Life Cycle Assessment Applied to Aquaculture

Joël Aubin

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Sustainable development

- "**Sustainable development** is **development** that meets the needs of the present without compromising the ability of future generations to meet their own needs.“ (Our Common Future; Brundtland Report 1987).

- For a sustainable development, to move from words to deeds, it is in the environmental field (at least):
  - Having technological solutions that are satisfactory for the user and society
  - Determining which are the priorities of action among all the possible ones, taking into account their environmental efficiency, their costs and the economic constraints
  - Having methods to drive future developments

Adapted from: Jolliet et al. 2005

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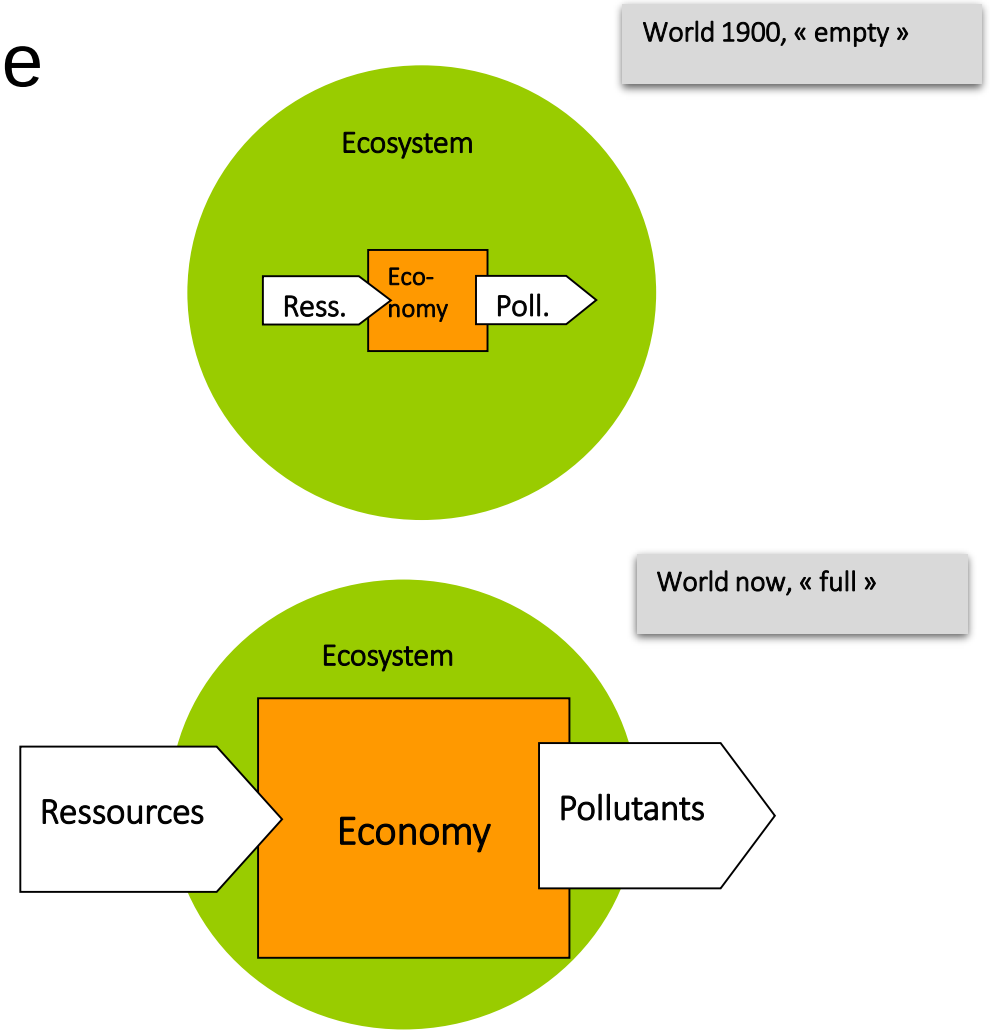
Sustainable Development Goals of United Nations

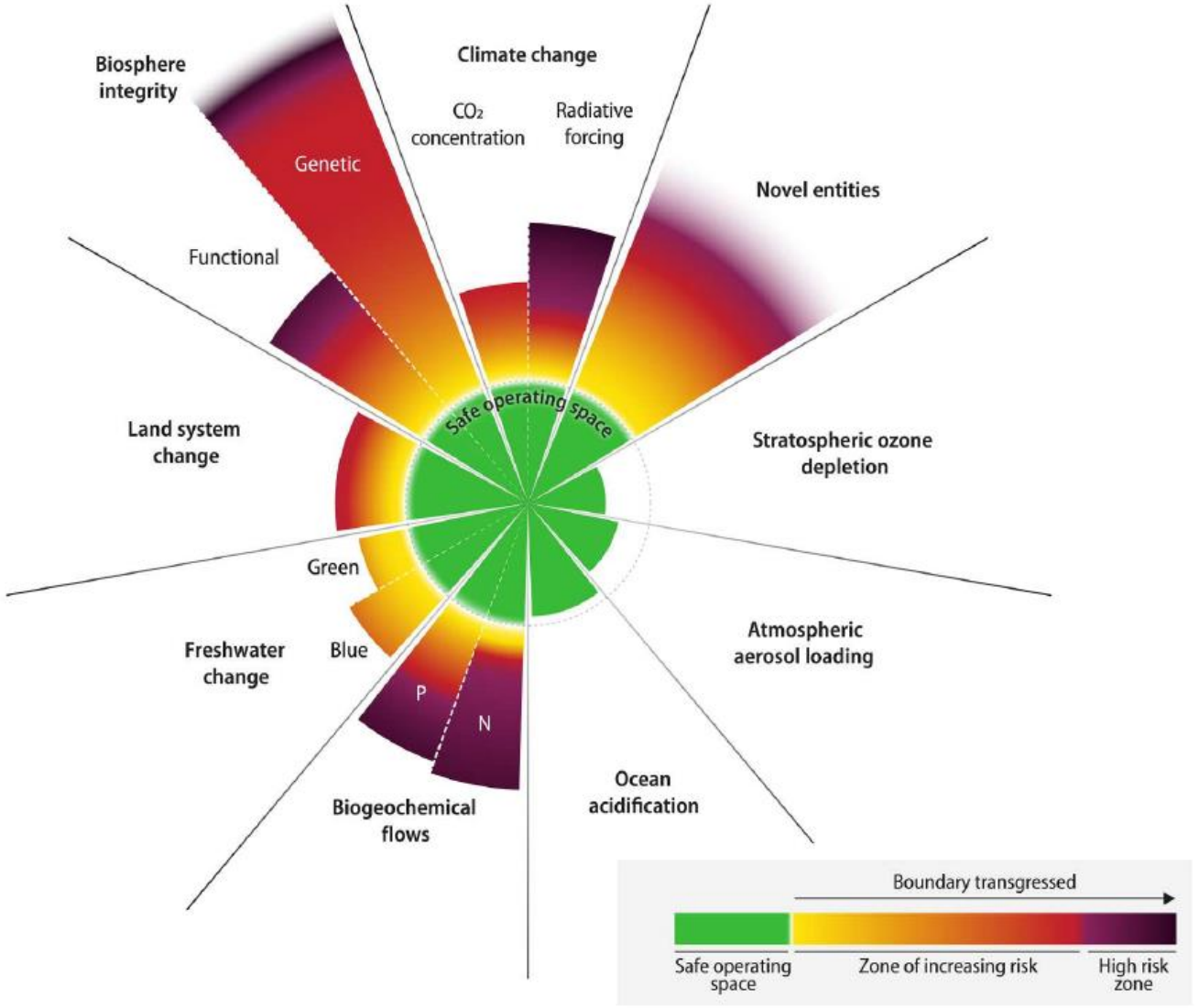
A few notions of ecological economics (Herman Daly, 1996)

- The economic system depends on the ecological system for :
  - resources (oil, phosphorus)
  - the assimilation of pollutants (carbon dioxide, nitrate)

  - The "size" of the economic system is increasing
  - The economic system must be adapted to the capacities of the ecological system



PLANETARY BOUNDARIES



Richardson *et al.*, *Sci. Adv.* **9**, eadh2458 (2023) 13 September 2023

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Methods?

- **Sustainable development** implies assessment methodologies to:

- **Describe** and analyse the current situation
- Define **hot spots**
- Propose **pathways to improvement**
- Abandon mono-criteria approaches for **overall evaluations**
- Combine different **geographic scales**

- In particular for **agricultural production systems** that cover **multiple functions** (food production, economic activity, territorial development, employment, landscape preservation, recycling …)

Introduction

Life Cycle Thinking and Life Cycle Assessment are the scientific approaches behind modern environmental policies and business decision support related to Sustainable Consumption and Production.

ILCD Handbook, 2011

LIFE CYCLE ASSESSMENT IS A TOOL TO:

Identify the most significant ecological burdens associated with a product system

Compare existing or potential systems

Indicate the areas were the most effective improvements can be made

Conceive new systems

Identify research needs for environmental performance improvement

Propose a basis for the certification of the modes of production

LCA USED IN LABELLING

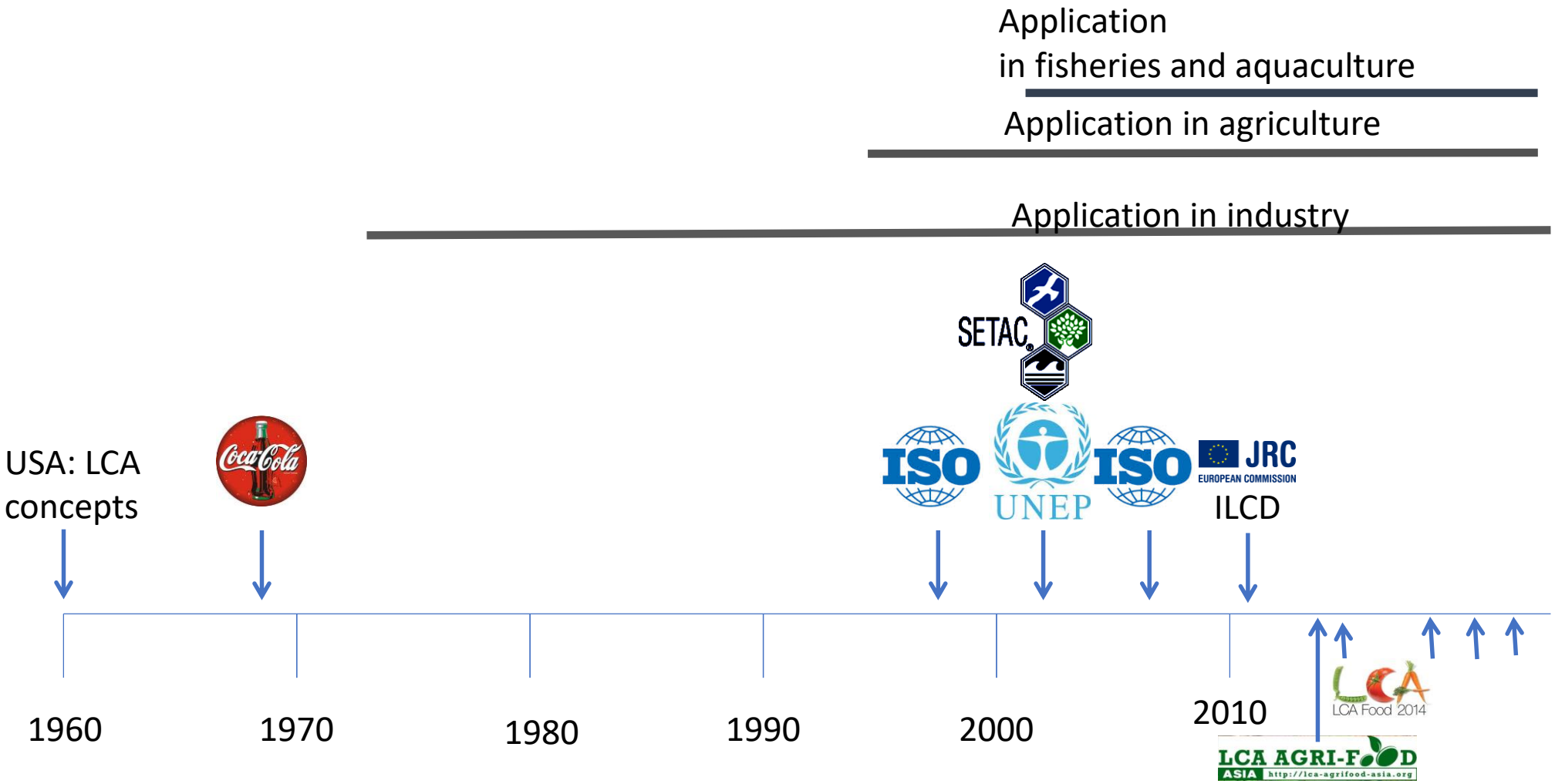
Carbon footprinting

Since 2008: wide range of products.

In France environmental labelling based on LCA methodology is on the way.

Supermarket Initiatives:
Casino (Fr), Tesco (UK)

BRIEF LCA HISTORY



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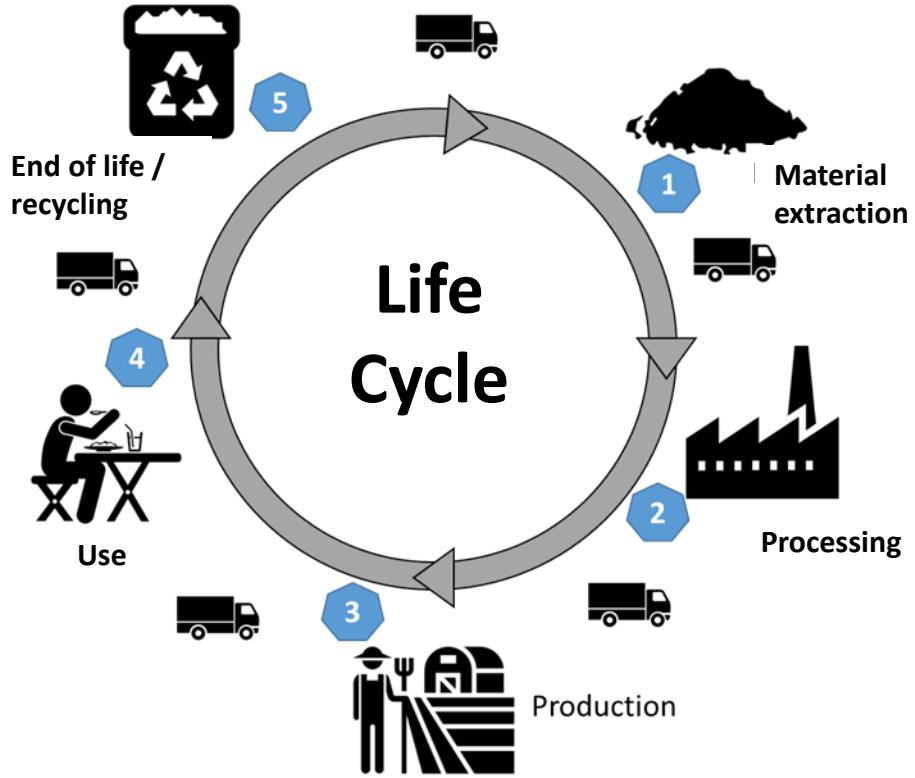
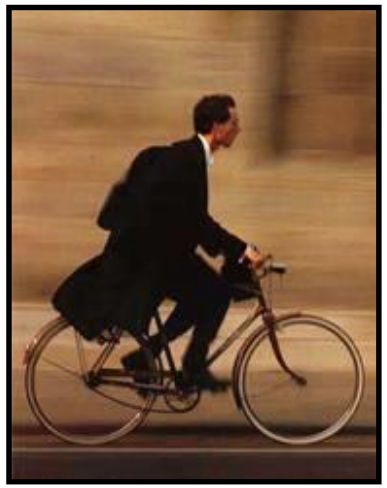
Life Cycle Assessment definition

- The purpose of a Life Cycle Assessment is to list and evaluate the environmental consequences of different options to fulfill a certain function.
  Guinée et al., 2002
- LCA quantifies the environmental impacts of a product or service throughout its life cycle
- An approach that integrates knowledge and interprets complex systems in order to help make decisions
- International recognition: ISO 14040 to 14043 (ISO,2006)
- Today: a coherent framework with room for improvement...



Life cycles of products: bike

Production



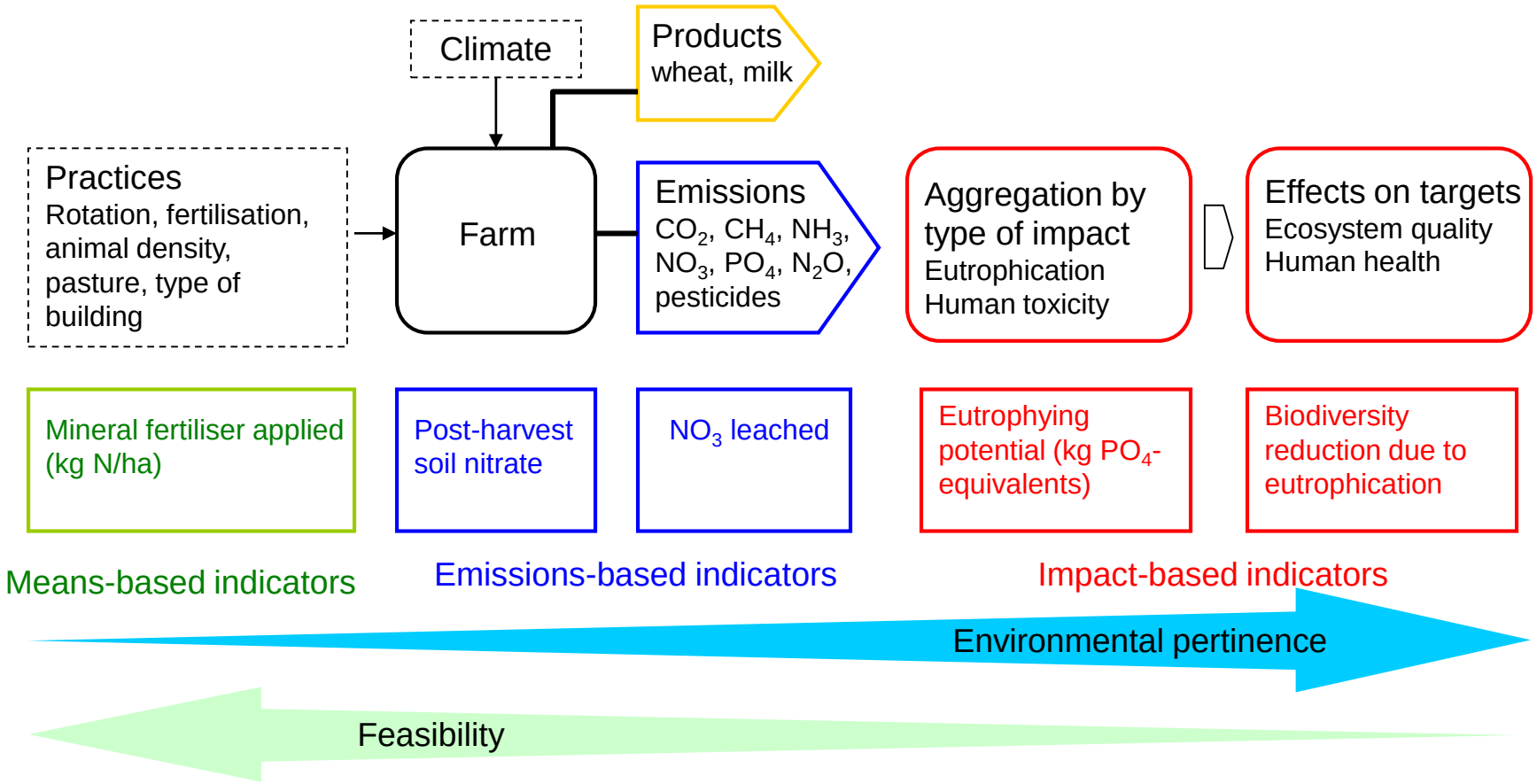
Use

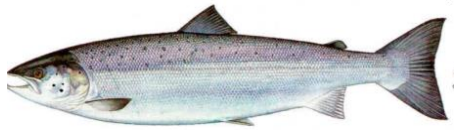
Disposal or recycling

Extraction of raw materials

Transformation of raw materials

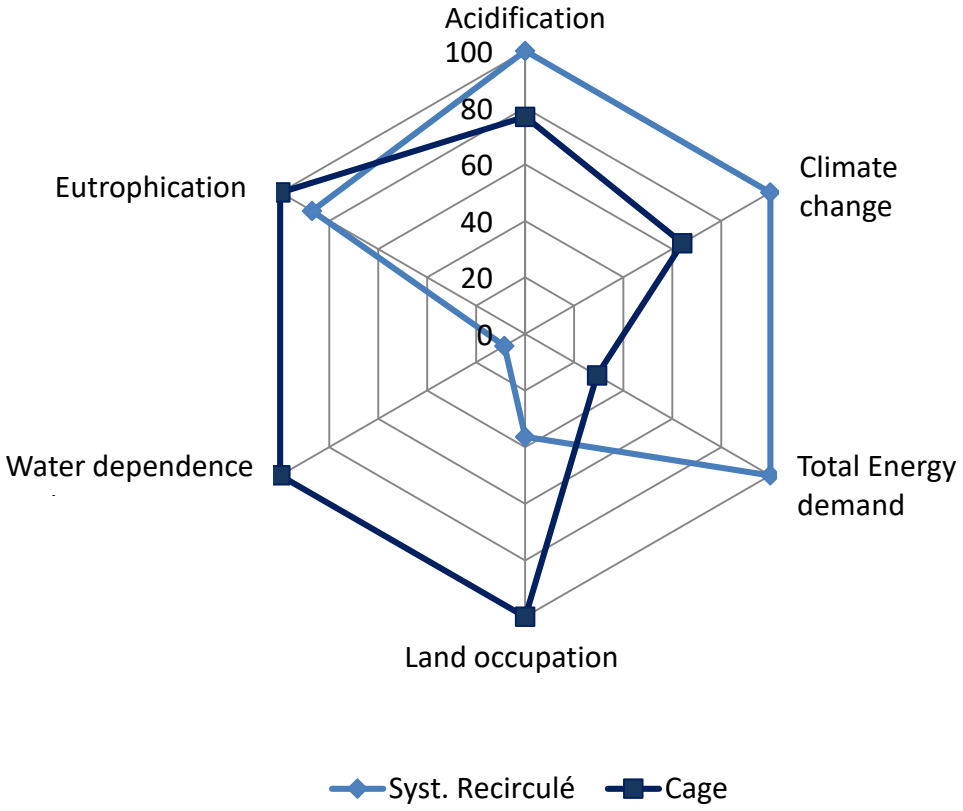
Environmental analysis: a causal chain of agricultural practices, emissions, and impacts





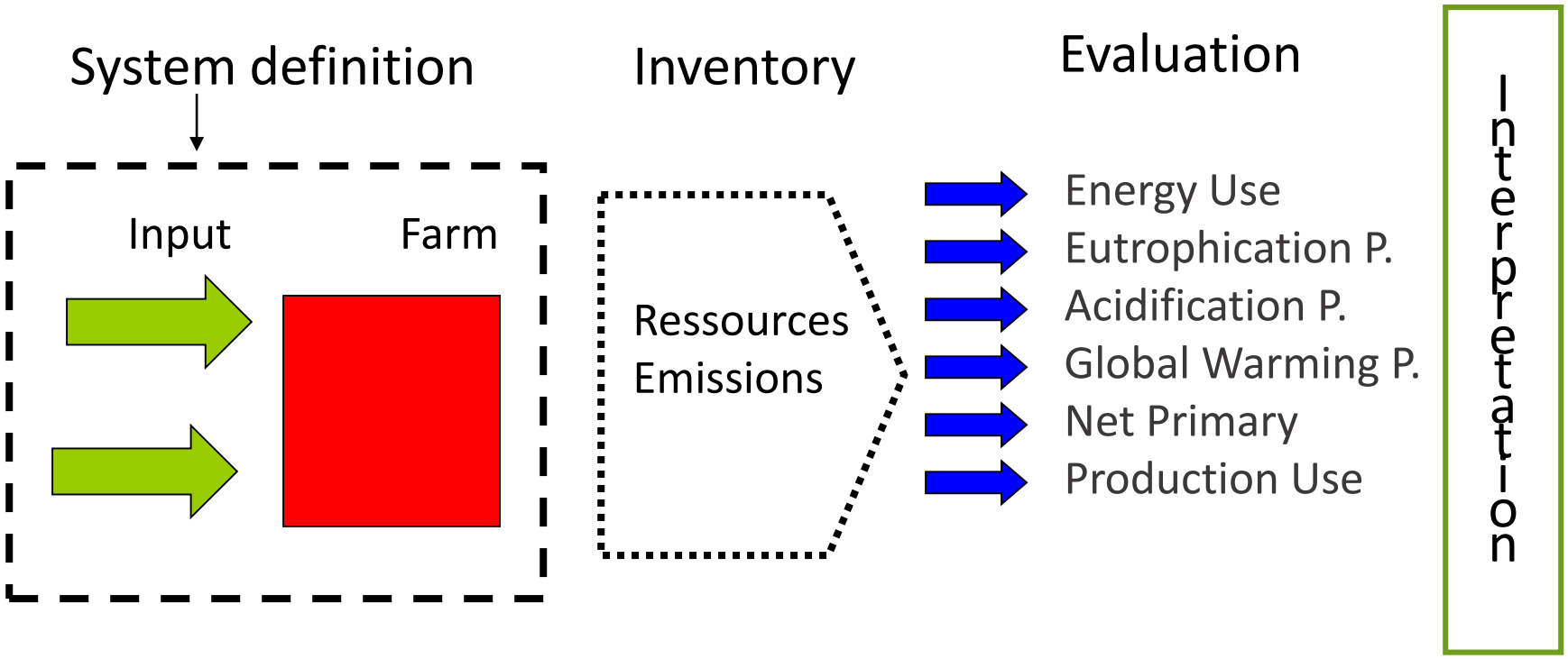
Multicriteria assessment

- Propose a significant number of environmental objectives
- Have a broader view of environmental implications
- To highlight the transfer of impacts
- Better inform the choices
- More difficult to make a decision



Adapted from Boissy et al. (2011) et Wilfart et al. (2013)

LCA stages



(According to Geier, 1999)

Expressed by a Functional Unit : 1 ton of fish

LCA steps

Definition of system limits and choice of farmers

Questionnaire redaction

Survey

Technical and scientific litterature

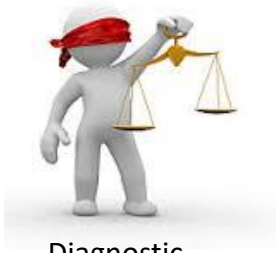
Databases

Inventory
Data checking

Impact Calculation
(Pisc'n'tool &Sima Pro)

Results analysis

Results presentation



Diagnostic

Ouf!

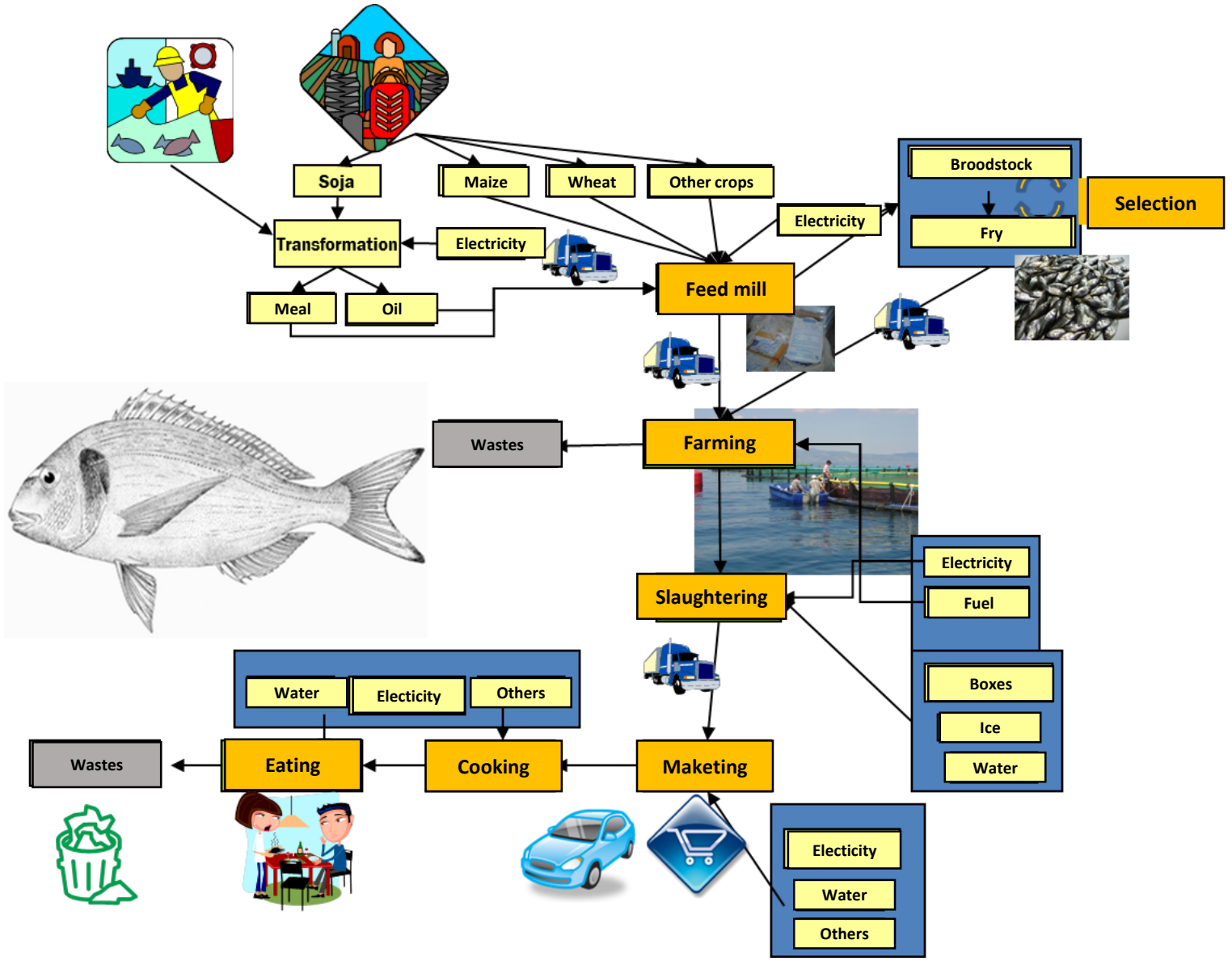
Step 1. Goal and scope

- **Definition of product system boundaries** :
  - Upstream and downstream processes
  - Choices between important and negligeable processes relatively to their contribution (cut-off),
- **Examples of boundaries**
  - Cradle to gate
  - Gate to gate
  - Cradle to grave

- Deal with multi-functionality: define an **allocation method**

Goal and scope

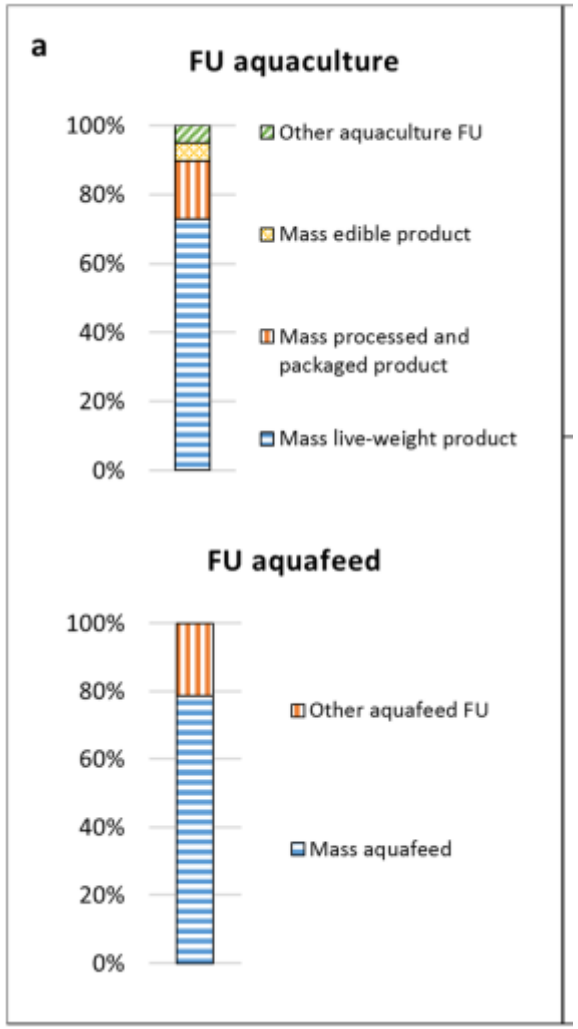
System boundaries

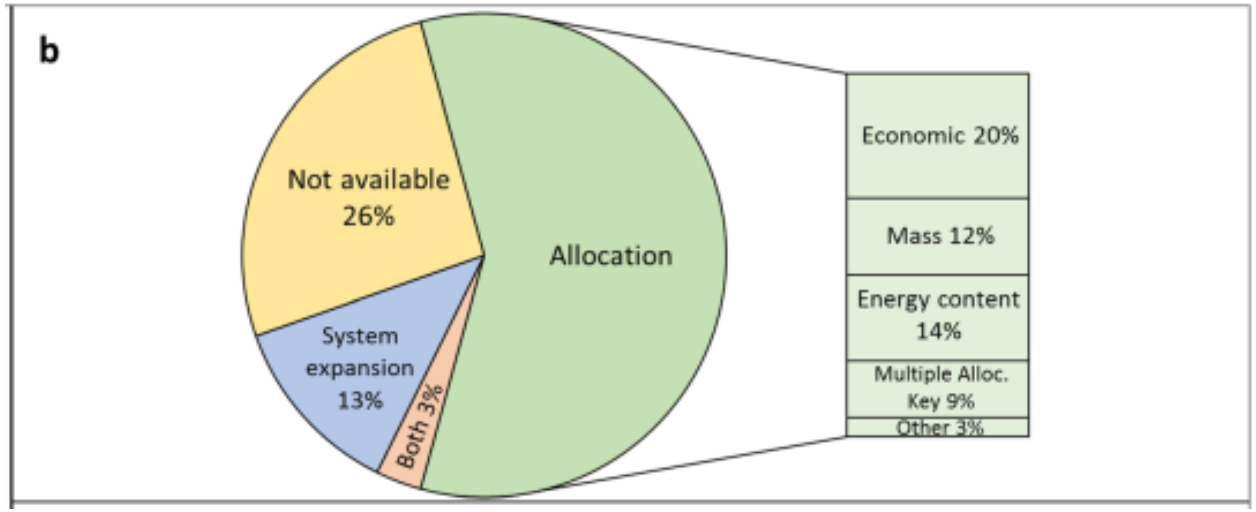


Fild'Or Project
(Acosta-Alba et al. 2014)

Goal and Scope definition

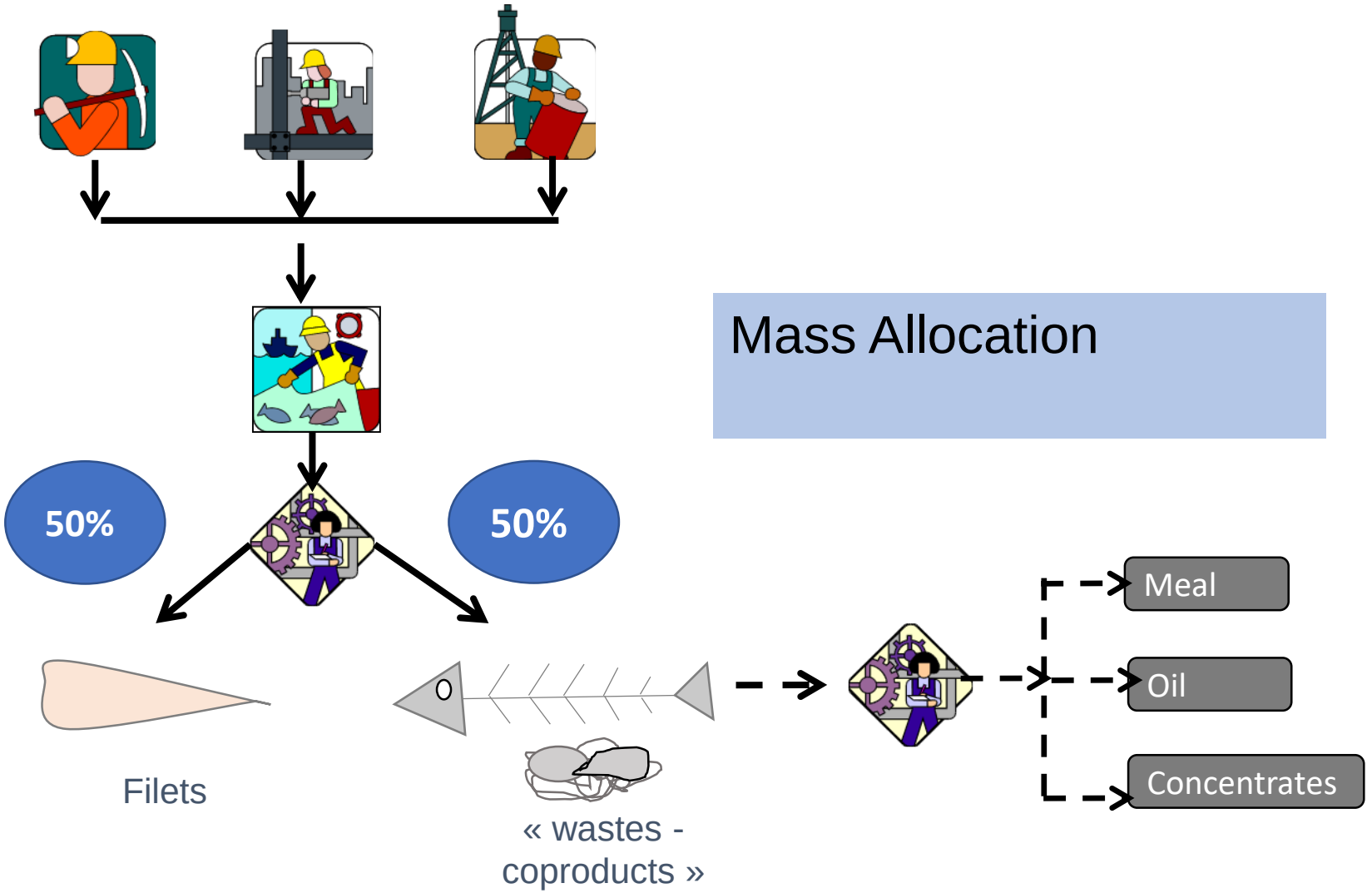
Functional unit in 65 reviewed LCA papers (Bohnes et al. 2019)





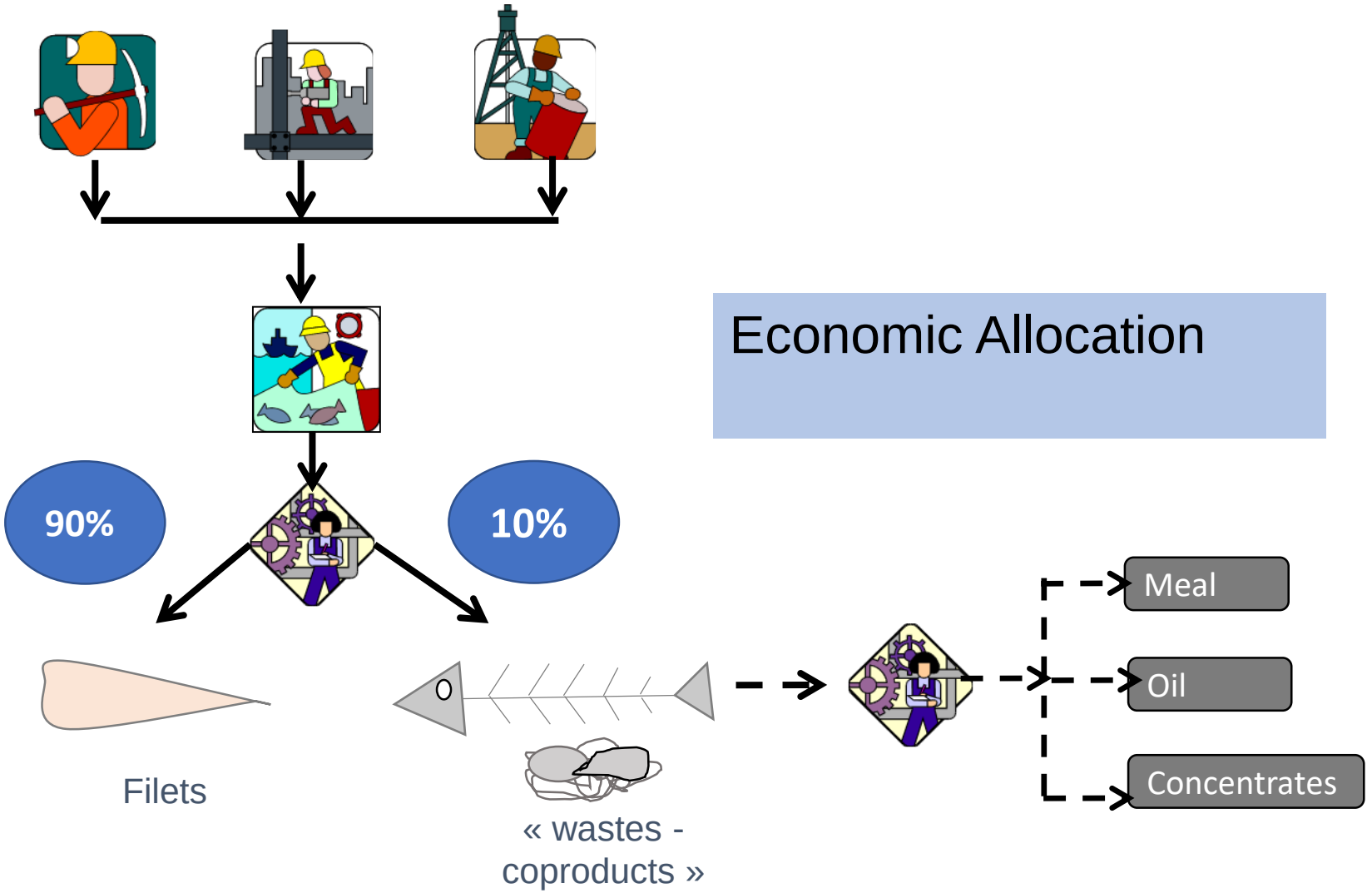
Multifunctionality in 65 reviewed LCA papers (Bohnes et al. 2019)

How to share the burden among coproducts



Mass Allocation

How to share the burden among coproducts



Economic Allocation

2- LIFE CYCLE INVENTOY (LCI)
RESOUCES AND EMISSIONS INVENTORIES

- **Surveys**: on fields data collection, description of infrastrucures and materials, accounting data…

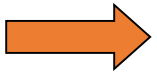
- **Production cycle reconstitution** from rearing performances and zootechnical reports

- **Use of modelling** to evaluate the missing or non measurable data.

- **Use of published data**

- **Use of of consumption / emission databases**

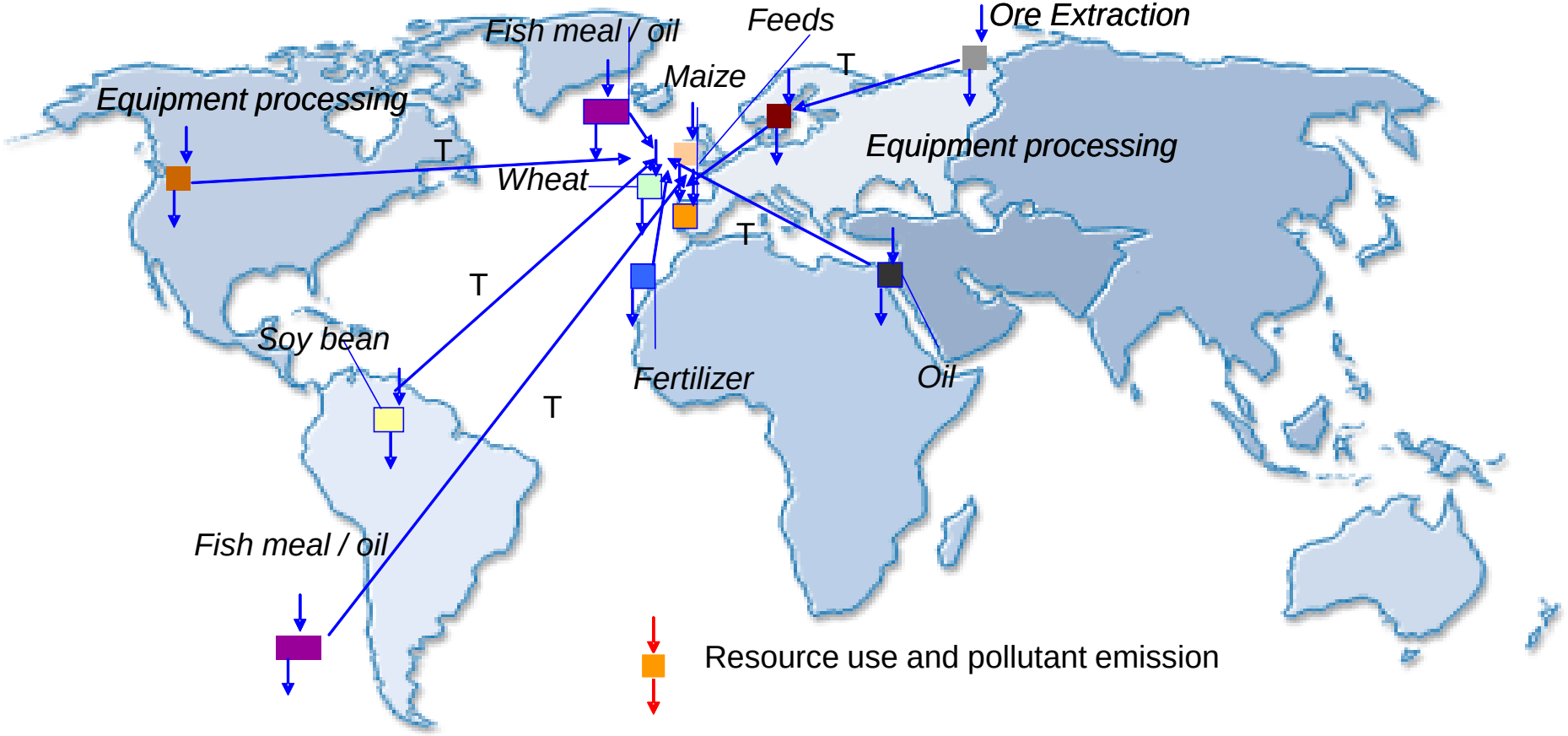


Validation and data control

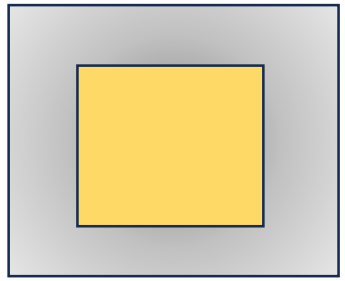
A WORLDWIDE INVENTORY…

Example of trout production in France

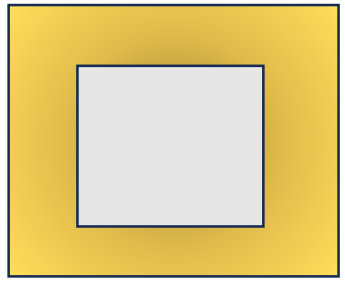


Background and foreground system

Two types of inventory systems according to what you control



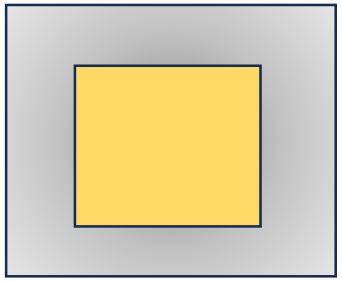
Foreground system: Stages in the life cycle that we control



Background system: Stages in the life cycle that we don’t control

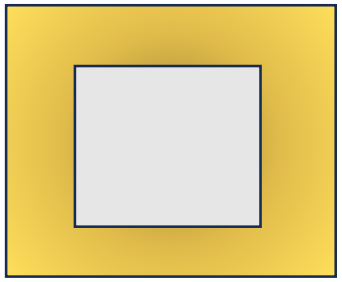
Background and foreground data

Two types of data according to the system boundaries



Foreground system → Primary data

- Directly measured or collected data
- To quantify the most relevant emissions/extractions/consumptions and product flows



Background system → tolerance of Secondary data

- Not directly collected, measured, or estimated, but rather sourced from a third-party life cycle inventory database

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Background data

- World's leading supplier of consistent and transparent life cycle inventory data
- 3500 documented industrial processes
- 9 sectors : Energy, transport, building materials, chemicals, washing agents, paper & board, agriculture and waste management
- The database is described at www.ecoinvent.ch

Other background databases

Food and agriculture

Multisectorial database included in a software

https://www.globallcadataaccess.org/search

Data provider

- Agribalyse (3747)
- Amaru (7)
- Cobalt Institute (5)
- ecoinvent (69472)
- ecoinvent SRI-LCI data (108)
- ecosystem (957)
- ESU-services (2572)
- European Solvents Industry Group (ESIG) (6)
- IBICT (21)
- IDEA (3756)
- Japan Iron and Steel Federation (16)
- KEITI (143)
- LCA Society of Japan (JLCA) (107)
- NorEnviro (36)
- PeruLCA (55)
- Plastics Europe (50)
- RSE SpA (1)
- Sphera (14082)
- TianGong (4092)
- US Federal LCA Commons (1738)
- VitalMetrics Group (389)
- worldsteel (81)

NUTRIENT ALLOCATION IN SEABASS CAGES

Distributed feed : 339 t
N: 25.26 t
P: 4.20 t

Fish growth gain: 199.4 t
N: 5.38 t 21,3 %
P: 1.2 t 42,4 %

Nutrient release:
N: 18.62 t 73.7 %
P: 2.80 t 57,6 %

Non ingested feed (5%)
N: 1.26 t 5 %
P: 0.21 t 5 %

Dissolved nutrient
N: 16.70 t 89.7 %
P: 0,80 t 28.6 %

Fecal waste
N: 1.92 t 10.3 %
P: 2.0 t 71.4 %

Total solids
N: 3.18 t
P: 2.21 t

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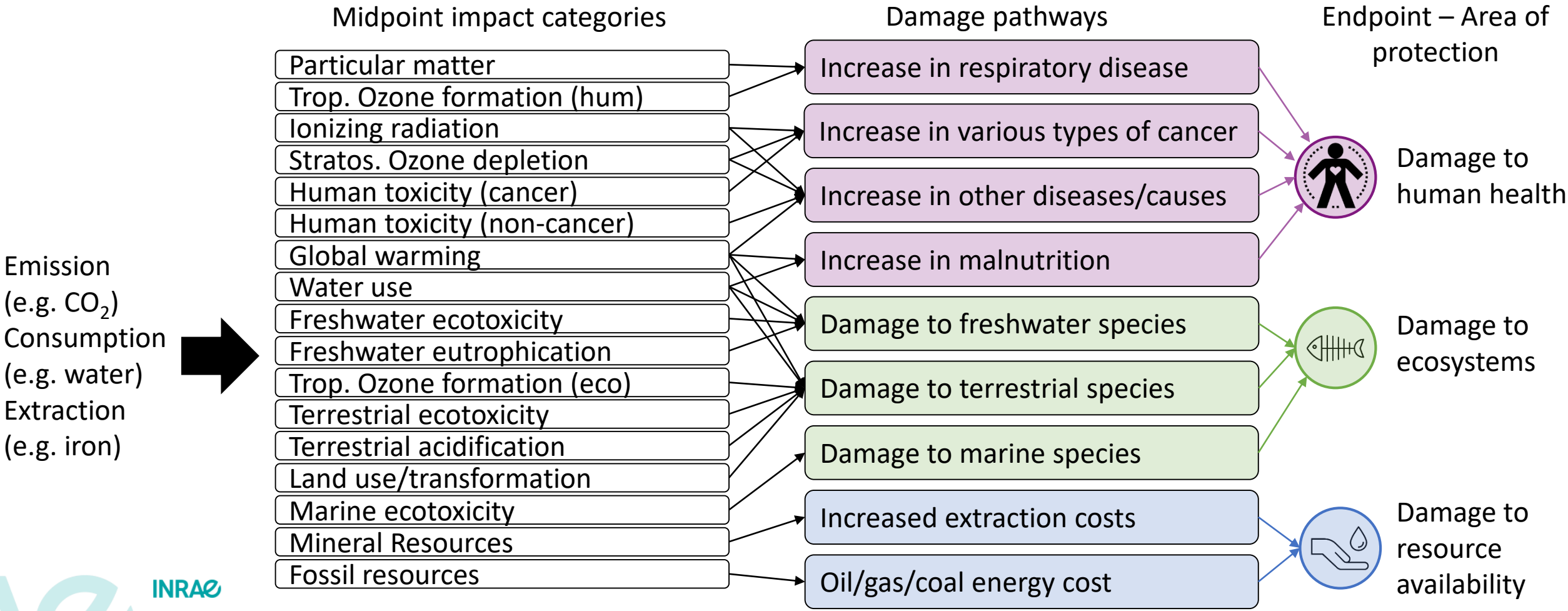
Step 3: Life Cycle Impact Asessment

- Principle: aggregate all the individual material flows into impact categories, using characterisation factors

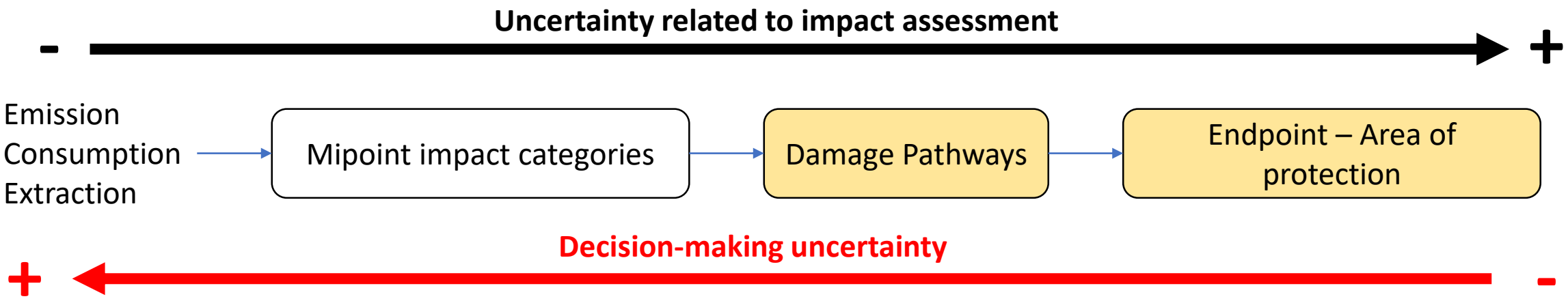
Life Cycle Impact Assessment (LCIA)

Impacts assessed by the LCA methodology

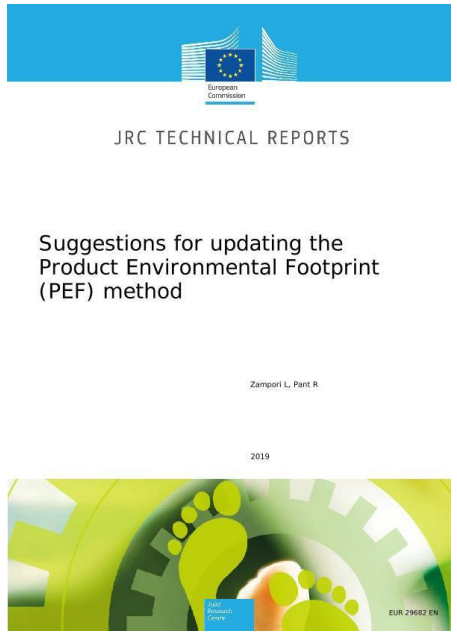


Source : Huijbrechts et al, 2016

Midpoint vs endpoint



Life Cycle Impact Assessment (LCIA)



LCIA methods → Allow to translate the emission/consumption/extraction in environmental impacts

- LCIA methods only considering midpoint :
  - Environmental Footprint 3.1 (EF3.1)→ recommended by the EU

- LCIA methods considering both midpoints and endpoints
  - ReCiPe 2016
  - IMPACT World +

- The choice of method could be based on policies, on the need for the spatial differentiation of the impacts as well as the current consensual impacts methods

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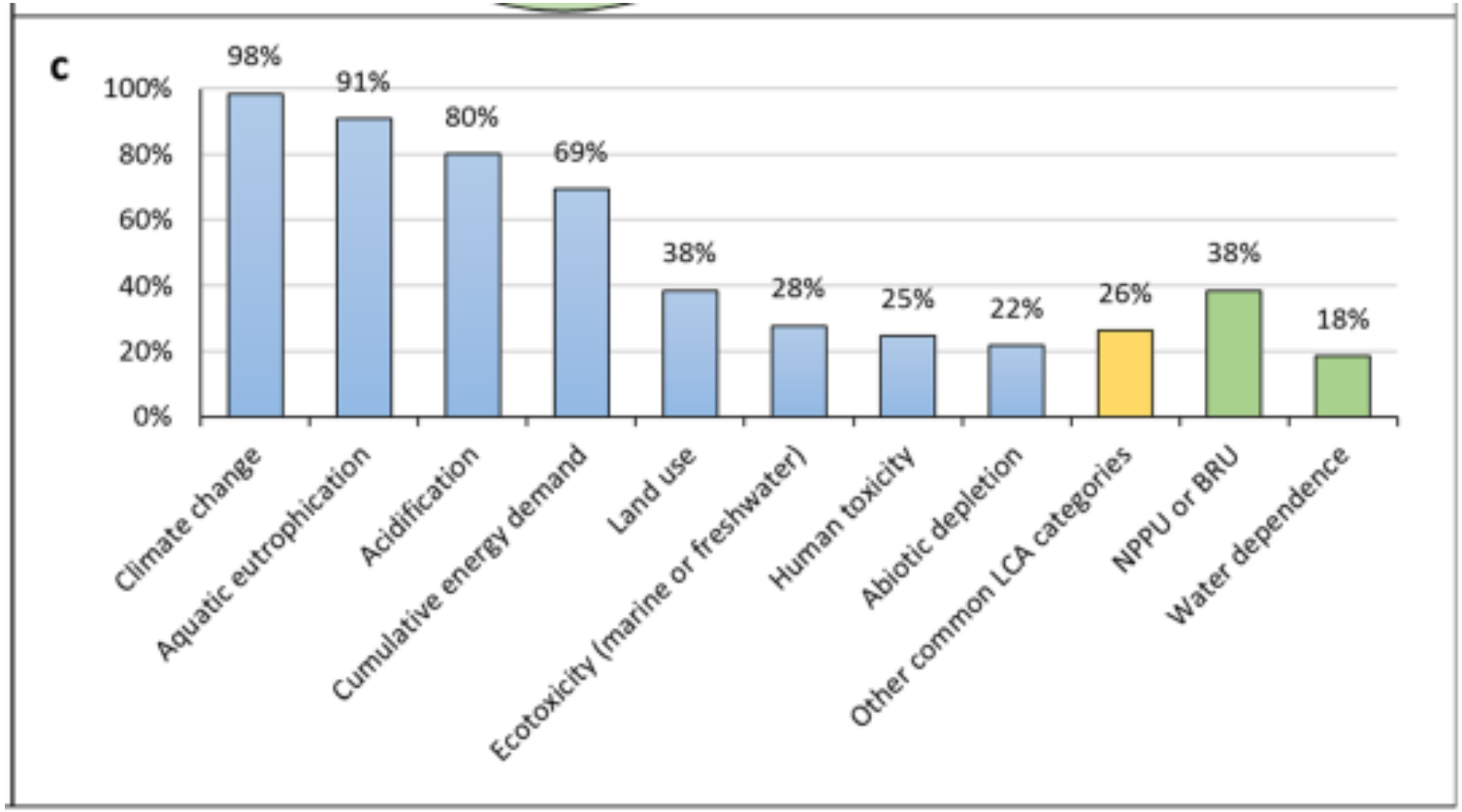
3. LIFE CYCLE IMPACT ASSESSMENT
POTENTIAL IMPACT CATEGORIES



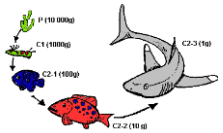
Impact categories in 65 reviewed LCA papers (Bohnes et al. 2019)

SEVERAL KEY IMPACT CATEGORIES FOR AQUACULTURE

- **Eutrophication:** Increase in the concentration of N and P in the aquatic environment producing a biomass that can asphyxiate the environment (kg PO4 -eq)

- **Climate Change:** Induced by greenhouse gas emissions **(kg CO2-eq)**

- **Acidification:** Due to the emission of molecules inducing acidification of aquatic and terrestrial environments (kg SO2 eq)



- **Net Primary Production Utilization (NPU):** Amount of carbon from primary production (photosynthesis), transiting through the trophic chain, to the product under consideration (kg C). Specific to aquaculture (Papatryphon et al., 2004)
- **Energy use,**
- **surface use**
- **water dependence**
- **Toxicity ...**

LCA: Impact assessment

Impact Category: Climate Change

- Inventory results: 1 ton of farmed salmon of 3kg (Aquamax 2010) :
  - 1870 kg CO2,
  - 3.22 kg CH4,
  - 0.72 kg N2O
- Characterization model: IPCC model defining the global warming potential of greenhouse gases,
- Characterization factor: Global Warming Potential (GWP):
  - GW CO2 = 1
  - GW CH4 = 27
  - GW N2O = 298
- Indicator: 1870*1 + 3.22*27 + 0.72*298 =
- 1870 + 86.9 + 214.6 = 2171.5 kg CO2eq / 1 ton

4. LIFE CYCLE INTERPRETATION

- Control of results consistency,
- Contribution analysis:
  - Of the different processes, (ie: feed)
  - Of a step of the life cycle, (ie: waste management)
  - Of a substance or resource (ie: CH_4 emission)
- Sensitivity and uncertainty analysis
- Comparison with other products or scenarios
- Conclusions and recommendations

Challenges for fish farming

- An increasing demand worldwide
- A sector dependent on fragile resources:
  - Water
  - Fish meal and oil
  - Sensitive ecosystems (biodiversity, nurseries...)
- A sector considered as polluting :
  - Discharges from fish farms
  - Escapees
  - Use of veterinary drugs in open environment...

→ It becomes necessary to :

- Define more economical and less polluting systems
- To propose strategies for the substitution of sensitive resources (fish oils and fish meal)
- To propose an agroecological transition of fish farming

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ENVIRONMENTAL ASSESSMENT USING LCA, OF FISH MEAL SUBSTITUTION IN ARTIFICIAL DIETS OF INDIAN MAJOR CARP POLYCULTURE.

Joël Aubin, Shiba S. Giri, Joachim Boissy,
Satyendra N. Mohanty, Sadasivam J. Kaushik

LCA METHOD USED IN THIS STUDY

- Method CML 2001 version 2.04
- Calculated using Simapro V7
- Economic allocation was applied for co-products
-Adaptations for aquaculture (Papatryphon et al. (2004))

- 2 steps:
  - Feed stage: calculated at the feed mill gate, for 1 tonne of feed
  - Farm stage: calculated at the experimental farm gate, for 1 tonne of fish

Polyculture experiment

MRIGAL *Cirrhinus mrigala* (30%)

ROHU *Labeo rohita* (35%)
standard and improved strains

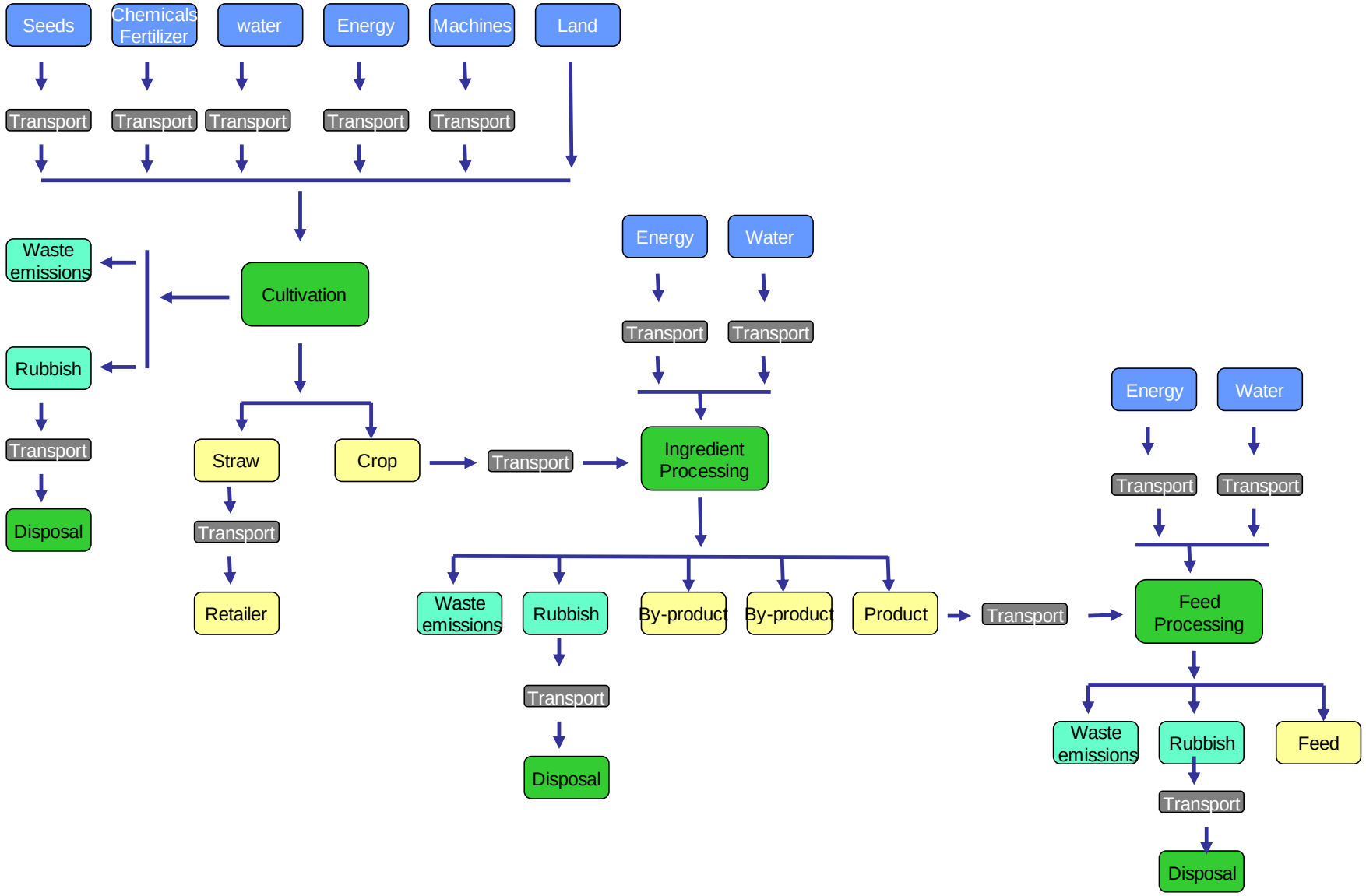
CATLA
Catla catla
(35%)

12 ponds of 0.6 ha
7000 fish/ha
2 feeds: Control – No fish meal

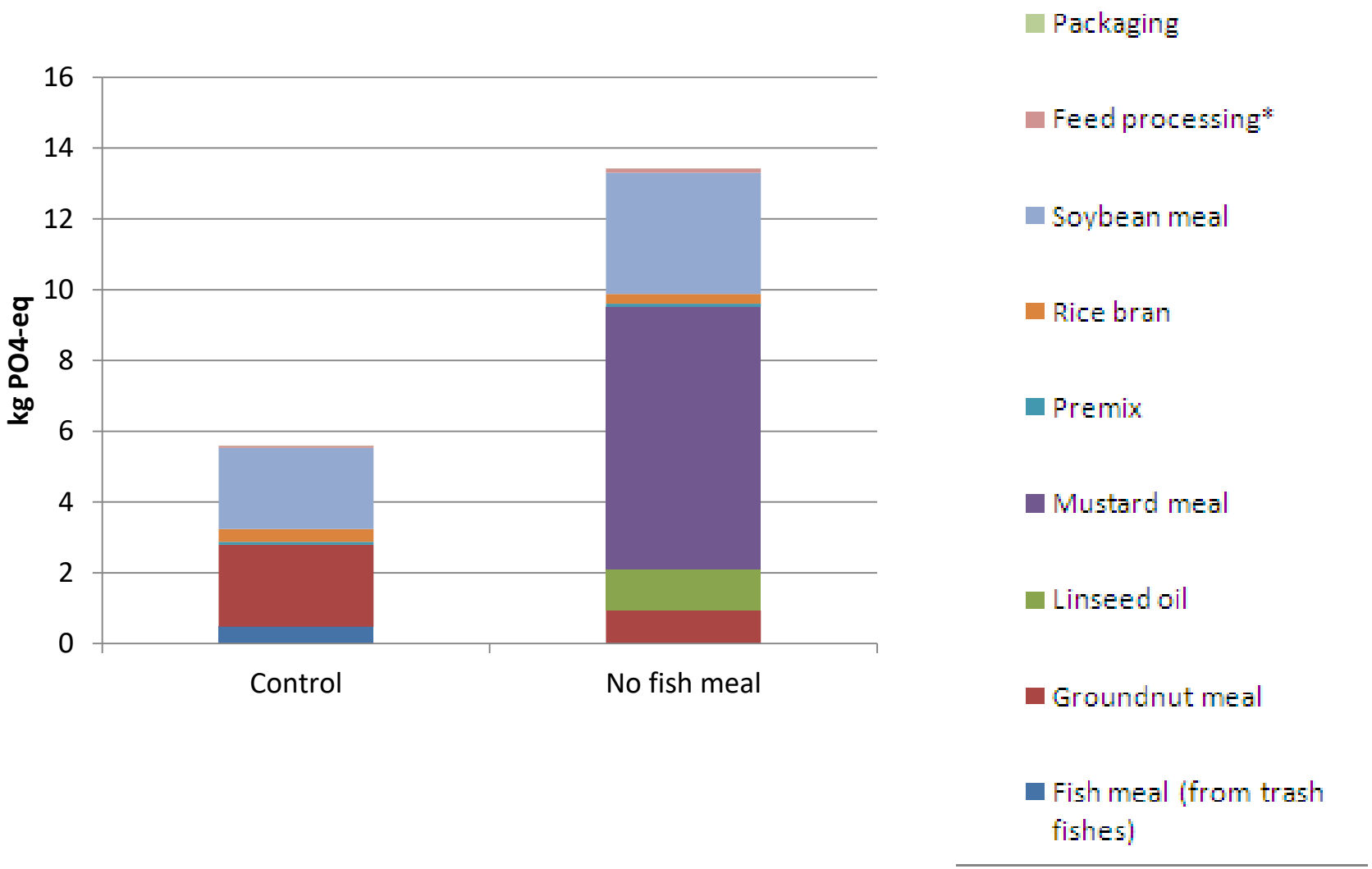
Ingredients and proximate composition of feeds

Ingredients (% as fed)	Control feed C Feed	No fish meal Feed NFM F
Ground nut oil cake	35	14
Mustard oil cake	0	24
Soybean meal	20	30
Rice bran (full fat)	38	29
Fish meal	5	0
Linseed oil	0	1
Vitamin and mineral mix	2	2
Moisture	5,7	5,6
CP (%DM)	30,7	30,4
EE (%DM)	8,1	8,1

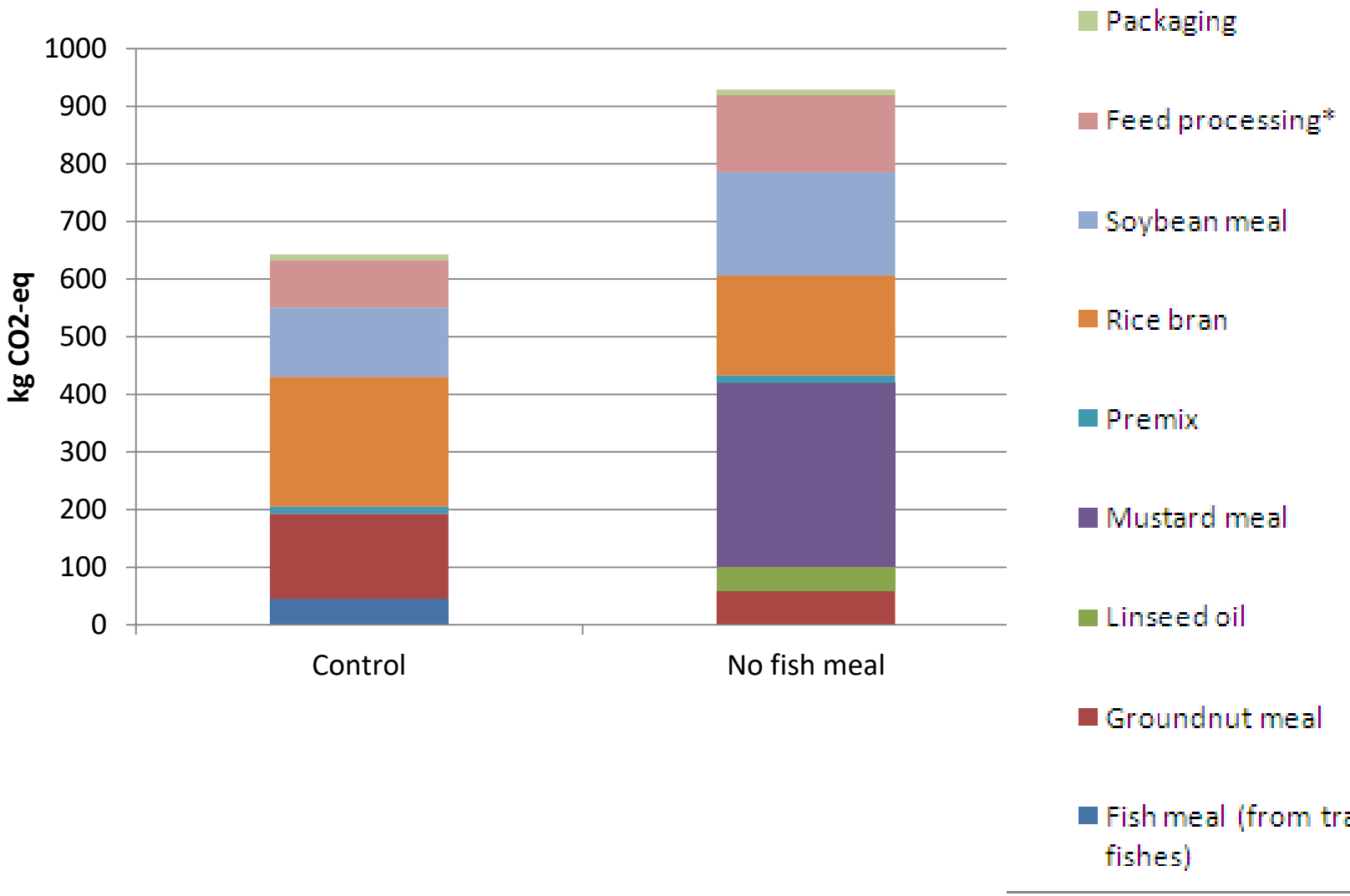
FEED PRODUCTION IN A LCA PERSPECTIVE



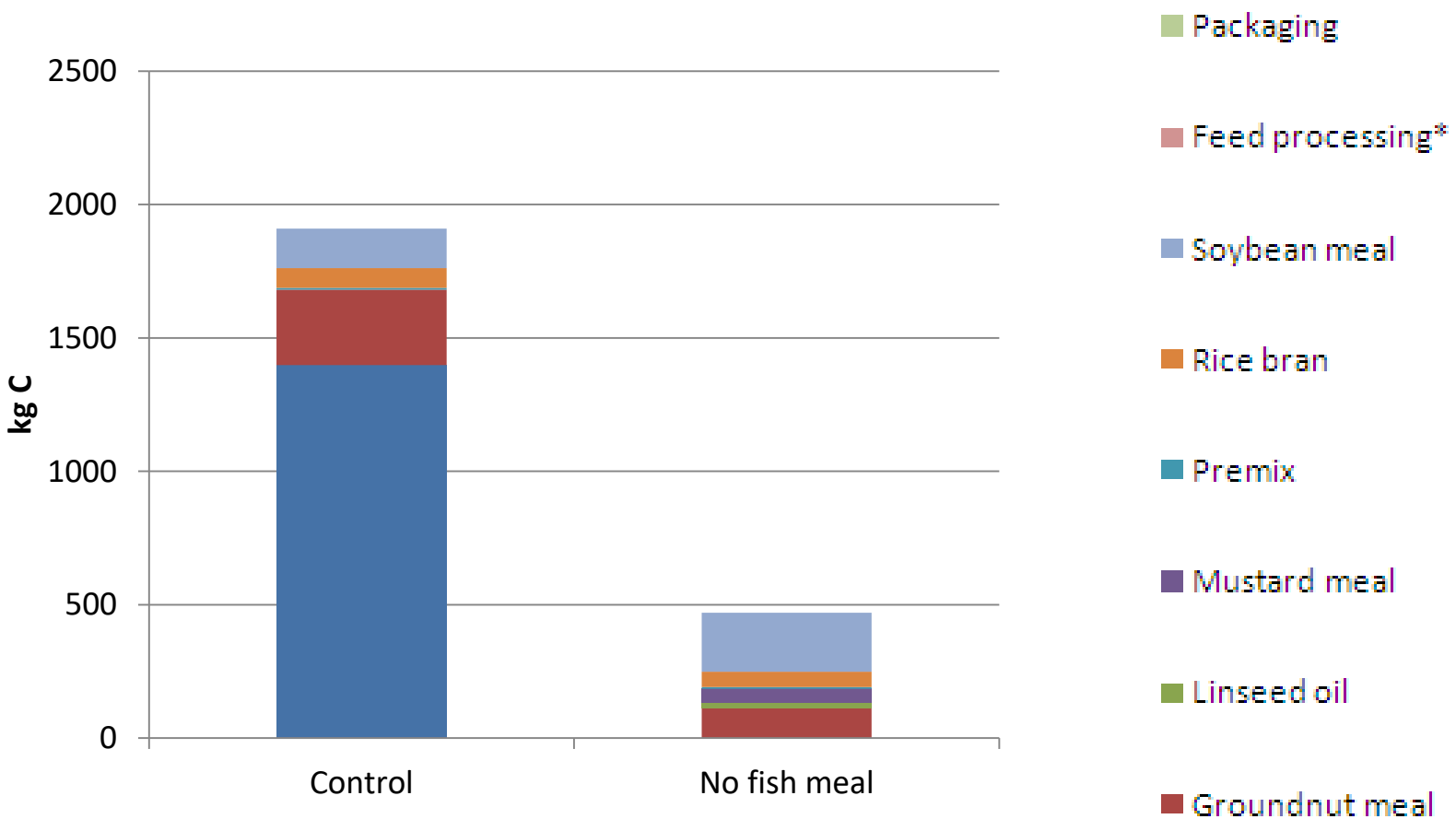
EUTROPHICATION FOR 1 TONNE OF FEED
CONTRIBUTION ANALYSIS



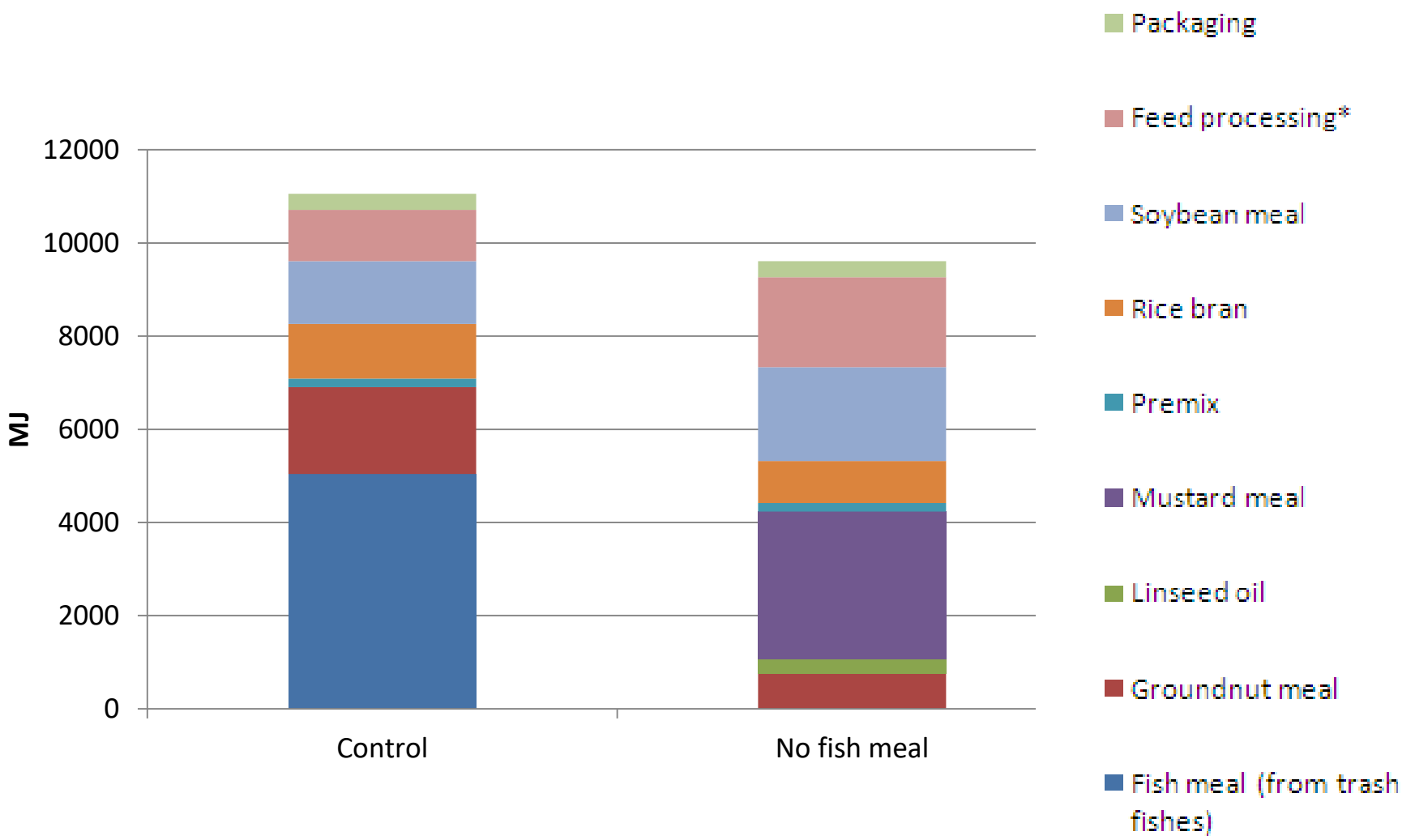
CLIMATE CHANGE FOR 1 TONNE OF FEED
CONTRIBUTION ANALYSIS



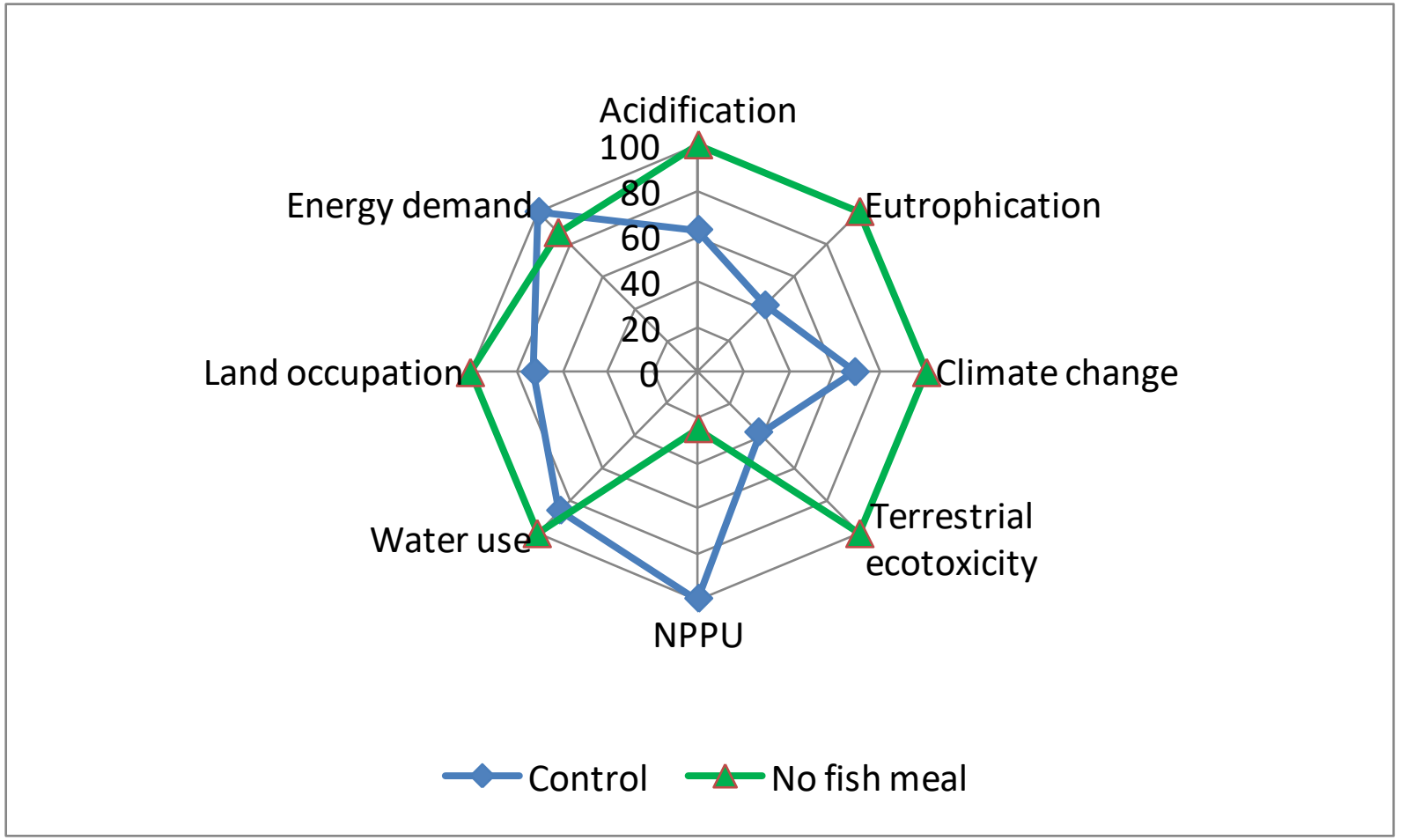
NET PRIMARY PRODUCTION USE
CONTRIBUTION ANALYSIS



ENERGY DEMAND FOR 1 TONNE OF FEED
CONTRIBUTION ANALYSIS

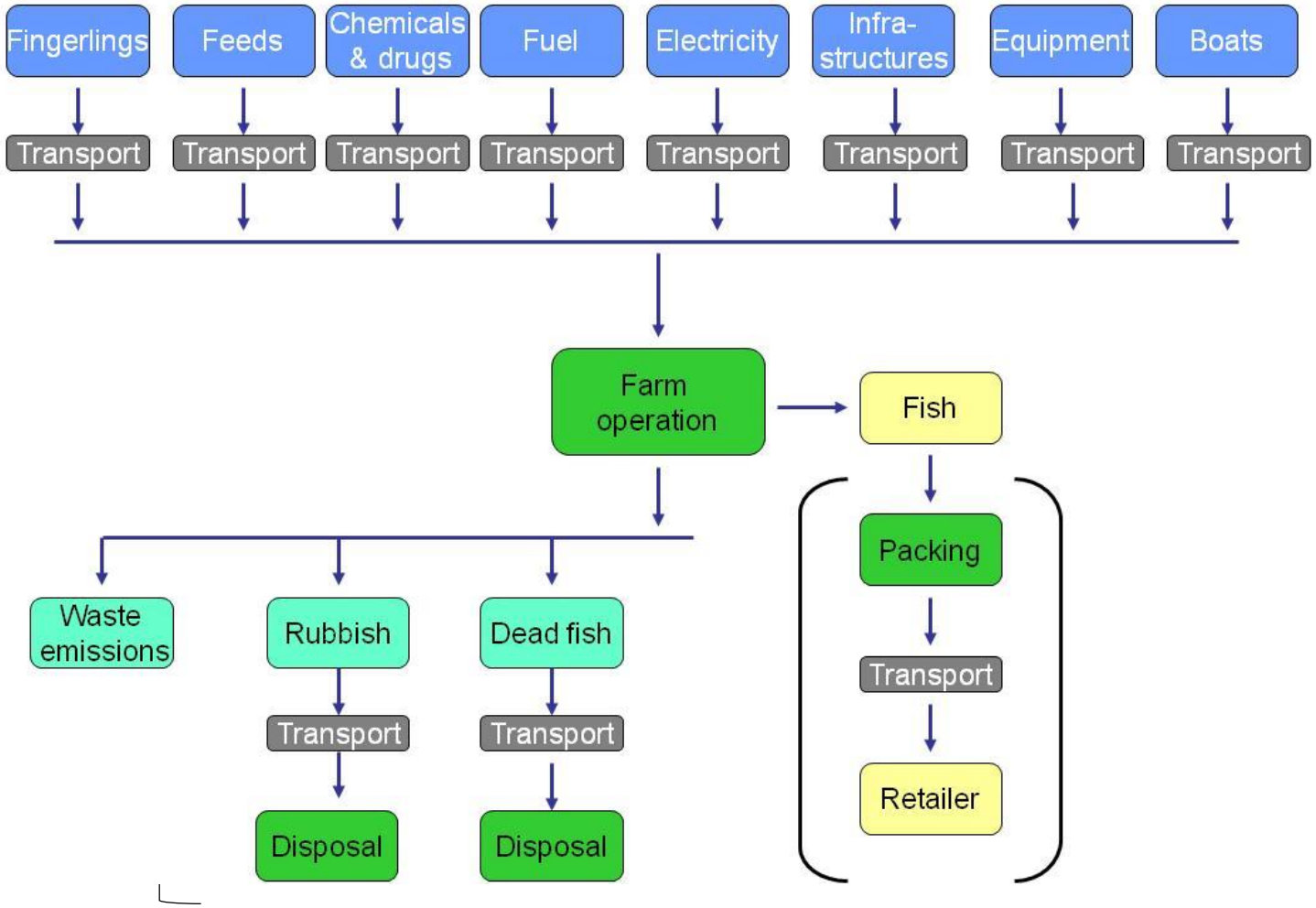


COMPARATIVE ENVIRONMENTAL PROFILE OF THE TWO DIETS

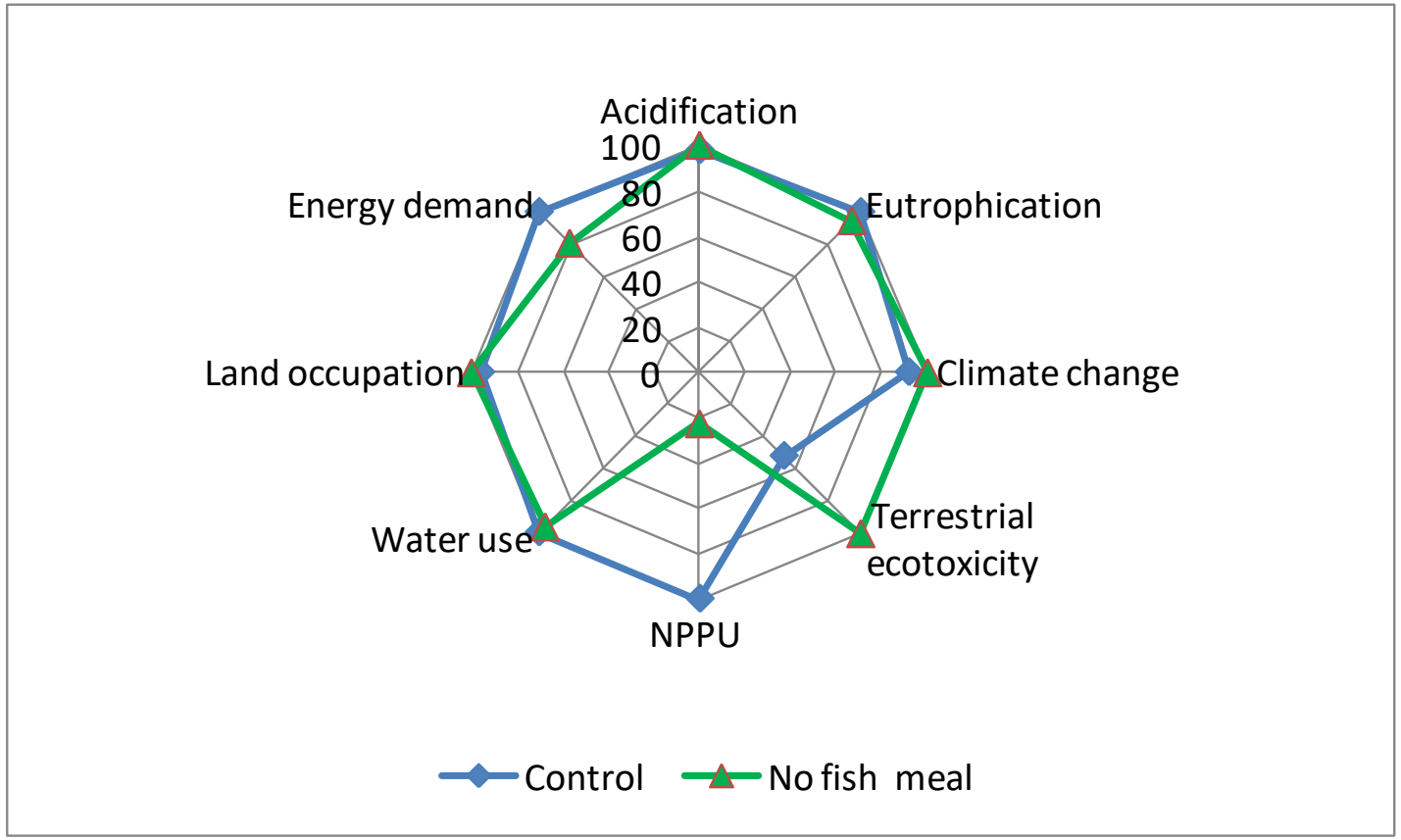


In % of the highest score of each impact category

FISH PRODUCTION SYSTEM IN A LCA PERSPECTIVE



COMPARATIVE ENVIRONMENTAL PROFILE OF THE TWO FISH PRODUCTION SYSTEMS

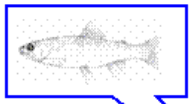


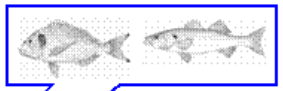
In % of the highest score of each impact category

Life Cycle Assessment

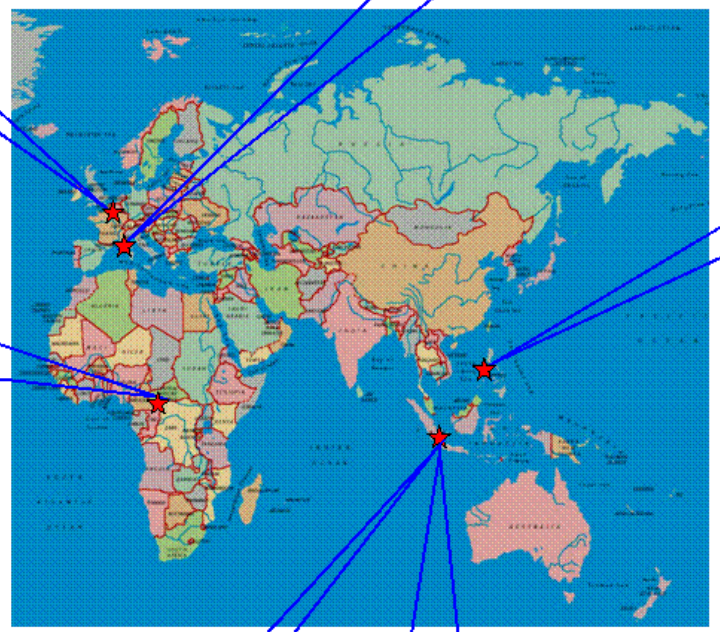
Fish Production Systems in Temperate and Tropical Areas

Rainbow trout in pond

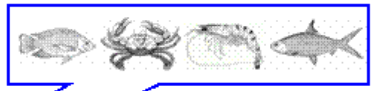




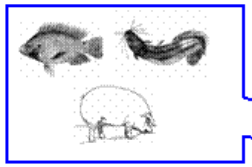
Sea bass and sea beam in cage



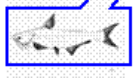
Shrimp, crab and fish polyculture

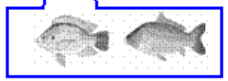


Tilapia, Catfish
in pond with pig



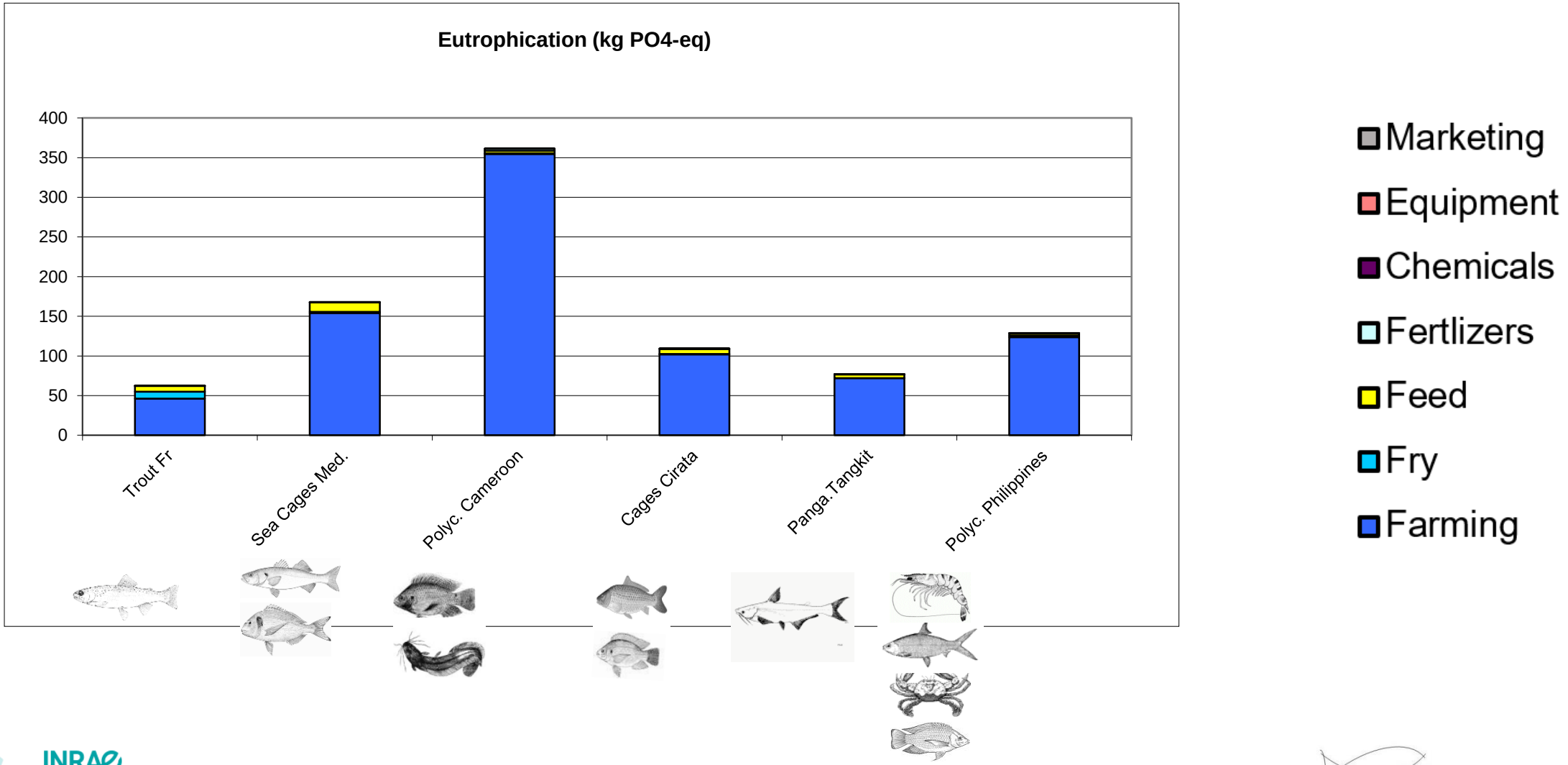
Catfish in pond



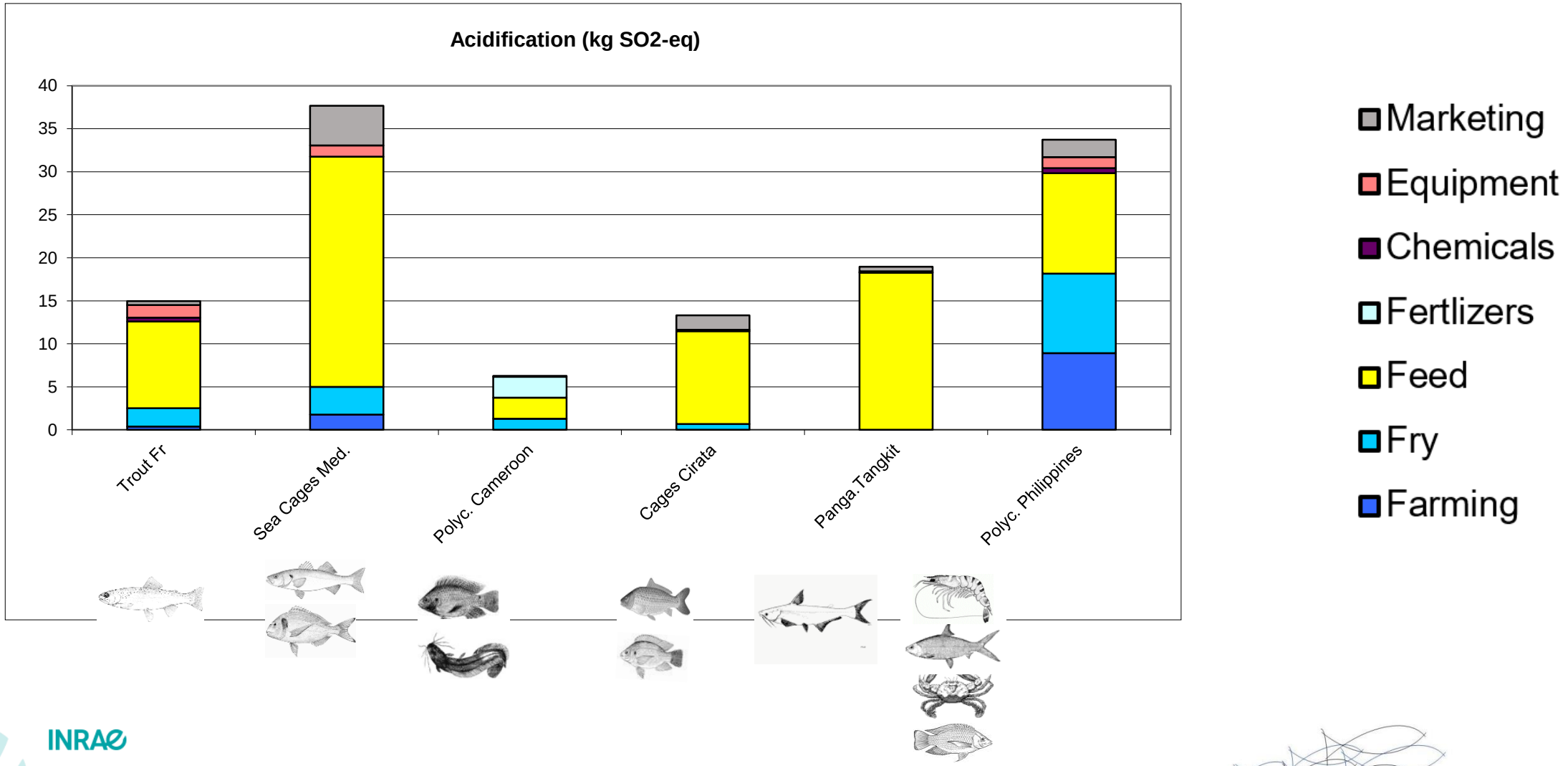


Carp and Tilapia in double-layer net cage

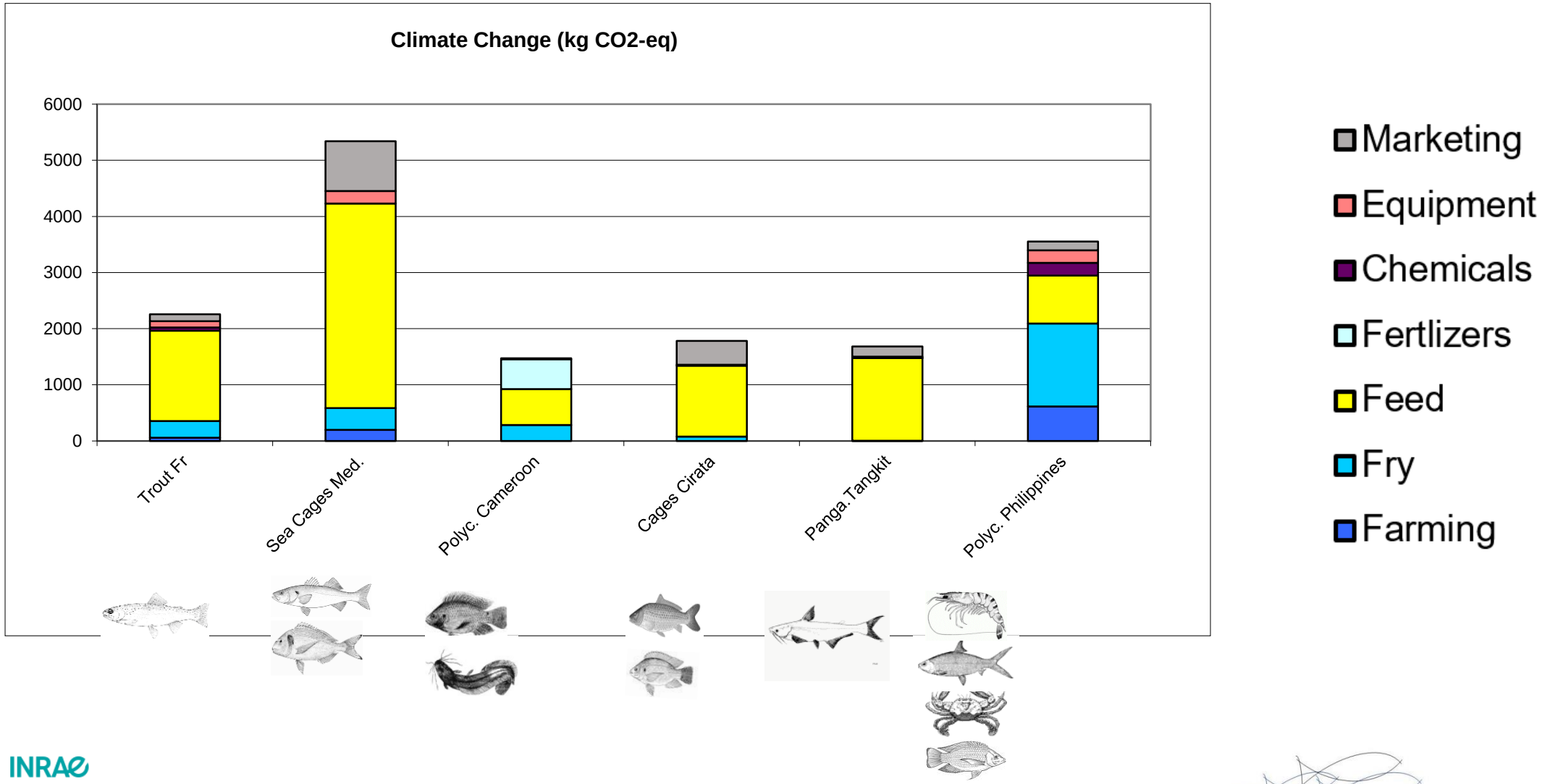
Eutrophication for 1 tonne of fish



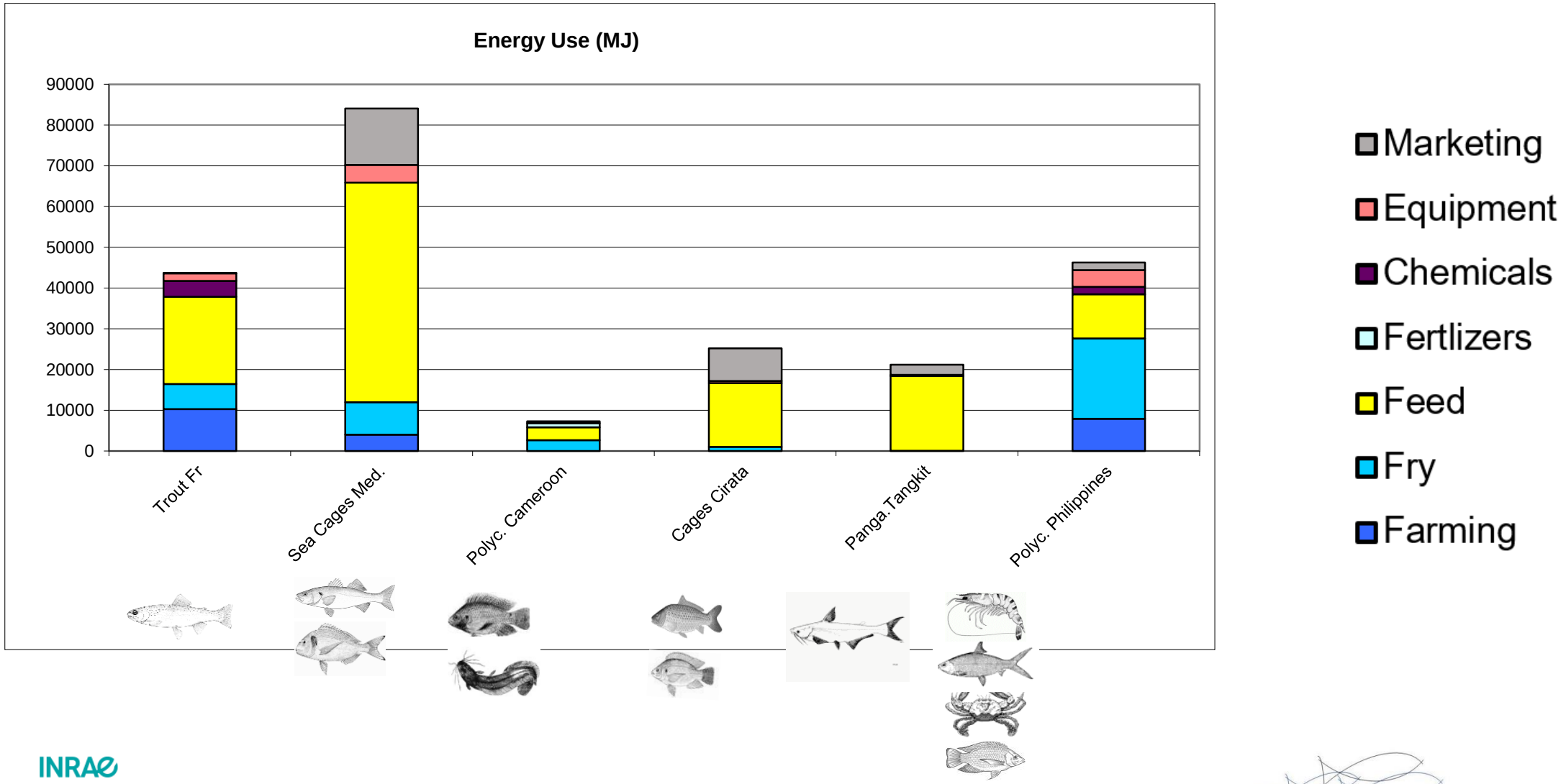
Acidification for 1 tonne of fish



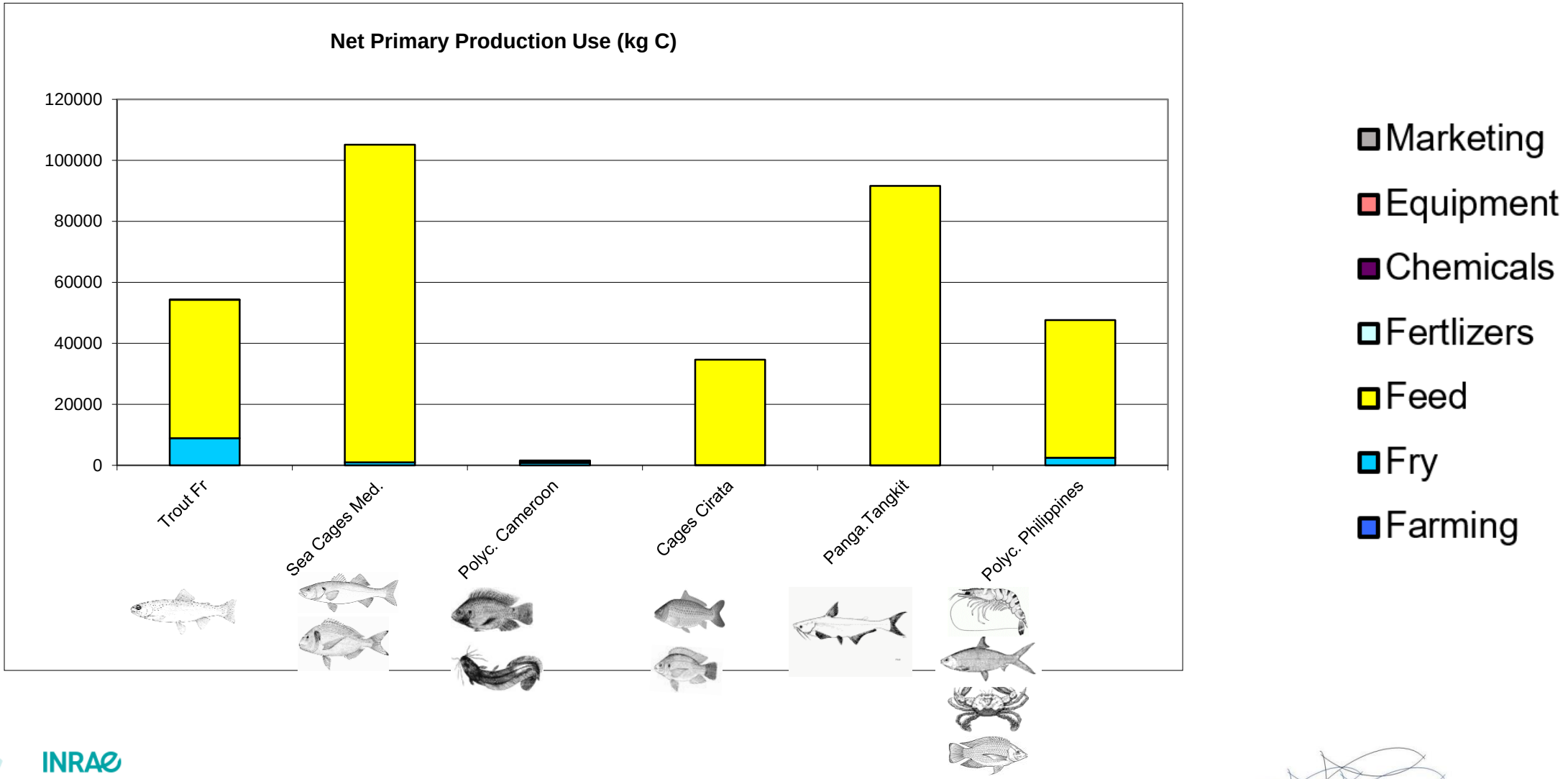
Climate change for 1 tonne of fish



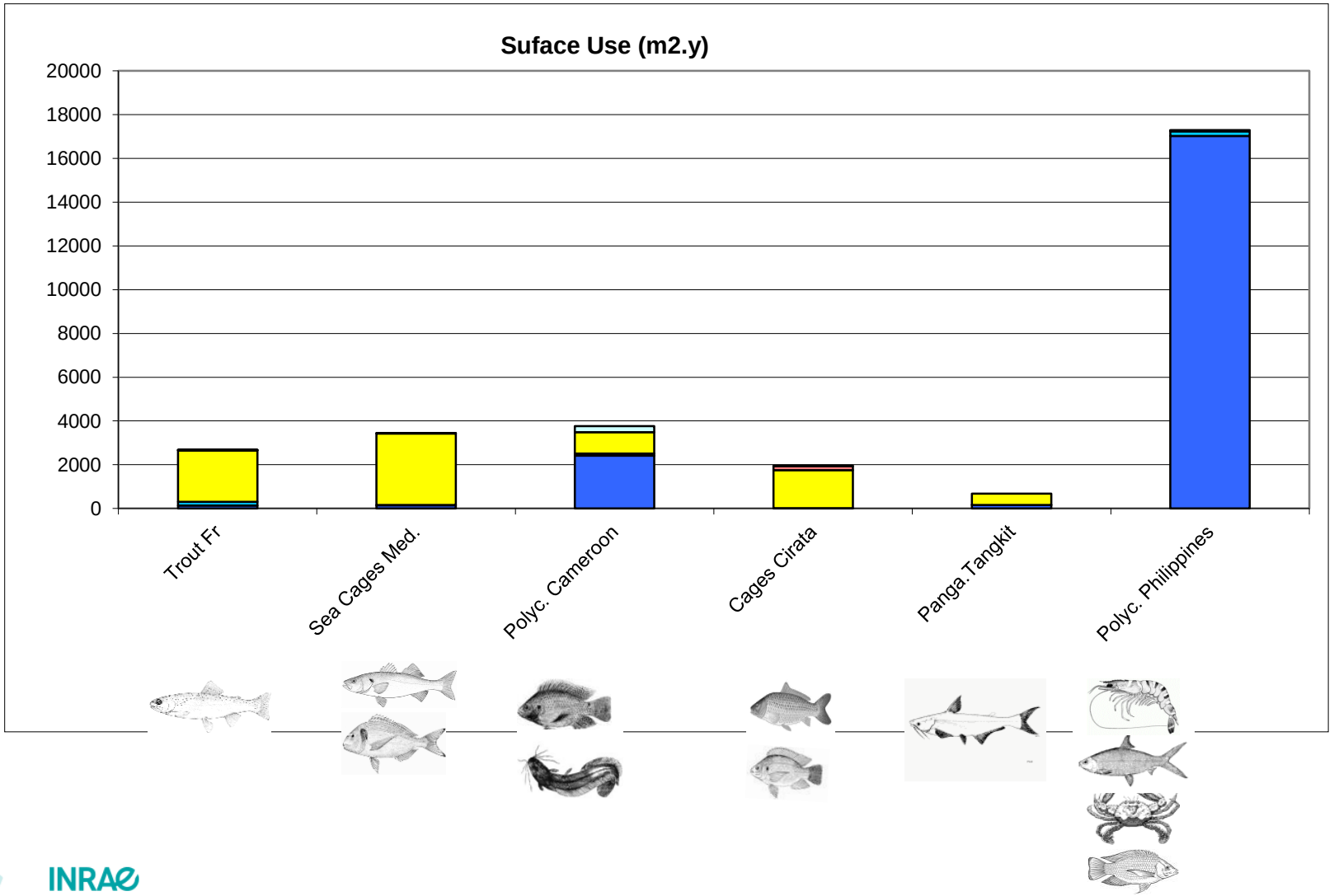
Energy use for 1 tonne of fish



NPP use for 1 tonne of fish



Land occupation for 1 tonne of fish



In practice what do we need to conduct LCA?

- Time: it is time consuming!
- Data:
  - good detailled data is a key point, description of the system, sensitive data (production, consumption…)
  - Background data: feed composition and the impacts of the ingredients! Local data are the best, but availability?

- Software: generally costly but open sources solution exist
- Skill

http://eplca.jrc.ec.europa.eu/ResourceDirectory/toolList.vm

http://eplca.jrc.ec.europa.eu/ResourceDirectory/databaseList.vm

SimaPro


LCA Explorer
Compare Electricity, ... CN U, Electricity, ... NORDEL U and Electricity, ... US U
Analyze Electricity, hard coal, at power plant/CN U
Impact assessment
Inventory
Process contribution
Setup
Checks
Characterization
Normalization
Skip categories
Never
Electricity, hard coal, at power plant/CN U
Electricity, hard coal, at power plant/NORDEL U
Electricity, hard coal, at power plant/US U
Multiple output allocation
Substitution allocation
Cut-off rules
System boundary
20 nodes visible of 1958
Start

To conclude

- A real potential of LCA to describe the systems and understand the environmental hot spots of the aquaculture systems
- The overall objective is to go towards an ecodesign of the production systems
- Developping a data base collection of the aquaculture systems, and of the production of the inputs is a key aspect
- There are many assumptions in LCAs and it is necessary to know them well in order to compare results
- Improvements are still needed to take into account specific questions, such as biodiversity
- It is an active field of research and important field of application

Thank you for your attention

Do you have questions?