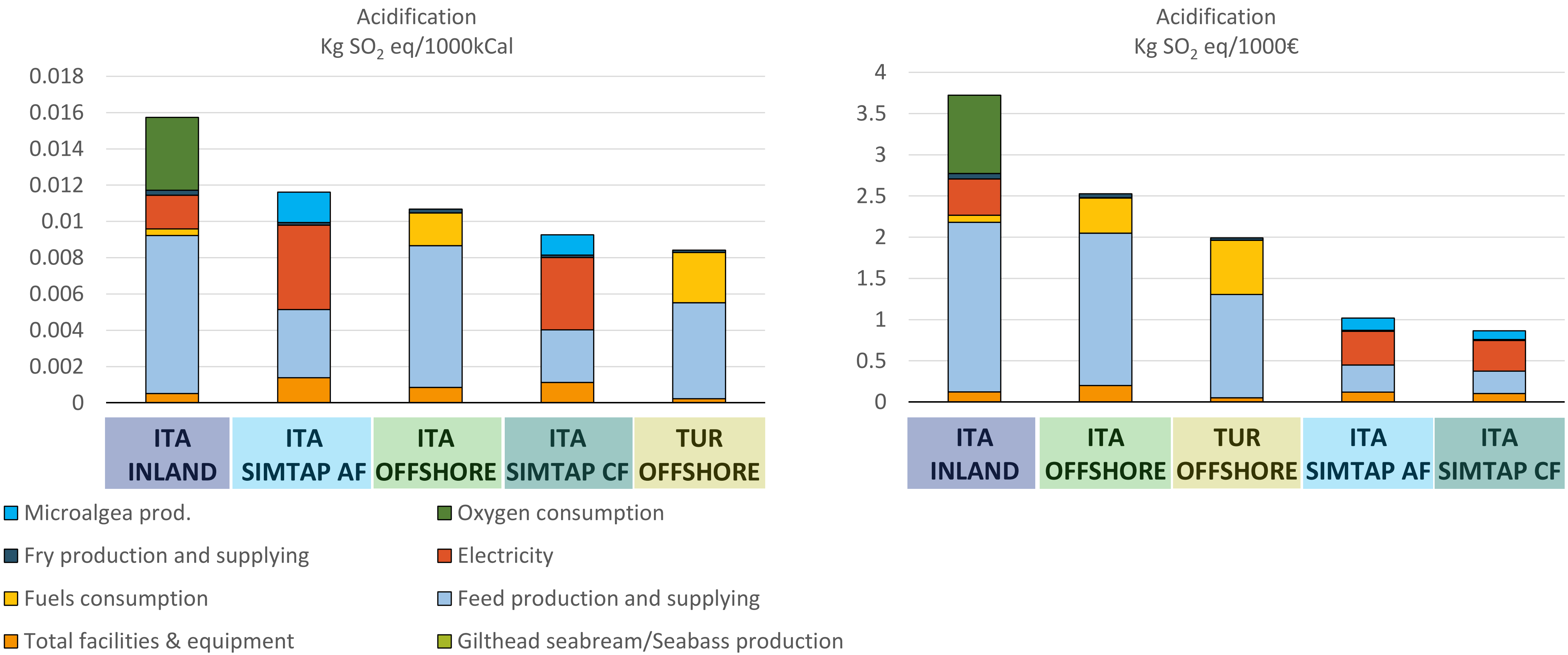
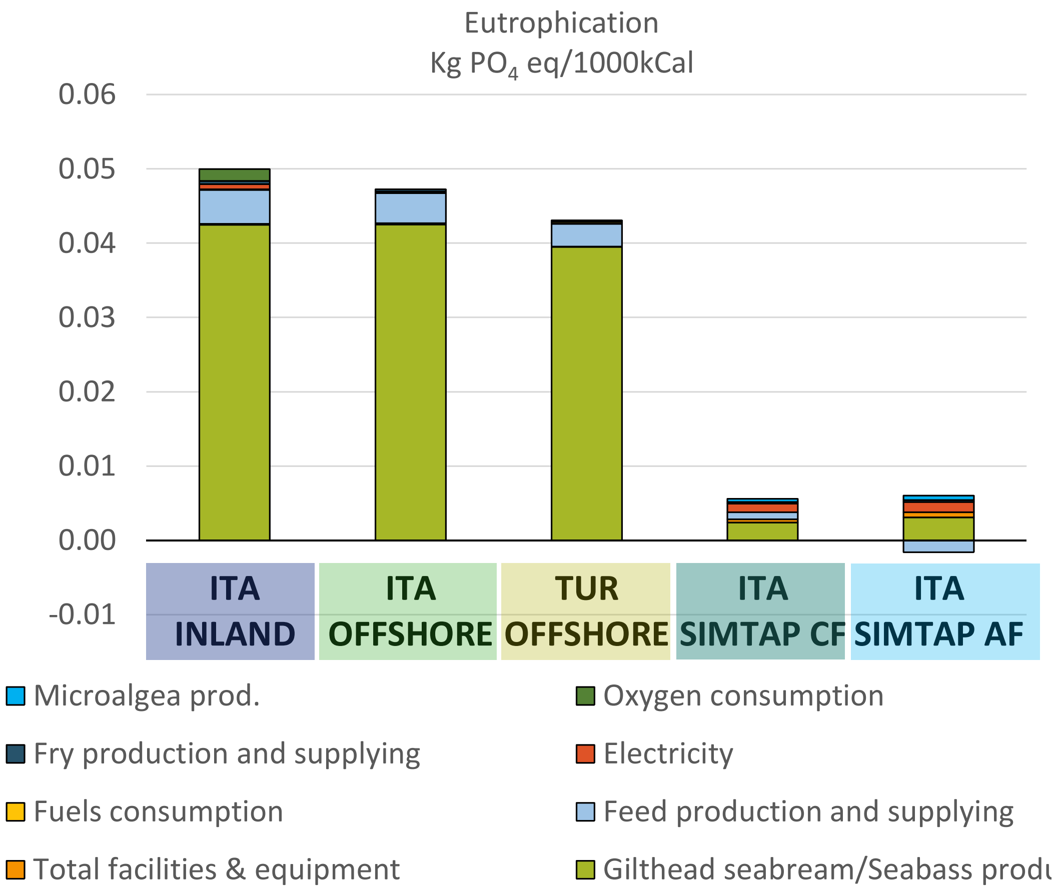
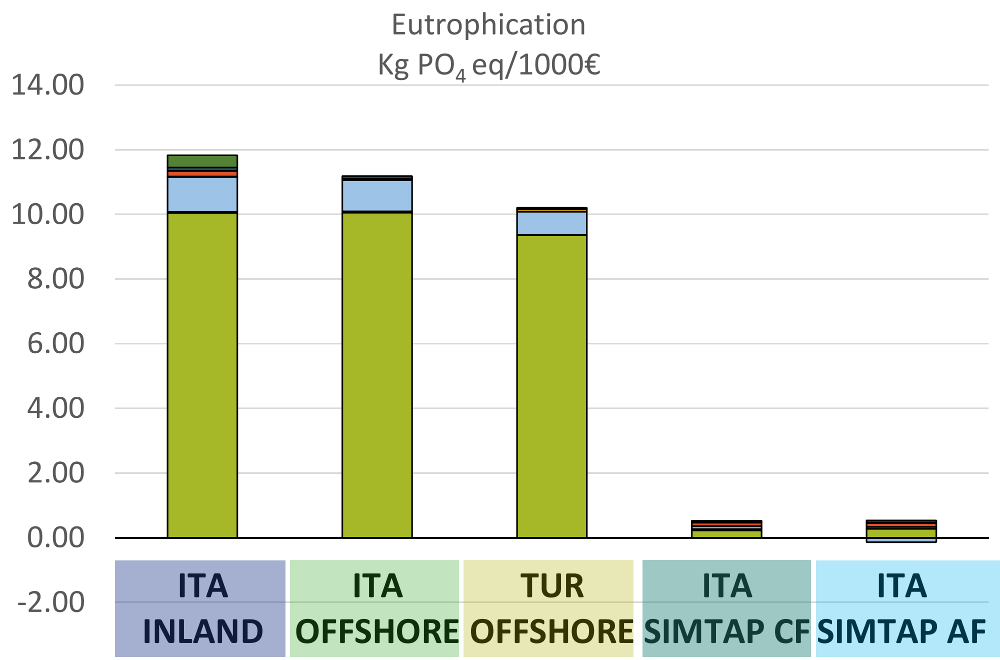
LCA Results



LCA Results



Eutrophication
Kg PO_4 eq/1000kCal
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
ITA INLAND
ITA OFFSHORE
TUR OFFSHORE
ITA SIMTAP CF
ITA SIMTAP AF
Microalgea prod.
Oxygen consumption
Fry production and supplying
Electricity
Fuels consumption
Feed production and supplying
Total facilities & equipment
Gilthead seabream/Seabass produ



Eutrophication
Kg PO_4 eq/1000€
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
ITA INLAND
ITA OFFSHORE
TUR OFFSHORE
ITA SIMTAP CF
ITA SIMTAP AF

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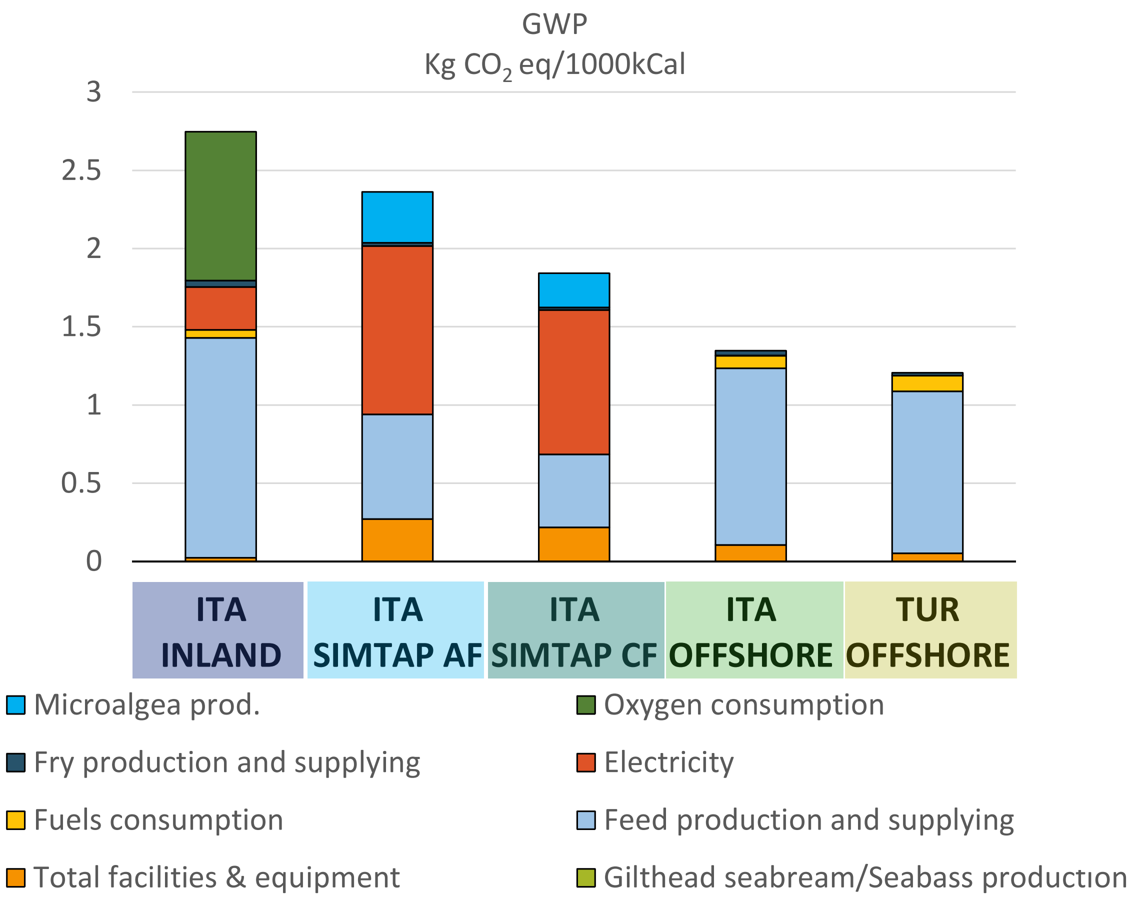
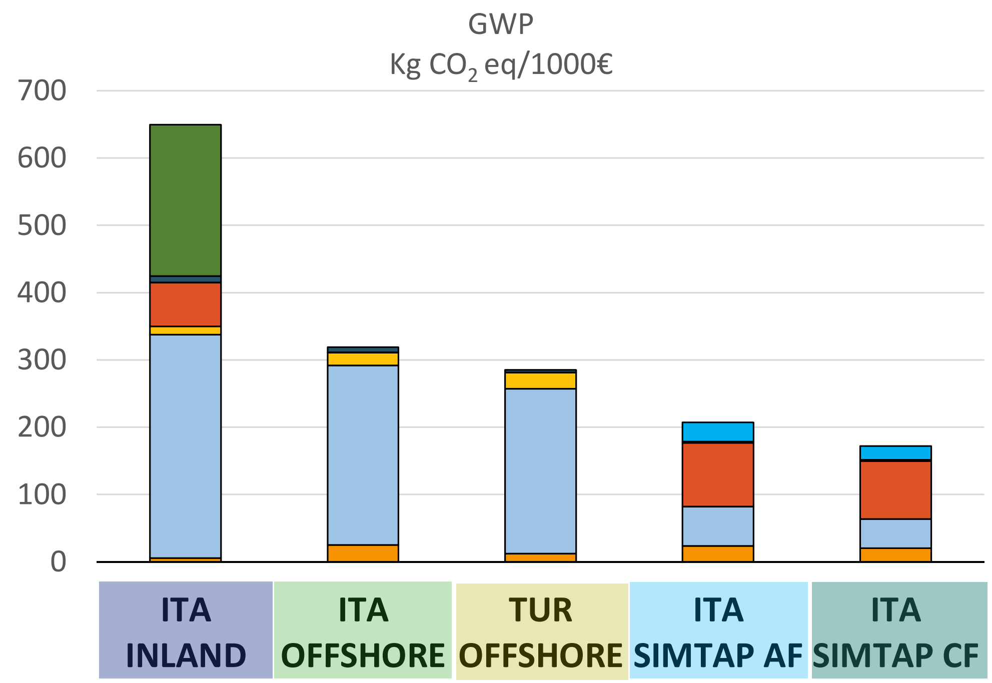
LCA Results





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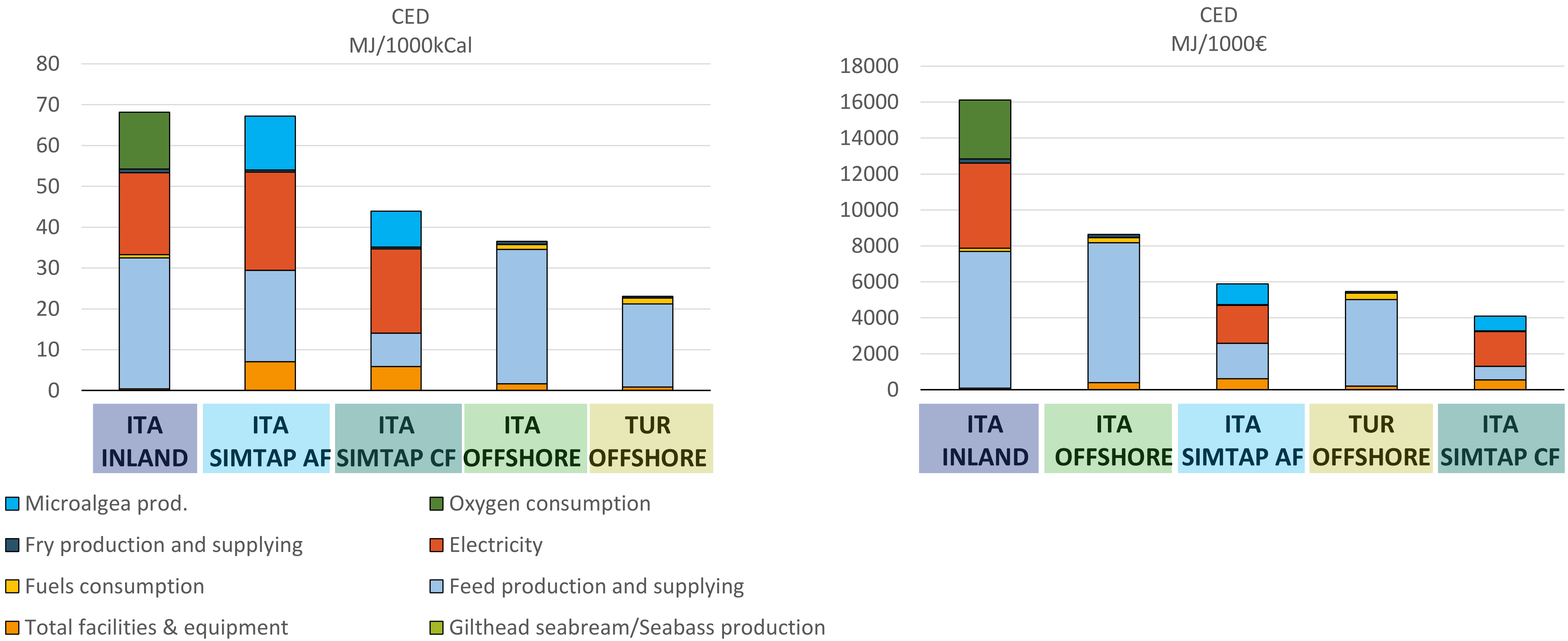
LCA Results


CED
MJ/1000kCal
80
70
60
50
40
30
20
10
0
ITA INLAND
ITA SIMTAP AF
ITA SIMTAP CF
ITA OFFSHORE
TUR OFFSHORE
CED
MJ/1000€
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
ITA INLAND
ITA OFFSHORE
ITA SIMTAP AF
TUR OFFSHORE
ITA SIMTAP CF
Microalgea prod.
Oxygen consumption
Fry production and supplying
Electricity
Fuels consumption
Feed production and supplying
Total facilities & equipment
Gilthead seabream/Seabass production

Lessons

LCA is a robust framework, but the devil is in the details

- The choice of function is not only communication, it reflects the assessment goal, and objectives of producers
- Our primary objective: improve fish culture and co-cultivation of halophytes; finally: 10 ton of fish but 130 t of salicornia! A real change in view point!
- SIMTAP has an important potential improvement in nutrient losses (eutrophication)
- There is a potential of improvement through nutritional loops in SIMTAP compared to conventional systems
- A high sensitivity to production yields
- Energy use (and related impacts) is a hot spot in recycling systems: the upscaling of experimental results is a delicate exercise

- In the next steps:

- Inclusion of uncertainty in the analysis to increase the robustness of the comparisons
- Complete the environnemental impact assessment in sustainability multicriteria assessment (Dexi)

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