Green Aquaculture Intensification

SUMMER SCHOOL

FROM AUGUST 30TH TO SEPTEMBER 3RD

This project receives funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 773330 (GAIN)

GAIN Green Aquaculture Intensification

SUMMER SCHOOL

LIFE-CYCLE ASSESSMENT: A MORE AND MORE POPULAR TOOL TO ASSESS SUSTAINABILITY

GAIN SUMMER SCHOOL

PROF. ROBERTO PASTRES
DR. SILVIO CRISTIANO

SEPTEMBER 2ND

This project receives funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 773330 (GAIN)

WHAT IS LCA?

A tool for quantifying the environmental performance of products/processes/services taking into account the complete life cycle, starting from the **production of raw materials** to the **final disposal of the products**, including material recycling if needed.

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A tool for quantifying the environmental performance of products/processes/services taking into account the complete life cycle, starting from the **production of raw materials** to the **final disposal of the products**, including material recycling if needed.

Developed from energy analysis to a comprehensive environmental burden analysis in the 1970s, with full-fledged LCAs introduced and booned in the 1980s and 1990s (Guinée et al., 2011)

Standardized method at the International Standard Organization: ISO 14040 (2006) and ISO 14044 (2006), the latter updated in 2018

WHAT IS LCA?

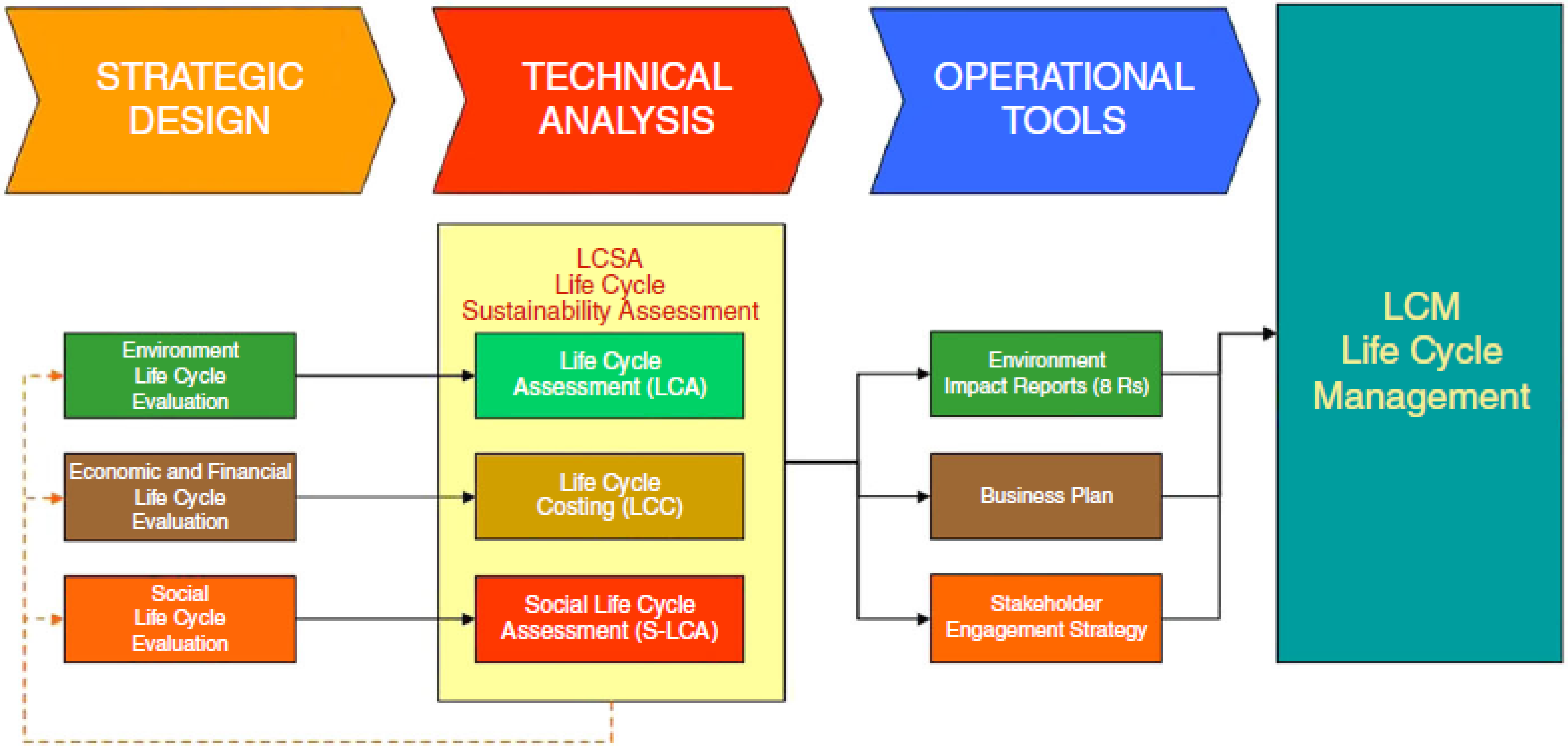
Allows for standardized environmental certification based on ISO 14021 (2016)

Currently used to track, monitor, and mitigate **environmental impacts** in production processes within many economic sectors, **including the agrifood one**, with focus on **carbon footprints**, ecological impacts, and waste management.

Used by an increasing number of companies to enhance the environmental sustainability of their production and commercialization strategies, implement best practices, and communicate these achievements to customers/consuemrs.

→ LCA is included in voluntary **Environmental Product Declarations** with third-party audits (e.g. Eco-label 3)

WHICH ARE THE MAIN LCA APPLICATIONS?



WHICH ARE THE MAIN LCA APPLICATIONS?

- Identification of improvement opportunities , through identifying **environmental hot spots** in the life cycle of a product.

- Analysis of the contribution of the life cycle stages to the overall environmental load, usually with the objective of prioritizing the improvement on products or processes.

- Comparison between products for internal or external communication, and as a basis for environmental product declarations.

- Standardization of metrics and identification of Key Performance Indicators, used in companies for life cycle management and decision support

LCA: WHY SHOULD WE BOTHER?

Reviews in Aquaculture / Volume 11, Issue 4 / p. 1061-1079

Review

Life cycle assessments of aquaculture systems: a critical review of reported findings with recommendations for policy and system development

Florence Alexia Bohnes, Michael Zwicky Hauschild, Jørgen Schlundt, Alexis Laurent

First published: 22 August 2018
https://doi.org/10.1111/raq.12280
Citations: 28

Review | Published: 16 August 2018

LCA of aquaculture systems: methodological issues and potential improvements

Florence Alexia Bohnes & Alexis Laurent

The International Journal of Life Cycle Assessment **24**, 324–337 (2019) | Cite this article
1593 Accesses | **16** Citations | **1** Altmetric | Metrics

ELSEVIER
Aquacultural Engineering
Volume 92, February 2021, 102130

Review

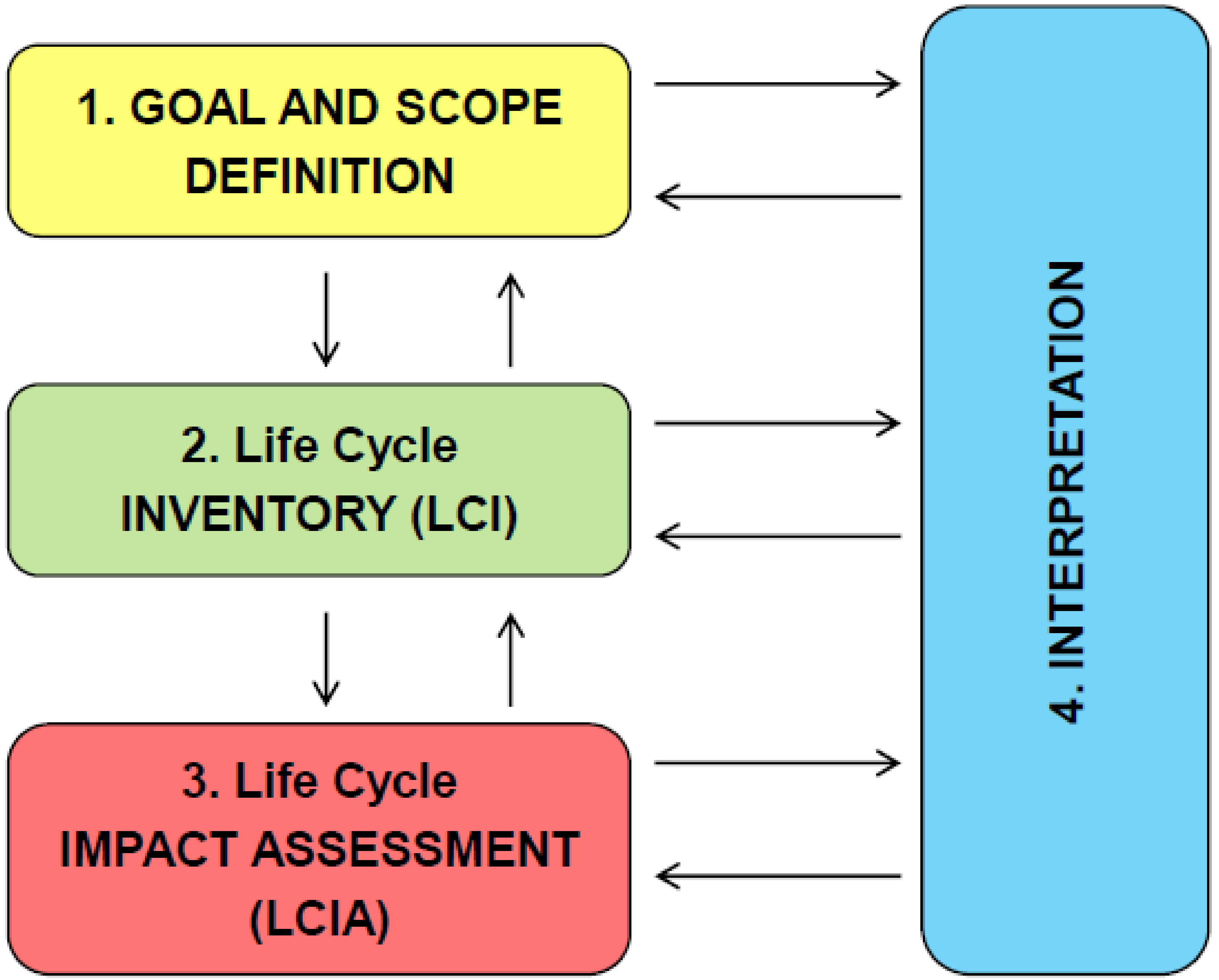
Life cycle assessment of aquaculture systems: Does burden shifting occur with an increase in production intensity?

Ramin Ghamkhar [a, 1], Suzanne E. Boxman [b, 1], Kevan L. Main [c], Qiong Zhang [b], Maya A. Trotz [b], Andrea Hicks [a]

A recent and still ongoing boost can be observed in publications and applications of LCA in aquaculture

LCA: HOW?

THE LCA METHOD



International Organization for Standardization

ISO 14040:2006

It describes the principles and framework for life cycle assessment (LCA) , namely:

1. GOAL AND SCOPE

- An LCA models a product, service, or system life cycle. What is important to realize is that a model is a simplification of a complex reality and as with all simplifications this means that the reality will be distorted in some way.

- The challenge for an LCA practitioner is to develop the model in such a way that the simplifications and distortions do not influence the results (too much).

1. GOAL AND SCOPE – FOCUS ON:

The reason for carrying out the LCA (the questions which need to be answered).

A precise definition of the product/process/service, **its life cycle** and the function it fulfills.

A definition of the **functional unit** (very important for comparing products).

A description of the **system boundaries** and the way co-production will be dealt with.

Data and **data quality** requirements, assumptions and limitations.

The requirements regarding the LCIA procedure, and the **subsequent interpretation** to be used.

The **intended audience(s)** and the way the results will be communicated.

The type and format of the report required for the study.

1. GOAL AND SCOPE – EXAMPLES

- To highlight unexpected hotspots of a single productive process.
- To compare 2 or more productive processes from a sustainable point of view.
- To be used as a basis to get an environmental label (e.g. the Environmental Product Declaration)

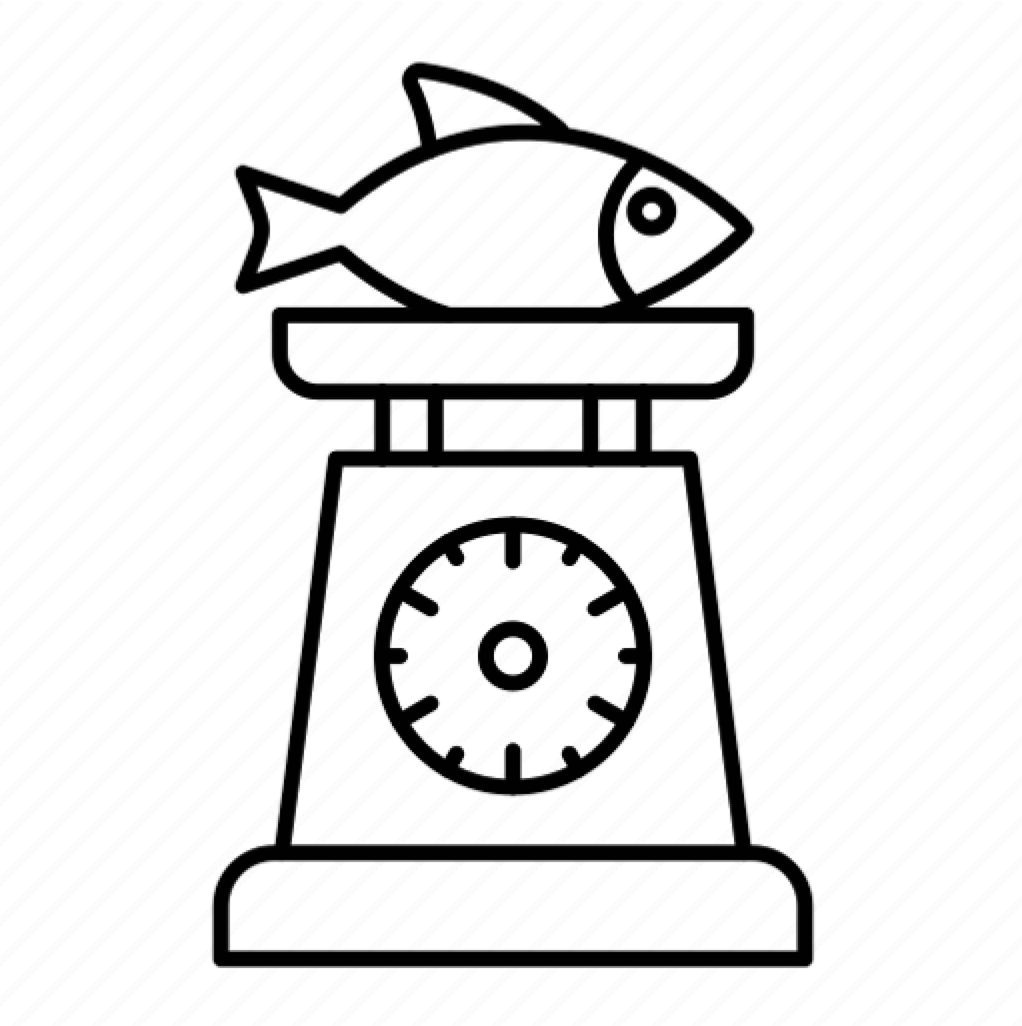
EPD®
THE INTERNATIONAL EPD® SYSTEM

1. GOAL AND SCOPE – FUNCTIONAL UNIT

All the impacts potentially caused to the environment **MUST BE** referred to the declared unit of measurement, which:

- should be clearly stated at the beginning of the analysis
- should reflect the function of the product

e.g. 1 ton of live-weight trout at the farm gate



1. GOAL AND SCOPE – AN EXAMPLE FROM A REAL CASE-STUDY

ELSEVIER

Contents lists available at ScienceDirect

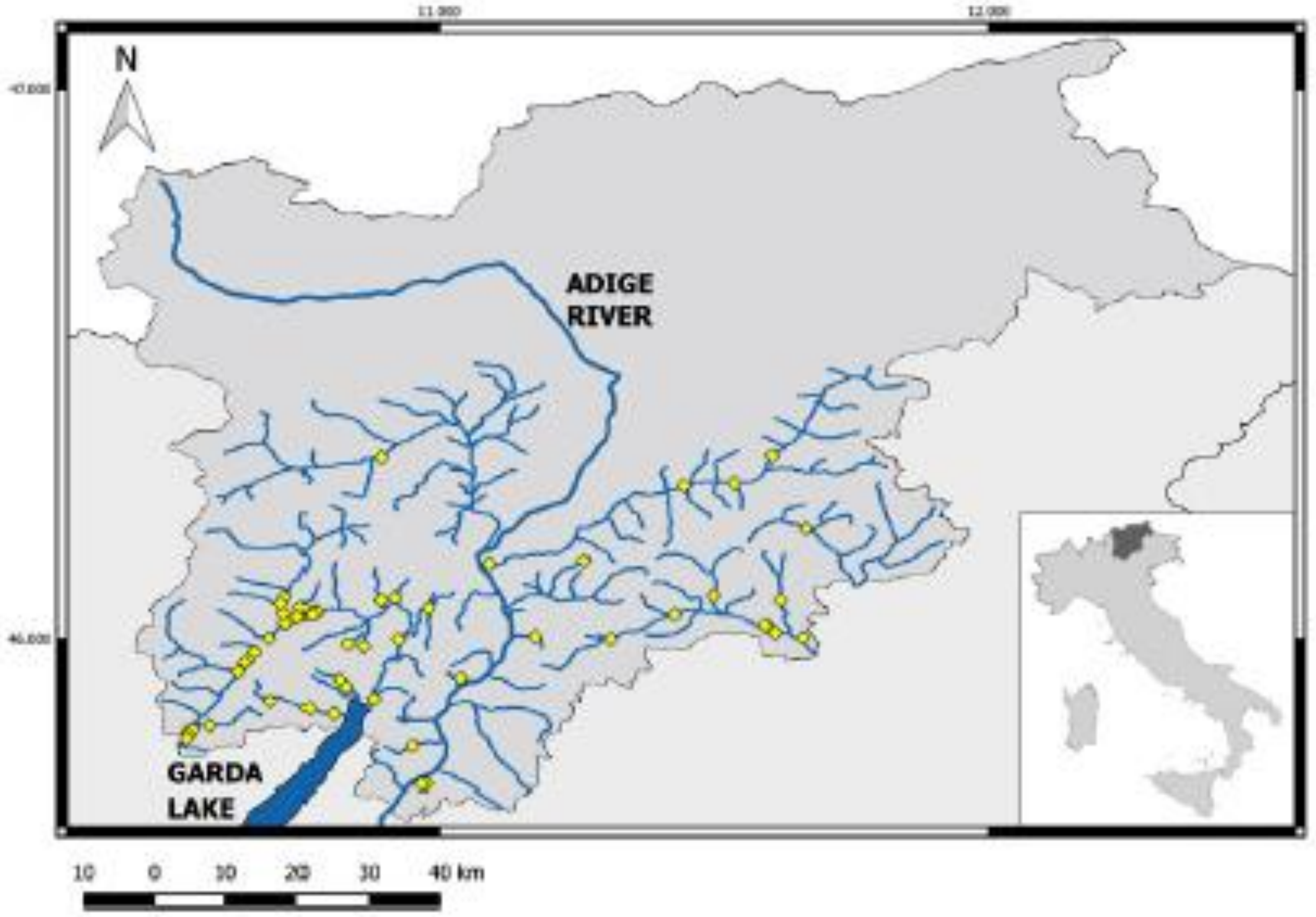
Journal of Cleaner Production

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

From feed to fork – Life Cycle Assessment on an Italian rainbow trout (*Oncorhynchus mykiss*) supply chain

Silvia Maiolo [a,*], Andrea Alberto Forchino [a], Filippo Faccenda [b], Roberto Pastres [a]

[a] Ca' Foscari University of Venice, Department of Environmental Sciences, Informatics and Statistics, Via Torino 155, 30170, Venezia Mestre, Italy
[b] Technology Transfer Centre, Fondazione Edmund Mach, Via E. Mach 1, 38010, San Michele All'Adige, Italy

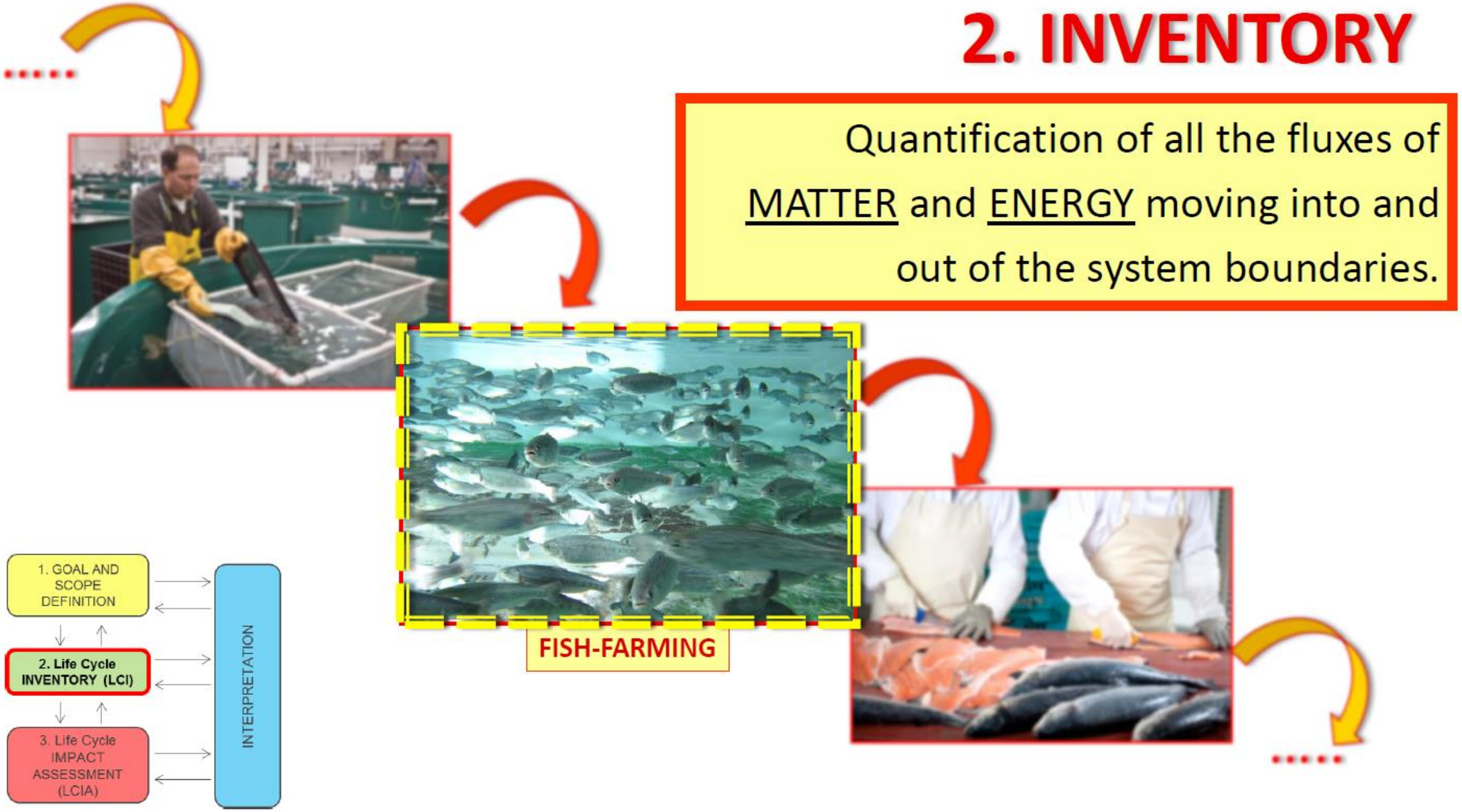


LCA of a rainbow trout production supply chain in North-Eastern Italy

Goal: to identify environmentally relevant hotspots of the supply chain

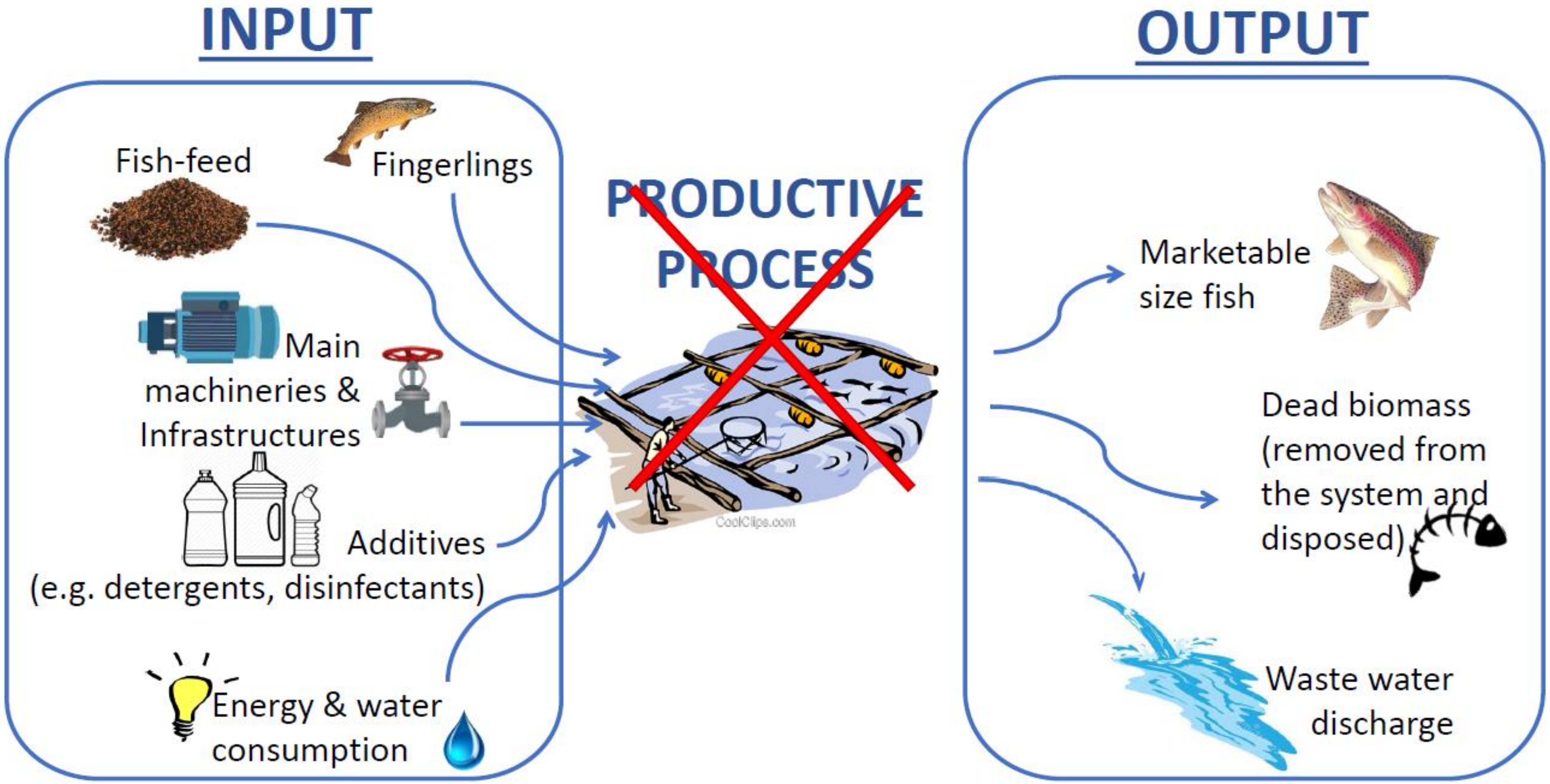
Functional unit: 1 ton of live-weight trout

2. INVENTORY

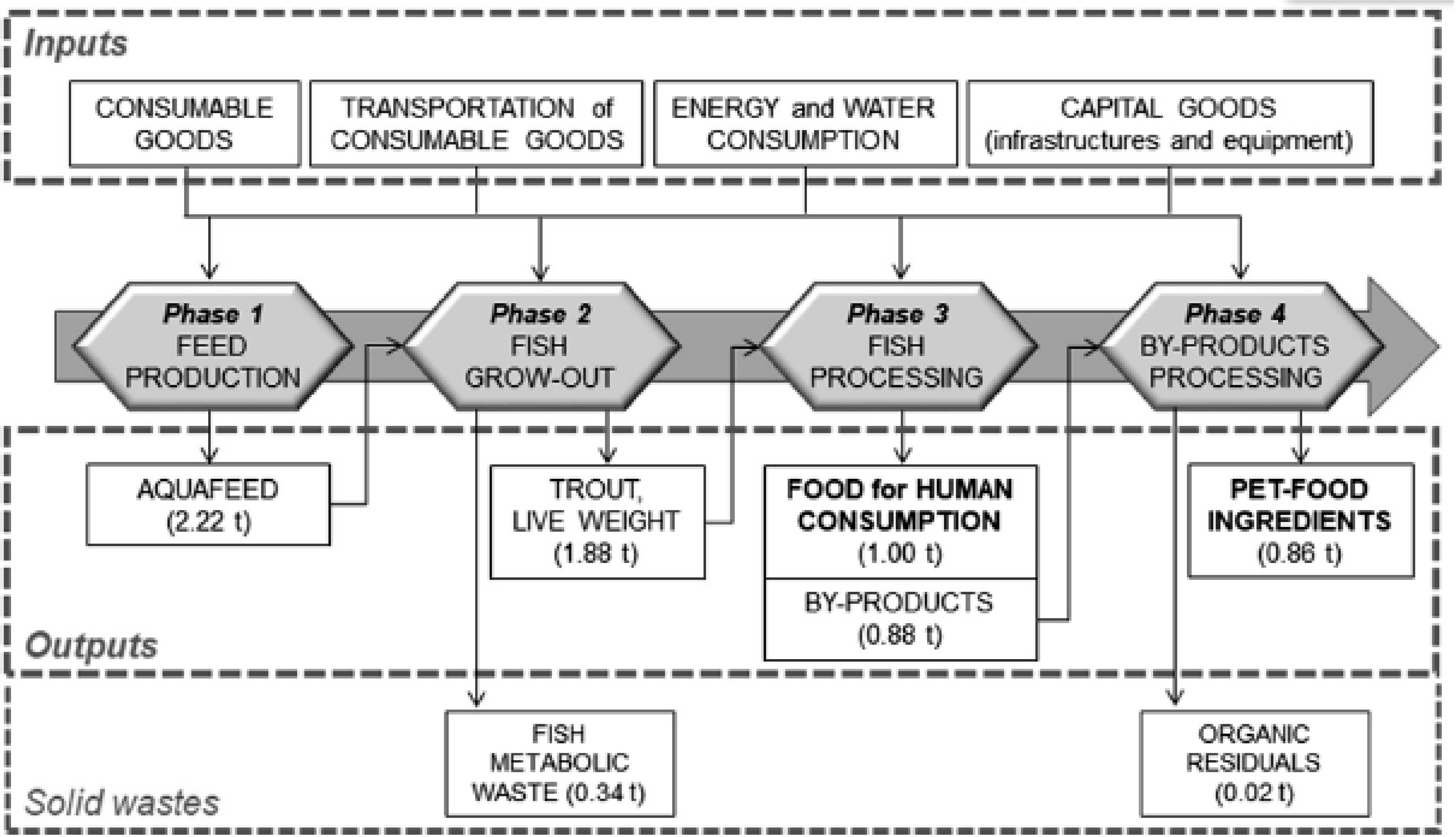


GAIN SUMMER SCHOOL

2. INVENTORY


INPUT
Fish-feed
Fingerlings
Main machineries & Infrastructures
Additives (e.g. detergents, disinfectants)
Energy & water consumption
PRODUCTIVE PROCESS
CoolClips.com
OUTPUT
Marketable size fish
Dead biomass (removed from the system and disposed)
Waste water discharge

2. INVENTORY – AN EXAMPLE FROM A REAL CASE-STUDY



2. INVENTORY – AN EXAMPLE FROM A REAL CASE-STUDY

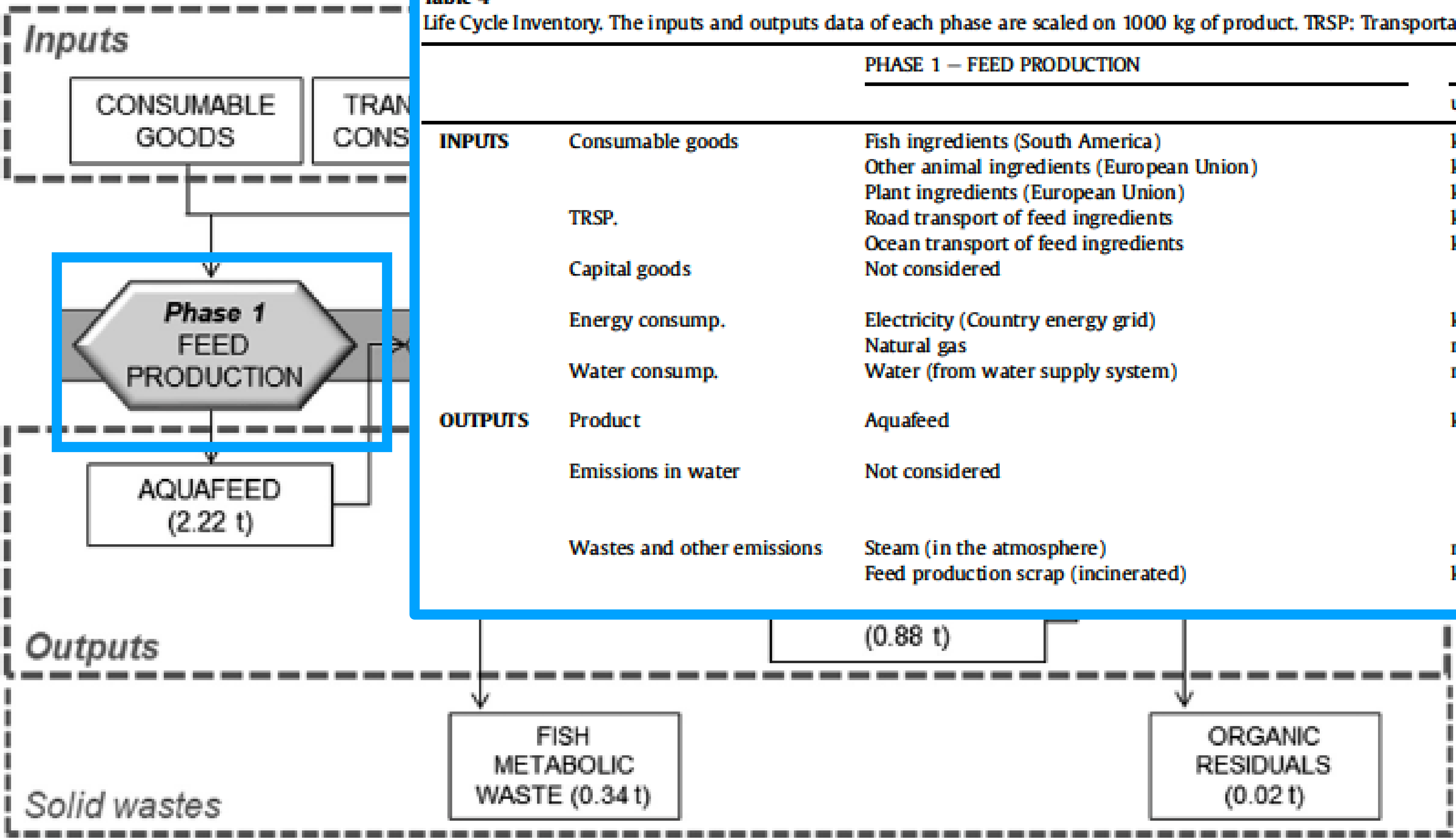


Table 4
Life Cycle Inventory. The inputs and outputs data of each phase are scaled on 1000 kg of product. TRSP: Transportation.

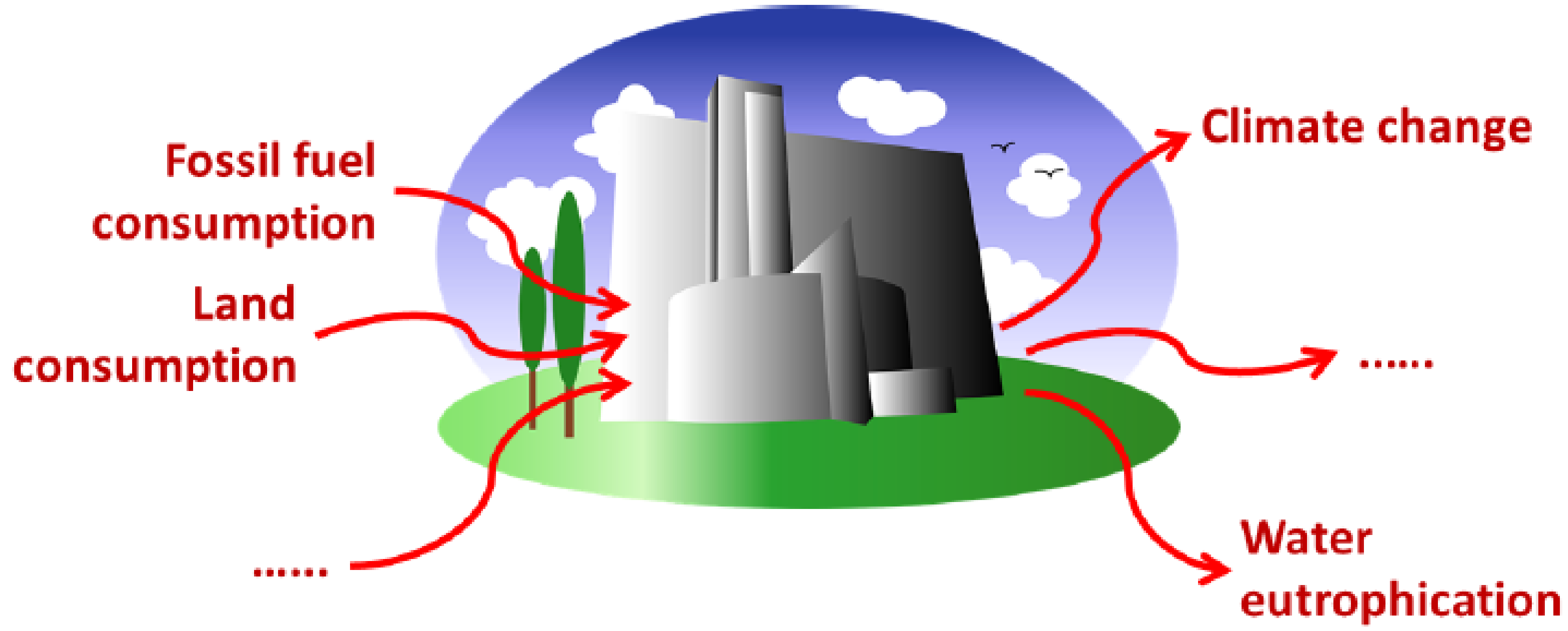
		PHASE 1 – FEED PRODUCTION	unit	quantity
INPUTS	Consumable goods	Fish ingredients (South America)	kg	320.00
		Other animal ingredients (European Union)	kg	310.00
		Plant ingredients (European Union)	kg	370.00
	TRSP.	Road transport of feed ingredients	kg km	622,960.00
		Ocean transport of feed ingredients	kg km	3,739,520.00
	Capital goods	Not considered		
	Energy consump.	Electricity (Country energy grid)	kwh	148.00
		Natural gas	m3	18.00
	Water consump.	Water (from water supply system)	m3	0.32
OUTPUTS	Product	Aquafeed	kg	1000.00
	Emissions in water	Not considered		
	Wastes and other emissions	Steam (in the atmosphere)	m3	0.32
		Feed production scrap (incinerated)	kg	1.02

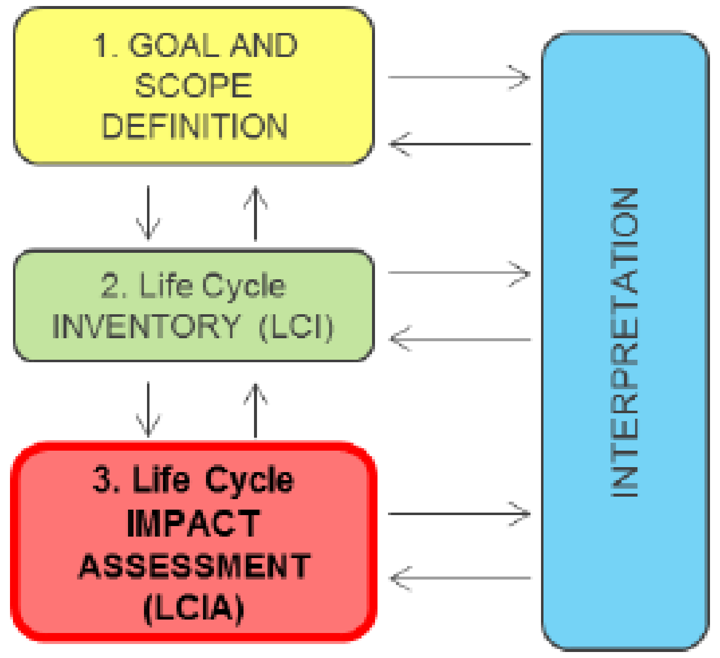
One table per phase

3. IMPACT ASSESSMENT (LCIA)

3. IMPACT ASSESSMENT

Conversion of the fluxes listed in the inventory….





…into the possible effects (negative or positive) on the Natural Environment.

These effects are named **IMPACT CATEGORIES**.

3. IMPACT ASSESSMENT – IMPACT CATEGORIES

Impact category	Unit	
Global Warming Potential, 100a	kg CO_2 eq	
Stratospheric ozone depletion	kg CFC11 eq	trichlorofluoromethane
Ionising radiation	kBq Co-60 eq	cobalt 60
Ozone formation, Human health	kg NOx eq	
Fine particulate matter formation	kg $PM_{2.5}$ eq	
Terrestrial acidification	kg SO_2 eq	
Eutrophication, freshwater	kg P eq	
Eutrophication, marine	kg N eq	
Terrestrial ecotoxicity	kg 1,4-DCB	1,4-dichlorobenzene
Freshwater ecotoxicity	kg 1,4-DCB	
Marine ecotoxicity	kg 1,4-DCB	
Human carcinogenic toxicity	kg 1,4-DCB	
Human non-carginogenic toxicity	kg 1,4-DCB	
Land use	m^2a crop eq	
Mineral resource scarcity	kg Cu eq	
Fossil resource scarcity	kg oil eq	
Water consumption	m^3	

3. IMPACT ASSESSMENT – IMPACT CATEGORIES

FREQUENTLY USED IN AQUACULTURE

	Impact category	Unit
→	Global Warming Potential, 100a	kg CO_2 eq
	Stratospheric ozone depletion	kg CFC11 eq
	Ionising radiation	kBq Co-60 eq
	Ozone formation, Human health	kg NOx eq
	Fine particulate matter formation	kg $PM_{2.5}$ eq
→	Terrestrial acidification	kg SO_2 eq
→	Eutrophication, freshwater	kg P eq
→	Eutrophication, marine	kg N eq
→	Terrestrial ecotoxicity	kg 1,4-DCB
→	Freshwater ecotoxicity	kg 1,4-DCB
→	Marine ecotoxicity	kg 1,4-DCB
	Human carcinogenic toxicity	kg 1,4-DCB
	Human non-carginogenic toxicity	kg 1,4-DCB
	Land use	m^2a crop eq
	Mineral resource scarcity	kg Cu eq
	Fossil resource scarcity	kg oil eq
	Water consumption	m^3

trichlorofluoromethane

cobalt 60

1,4-dichlorobenzene

3. IMPACT ASSESSMENT – IMPACT CATEGORIES

ALL
FREQUENTLY USED IN AQUACULTURE

Cumulative exergy demand	
Non renewable, fossil	MJ
Non renewable, nuclear	MJ
Renewable, kinetic	MJ
Renewable, solar	MJ
Renewable, potential	MJ
Non renewable, primary	MJ
Renewable, biomass	MJ
Renewable, water	MJ
Non renewable, metals	MJ
Non renewable, minerals	MJ

3. IMPACT ASSESSMENT – IMPACT ASSESSMENT METHODS

Impacts are defined as the effects caused on humans and/or the rest of the environment by the energy and materials directly or indirectly included in the life-cycle inventory, including end-of-life disposal.

Phase 1: Classification: inventory data are divided into themes and categories.

Phase 2: Characterisation: quantifies the impacts from the inventory.

3. IMPACT ASSESSMENT – IMPACT ASSESSMENT METHODS

Impacts are defined as the effects caused on humans and/or the rest of the environment by the energy and materials directly or indirectly included in the life-cycle inventory, including end-of-life disposal.

Phase 1: Classification: inventory data are divided into themes and categories.

Phase 2: Characterisation: quantifies the impacts from the inventory.

ENVIRONMENTAL THEMES:

- Raw material potential depletion
- Energy source potential depletion
- Global warming potential (GWP)
- Ozone depletion potential (ODP)
- Water and soil exotoxicity
- Acidification potential (AP)
- Human toxicity
- Eutrophication, or Nutrification potential (NP)

3. IMPACT ASSESSMENT – IMPACT CATEGORIES AND METHODS

METHODS	Acidification	Climate change	Resource depletion	Ecotoxicity	Energy Use	Eutrophication	Human toxicity	Ionising Radiation	Land use	Odour	Ozone layer depletion	Particulate matter/ Respiratory inorganics	Photochemical oxidation
CML (baseline)	✓	✓	✓	✓	-	✓	✓	-	-	-	✓	-	✓
CML (non baseline)	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	-	✓
Cumulative Energy Demand	-	-	-	-	✓	-	-	-	-	-	-	-	-
eco-indicator 99 (E)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	-
eco-indicator 99 (H)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	-
eco-indicator 99 (I)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	-
Eco-Scarcity 2006	-	-	✓	-	-	-	-	-	-	-	-	-	-
ILCD 2011, endpoint	✓	✓	-	-	-	✓	✓	✓	✓	-	✓	✓	✓
ILCD 2011, midpoint	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Endpoint (E)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Endpoint (H)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Endpoint (I)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Midpoint (E)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Midpoint (H)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Midpoint (I)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
TRACI 2.1	✓	✓	✓	✓	-	✓	✓	-	-	-	✓	✓	✓
USEtox	-	-	-	✓	-	-	✓	-	-	-	-	-	-

Table 1: Availability of impact categories per method. ✓ represents that the impact category is contained in the correspondent method and - that not.

3. IMPACT ASSESSMENT – EXAMPLE FROM A REAL CASE-STUDY

Table 7
LCIA on Feed Production (phase 1). The impacts, assessed with the ReCiPe H method and with CED indicator, are scaled on 1 ton of aquafeed produced.

SUB-CATEGORIES	GWP (kg CO_2 eq. to air)	TAP (kg SO_2 eq. to air)	FEP (kg P eq. to fresh water)	TETP (kg 1,4-DCB eq. to industrial soil)	FETP (kg 1,4-DCB eq. to fresh water)	CED (MJ)
Fish ingredients	358.36	1.23	0.02	281.40	1.40	5382.12
Other animal ingredients	603.78	9.50	0.19	1045.78	8.10	13,913.83
Plant ingredients	535.27	5.33	0.62	1055.68	12.55	15,177.01
Transportation	145.83	1.10	0.01	1434.18	1.87	2351.43
Energy consumption	75.20	0.29	0.02	139.88	4.67	2111.54
Water consumption	0.12	0.00	0.00	0.29	0.00	2.28
TOTAL	1718.57	17.46	0.86	3957.20	28.60	38,938.21

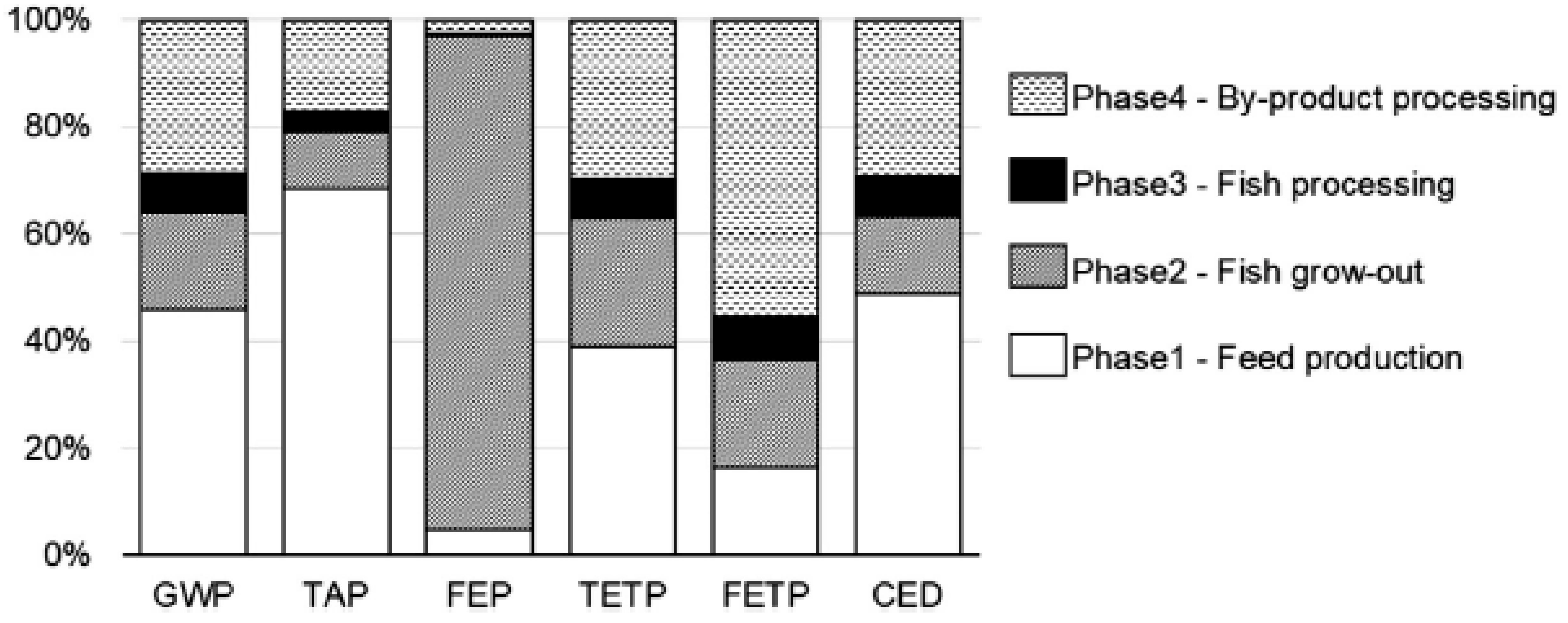


Fig. 3. Contribution analysis. Each column represents the contribution of the four phases to one of the six impact categories.

One table per phase

All phases visualized in graphs (here, histograms)

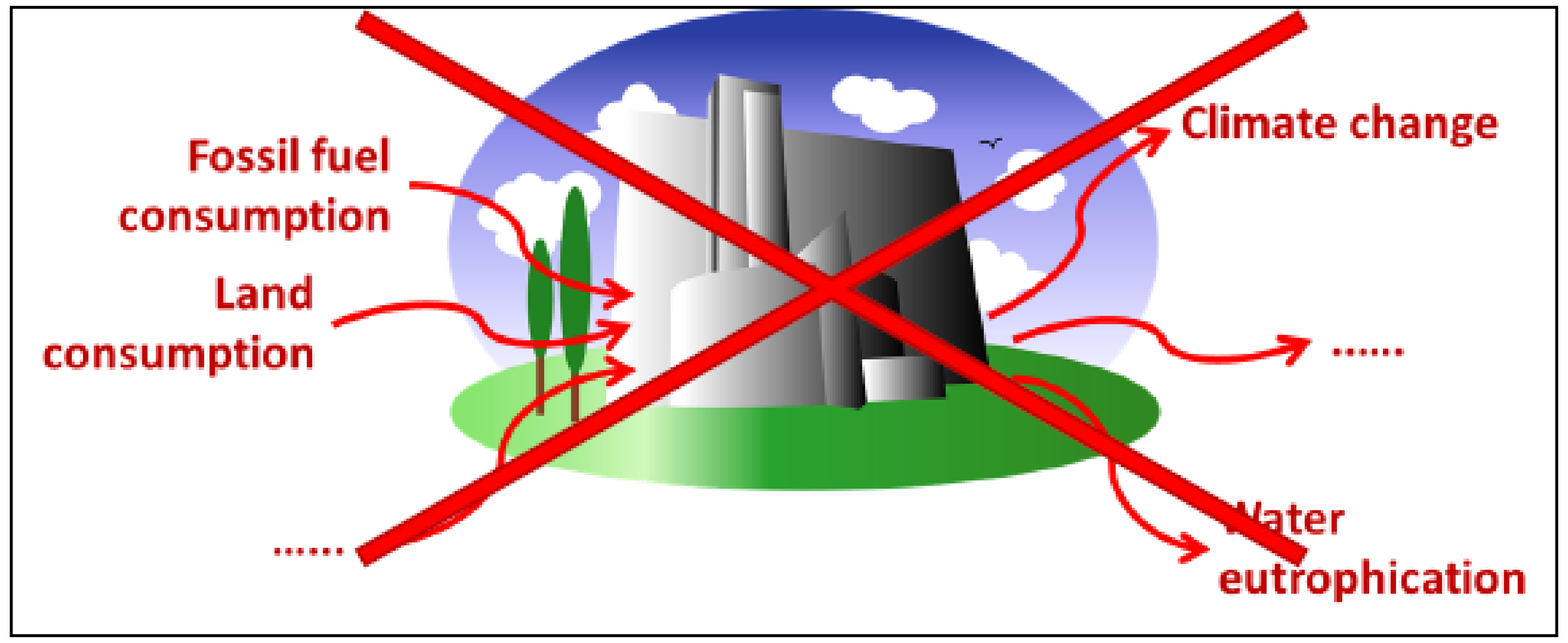
GAIN SUMMER SCHOOL

4. INTERPRETATION OF THE RESULTS

ANALYSIS of the CONTRIBUTIONS

Instead of assessing the <u>**overall impacts**</u> of a production…

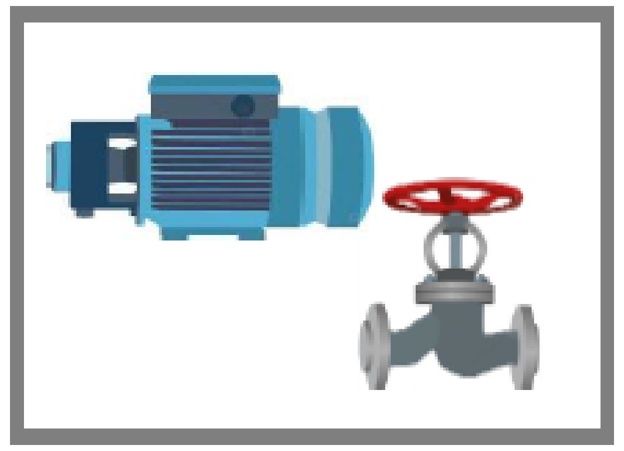
…it is way more interesting to assess the impacts caused by the <u>**different activities carried on**</u> inside it !!!



ENERGY CONSUMPTION

TRANSPORTATION

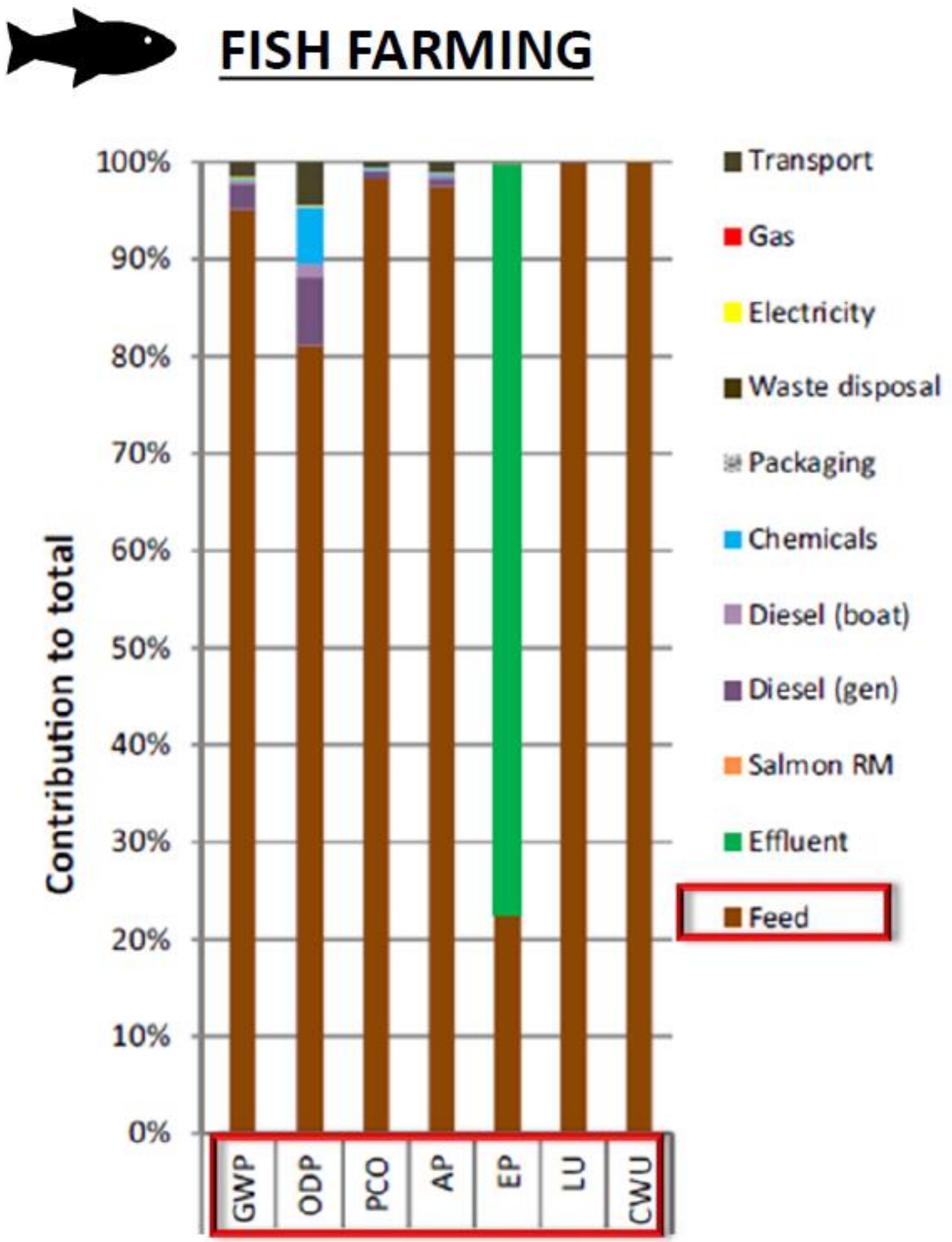
INFRASTRUCTURES & MACHINERIES



WATER CONSUMPTION

ADDITIVES

4. INTERPRETATION OF THE RESULTS



The LCA can highlight critical issues of a productive system...

4. INTERPRETATION OF THE RESULTS – TROUT FARMING

Phase 1 (aquafeed production) is confirmed as a key hotspot. Impact can be reduced by :
- increasing sustainability of feed ingredients;
- improving feed nutritional properties, digestibility, and palatability.

Further research is needed to tailor LCA inventories and impact assessments methods capable of providing more precise and accurate measurements.

Phase 2 (fish grow-out): eutrophication is a key issue.
It is important to track the effects of an increased nutrient release on freshwater ecosystems.
The contribution to impacts of on-farm energy consumption should not be underestimated, especially when considering **climate change**.
Further improvements in the renewable energy production and storage and higher control over on-farm activities (e.g. Precision Fish Farming) may lead to decrease the impact of this phase .

4. INTERPRETATION OF THE RESULTS – TROUT FARMING

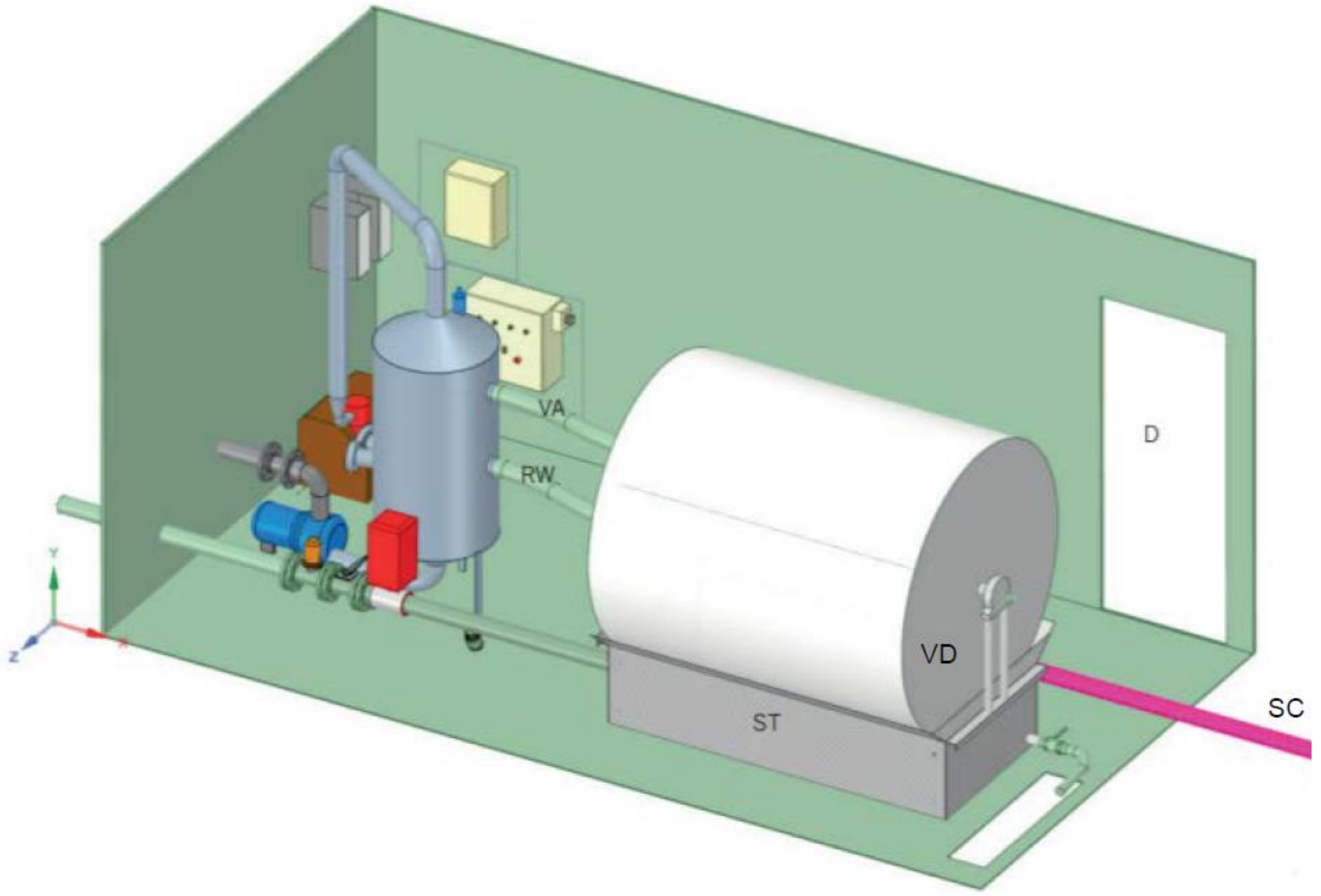
Phase 3 (fish processing) appears as a highly efficient production, already optimizing the use of resources.

- The environmental and economic burdens of the single processing plant are shared among the consortium associates;
- To minimize fish waste, the harvested trout is delivered to the processing plant within a short period of time, thus guaranteeing the cold chain compliance (and the preservation of the fish);
- Fish not fit for market as a whole is not discarded but processed into minced fish.
- **Phase 4**
- Finally, the last phase of the supply chain provided a quite unexpected result, since the recycling of fish by-products into pet-food ingredients appears less sustainable than the incineration option. In this case, more attention must be paid towards the amount and source of energy used, since this aspect stands out as the most critical one.

ANOTHER CASE STUDY

Eco-intensification proposals for sludge treatment in Recirculating Aquaculture Systems (RAS)
as presented yesterday mording by Christian Bruckner (Salten Havbrukspark, Norway)

SLUDGE: filtered and dried
Valorization options: fertiliser, energy in cement factory, biogas substrate



Innovation:
S3 filter- dryer

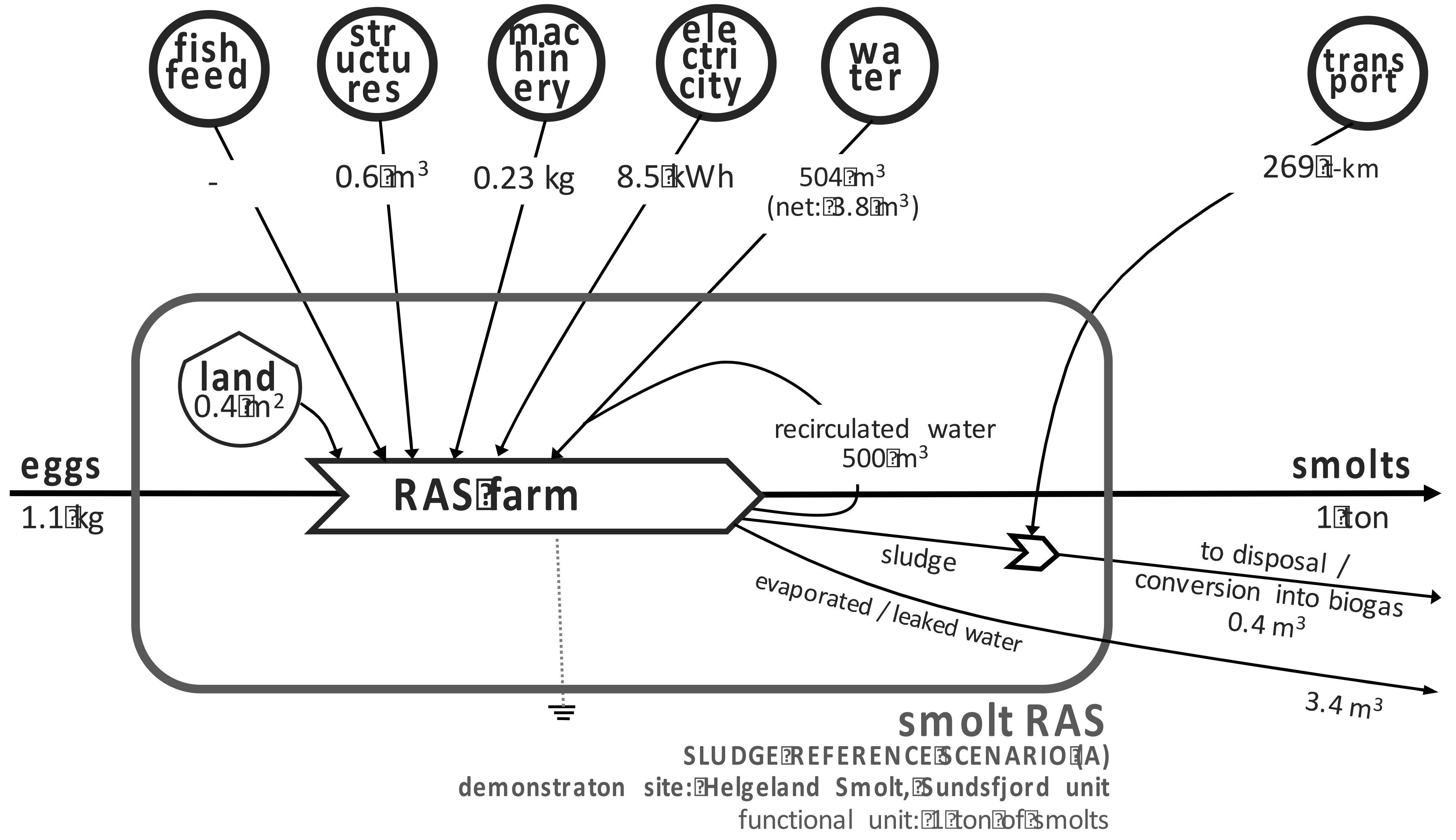
1. GOAL AND SCOPE

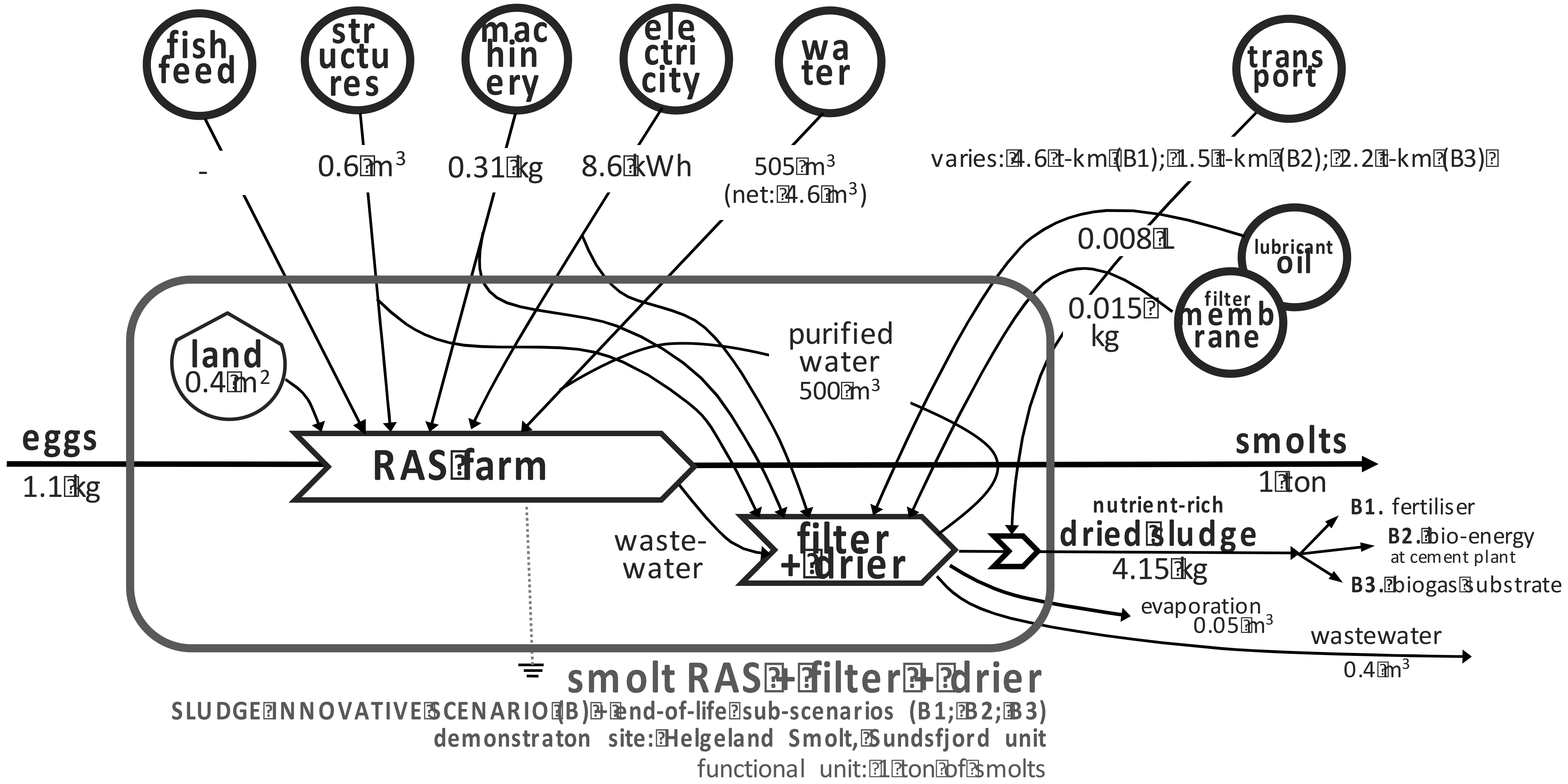
Goal:
to assess the environmental performances of the innovation and its end-of life valorization options compared to busines-as-usual (i.e. not drying the sludge but just disposing of a liquid sludge)

Functional unit:
1 ton of smolts

ANOTHER CASE STUDY

2. INVENTORY





BUSINESS-AS-USUAL SCENARIO (LEFT) AND PROPOSED INNOVATION (RIGHT), WITH THREE INNOVATIVE SUB-SCENARIOS

ANOTHER CASE STUDY

3. IMPACT ASSESSMENT

Table 4. LCIA indicators for sludge treatment evaluation at the selected demonstration plant.

Impact category	Unit	Scenarios				Comparison with A			Method
		A	B1	B2	B3	B1	B2	B3	
Global Warming Potential	kg CO_2 eq	233	99	98	98	**-57%**	**-58%**	**-58%**	[a]
Stratospheric ozone depletion	kg CFC11 eq	1.E-04	4.E-05	4.E-05	4.E-05	**-67%**	**-67%**	**-67%**	[b]
Terrestrial acidification	kg SO_2 eq	0.7	0.3	0.3	0.3	**-56%**	**-57%**	**-57%**	[b]
Eutrophication, freshwater	kg P eq	0.04	0.03	0.03	0.03	**-33%**	**-33%**	**-33%**	[b]
Eutrophication, marine	kg N eq	0.003	0.002	0.002	0.002	**-41%**	**-42%**	**-42%**	[b]
Mineral resource scarcity	kg Cu eq	2.5	2.1	2.1	2.1	**-16%**	**-16%**	**-16%**	[b]
Fossil resource scarcity	kg oil eq	67	21	20	21	**-68%**	**-69%**	**-69%**	[b]
Water consumption	m^3	5.7	6.1	6.1	6.1	**+7%**	**+7%**	**+7%**	[b]
Cumulative Exergy Demand	MJ	3,663	1,522	1,453	1,506	**-58%**	**-60%**	**-59%**	[c]
Land occupation	m^2 * a	24.6	18.9	18.8	18.7	**-23%**	**-24%**	**-24%**	[d]
Biochemical Oxygen Demand	kg	0.6	0.2	0.2	0.2	**-64%**	**-64%**	**-64%**	[d]

Functional unit: 1 ton of produced smolts out of a RAS plant. **Method key**: [a] IPCC GWP 100a; [b] ReCiPe 2016 Midpoint (E); [c] Cumulative Exergy Demand; [d] Selected LCI results V1.4.

ANOTHER CASE STUDY

4. INTERPRETATION OF THE RESULTS

The innovation **leads to a decrease in all impact indicators**, **except for the water use, which showed a 7% increase**: among the largest variations compared to reference scenario A, Cumulative Exergy Demand decreases by nearly –60%, with minor oscillations in the three sub-scenarios. Reductions greater than –50% are also found in Global Warming Potential, Terrestrial acidification.

The three end-of-life options for the valorisation of the new by-product, i.e. nutrients reuse as ingredient in fertiliser, energy in cement plant, and conversion into biogas, do not show significant differences.

Mineral resource scarcity and Land occupation might be directly and indirectly influenced by the need for new machinery when passing from reference scenario A to the innovative scenarios (B1, B2, B3), with minerals and processing plants required for the production of metal components.

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GOING OPERATIONAL: SOFTWARE FOR CARRYING OUT LCA

- LCA software tools facilitate the implementation of steps 2-4.

- In the hands-on session we are going to introduce, SimaPro.

- SimaPro is among the most widespread professional software tools for carrying out LCA.

- It is expensive but the cost is lower for educational purposes.

- SimaPro allows one to:
    - define the system boundaries and functional unit;
    - organize the inventory in a logical manner;
    - select methodologies for “allocation” of the environmental burden and conversion of the inventory data into impact categories;
    - interpret the results, by means of tables & plots.

SimaPro

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