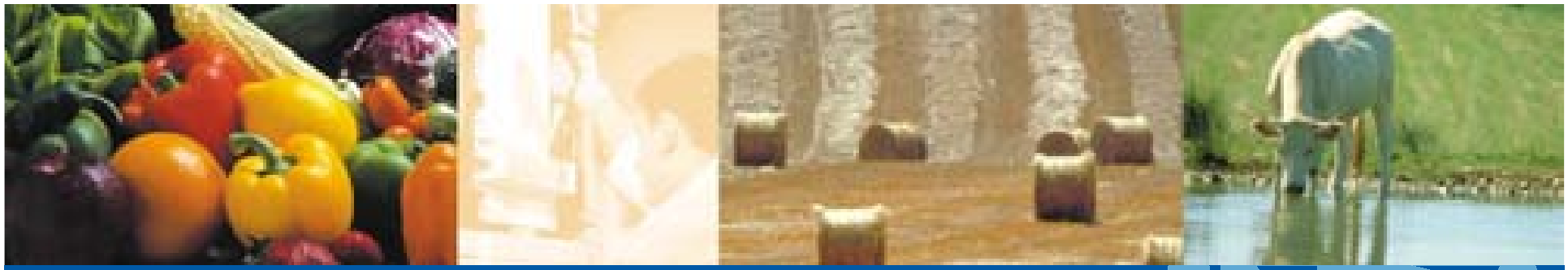
Comparing environmental impacts of livestock production systems of varying intensity

Michael Corson, Joël Aubin, and Hayo van der Werf

Soil, Agro- and hydroSystems Unit, Rennes, France



ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

INRA

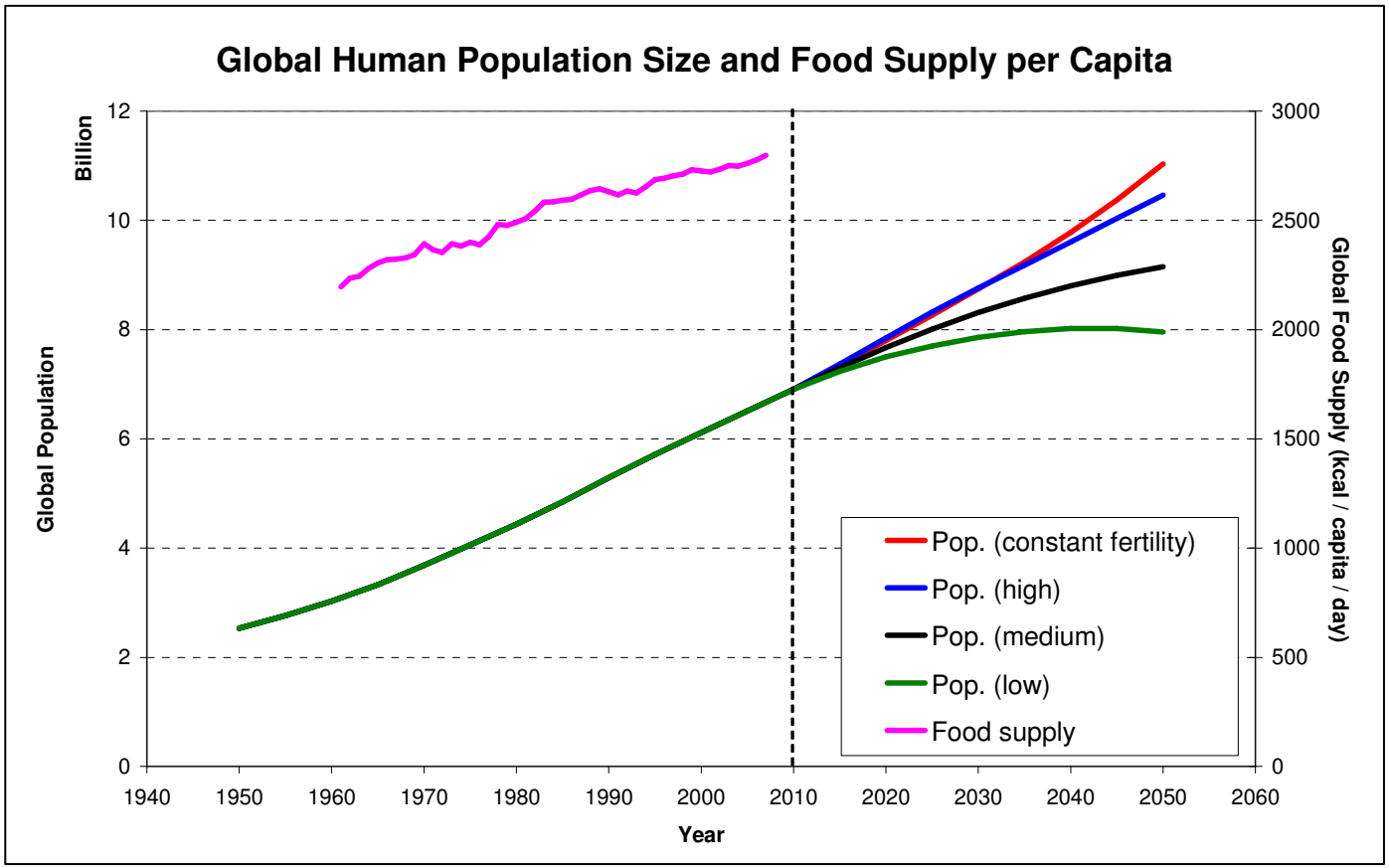
25 Aug 2010

Outline

- **Background**
- **Environmental Analysis via Life Cycle Assessment (LCA)**
- **Intensification gradients and impacts of aquaculture, pig, and dairy production systems**
- **Comparing effects of intensification**
- **Impacts vs. sustainability**

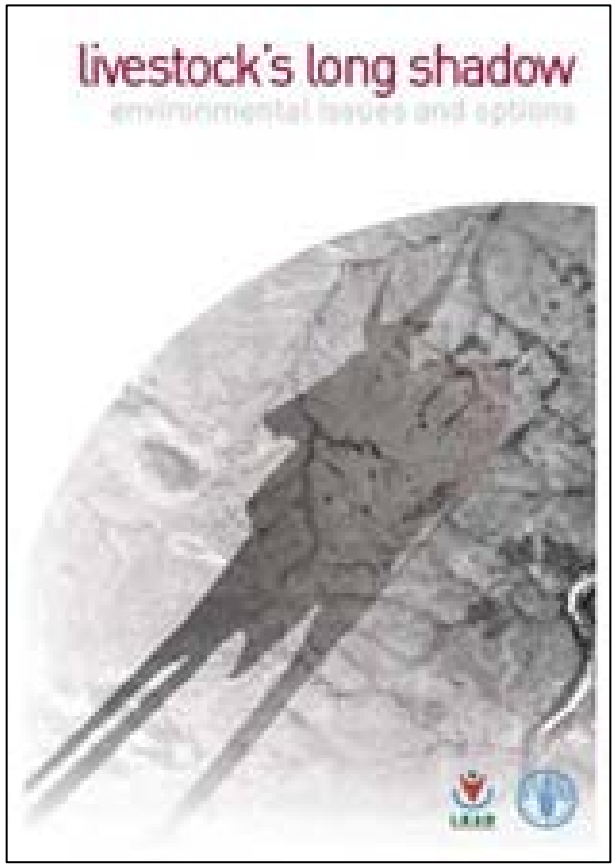
Background

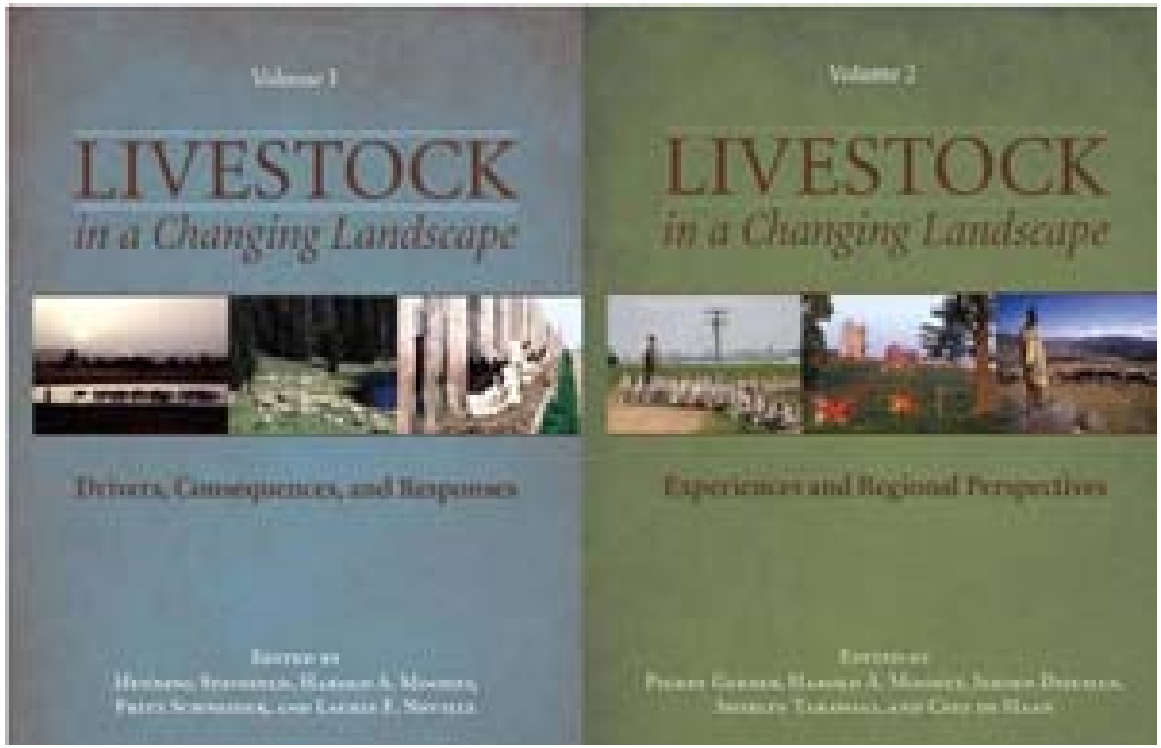
Population growth and food supply



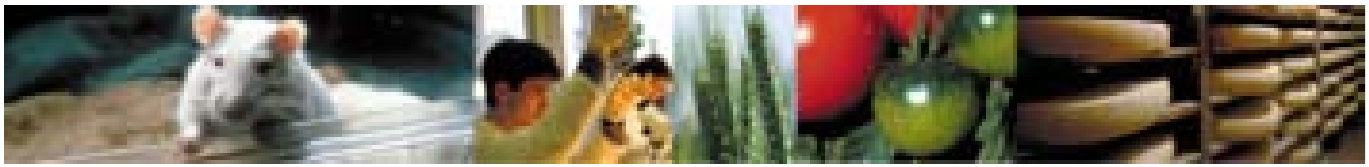
Sources: Population – United Nations Population Division; Food supply - FAOSTAT

Environmental impacts of livestock





Environmental Analysis via LCA



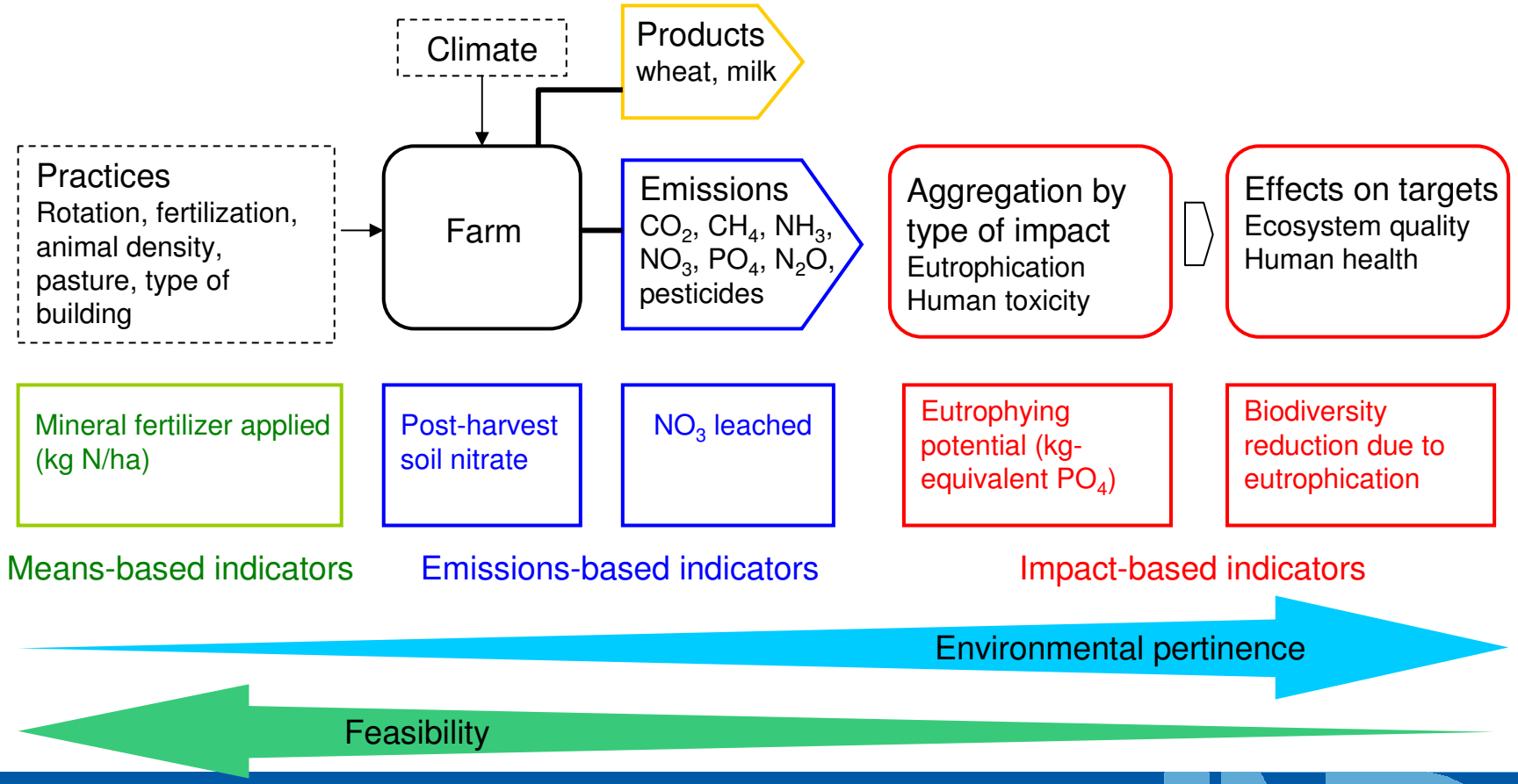
25 Aug 2010

ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

INRA

Environmental Analysis via LCA

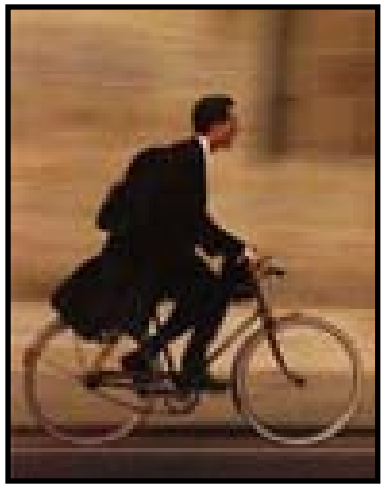
Causal chain from practices to impacts



Environmental Analysis via LCA

Life cycle of a bicycle

Production



Use

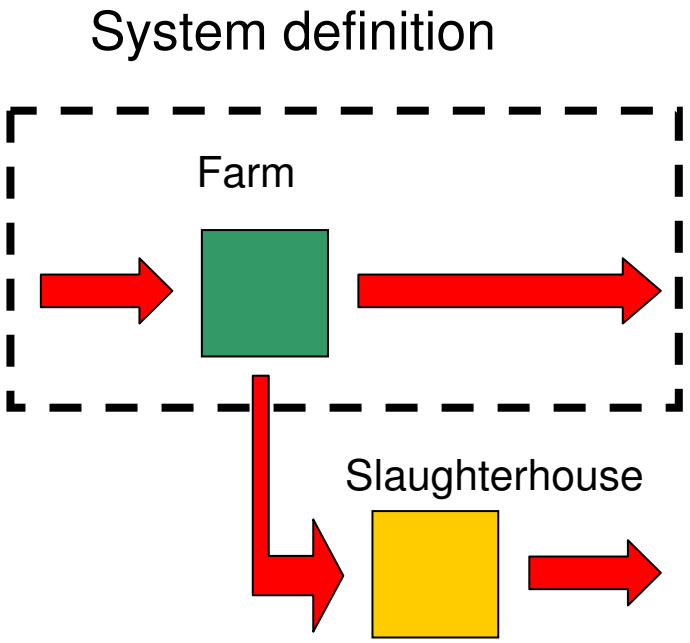
Disposal or recycling

Extraction of raw materials

Transformation of raw materials

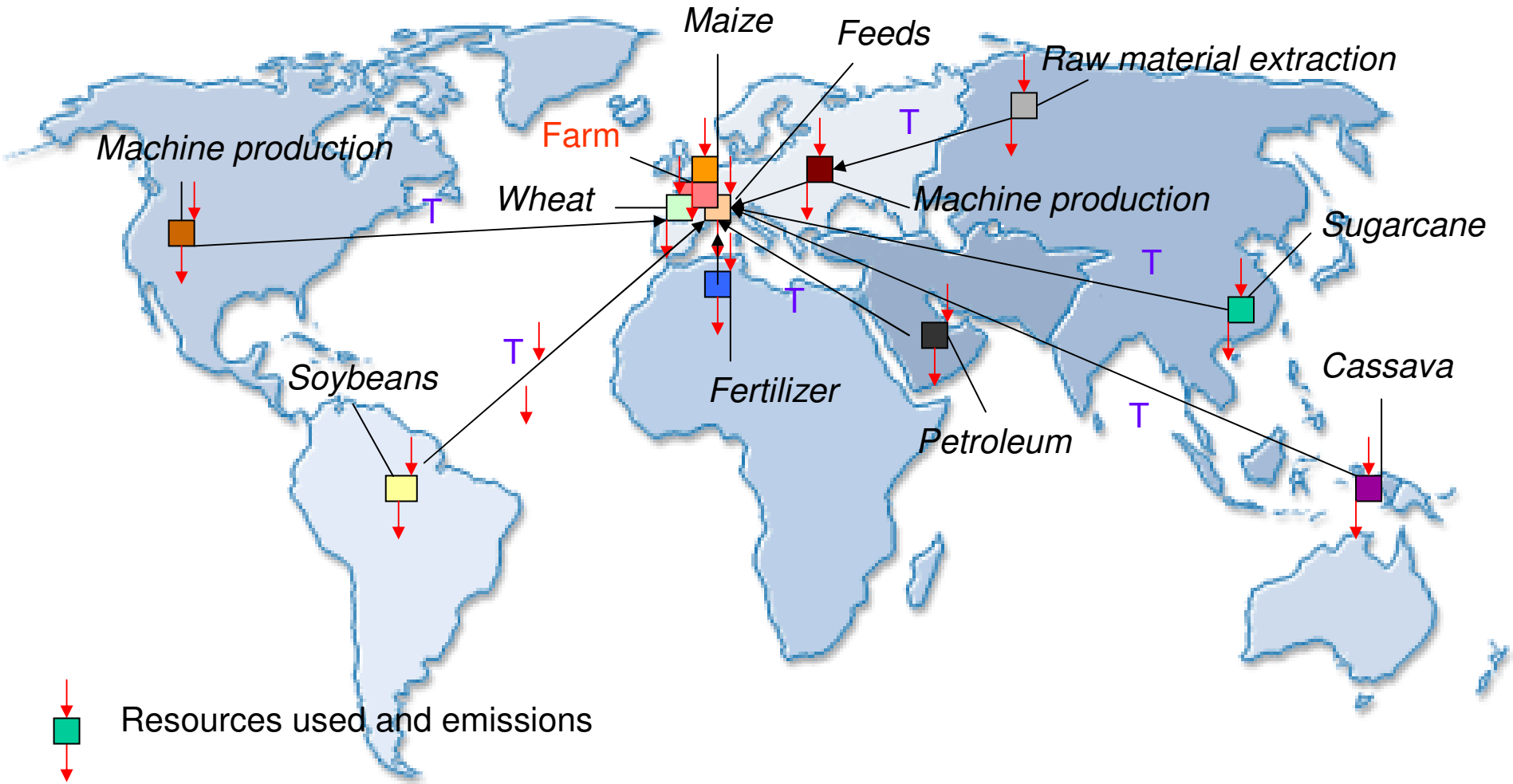
Environmental Analysis via LCA

LCA approach



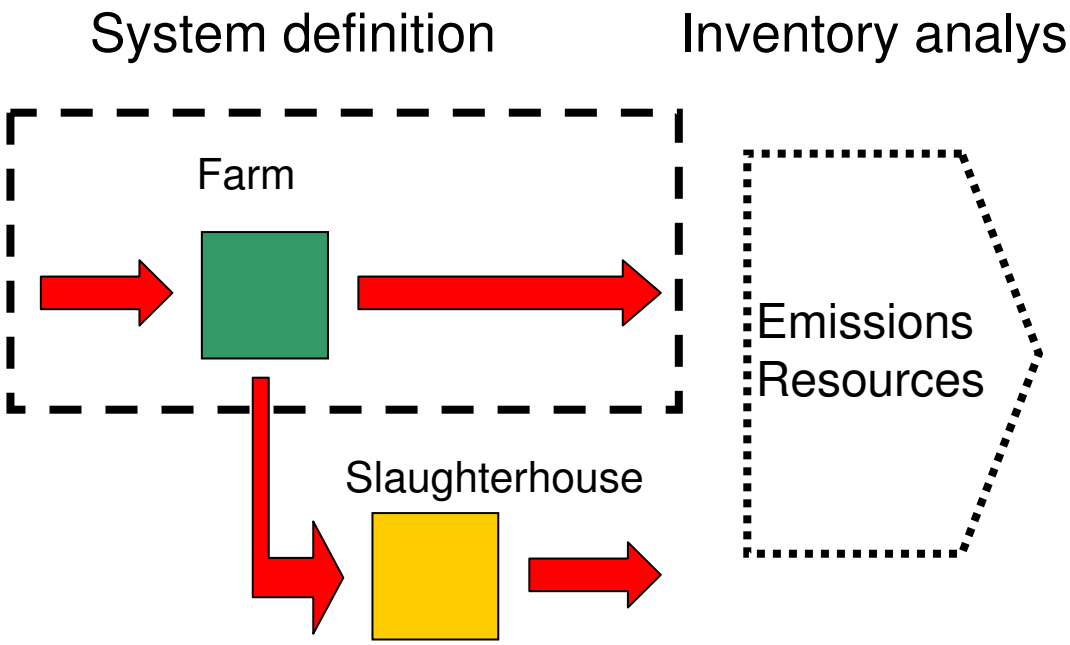
Environmental Analysis via LCA

Global inputs



Environmental Analysis via LCA

LCA approach



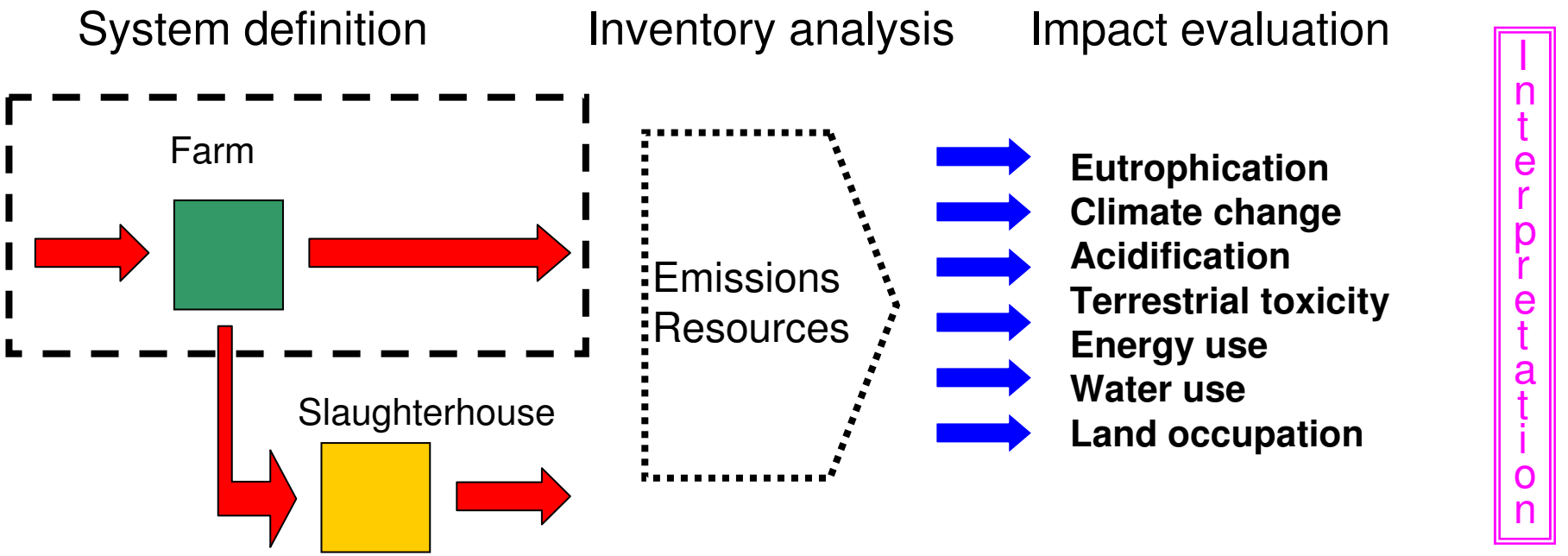
LCA impact categories

Basic impact categories	Complementary impact categories
Abiotic resource depletion	Biodiversity loss
Land occupation / use	Impact of ionizing radiation
Climate change	Odors
Destruction of ozone layer	Noise
Human toxicity	Desertification
Ecotoxicity	
Photo-oxidant formation	
Acidification	
Eutrophication	

Source: Guinée et al., 2002

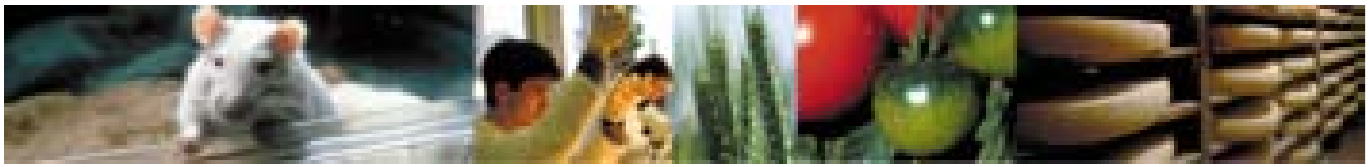
Environmental Analysis via LCA

LCA approach



Expressed per Functional Unit (e.g., kg of meat, ha of land)

Intensification Gradients and Impacts of Animal Production Systems



25 Aug 2010

ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

INRA

Intensification Gradients

Defining agricultural intensification

One definition:

Increasing production of agricultural products per unit (surface area or volume) of land or water.

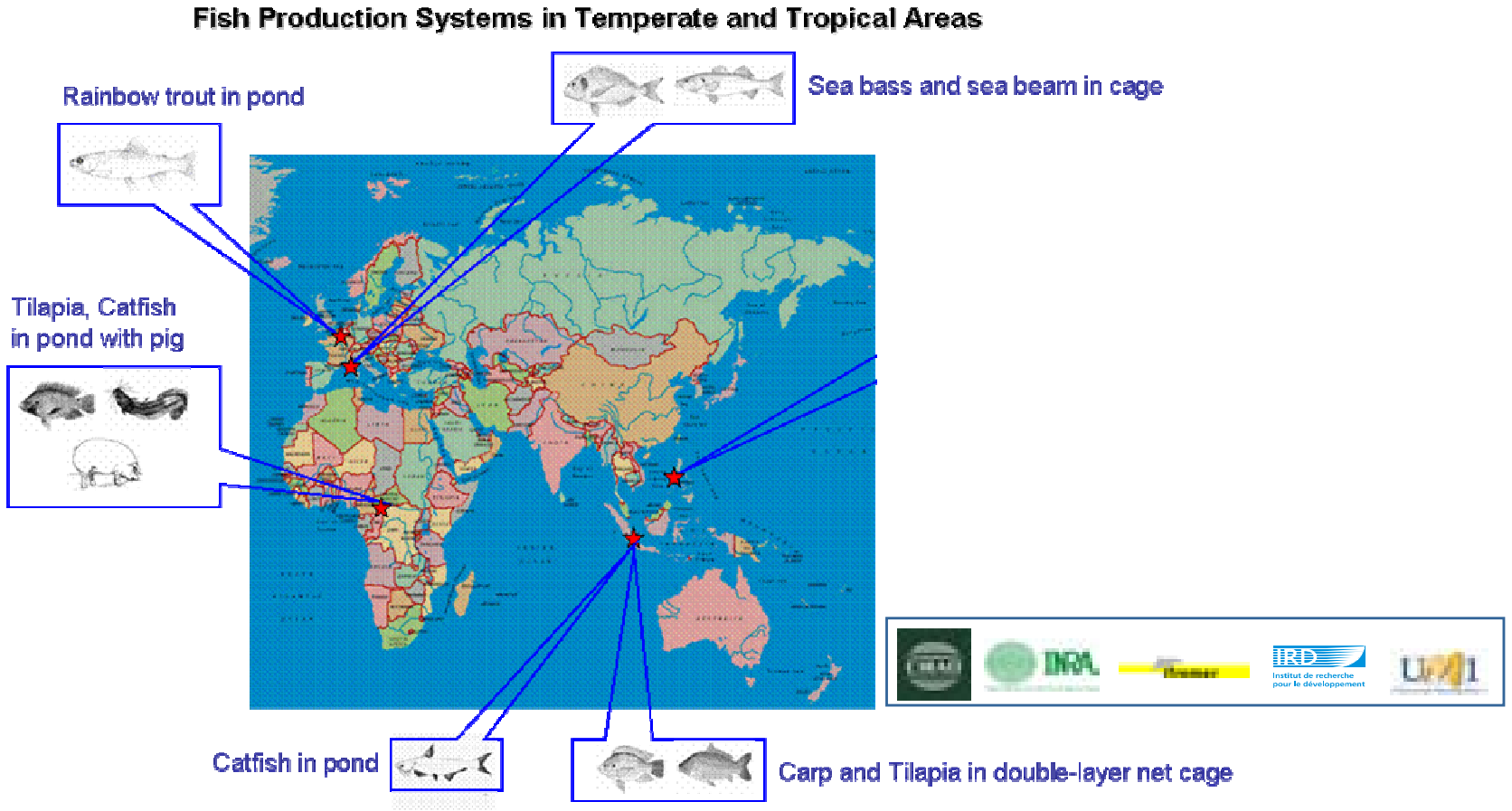
which implies

Increasing inputs (i.e., energy, net primary production, chemicals, water) per unit of land or water.

Other definitions: input:output ratio, emergy content

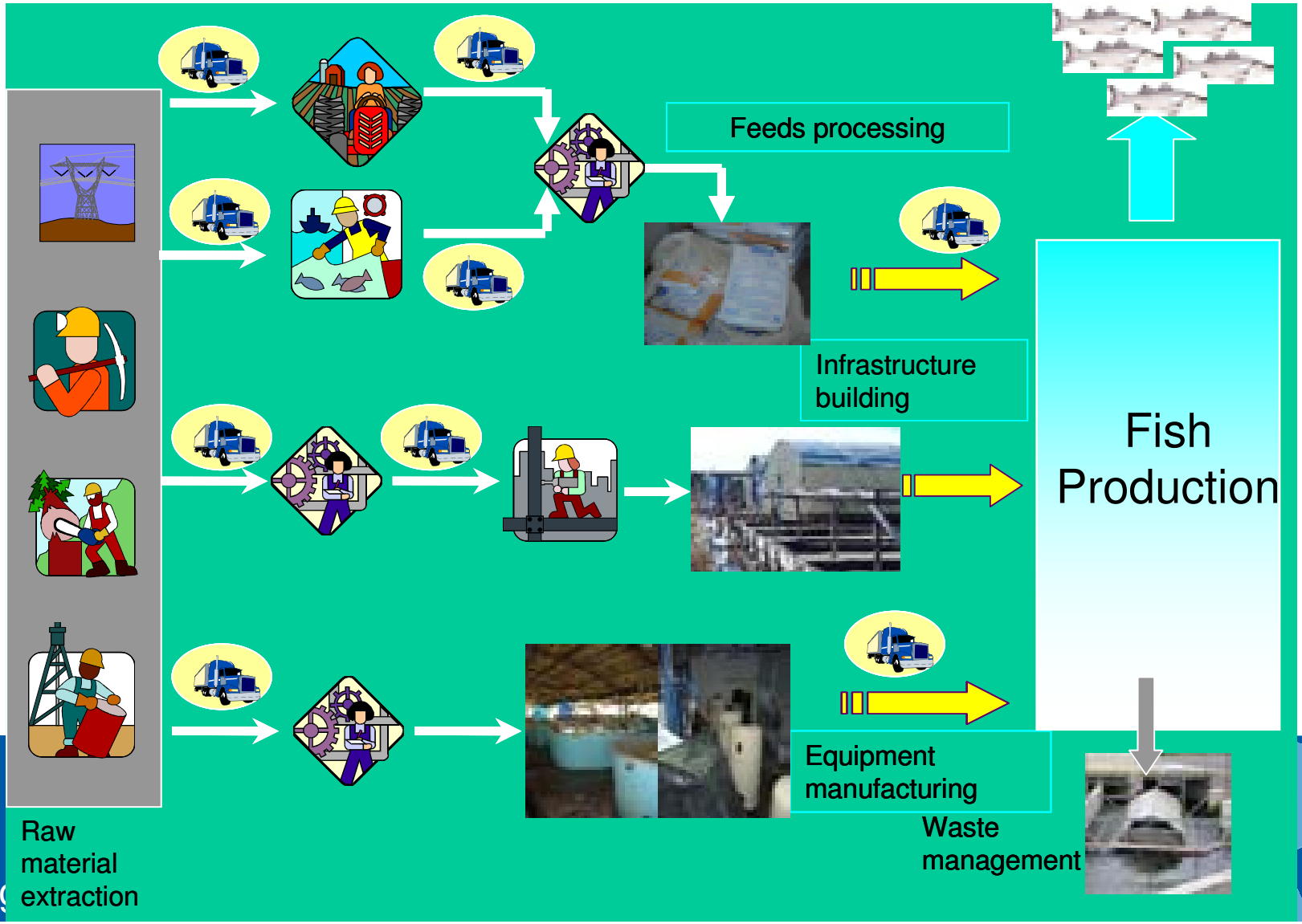
Intensification Gradients

Aquaculture Production



Aquaculture

System boundaries



Aquaculture

Potential impacts

Impact Categories	Unit	Resources and Emissions
Non-renewable Energy Use	GJ	Coal, oil, gas, uranium, lignite
N. Prim. Production use	t C	Biotic resources
Climate Change	kg CO_2-eq	CO_2, N_2O, CH_4
Acidification	kg SO_2-eq	NH_3, NO_2, NO_x, SO_2
Eutrophication	kg PO_4-eq	NH_3, NO_3, NO_2, NO_x, PO_4, COD, ThOD
Surface use	ha / yr	Land / water

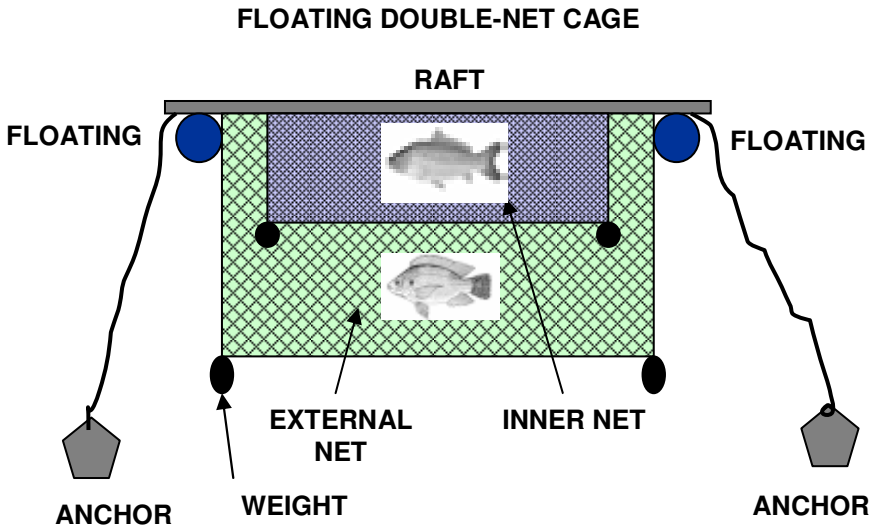
Two-species polyculture in ponds in Cameroon

- Association of tilapia (*O. niloticus*) and clarias (*Clarias gariepinus*)
- Pond size around 200 m^2
- Ponds fed with pig or chicken manure and vegetable wastes
- Ponds integrated in family agriculture system
- Yield: around 5 t/ha/year

Pangasius in ponds in Sumatra, Indonesia

- Pond size 600 m^2
- Locally-made feed (dried fish 45% and rice bran 40%)
- F:G ratio: varies from 1.4-2.0
- Growing period partially depends on market demand (harvested size is 4-5 fish/kg)
- Yield: around 1-1.5 t/pond

Tilapia and carp in net cages in Java, Indonesia



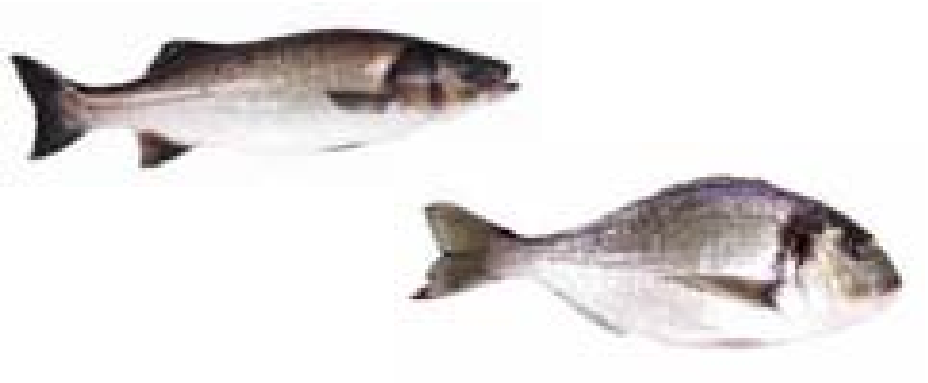
Cirata Lake

- Association of tilapia (*O. niloticus*) and carp
- Double-net cages
- Feeds (around 25% protein) composed of 20% fish meal
- F:G ratio: around 1.7
- Yield: 9-18 kg/m^3/yr

Rainbow trout flow-through system in Brittany, France

- Carnivorous fish
- Artificial feeds 40% protein
- F:G ratio: around 1.0
- Growth: 8-24 months (depending on final fish size)
- Yield: 50-400 t per farm/yr
- No water recirculation
- Often uses liquid oxygen
- Water outlet filtering

Seabass and seabream in cages in the Mediterranean Sea



- Carnivorous fish
- Sea cages
- 45-50% of protein in feeds, with high level of marine sources
- F:G ratio: around 2.0
- Growth: 18-30 months
- Yield: 200-600 t per farm/yr
- Direct release of wastes into the sea

System productivity (intensification)

System	Production (t/ha/yr)
tilapia-clarias ponds	5
pangasius ponds	20
tilapia-carp cages	30
trout flow-through	800
bass-bream cages	1000

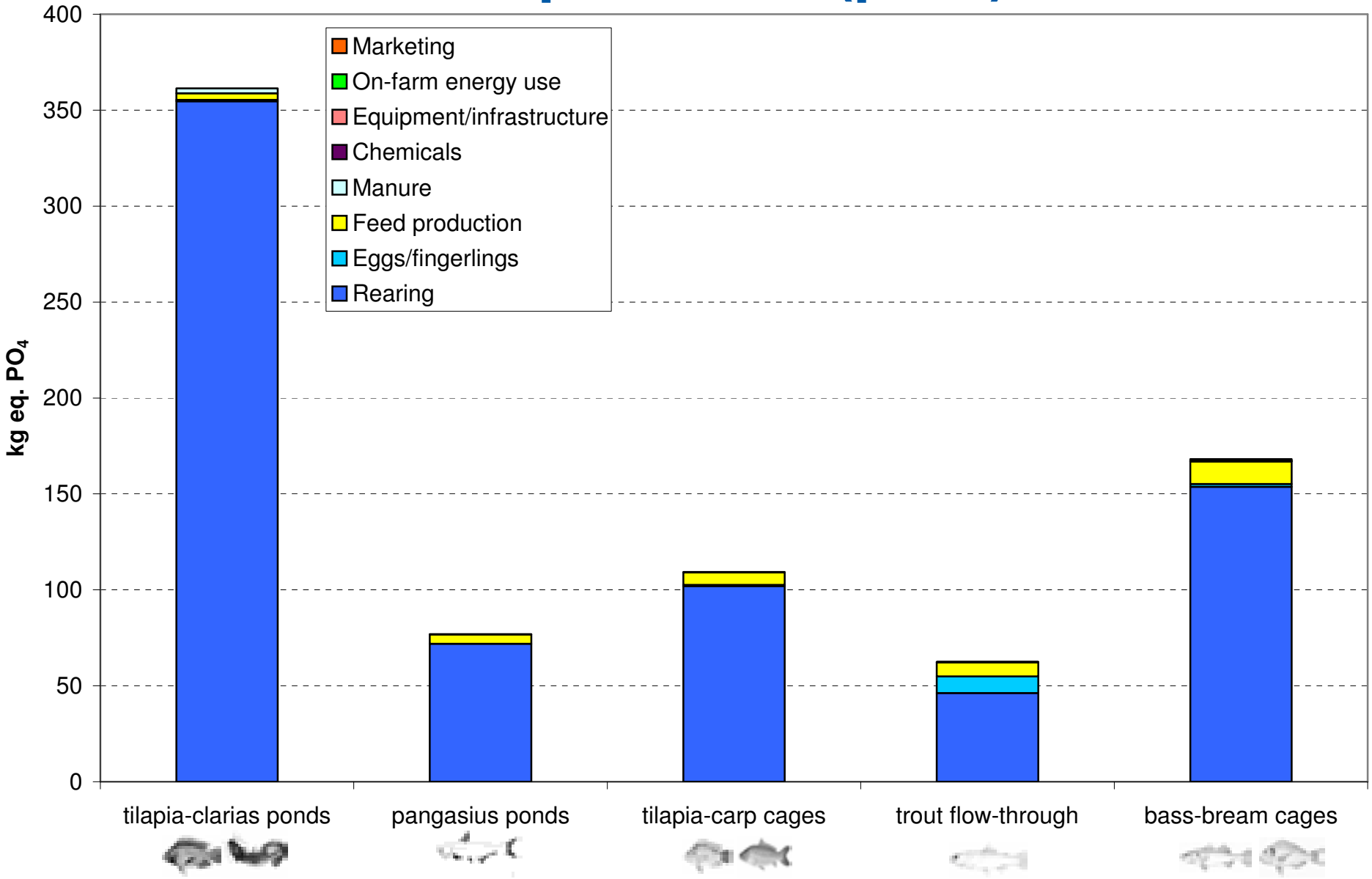
Aquaculture
Functional unit

- per **t fish** – emphasizes production function of systems

Intensification

Aquaculture

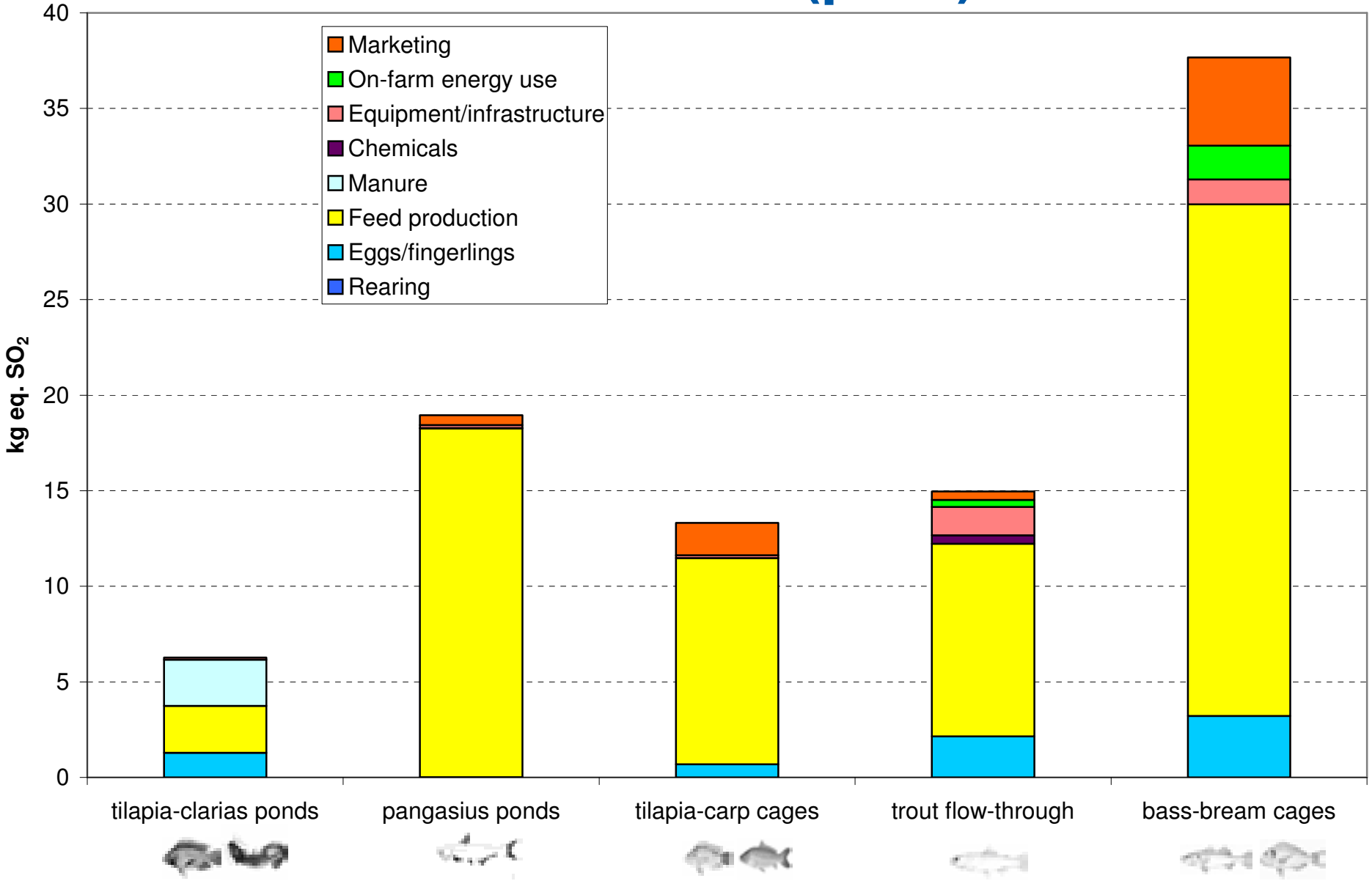
Eutrophication (per t)



Intensification

Aquaculture

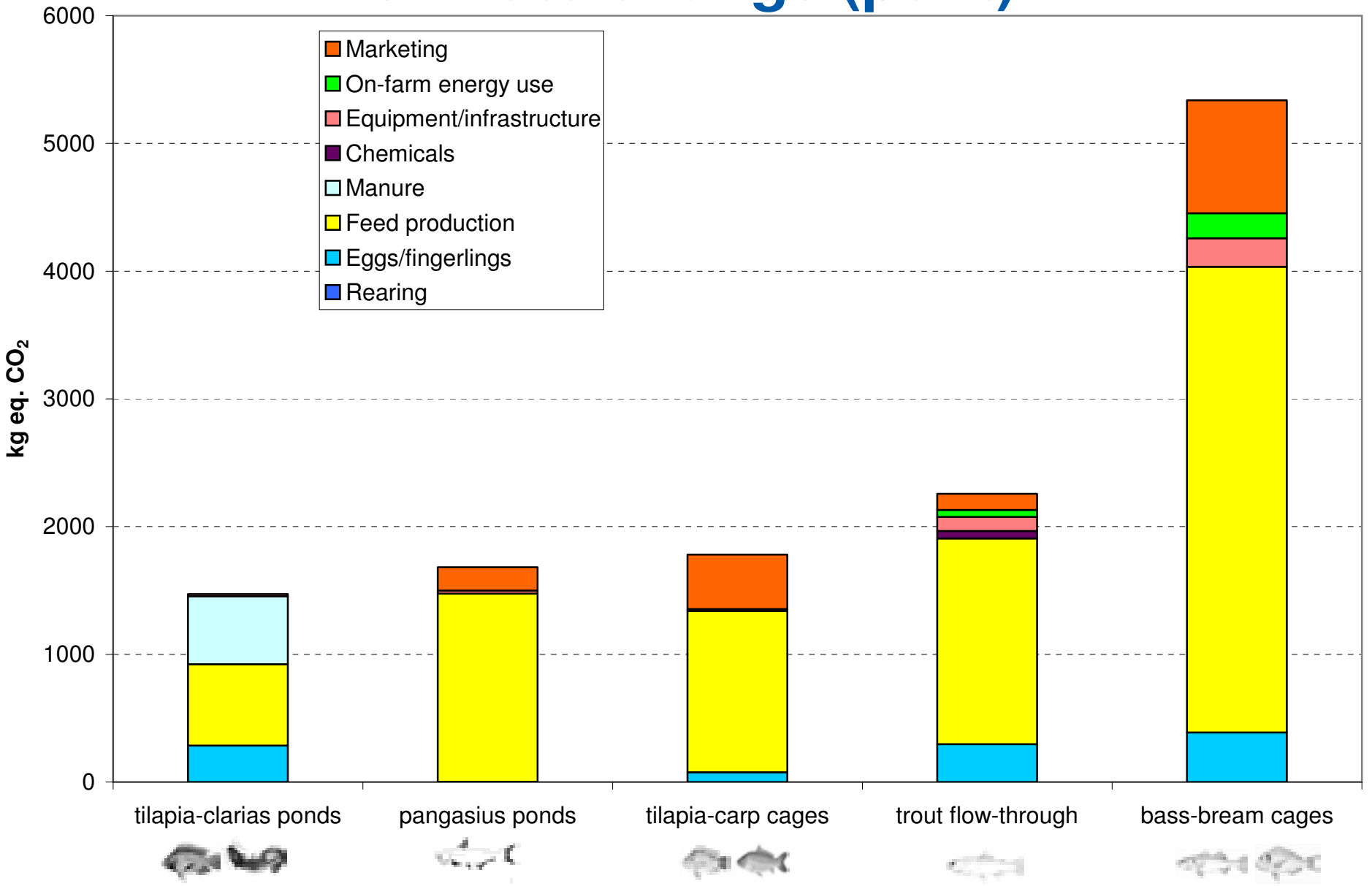
Acidification (per t)



Intensification

Aquaculture

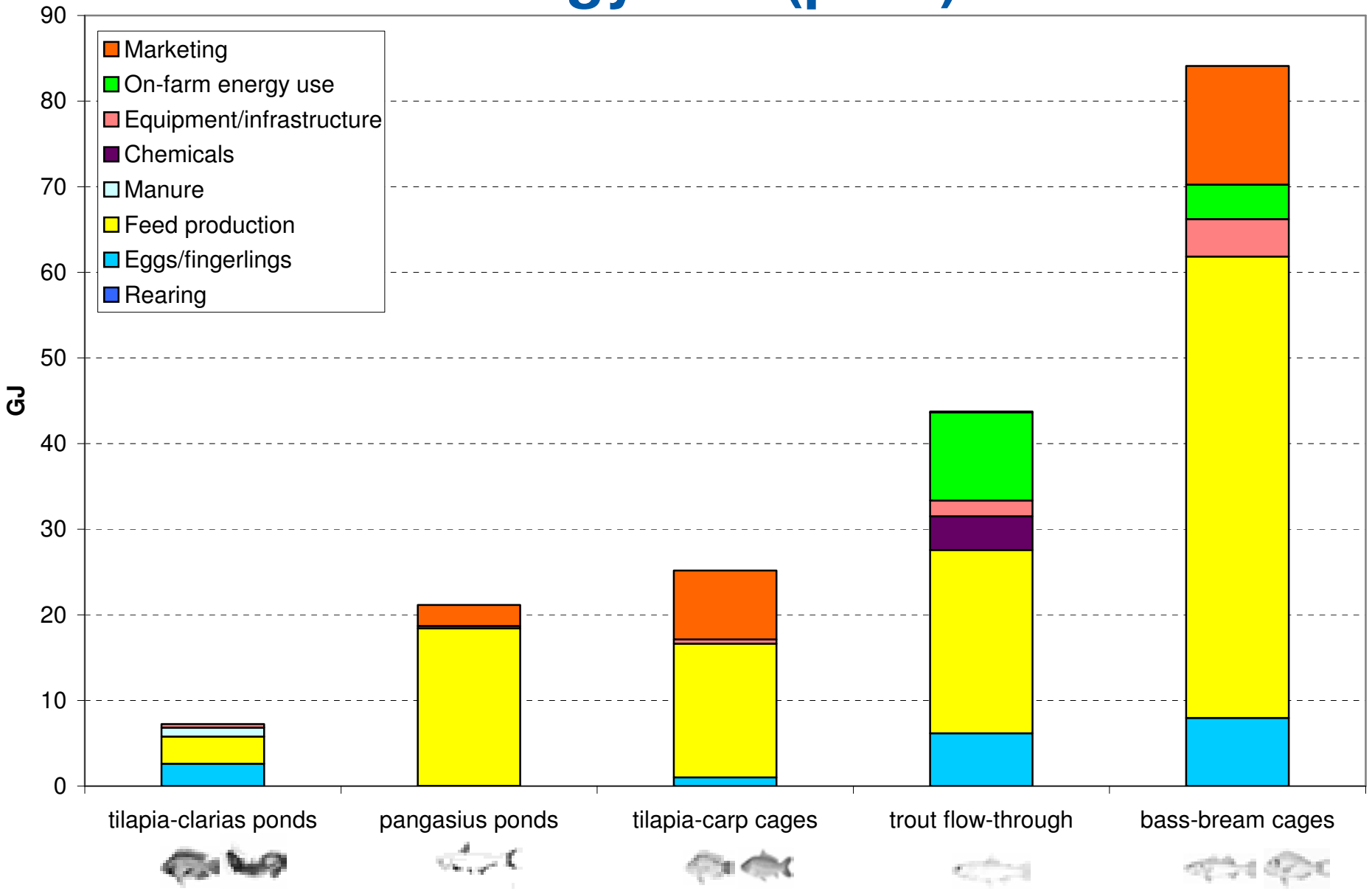
Climate change (per t)



Intensification

Aquaculture

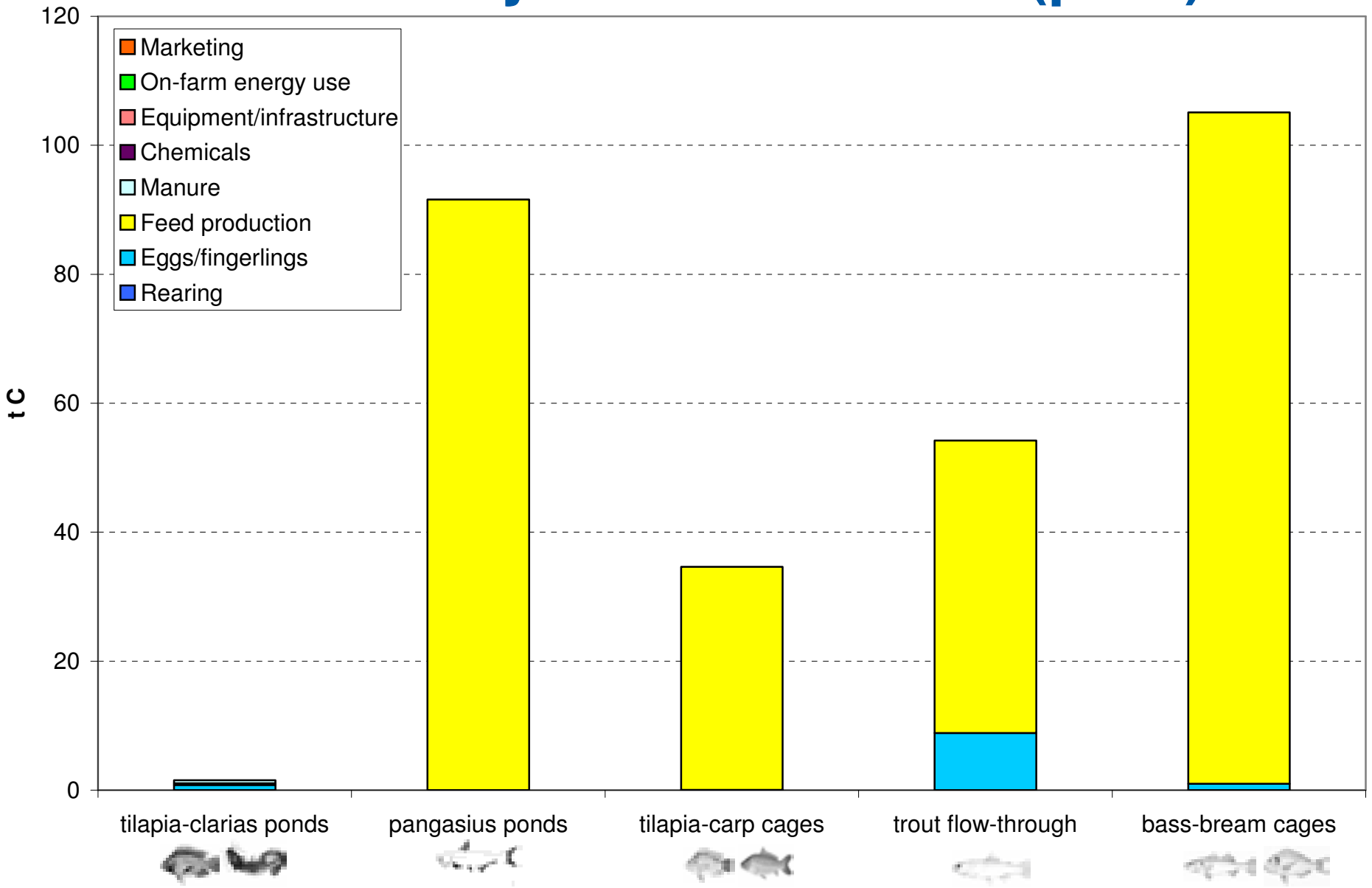
Energy use (per t)



Intensification

Aquaculture

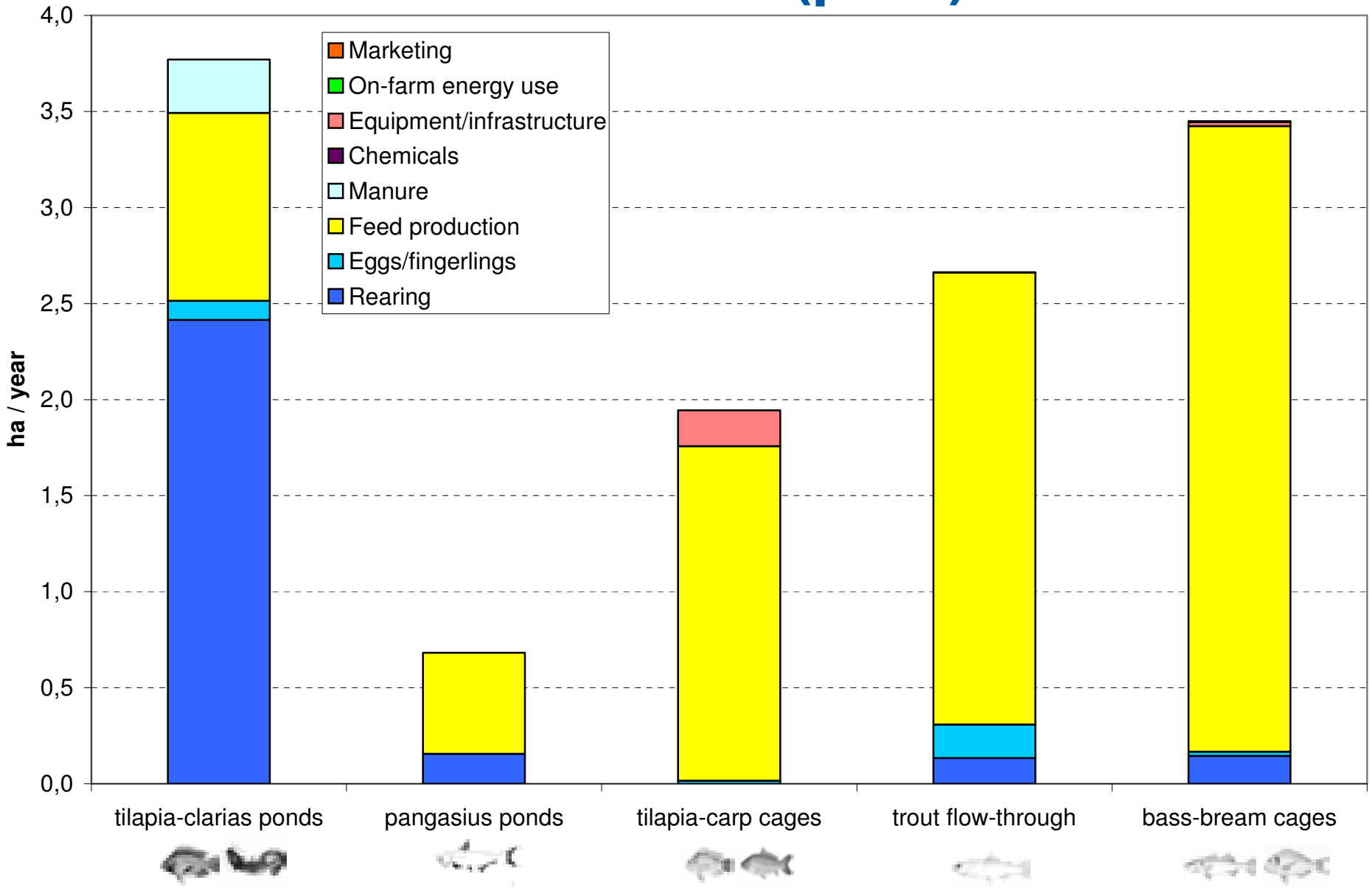
Net Primary Production use (per t)



Intensification

Aquaculture

Surface use (per t)

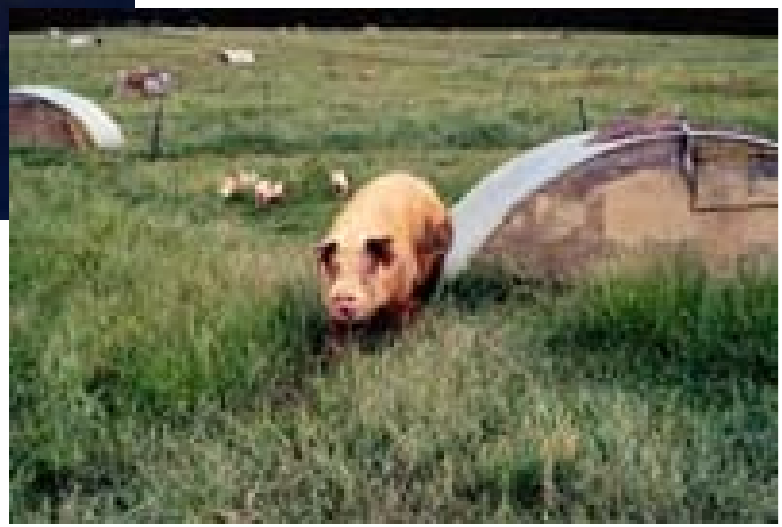


Aquaculture
Remarks

- Heterogeneous systems adapted to local conditions and species
- With increasing intensification, potential acidification, climate change, and energy use impacts per t of production tended to increase
- Hotspots in aquaculture systems
  - Efficiency of input use
  - Feed ingredients and feeding management
  - Energy consumption and energy carriers
- Improvement paths
  - Trophic chain optimization (e.g., polycultures)
  - Substitution of marine proteins with plant proteins
  - Recycling of nutrients (e.g., co-production in integrated systems)
  - Energy management

Intensification Gradients

Pig Production in Brittany, France



Basset-Mens and van der Werf, 2005

ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

INRA

Pigs

Production modes

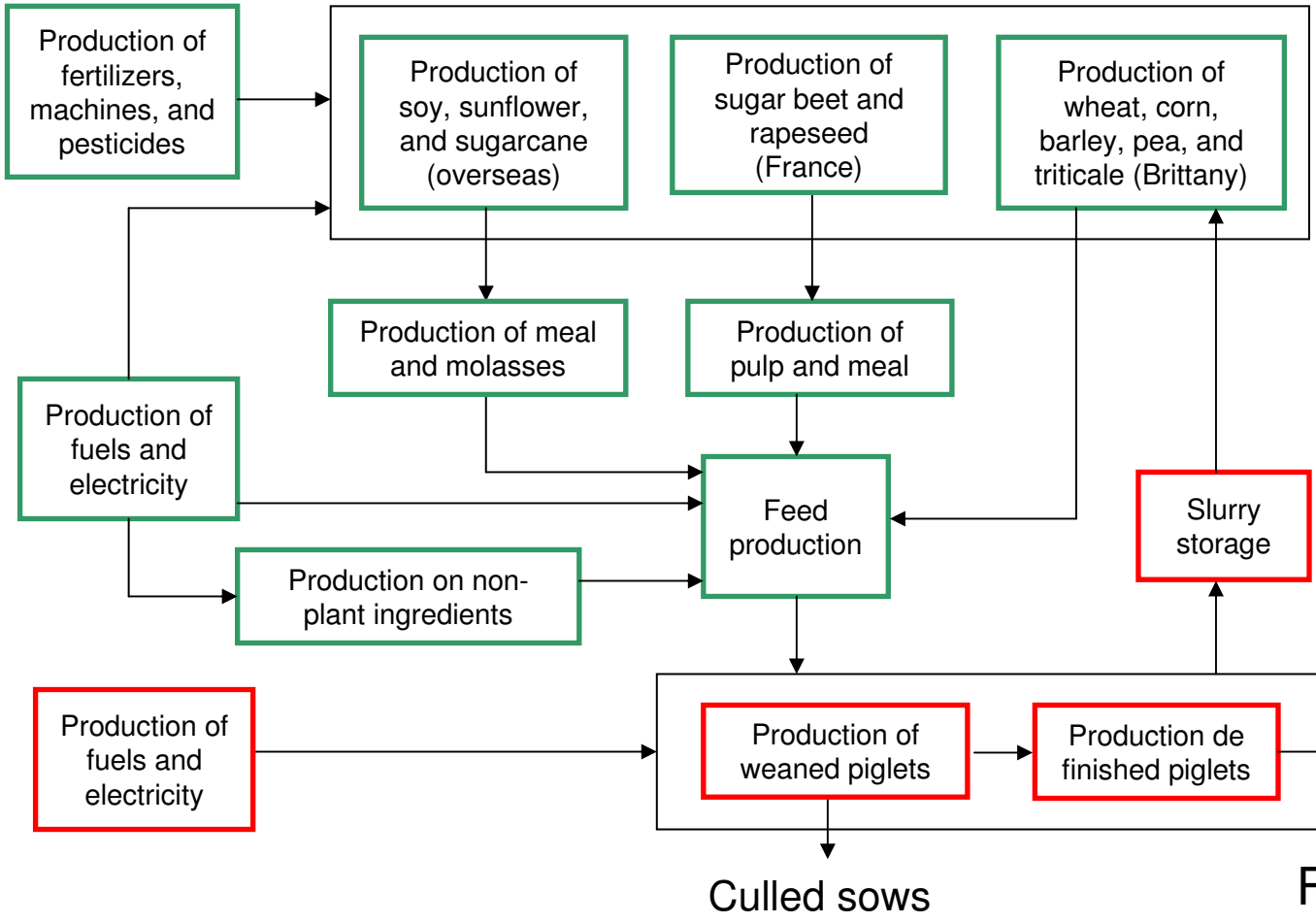
1. Good Agricultural Practice (GAP) (conventional)

2. Label Rouge (LR) (quality label)

3. Agriculture Biologique (AB) (organic)

Pigs

System boundaries



Intensification

Pigs

System characteristics

	GAP	LR	AB
Piglet production			
Housing	Slatted floor	Outdoor	Outdoor
Weaned piglet/productive sow/year	25.5	22.6	20.3
Weaning age, days	25.7	28	42
Surface per sow, m^2	<4	1000	1000
Feed per sow (boar included), kg/year	1313	1490	1695
Weaning to slaughtering			
Housing	Slatted floor	Straw litter	Straw litter
Surface per pig, m^2	0.85	2.6	2.3
Feed:gain ratio	2.7	2.9	3.2
Slaughter age, days	175	190	195
Slaughter weight, kg	113	115	120
Pig production, kg/ha	1842	1592	1013

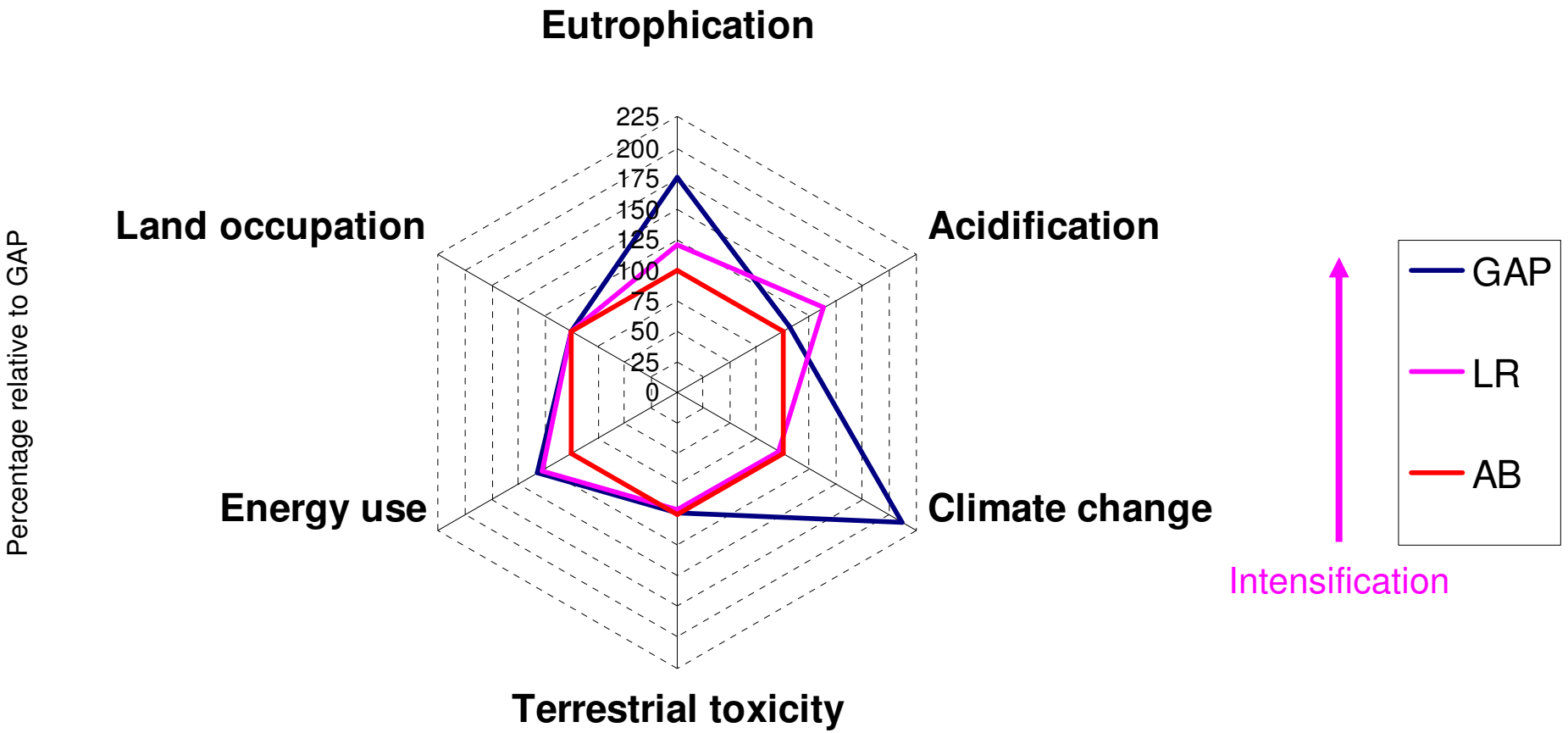
Pigs

Functional units

- per **ha** – emphasizes land use function of systems
- per **kg pig** – emphasizes production

Pigs

Relative impacts per ha

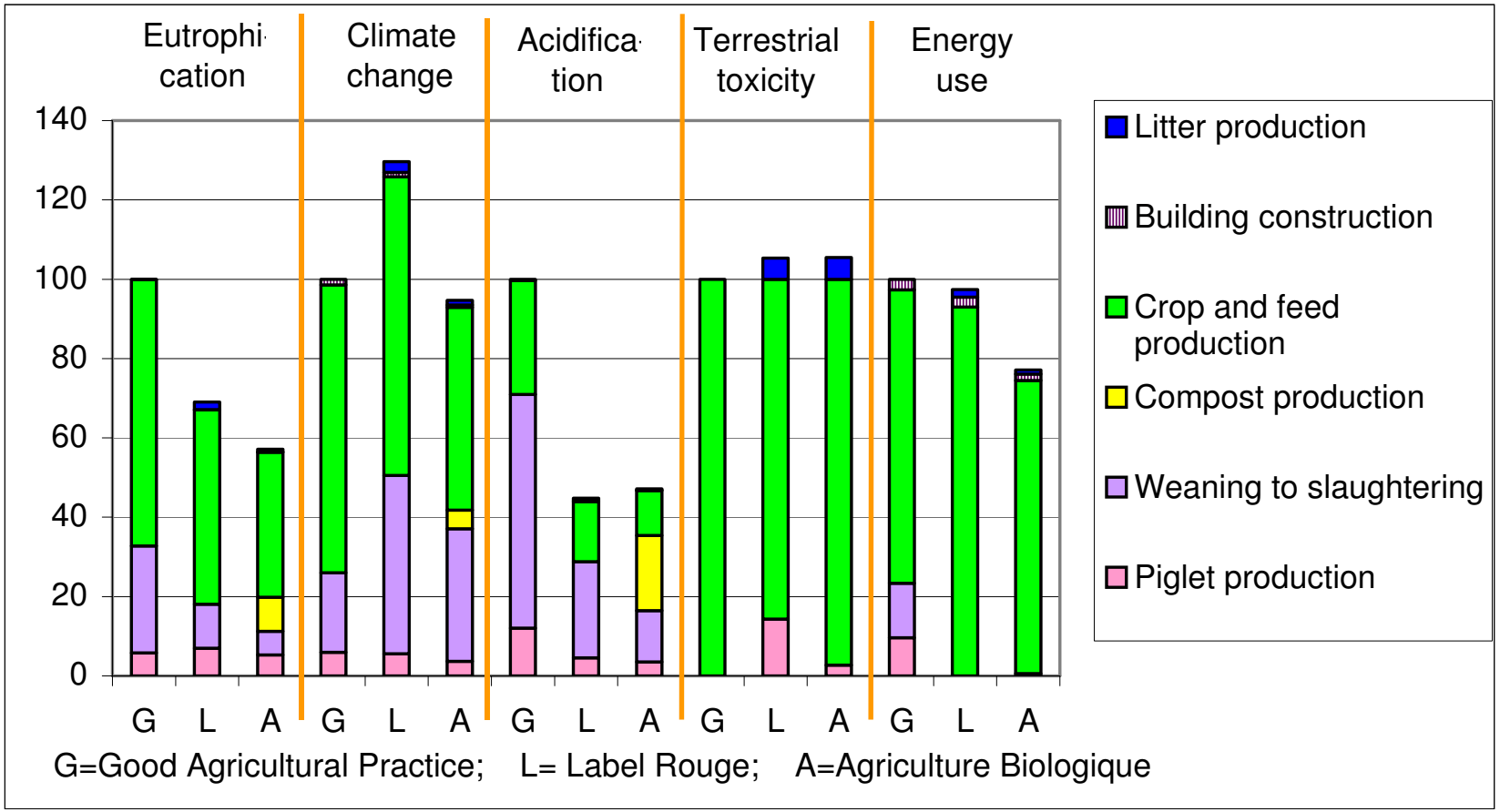


GAP = Good Agricultural Practice; LR = Label Rouge; AB = Agriculture Biologique

Intensification

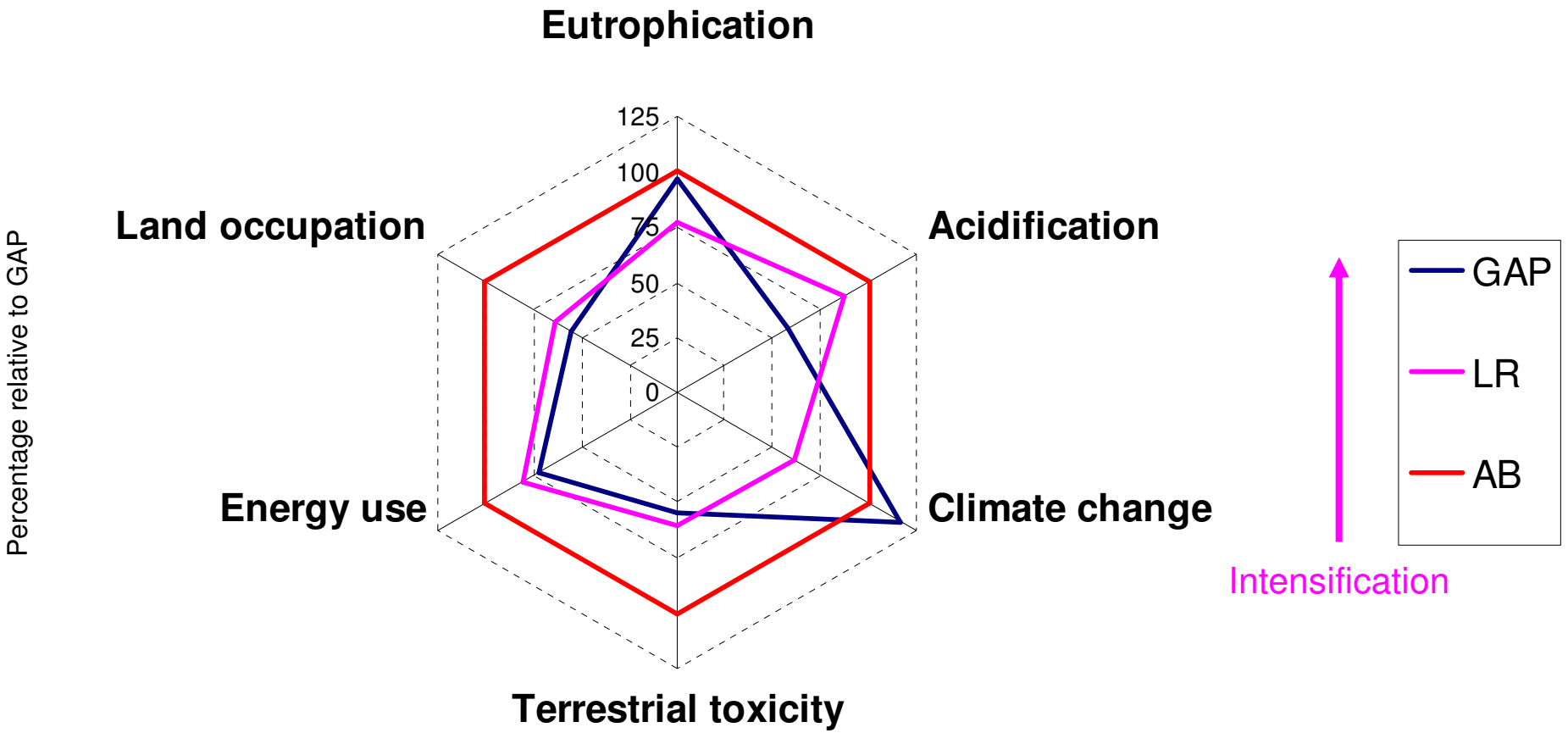
Pigs

Relative impacts per ha (by stage)



Pigs

Relative impacts per kg pig



GAP = Good Agricultural Practice; LR = Label Rouge; AB = Agriculture Biologique

System with least impact according to the category of impact and functional unit

	per ha	per kg pig	Overall
Eutrophication	Organic	Conv.	?
Climate change	Organic	Conv.	?
Acidification	Organic	Label Rouge	?
Terrestrial toxicity	Label Rouge	Conv.	?
NR energy use	Organic	Conv.	?
Land occupation	1	Conv.	Conv.
Pesticide use	Organic	Organic	Organic

Results depend on the functional unit

Pigs

Remarks

- Intensification required relatively moderate structural change
- With increasing intensification, impacts per ha tended to increase but impacts per kg tended to decrease
- The stages feed production (via NO_3 emissions and fertilizer use) and weaning (via NH_3 and NO_2 emissions) tended to dominate impacts

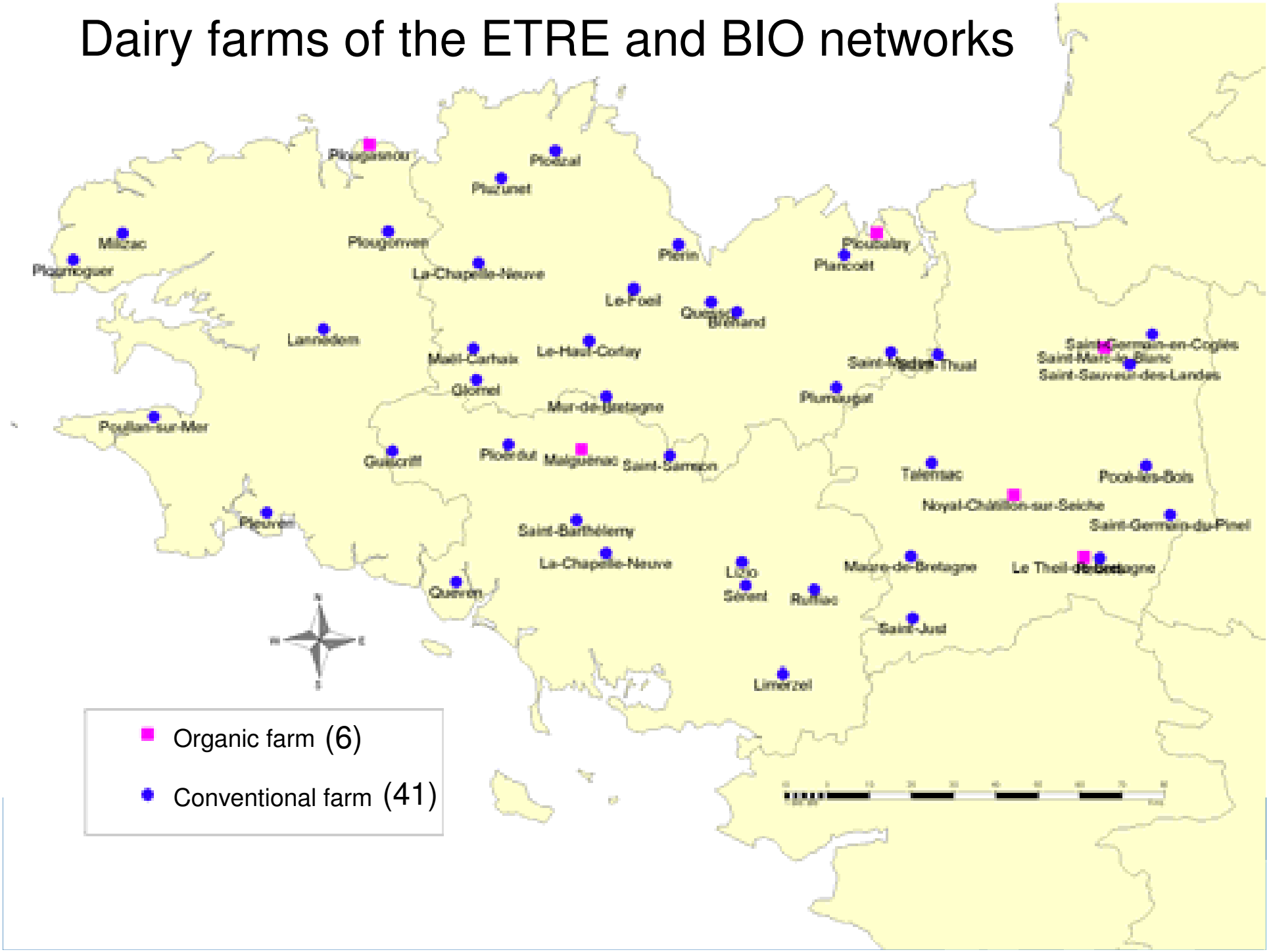
Intensification Gradients

Dairy Production in Brittany, France

Source: USDA-ARS

van der Werf et al., 2009

Dairy farms of the ETRE and BIO networks



Dairy

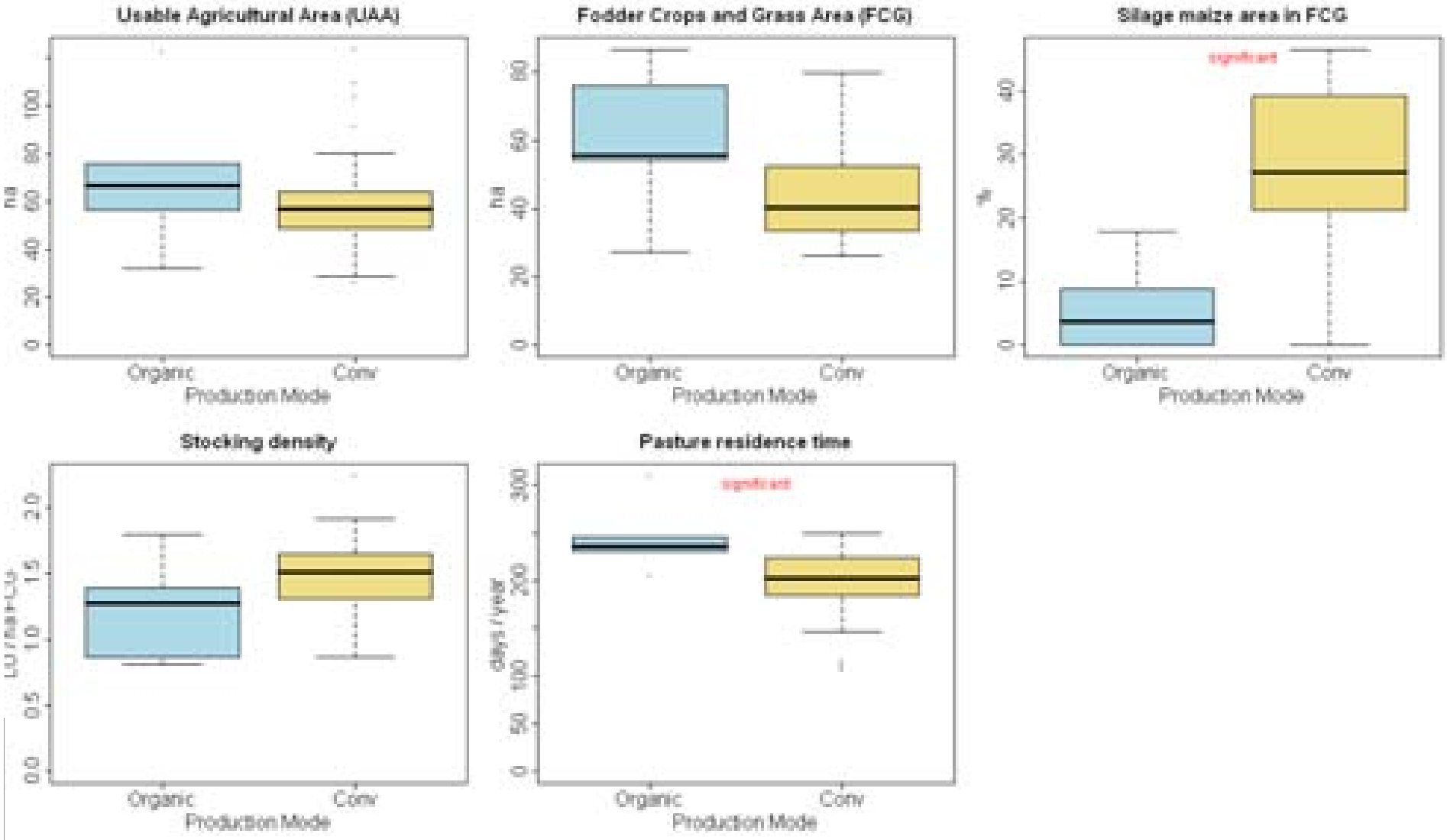
System boundaries

- farm structures
- livestock
- herd management
- buildings and wastes
- crops and fertilizer management
- mineral fertilizers
- concentrated feed
- forages and other plants
- pesticides
- energy consumed
- plastics consumed
- farm machinery
- transportation

Intensification

Dairy

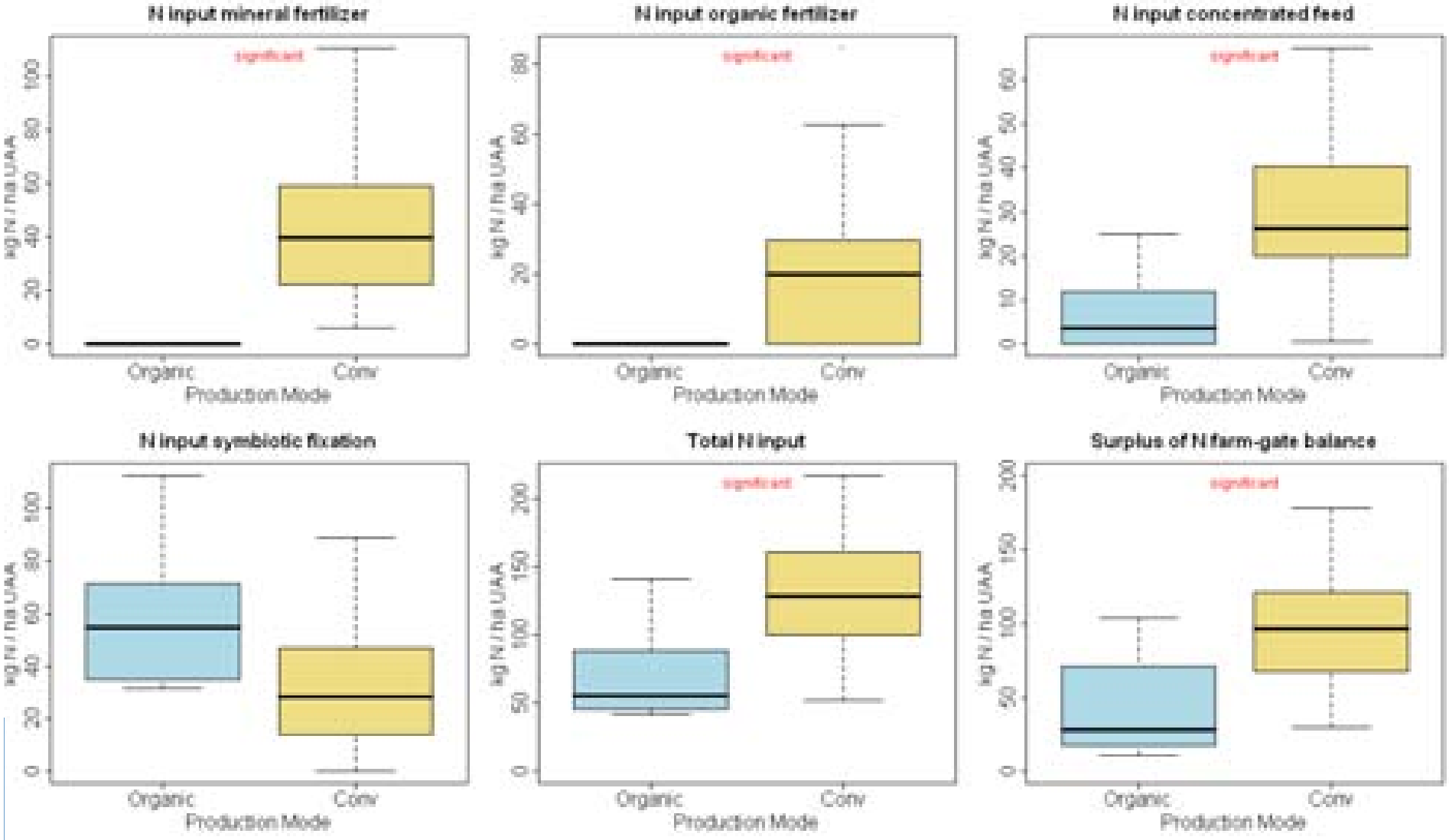
Farm characteristics



Intensification

Dairy

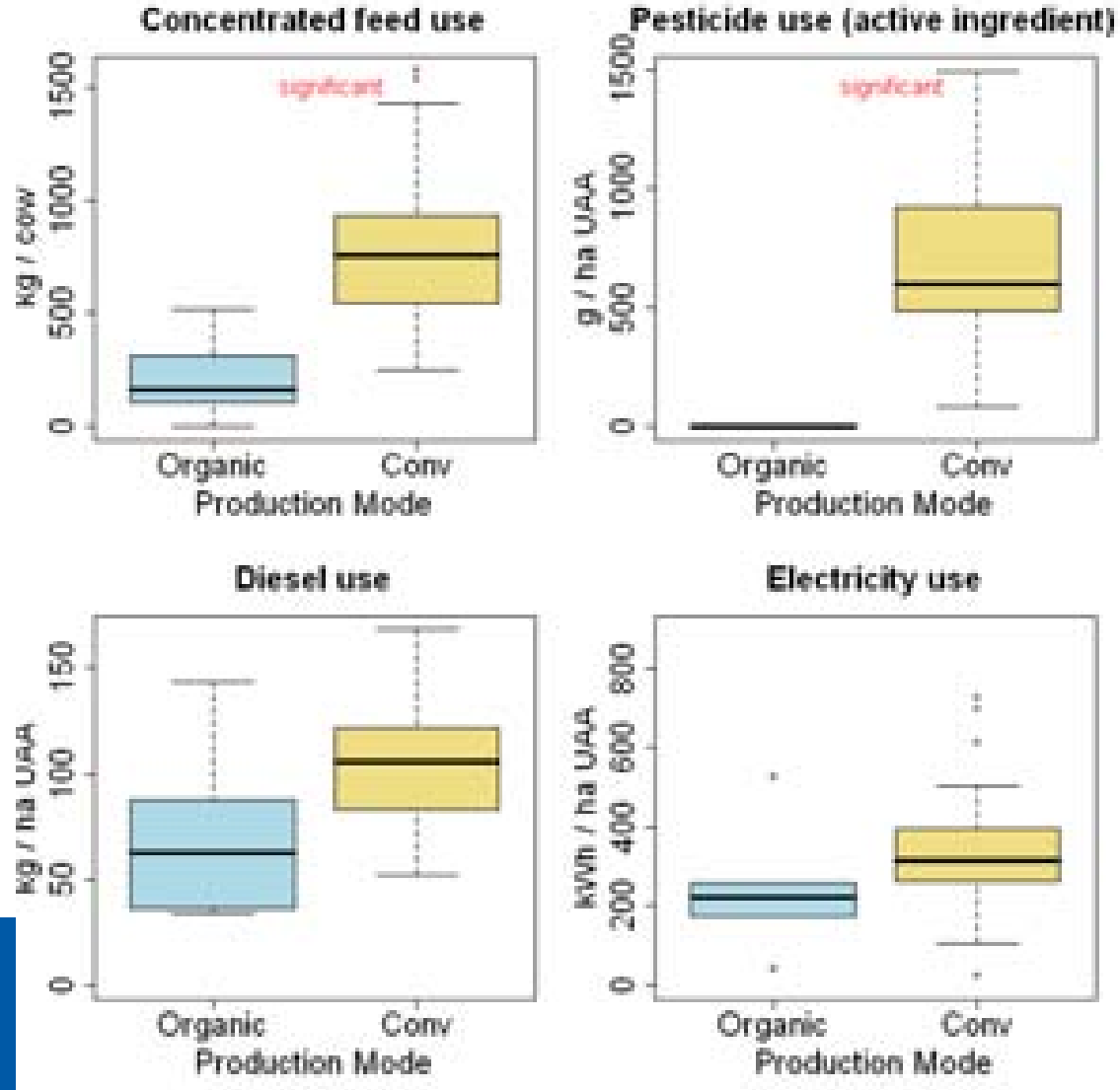
Nitrogen inputs



Intensification

Dairy

Other inputs



Dairy

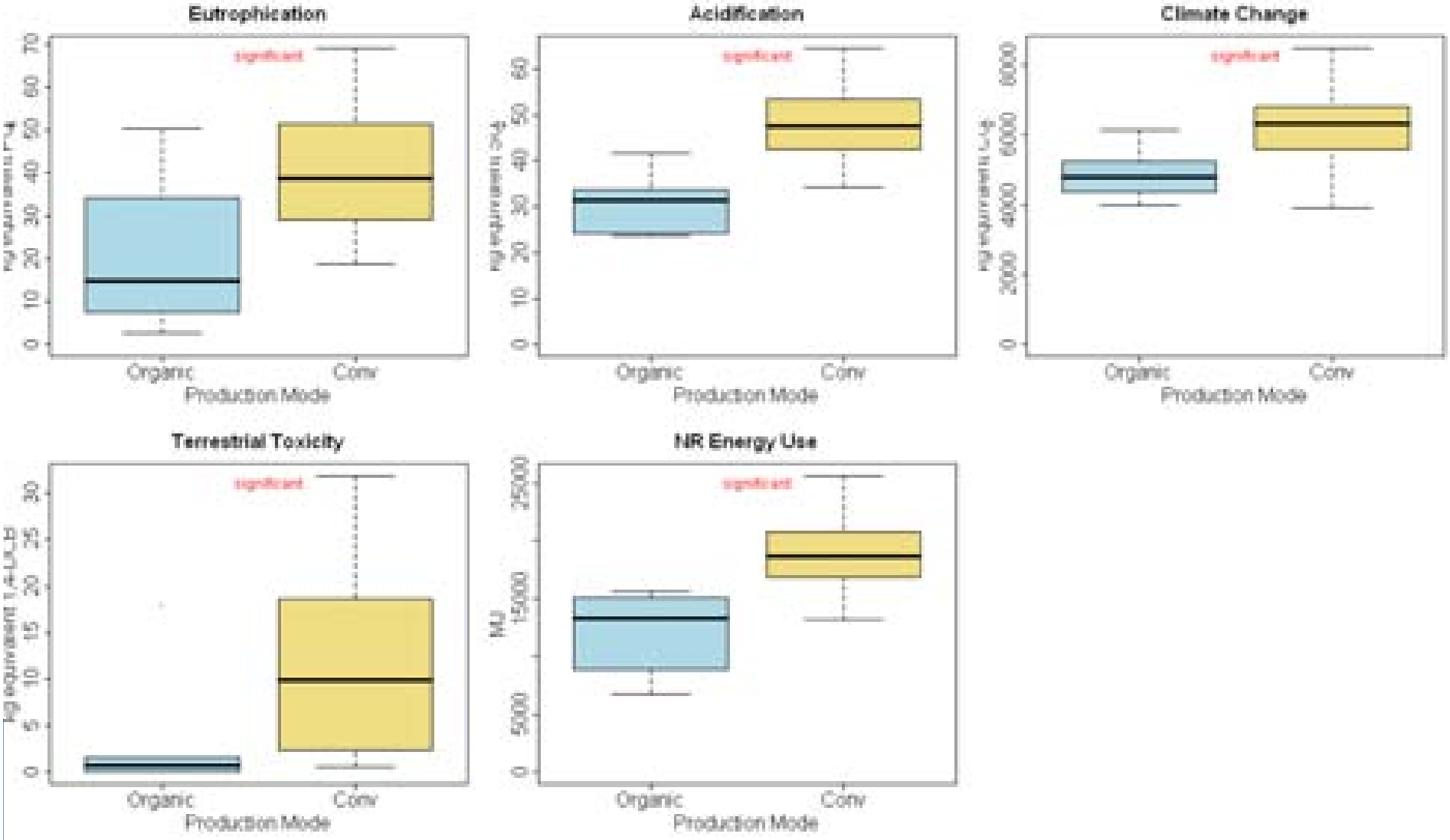
Functional units

- per **ha** – emphasizes land use
- per **1000 kg milk** (fat and protein corrected: FPCM) – emphasizes production
- per **1000 € of milk "value"** (i.e., milk revenue) – emphasizes production × value
  - Assumption: farmer's sale price of organic milk is 33% higher than that of conventional milk (387 and 291 € per 1000 l, respectively)

Intensification

Dairy

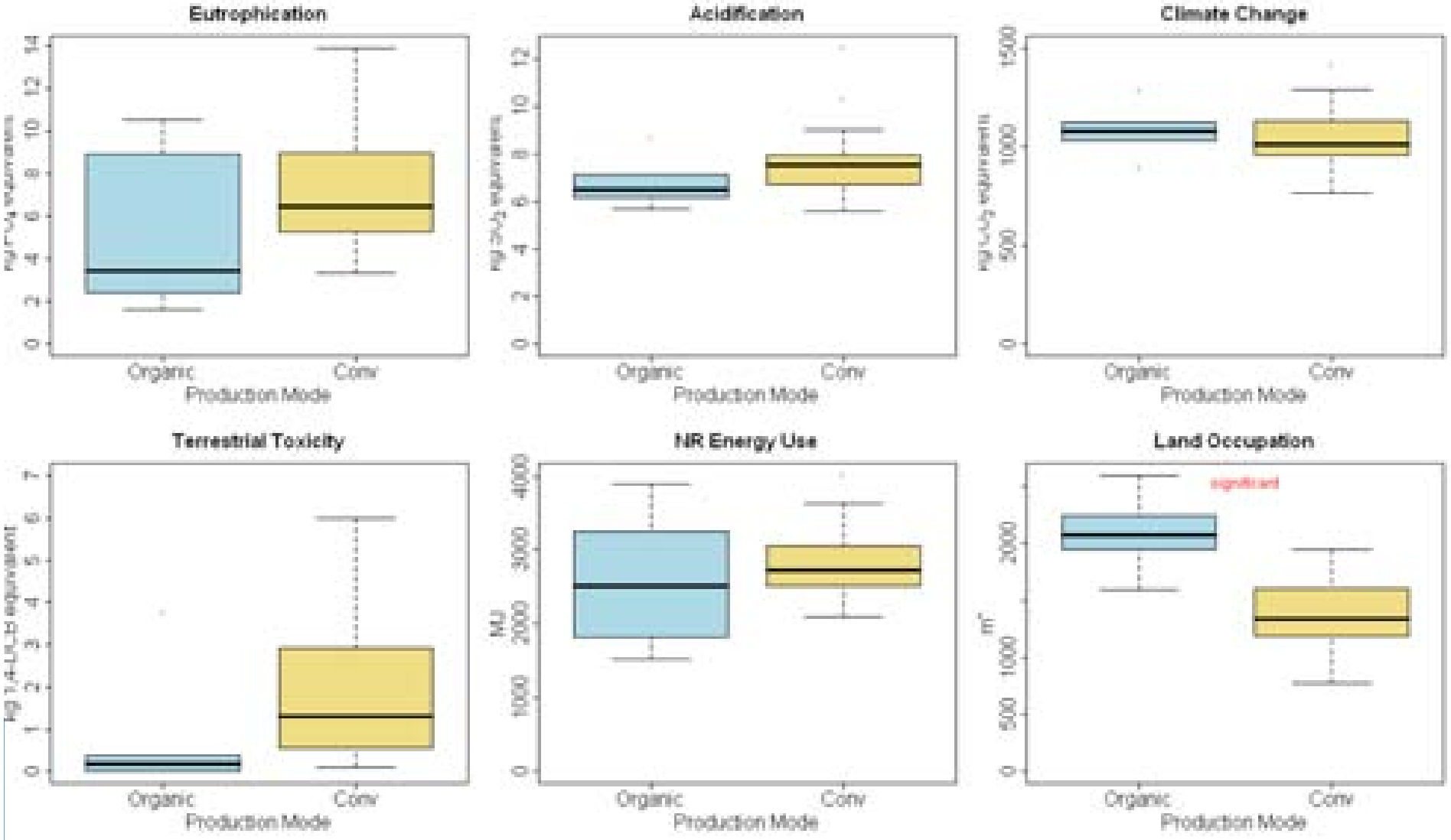
Impacts per global ha



Intensification

Dairy

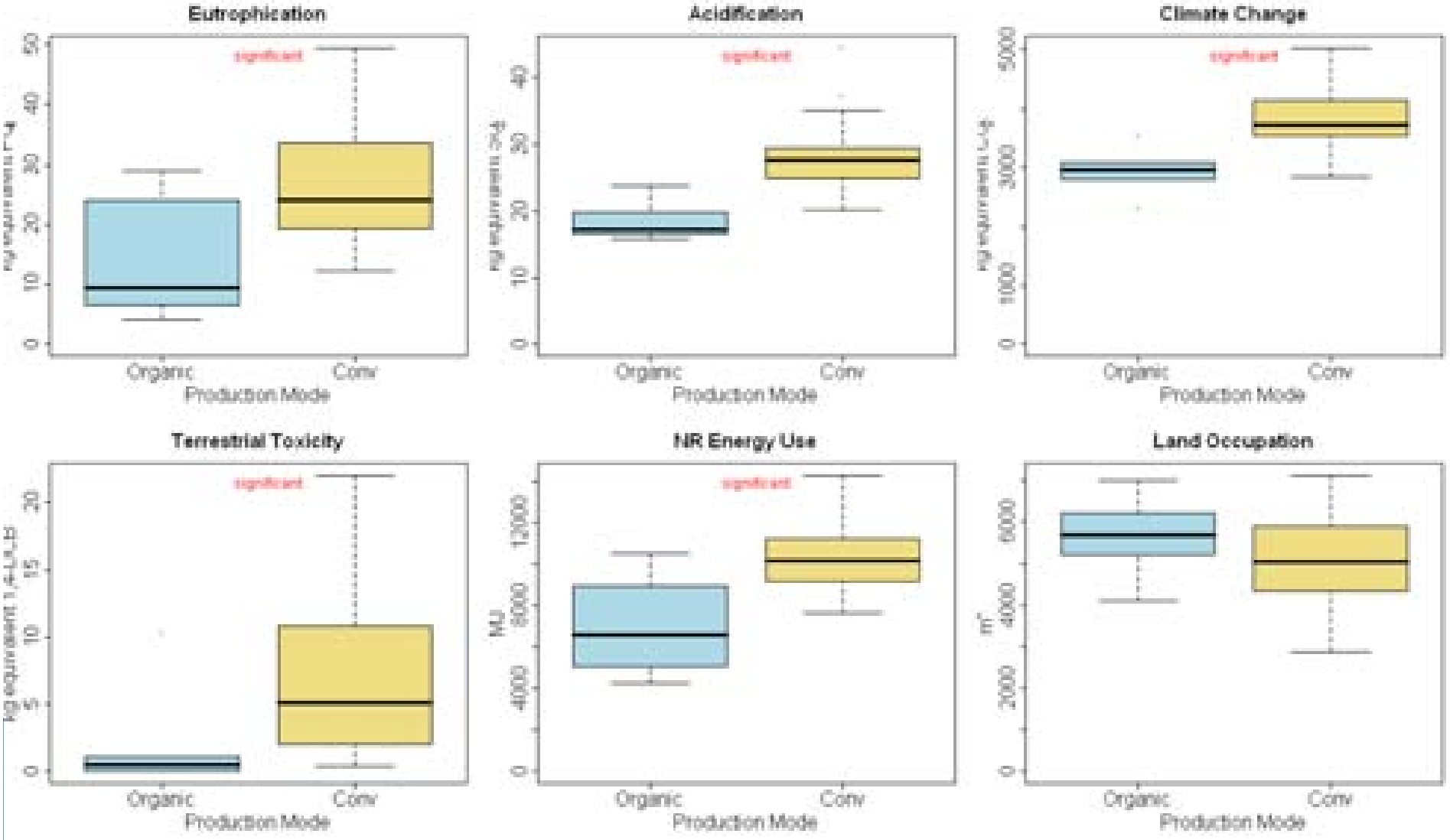
Impacts per 1000 kg FPCM



Intensification

Dairy

Impacts per 1000 € of value



System with less impact according to the category of impact and functional unit

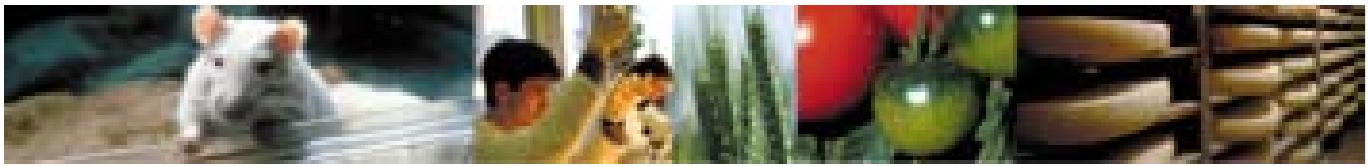
	per ha	per 1000 kg of milk	per 1000 € value	Overall
Eutrophication	Organic	NS	Organic	?
Climate change	Organic	NS	Organic	?
Acidification	Organic	NS	Organic	?
Terrestrial toxicity	Organic	NS	Organic	?
NR energy use	Organic	NS	Organic	?
Land occupation	1	Conv.	NS	?
Pesticide use	Organic	Organic	Organic	Organic

Results depend on the functional unit

Dairy
Remarks

- Strong variability in potential environmental impacts exists among farms, even within the same production mode (conventional or organic)
- Intensification tended to increase potential impacts per ha or 1000 € of milk revenue but not per 1000 kg of milk sold
- Structural differences between extensive and intensive systems smaller than those in aquaculture or pig systems (confinement systems)

Comparing Effects of Intensification



25 Aug 2010

ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

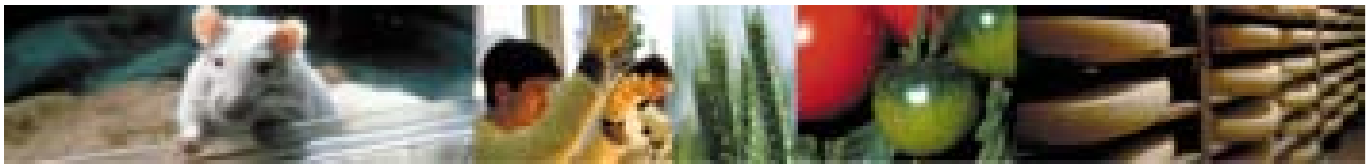
INRA

System Comparison

Impact trends of intensification

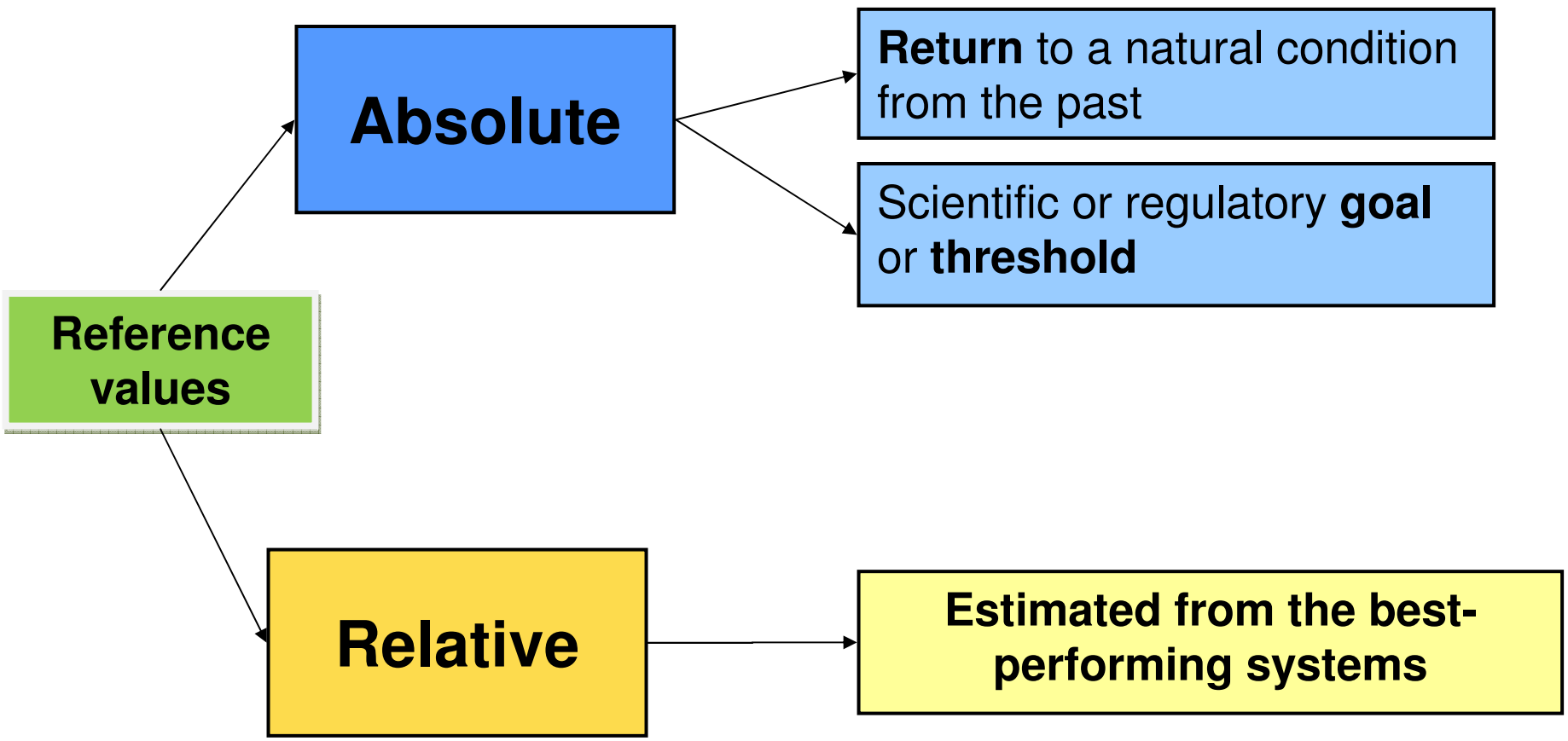
Impact	per ha		per unit mass			per 1000 €
	pig	dairy	aqua.	pig	dairy	dairy
eutrophication	↑	↑	-	-	-	↑
acidification	↑	↑	↑	-	-	↑
climate change	-	↑	↑	↓	-	↑
energy use	↑	↑	↑	↓	-	↑
surface occupation			-	↓	↓	↑
terrestrial toxicity	-	↑		↓	-	-
pesticide use	↑	↑		↑	↑	↑
net prim. prod. use			-			

Impacts vs. sustainability



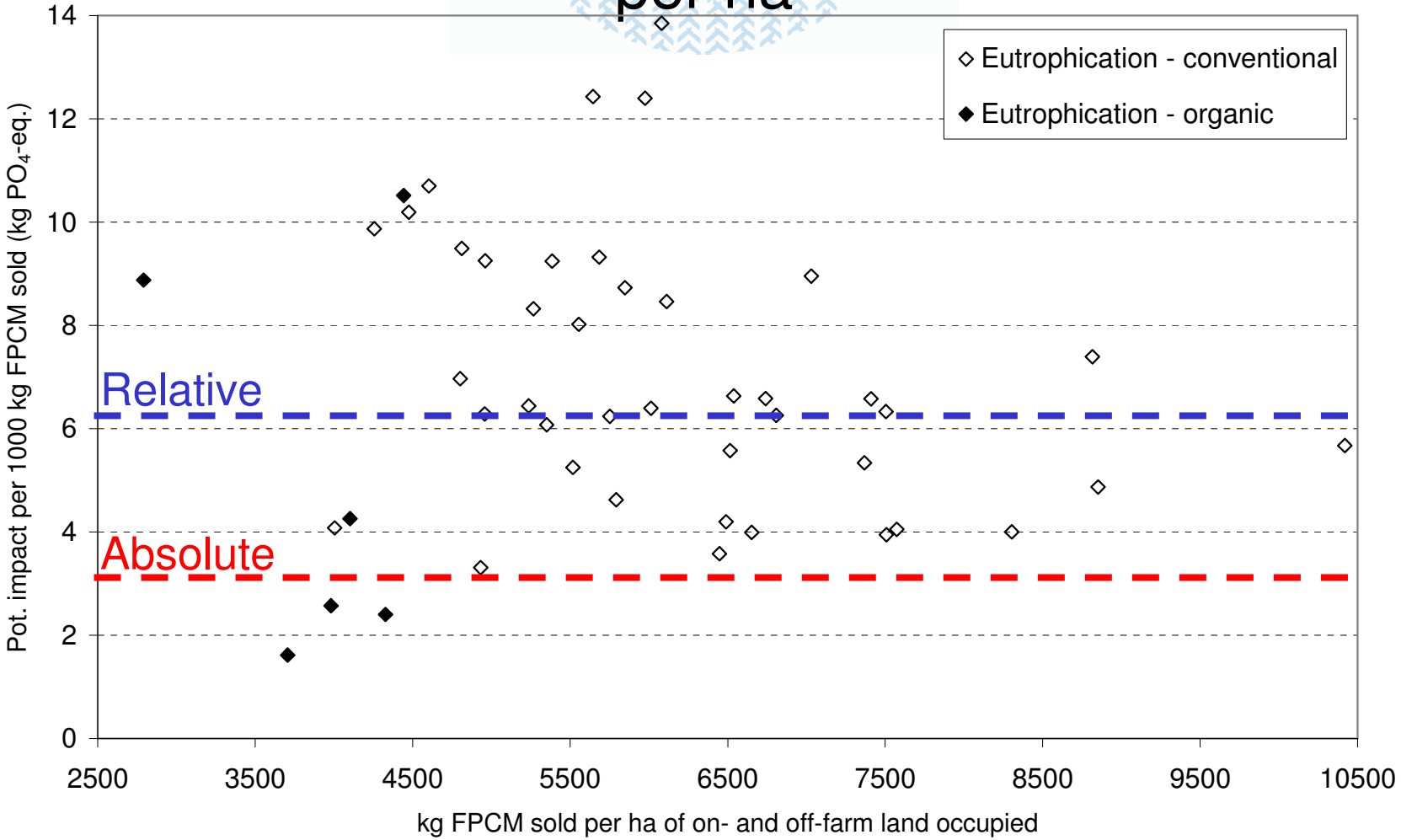
Impacts vs. Sustainability

Reference values



(Adapted from van Cauwenbergh et al., 2006)

Eutrophication per 1000 kg of milk *versus* kg milk sold per ha



ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

INRA

Environmental Impacts of Intensification

Concluding remarks

- Intensification of aquatic and terrestrial animal production systems tends to increase their environmental impacts per ha but can have mixed effects on impacts per unit mass of products
- Implementing less intensive production modes in confinement systems may require larger changes to system design than doing so in pasture-based systems
- Feed-production impacts predominate; thus, research to decrease them (e.g., changing ingredients) or increase feed:gain ratios (e.g., decreasing waste, increasing digestibility) has high importance
- The scales of potential environmental impacts (local vs. global) and their functional units must be considered and weighed before making decisions
- LCAs should include uncertainty, sensitivity, and allocation analyses
- To address the issue of sustainability directly, thresholds of sustainability must be defined and tested
- Comprehensive studies also should evaluate and weigh the economic viability and social acceptability of alternative production systems