Life Cycle Assessment of Agricultural Systems: Introduction

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Oveview

- Specific aspects of agriculture
- Consequences for agricultural LCA
- Defining system boundaries
- Defining the functional unit
- Impact assessment for biodiversity and soil quality
- Variability of agricultural production and use of multivariate statistics
- Examples of application of LCA:
  - Cropping system analysis
  - Animal production, meat, milk and cheese
  - Biofuels
  - Environmental assessment of farms

Specific aspects of agricultural systems

- Strong reliance on natural resources: land, water, sunlight, nutrients, soil, biodiversity
- Dependence on living organisms
- Open systems
- Processes are difficult to control: e.g. nutrient leaching, erosion, N_2O emissions
- Emissions are difficult to measure, due to the open nature of the systems
- Small-scale structure: numerous farm businesses
- Complex systems, only partly understood
- Nonlinear nature of many environmental mechanisms
- High variability of processes and products, due to soil, climate, topography, agricultural management, traditions

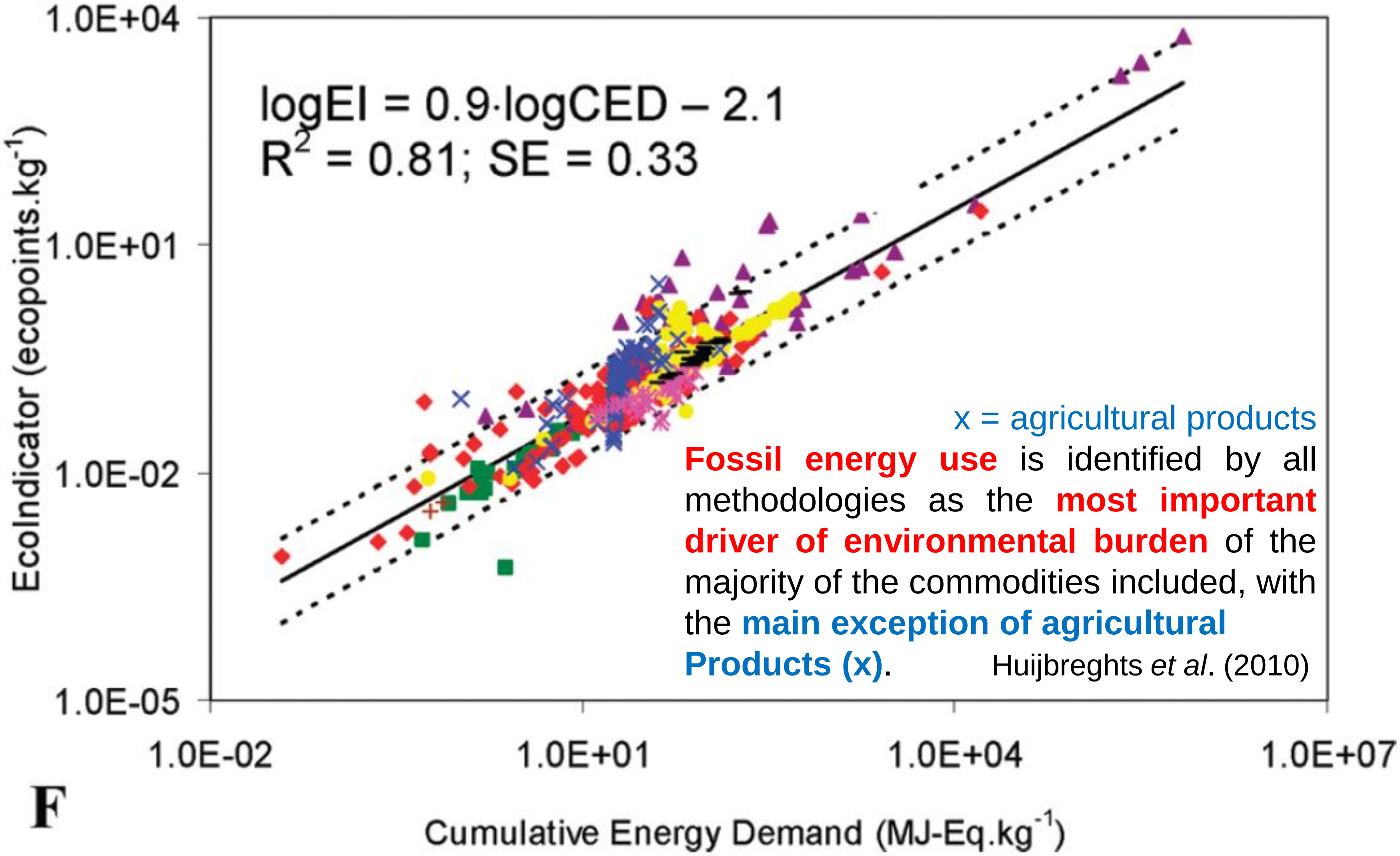
Consequences of these specificities of agriculture (1)

- Environmental models and data need to be developed or adapted to agriculture
- Account for non-linear relationships of environmental processes
- Difficulty to clearly delimit the ecosphere (environmental system) and the technosphere (economic system): e.g. agricultural soil, biodiversity in the field
- Due to the variability a large number of observations is needed to get representative data (but often insufficient resources)
- Efficient LCA databases and calculation procedures are required to manage this large number of observations

Consequences of these specificities of agriculture (2)

- Since measurements at a large scale are not feasible environmental models are needed, reflecting the main influencing factors
- Need to include specific impact categories, related to the use of natural resources: land use, land use change, biodiversity, soil quality, water resources
- Need to adapt some impact categories, e.g. impact of pesticides on ecotoxicity
- Collaboration between agronomists, environmental scientists and local experts is required

Fossil energy and carbon footprint are not enough for agricultural systems

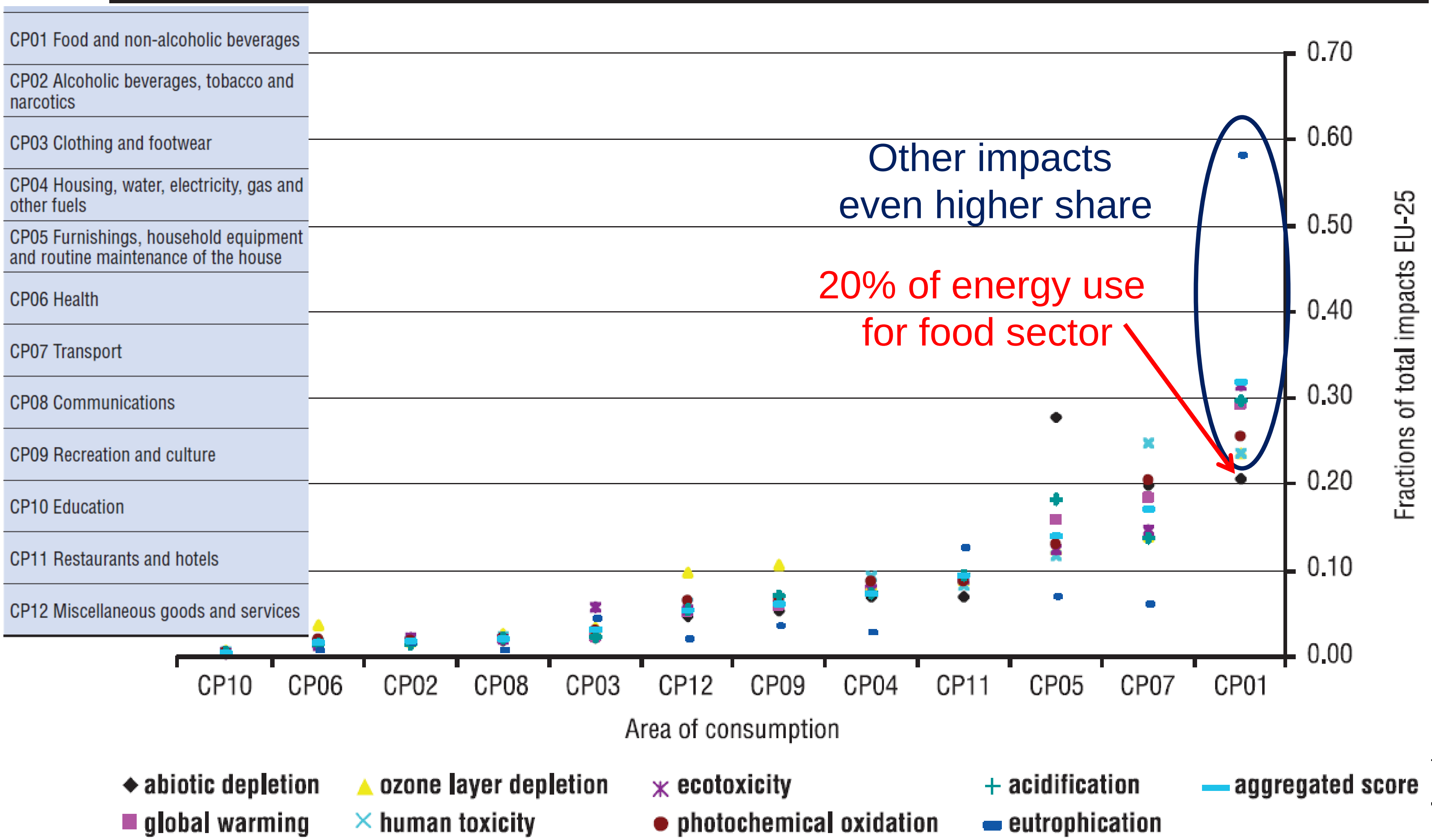


x = agricultural products

Fossil energy use is identified by all methodologies as the **most important driver of environmental burden** of the majority of the commodities included, with the **main exception of agricultural Products (x)**. Huijbreghts *et al*. (2010)

20-60% of environmental impacts in Europe related to the food sector

Figure 5.4.6: Scores per consumption area (COICOP level 1) for all impact categories, areas ordered as to increasing aggregate score



Source: EIPRO study (Tukker et al. 2006)

Defining system boundaries: Temporal system boundaries

- Annual crops:
  - Starting after harvest of previous crop (including fallow period or catch crop, if no product)
  - Ending with harvest of the considered crop
- Permanent crops:
  - Annual basis (1st January to 31st December) or
  - Multiannual cropping cycle (distinguishing different phases: planting, young plantation, main yielding phase, eradication)

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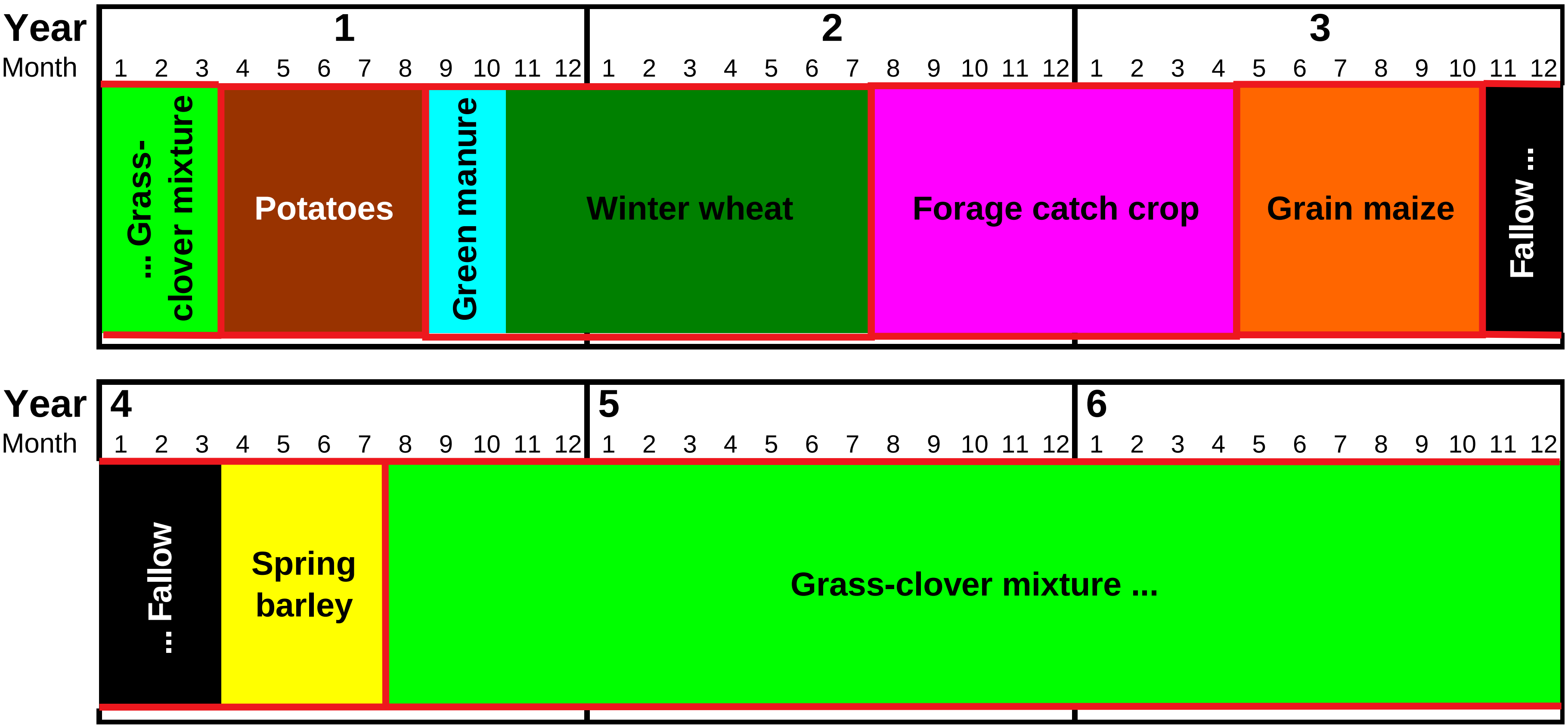
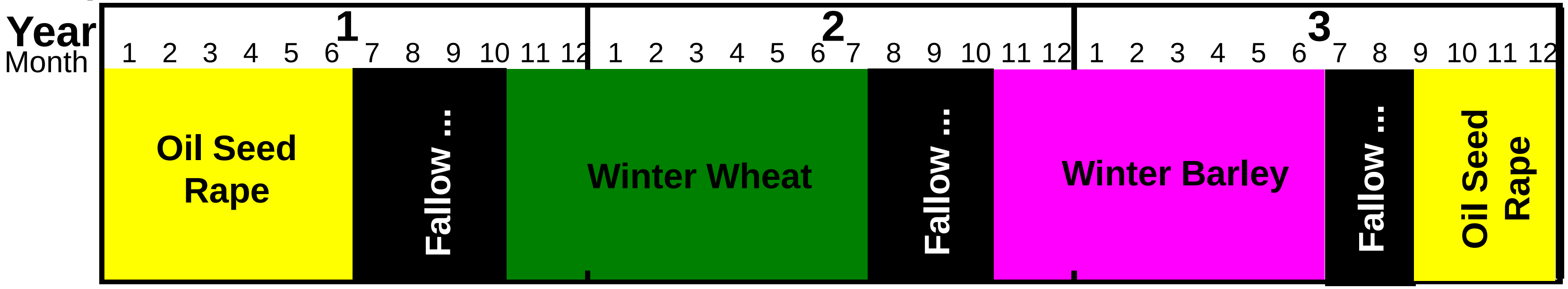
Single crop or cropping system?

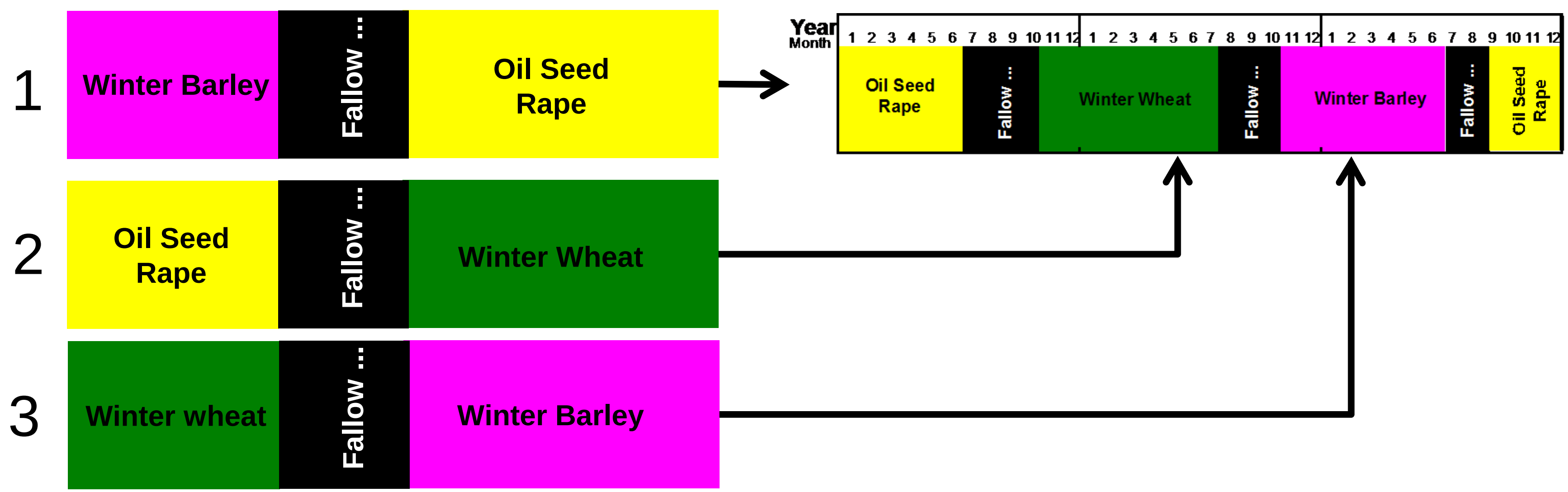


Methodology: Crop combinations

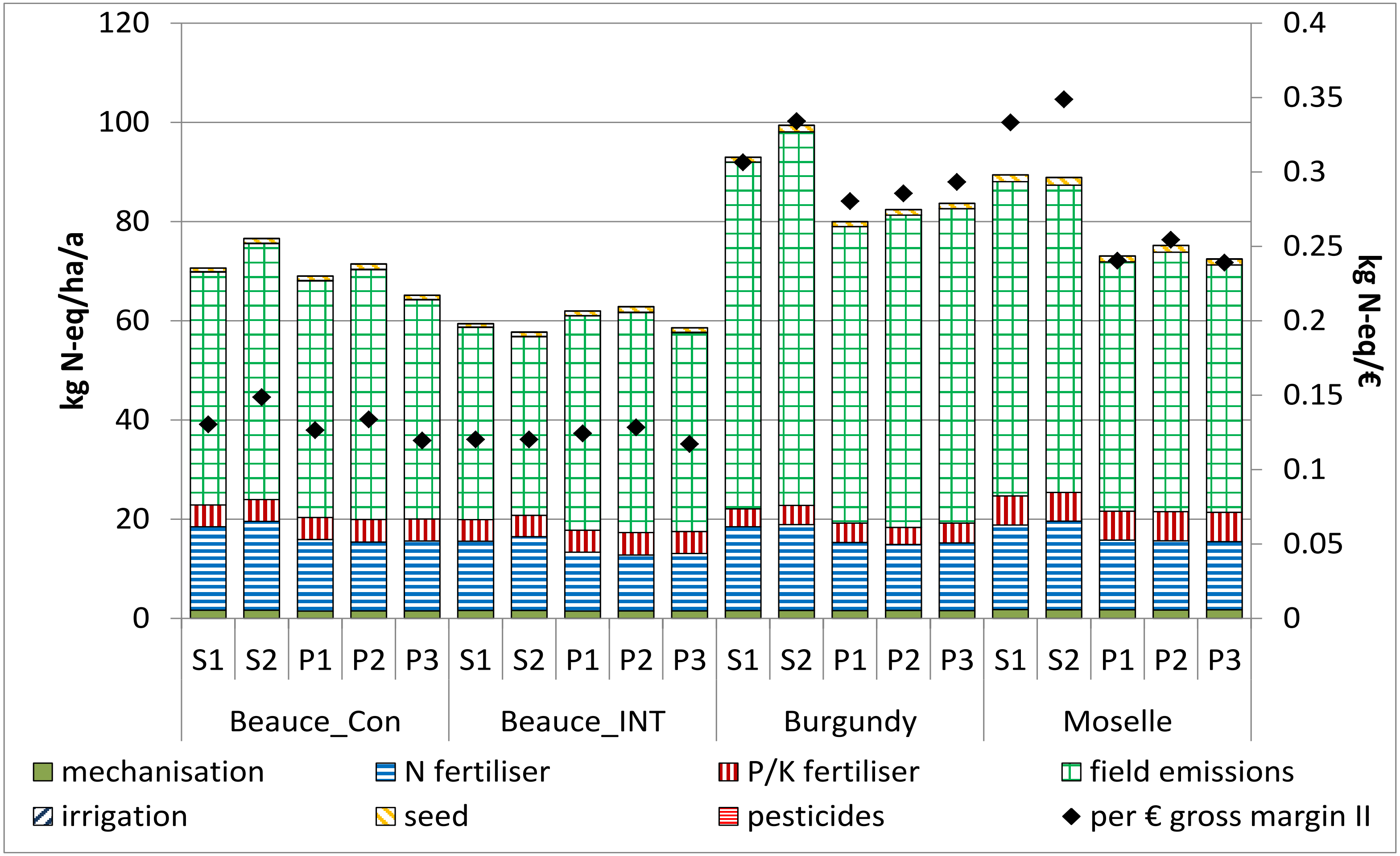
Crop Rotation



Crop Combination

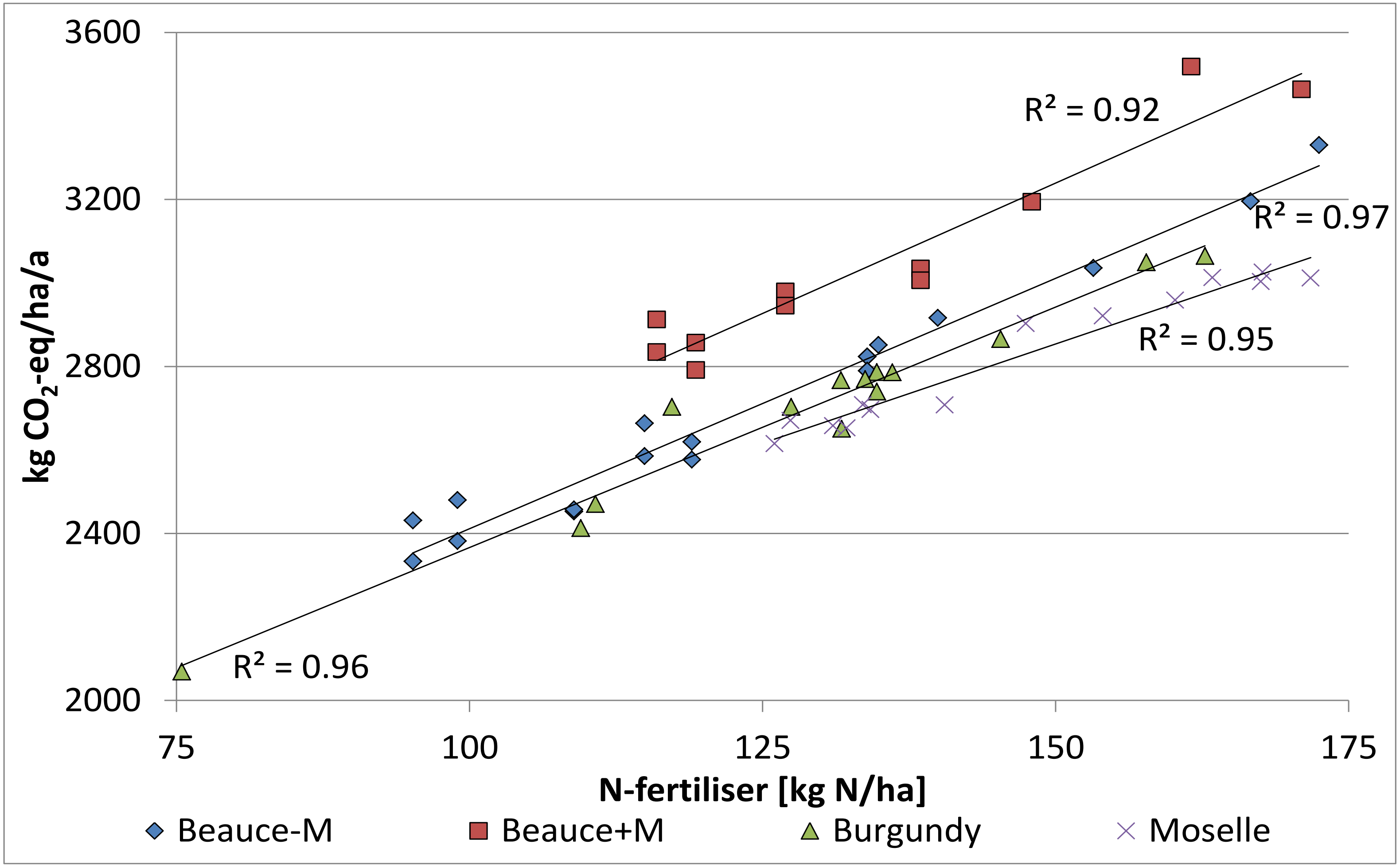


Comparison of different crop rotations with (P) and without (S) pea



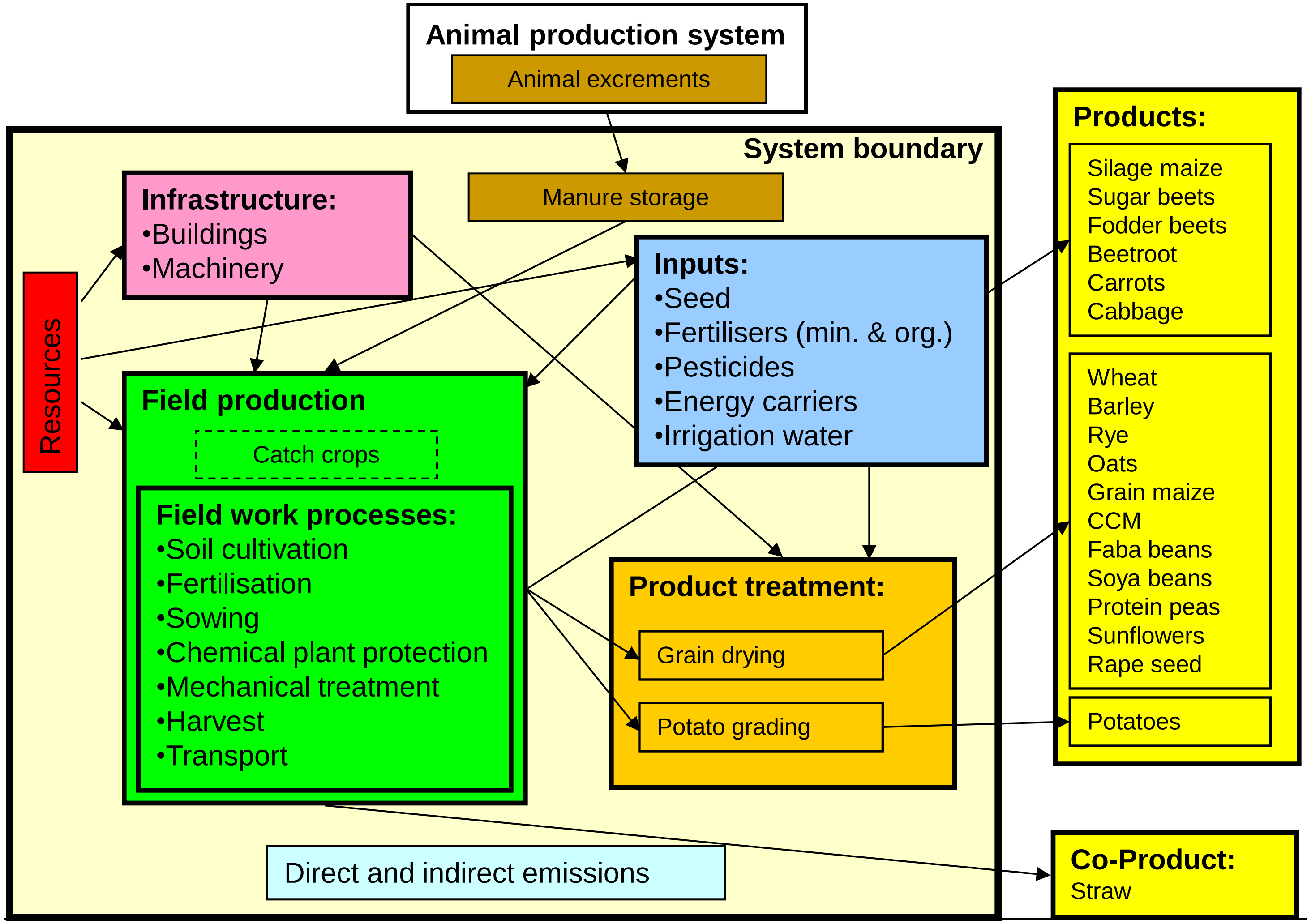
Source: Hayer *et al*. (2011)

Relationship between N fertilisation and global warming potential

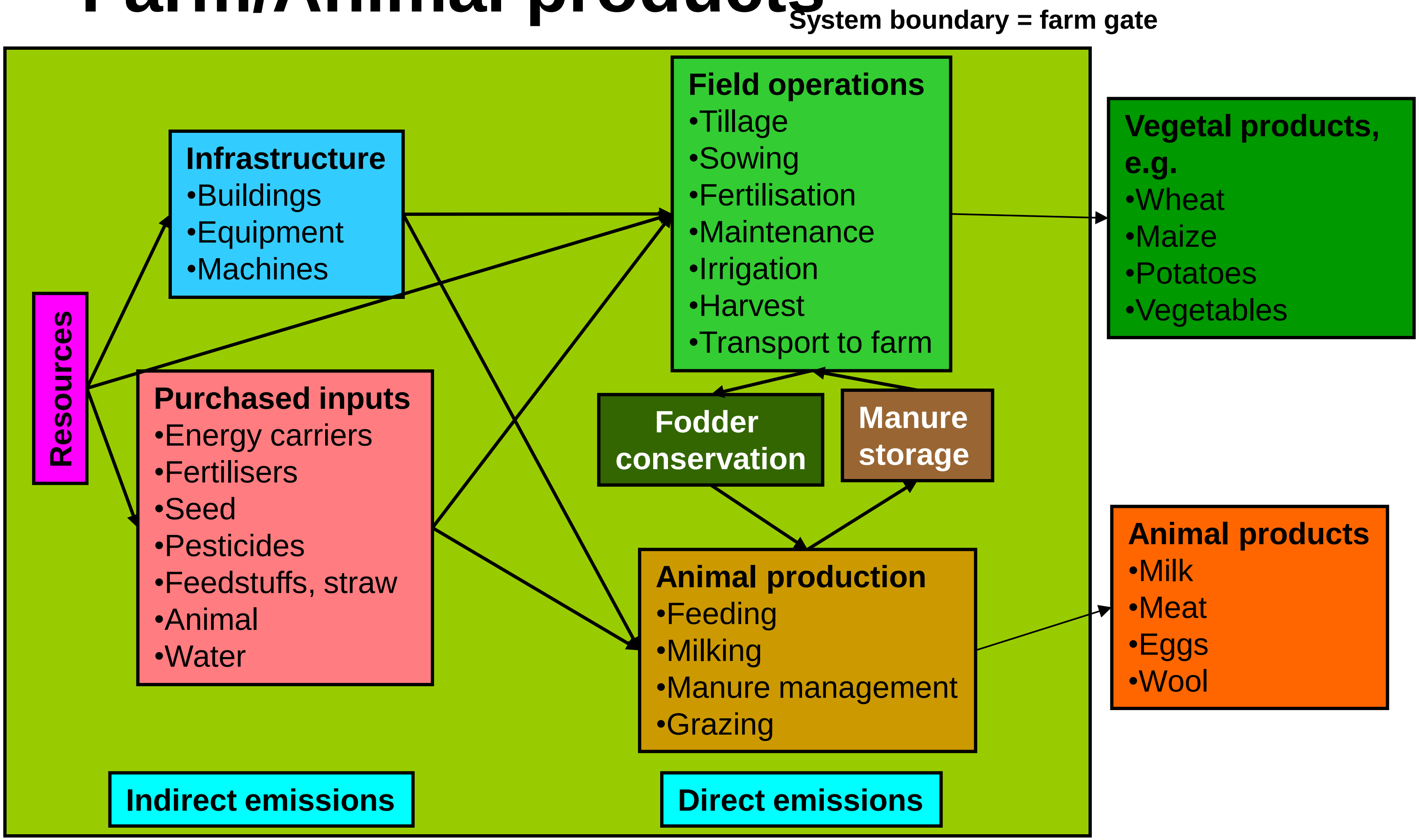


Source: Hayer *et al*. (2011)

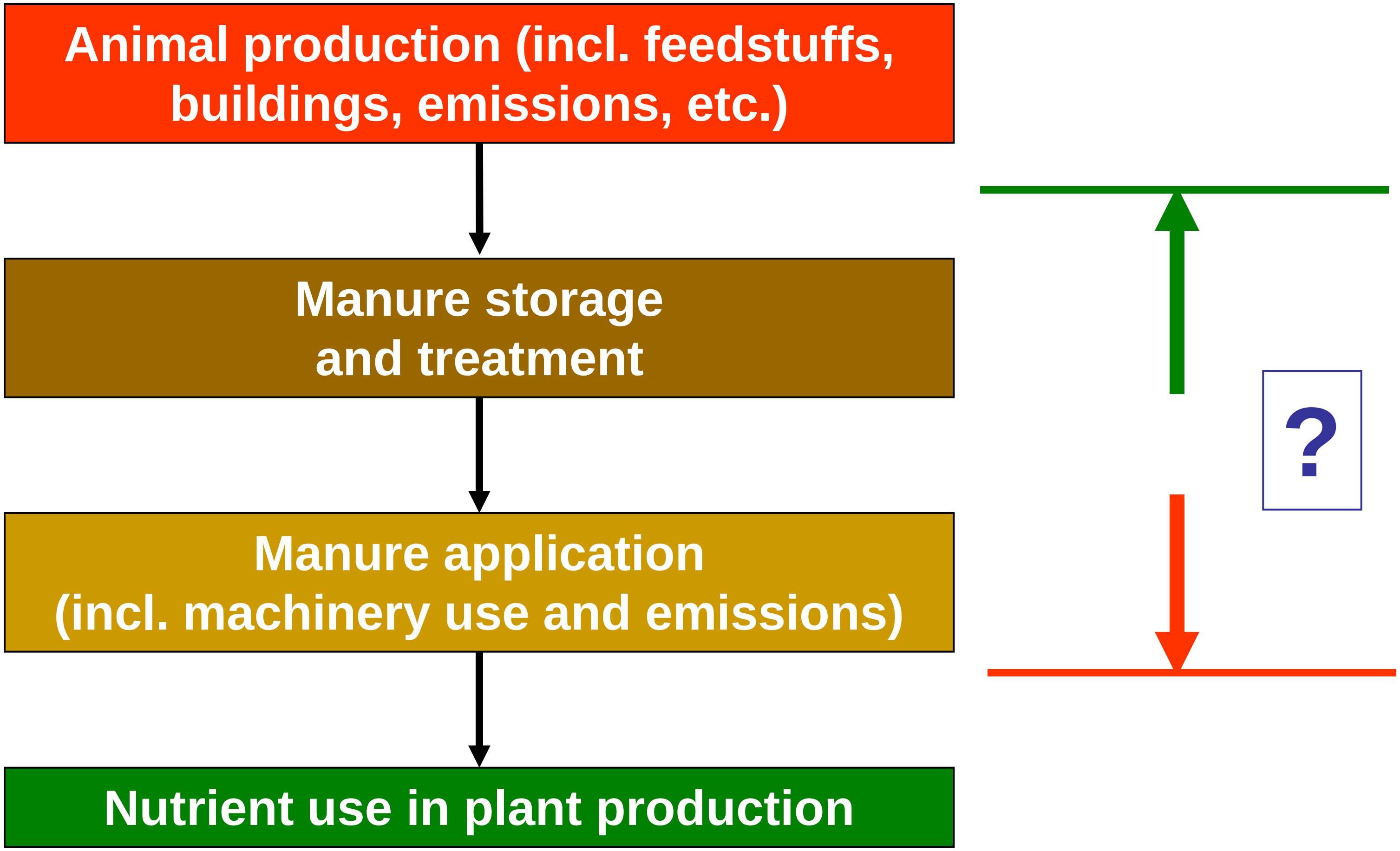
Defining system boundaries: Example of crop production



Defining system boundaries: Farm/Animal products



Defining system boundaries: Where to draw the line between animal and plant production?



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Multifunctionality of agriculture: Functions and functional units

1. **Land management function**: ha*year
→ goal: minimize land use intensity
2. **Productive function**: physical unit (MJ gross calorific value) → goal: optimise eco-efficiency (minimal impact per produced energy unit)
3. **Financial function**: monetary unit
→ goal: optimise eco-efficiency
(minimal impact per € gross margin 1)

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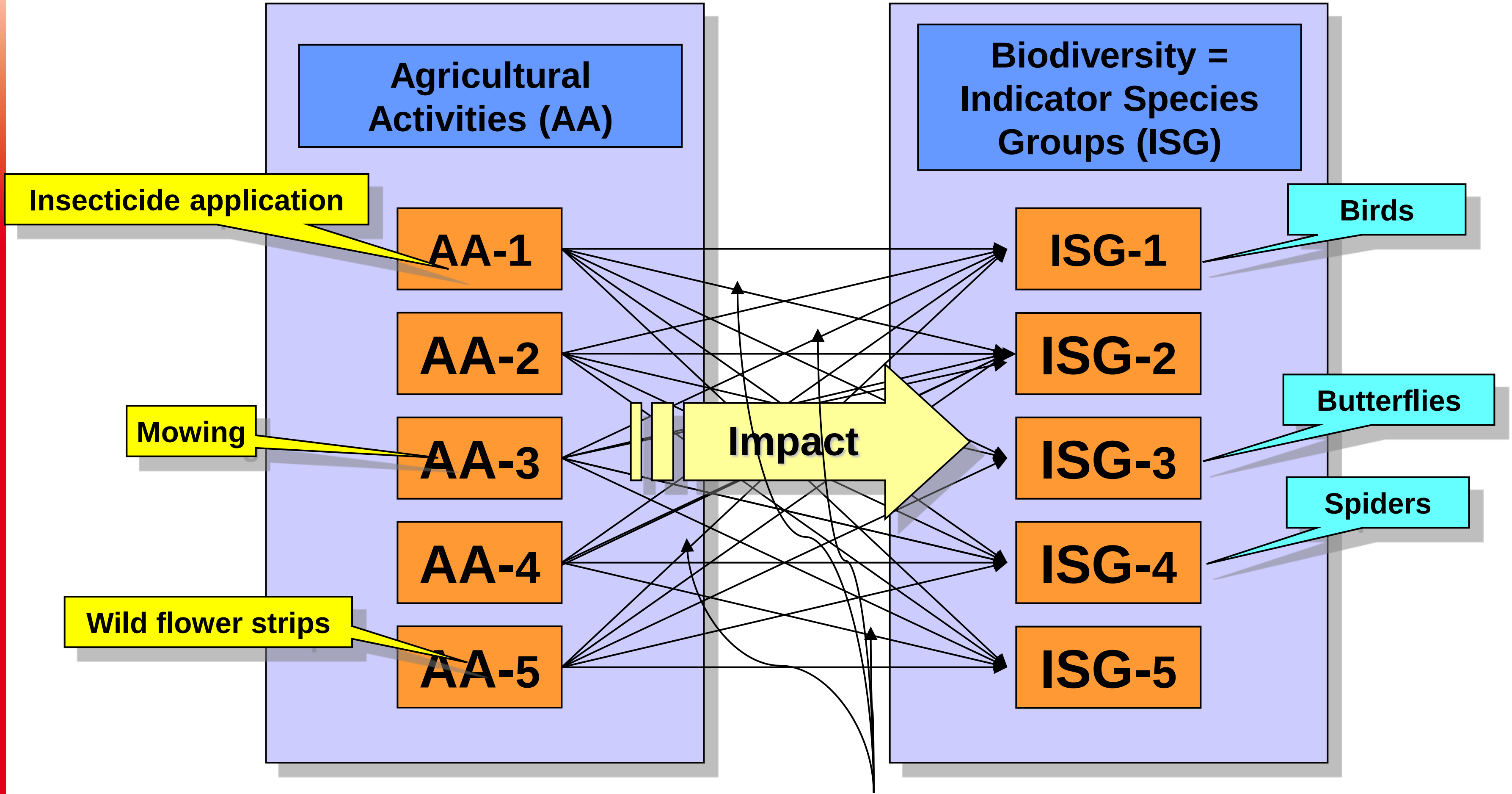
SALCA methodology
Method for biodiversity - framework

- **11 Indicator species groups** were determined considering ecological and LCA criteria: flora, birds, mammals, amphibians, molluscs, spiders, carabids, butterflies, wild bees, and grasshoppers.
- Two characteristics: **overall species diversity** of the indicator species groups and **ecologically demanding species**
- Extensive **inventory data about agricultural practices**: occupation, emissions, farming intensity indicators (e.g. number of cuts) and process figures (e.g. herbicide type). Beside typical cultivated fields, semi-natural habitats were integrated.
- **Characterisation based on scoring system** was evolved to estimate every indicator species group's reaction to agricultural activities followed by an aggregation step resulting in **scores**.
- **Aggregation** and **normalisation** of scores: biodiversity value and biodiversity potential

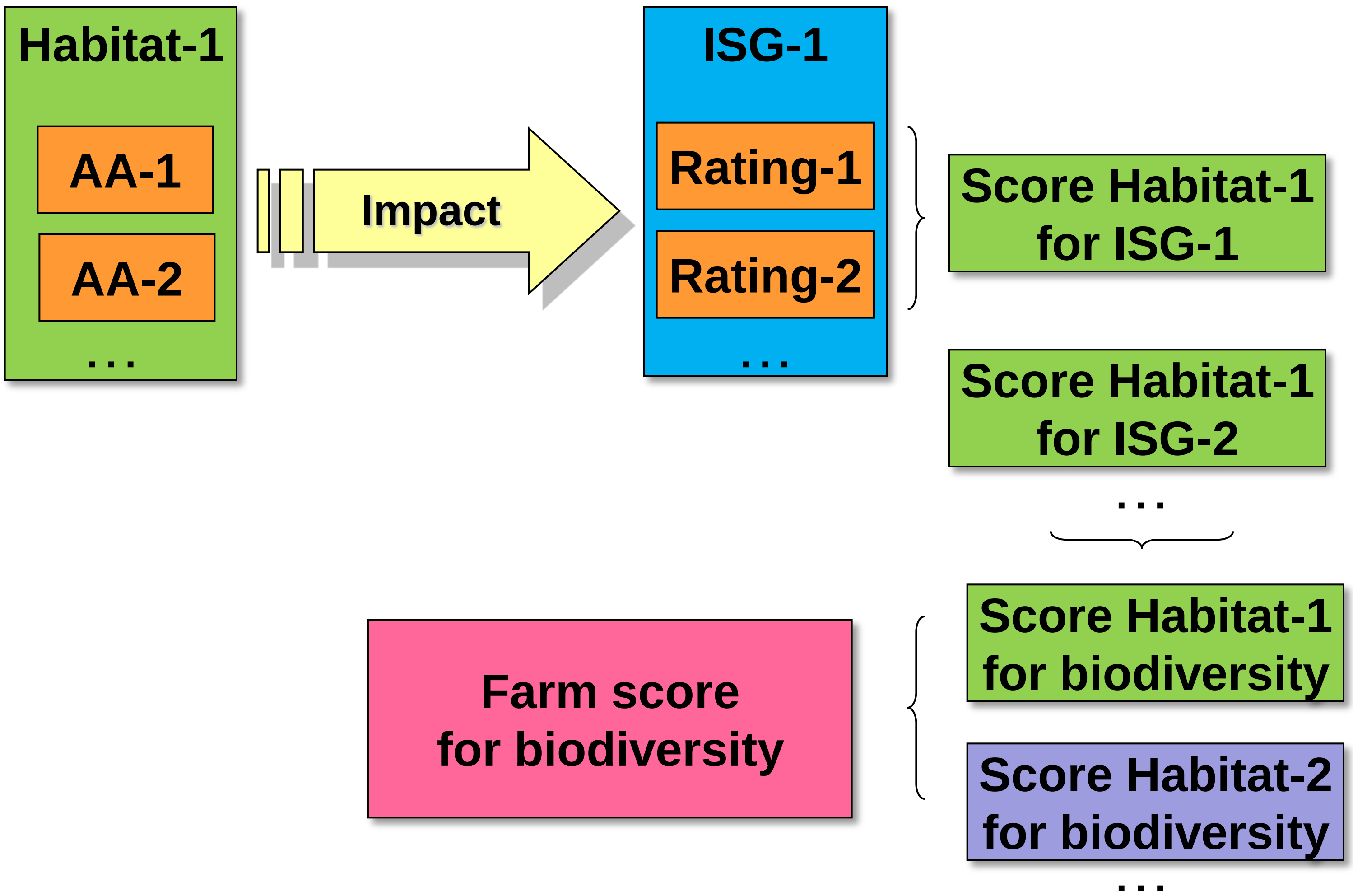
SALCA-Biodiversity

Estimation of impacts on biodiversity



Bottom-up approach: Scores based on scientific and expert knowledge

SALCA-Biodiversity: Aggregation steps



SALCA methodology
Method for biodiversity – DOK trial

Biodiversity points	**D0**	**D1**	**D2**	**O1**	**O2**	**C1**	**C2**	**M2**
Total species richness								
Total aggregated	**8.7**	**8.1**	**8.0**	**8.0**	**8.0**	**7.7**	**7.6**	**7.6**
Flora arable land	14.8	13.9	13.9	13.8	13.8	12.8	12.6	12.5
Flora grassland	4.9	4.3	4.1	4.2	4.2	4.1	3.9	3.9
Birds	10.3	8.7	8.6	8.5	8.5	8.0	8.0	7.9
Small mammals	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Amphibians	2.5	2.1	2.1	2.1	2.1	2.0	2.0	2.0
Molluscs	2.5	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Spiders	13.9	13.2	13.2	13.0	13.0	12.2	12.0	12.1
Carabids	14.7	14.0	14.0	14.0	14.0	13.7	13.5	13.6
Butterflies	9.8	8.8	8.6	8.8	8.6	8.5	8.4	8.5
Wild bees	4.9	4.8	4.8	4.8	4.8	4.8	4.8	4.9
Grasshoppers	11.0	9.8	9.5	9.9	9.6	9.4	9.3	9.3
Species with high ecological requirements								
Amphibians	1.7	1.4	1.3	1.3	1.3	1.3	1.2	1.3
Spiders	13.4	12.7	12.6	12.5	12.4	11.6	11.5	11.6
Carabids	14.7	14.0	14.0	14.0	14.0	13.7	13.6	13.7
Butterflies	9.8	8.8	8.5	8.8	8.5	8.4	8.4	8.5
Grasshoppers	10.9	9.6	9.3	9.6	9.4	9.2	9.1	9.2

Higher values mean higher species richness

favourable	(light green)	compared to reference C2
very favourable	(dark green)	

D = Bio-dynamic
O = Organic
C = Conventional (mixed min./org. fertilisation)
M = Conventional (mineral fertilisation)
2 = normal fertilisation level
1 = 50% fertilisation level
0 = no fertilisation

Source: Nemecek *et al*. (2005)

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SALCA methodology
Method for biodiversity – case study 1/2

Biodiversity scores

Production system	Grassland (A)	Grassland (B)	Grassland (C)	Grassland (D)	Winter Wheat (A)	Winter Wheat (B)	Winter Wheat (C)	Winter Wheat (D)
Overall species diversity	**6.2**	**6.4**	**13.8**	**21.3**	**7.7**	**7.5**	**8.4**	**8.7**
Grassland flora	3.7	3.9	11.4	18.5				
Crop flora					15.2	15.1	16.0	17.3
Birds	6.4	6.7	13.8	22.0	5.3	5.0	6.2	6.4
Mammals	7.3	7.3	11.1	11.1	4.6	4.6	4.6	4.6
Amphibians	2.1	2.1	5.2	9.5	1.7	1.7	1.8	1.8
Molluscs	5.4	5.6	5.8	11.3	2.2	2.2	2.2	2.2
Spiders	9.1	9.3	15.8	22.4	8.2	8.0	10.5	10.7
Carabid Beetles	7.0	7.4	13.6	21.0	10.9	10.6	11.7	11.9
Butterflies	6.8	7.0	20.0	36.0				
Wild Bees	7.4	7.6	18.6	23.0	5.2	4.9	5.0	4.8
Grasshoppers	6.9	6.9	19.4	33.1				
Species with high ecological requirements								
Amphibians	0.8	0.8	2.9	4.8	1.5	1.4	1.6	1.6
Spiders	8.9	9.0	15.3	21.6	8.0	7.8	10.3	10.5
Carabid Beetles	7.0	7.3	13.4	20.6	10.6	10.1	11.2	11.3
Butterflies	6.7	6.8	19.4	36.0				
Grasshoppers	6.8	6.8	19.3	32.9				

Source: Jeanneret et al. 2006

Results of SALCA-Biodiversity. Biodiversity scores are given per ha cultivated crop. A, B, C, D are management systems with main characteristics :

Grassland systems (hay production):

(A) 5 cuts/year, fertilised with slurry; 11t DM/ha

(B) 4 cuts/year, fertilised with slurry; 9t DM/ha

(C) 3 cuts/year, fertilised with solid manure; 5.6t DM/ha

(D) 1 cut/year, no fertilisation; 2.7t DM/ha

Winter wheat systems:

(A) Conventional production; 5.8t DM/ha

(B) Integrated production – intensive; 5.5t DM/ha

(C) Integrated production – extensive; 4.5t DM/ha

(D) Organic production; 3.5t DM/ha

Scores of grassland (A) and winter wheat (B) systems are set as **reference scores**. Color codes are given for rough comparison:

- similar to the reference (95%<score<104%)
- better than the reference (105%<score<114%)
- much better than the reference (score >115%)
- no relevance for the considered system

SALCA methodology
Method for soil quality - framework

- Spatial system boundary = farm;
- Temporal system boundary = crop rotation period (6-8 years)
- Management data of all plots of a farm in a single year are considered as representative for a whole crop rotation
- Only influences of agricultural management practices are included, not immissions
- The development trend of soil properties is assessed, not absolute values

Soil properties
Physical
Chemical
Biological

Criteria
According to ISO 14040 and ISO 14042
Depending on the needs of Life Cycle Assessment

9 Direct Indicators = measurable soil properties

Physical	**Rooting depth of soil**
	Macropore volume
	Aggregate stability
Chemical	**Soil organic matter**
	Inorganic pollutants
	Organic pollutants
Biological	**Earthworm biomass**
	Microbial biomass
	Microbial activity

Source: Oberholzer et al. (2006)

SALCA methodology
Method for soil quality – impact assessment

Example: slurry application

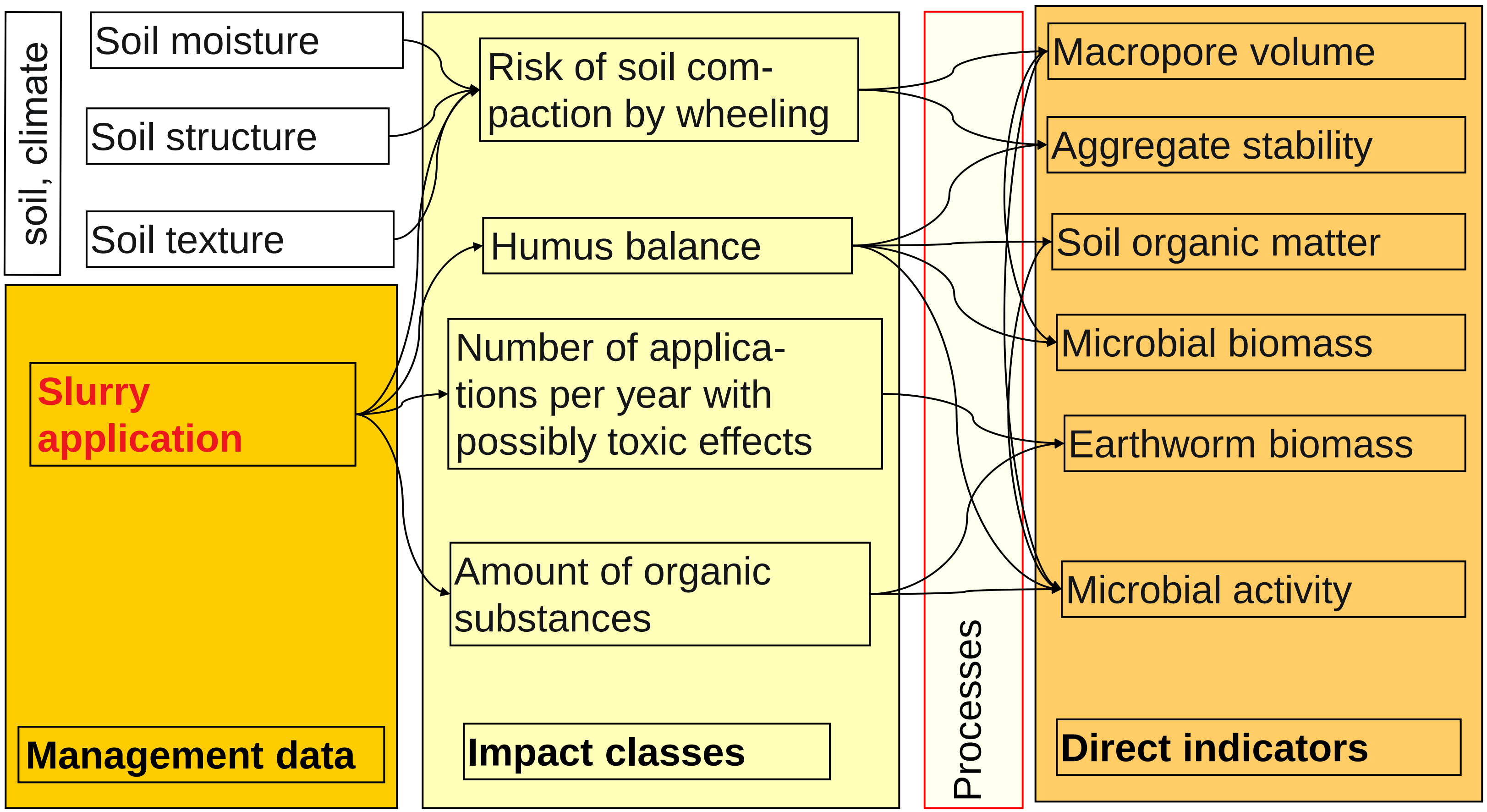


Figure 1: Example of impact assessment of a slurry application

SALCA methodology
Method for soil quality – example DOK

Main characteristics of the analysed cultivation systems

	No fer-tiliser D0	Bio-dyna-mic D2	Bio-orga-nic O2	Conventional K2	Mineral fertiliser M
Soil tillage	ploughing			ploughing	
Fertiliser type	no	Liquid manure, compost	Liquid manure, dung	Org. and mineral fertiliser	Mineral fertiliser
Fertiliser kg N/ha	0	93	86	165	125
Growth regulators and Fungicides	no			Yes	
Weed regulation type	mechanical			herbicides	
Weed regulation, period and frequ.	Spring, 3 applications			Spring and autumn, 2 applications	
Seeding month	October			October	
Harvest month	August			August	
Crop residues	removed			removed	

SALCA methodology
Method for soil quality – Results DOK

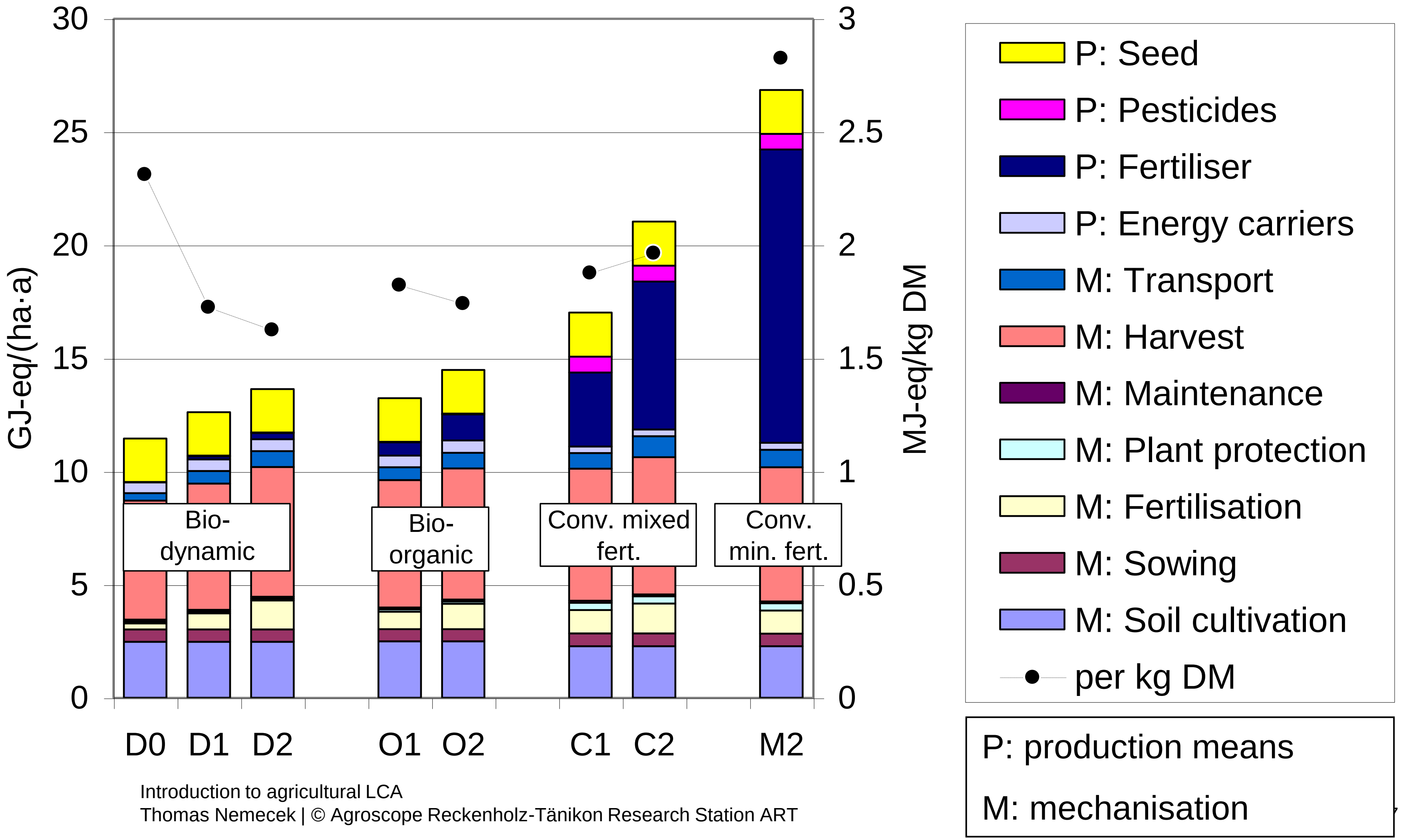
Results of SALCA-Soil Quality for the five treatments

Direct Indicators for soil quality		D0	D2	O2	K2	M
Physical	Rooting depth of soil	0	0	0	0	0
	Macropore volume	0	0	+	+	0
	Aggregate stability	-	+	+	+	-
Chemical	Corg content	--	+	+	+	--
	Heavy metal content	0	0	0	0	0
	Organic pollutants	0	0	0	0	0
Biological	Eathworm biomass	0	0	0	+	0
	Microbial biomass	-	0	+	+	-
	Microbial activity	-	0	+	+	-

- **Minor differences between the three farming systems** because most management practices are similar or equal regarding soil quality. Some indicators do not show a positive effect in D2 because of slightly less organic input compared to O2 and K2.
- **D0 and M:** Impacts on soil quality because of insufficient organic carbon supply without organic fertilisers and removal of crop residues.
- **O2 and K2:** Positive effect of crop rotation on macropore volume is not negated by a high compaction risk.

Example of cropping systems research:

Organic and integrated farming / Energy demand in the DOC-trial



Source: FAL report 58 (2006)

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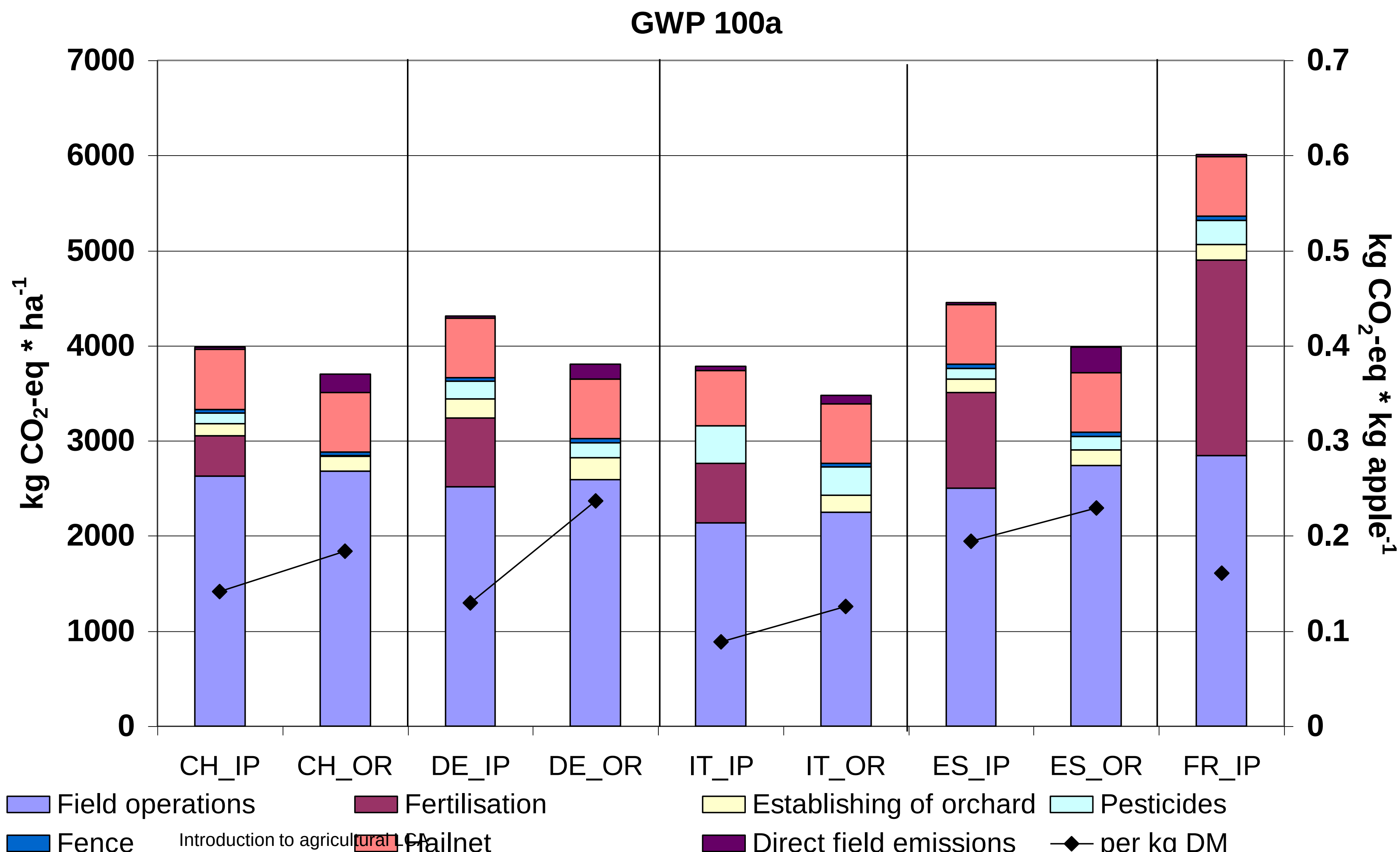
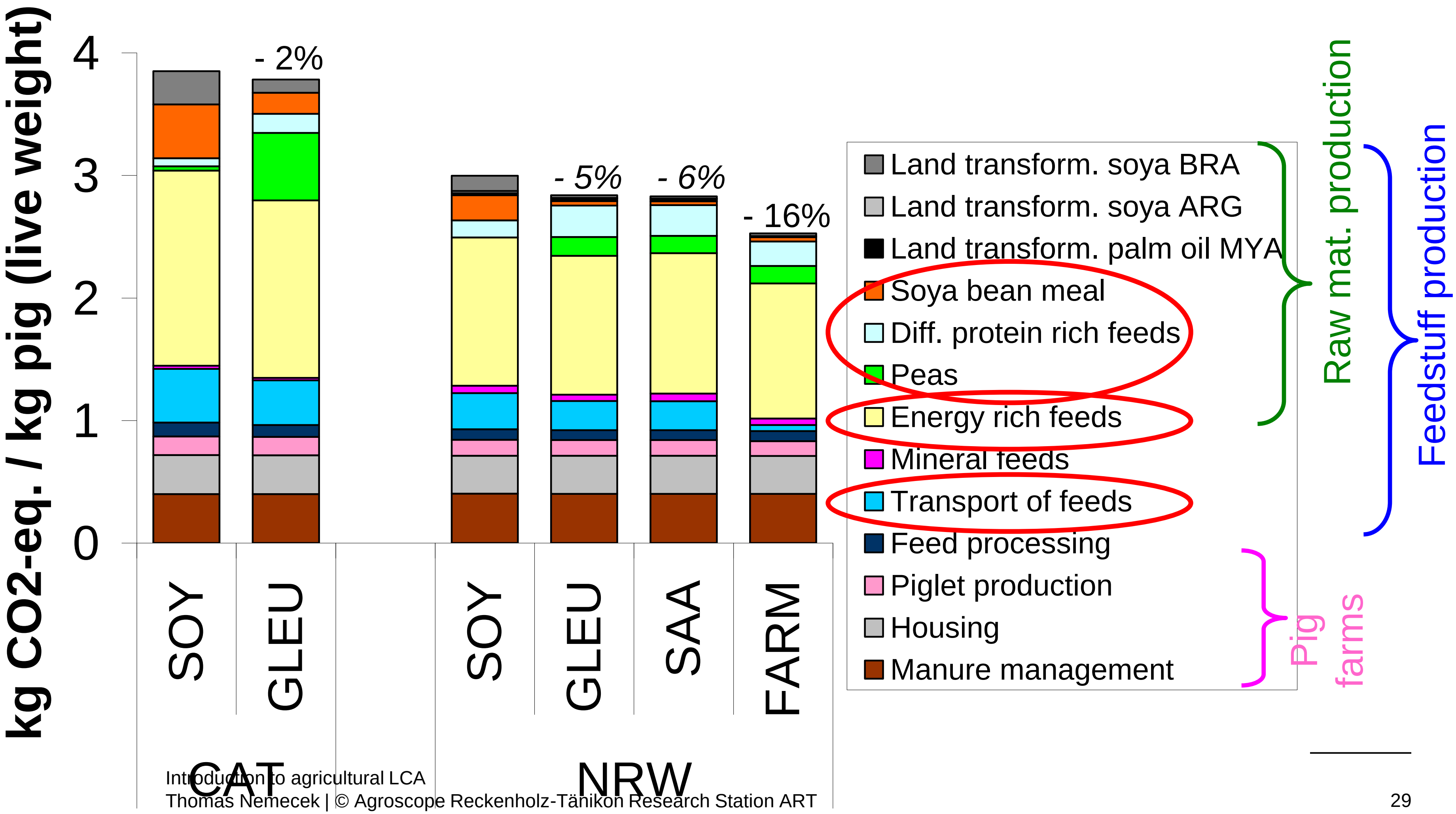
Example of horticultural research (EU-project ENDURE): Global warming potential pome-fruit



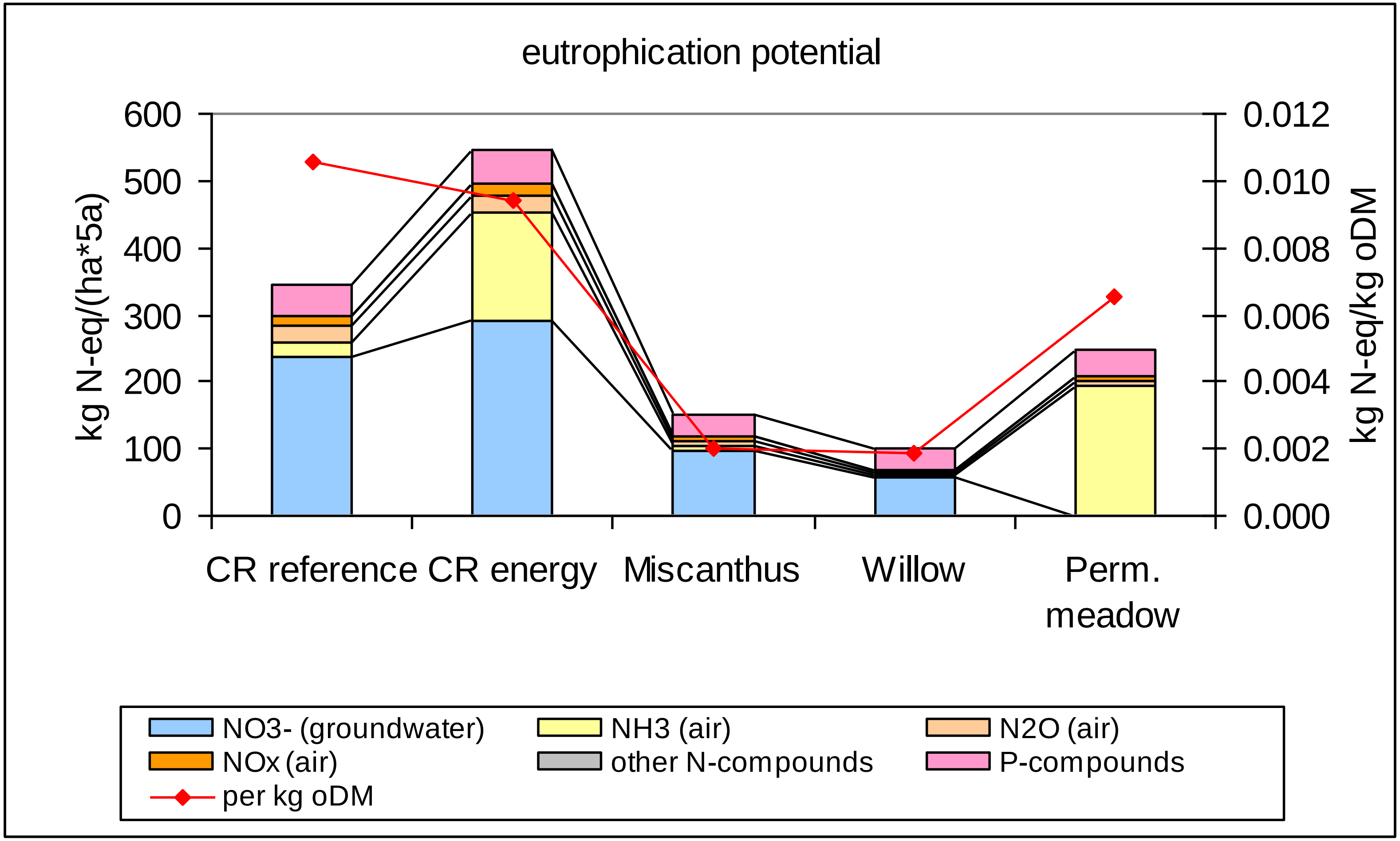
Source: Frank Hayer (ART)

Example of animal production research: EU-Project Grain Legumes (GLIP)
Effect of replacing soya beans in pig feed



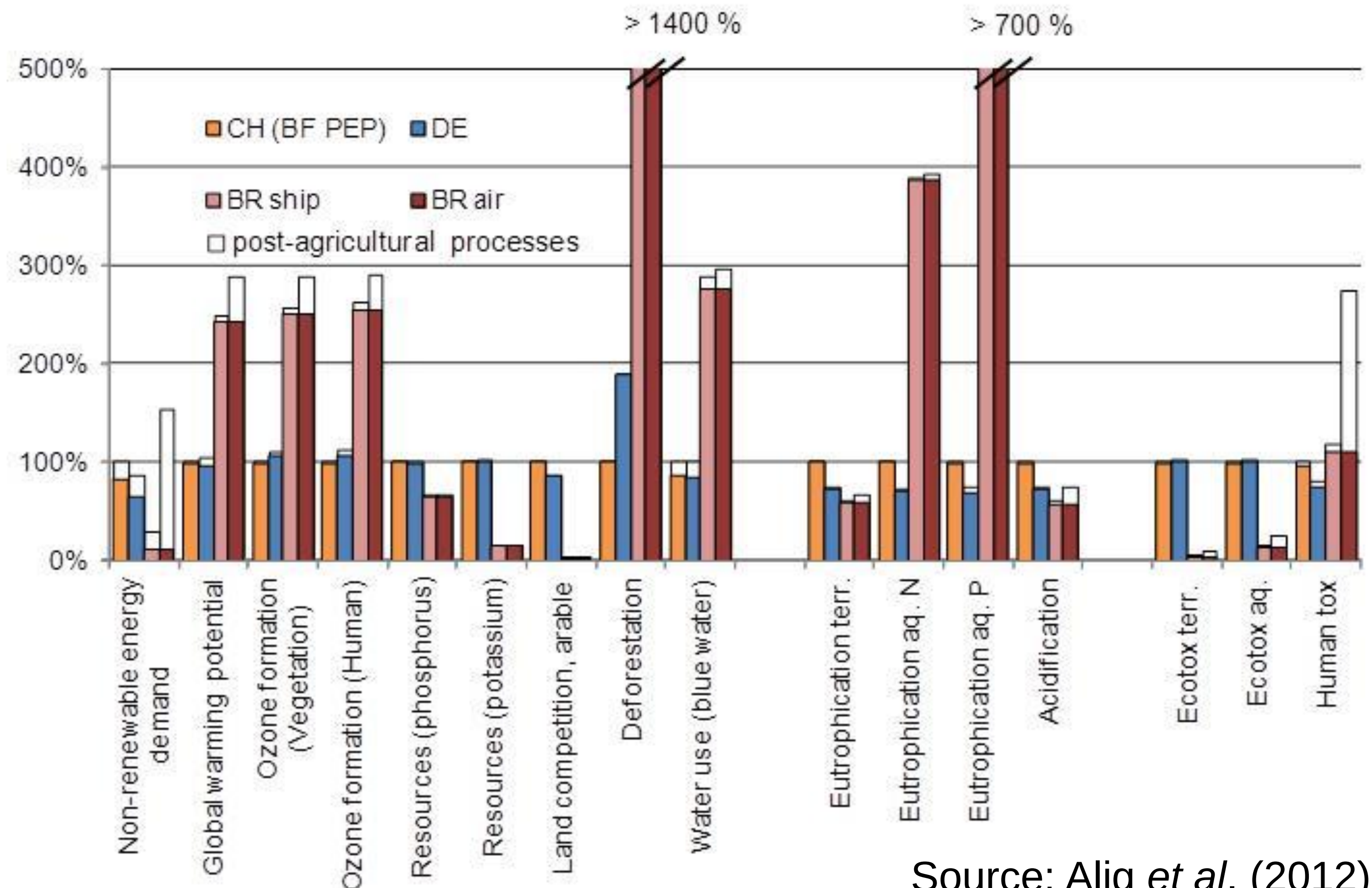
Source: Daniel Baumgartner (ART)

Evaluation of bioenergy production systems: Eutrophication potential



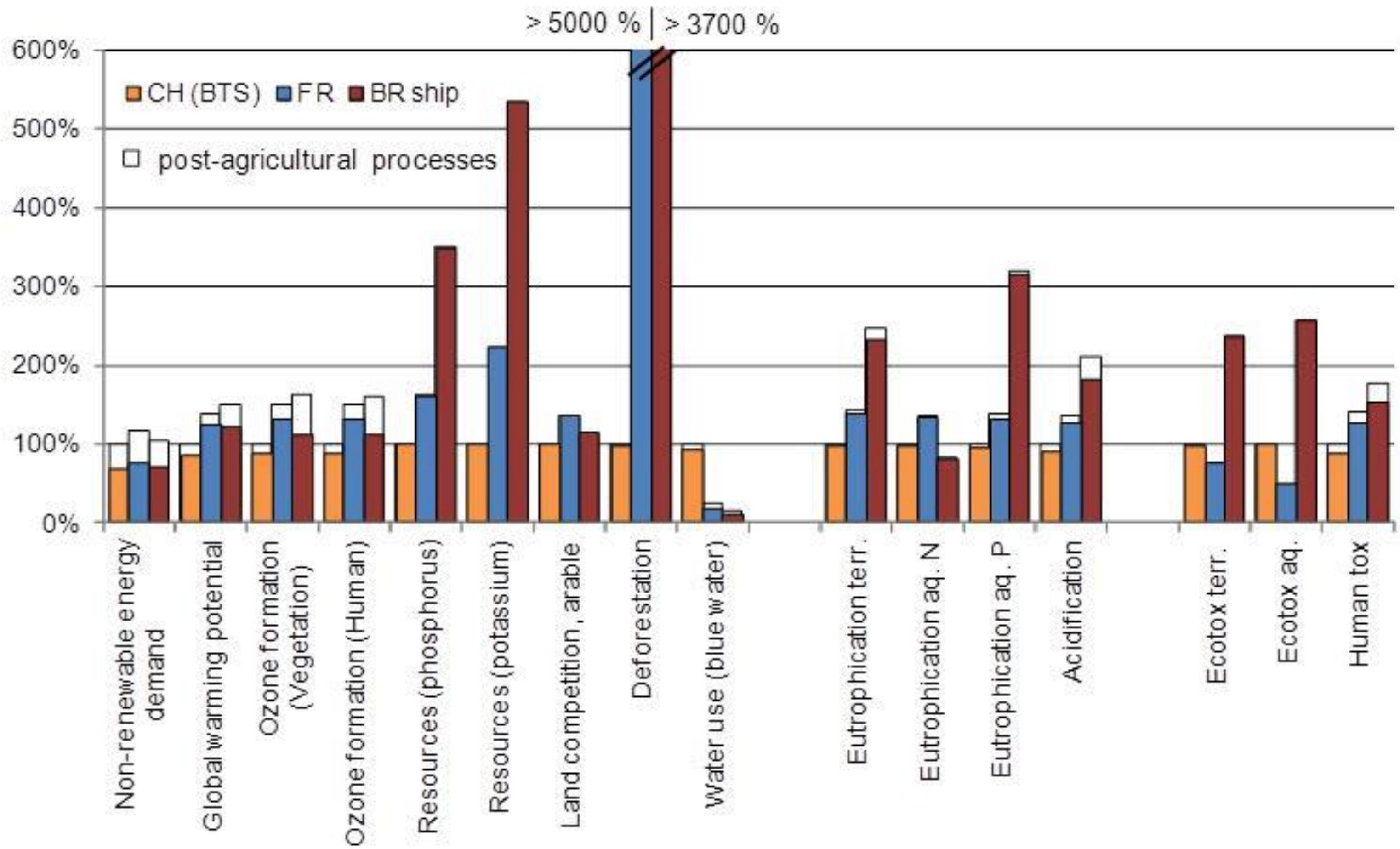
Source: Thomas Kägi (ART)

Food LCA:
Beef at point of sale



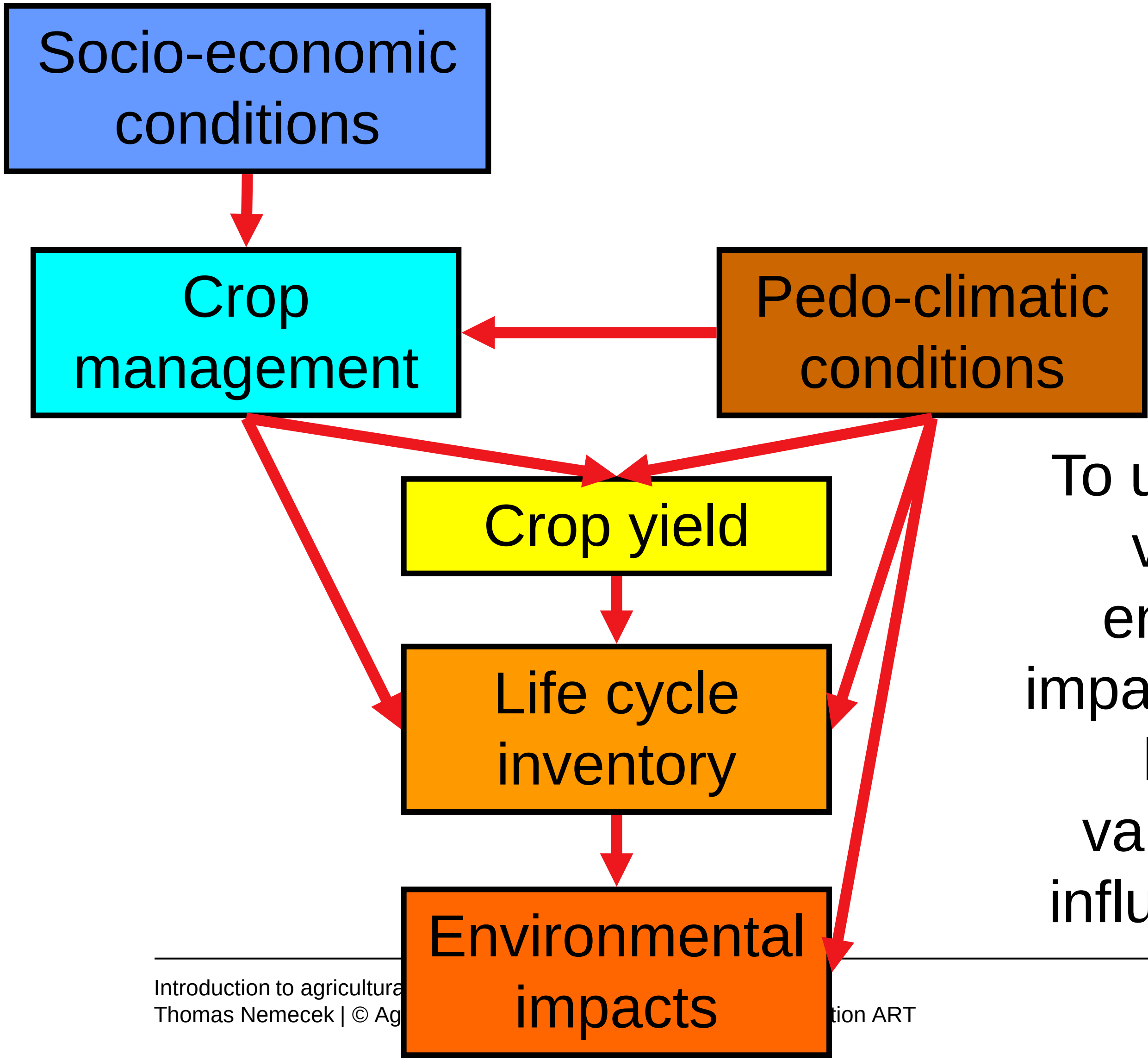
Source: Alig *et al*. (2012)

Food LCA: Chicken at point of sale



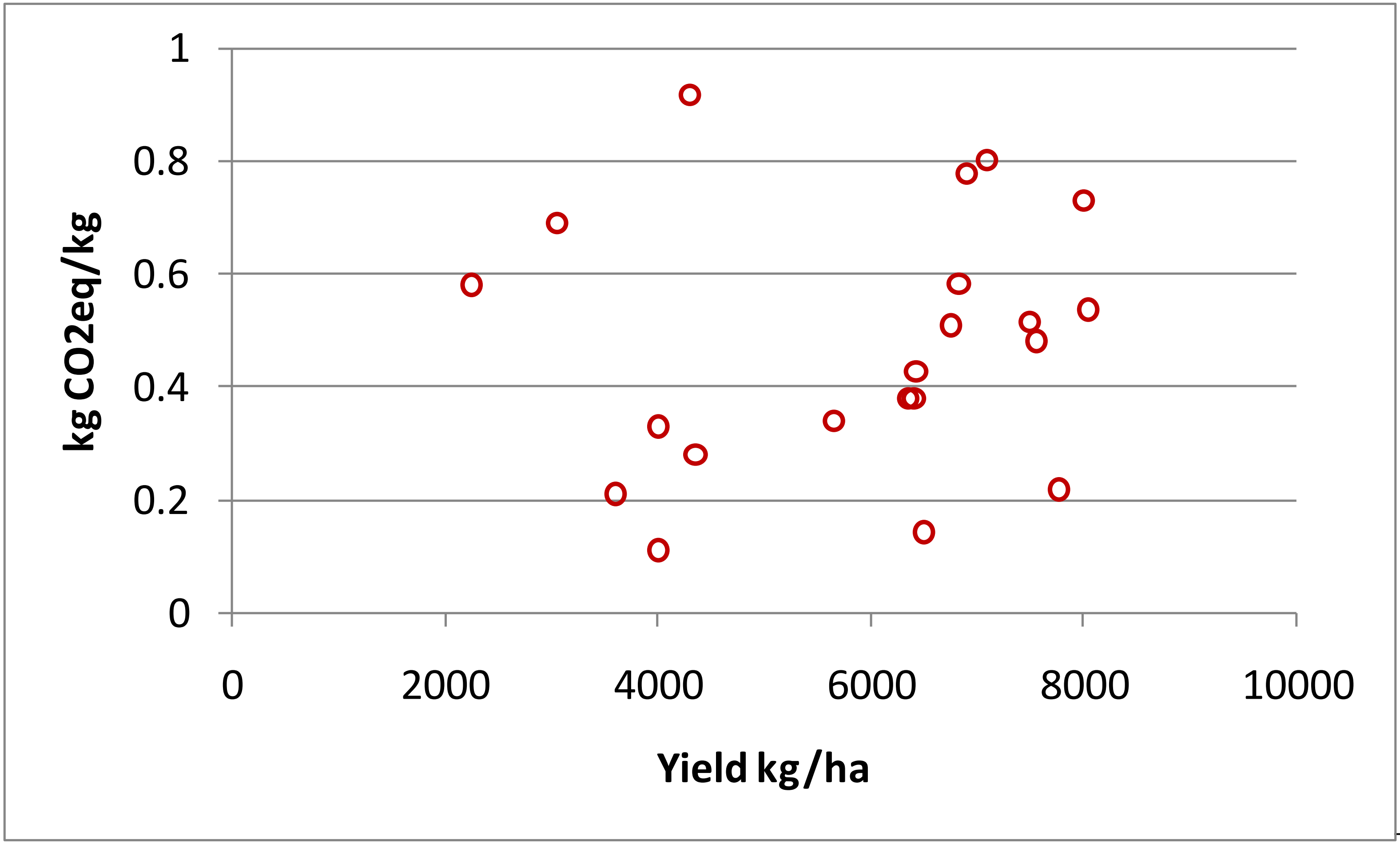
Source: Alig *et al*. (2012)

Variability and uncertainty: Factors influencing environmental impacts



To understand the variability of environmental impacts, we need to look on the variability of the influencing factors

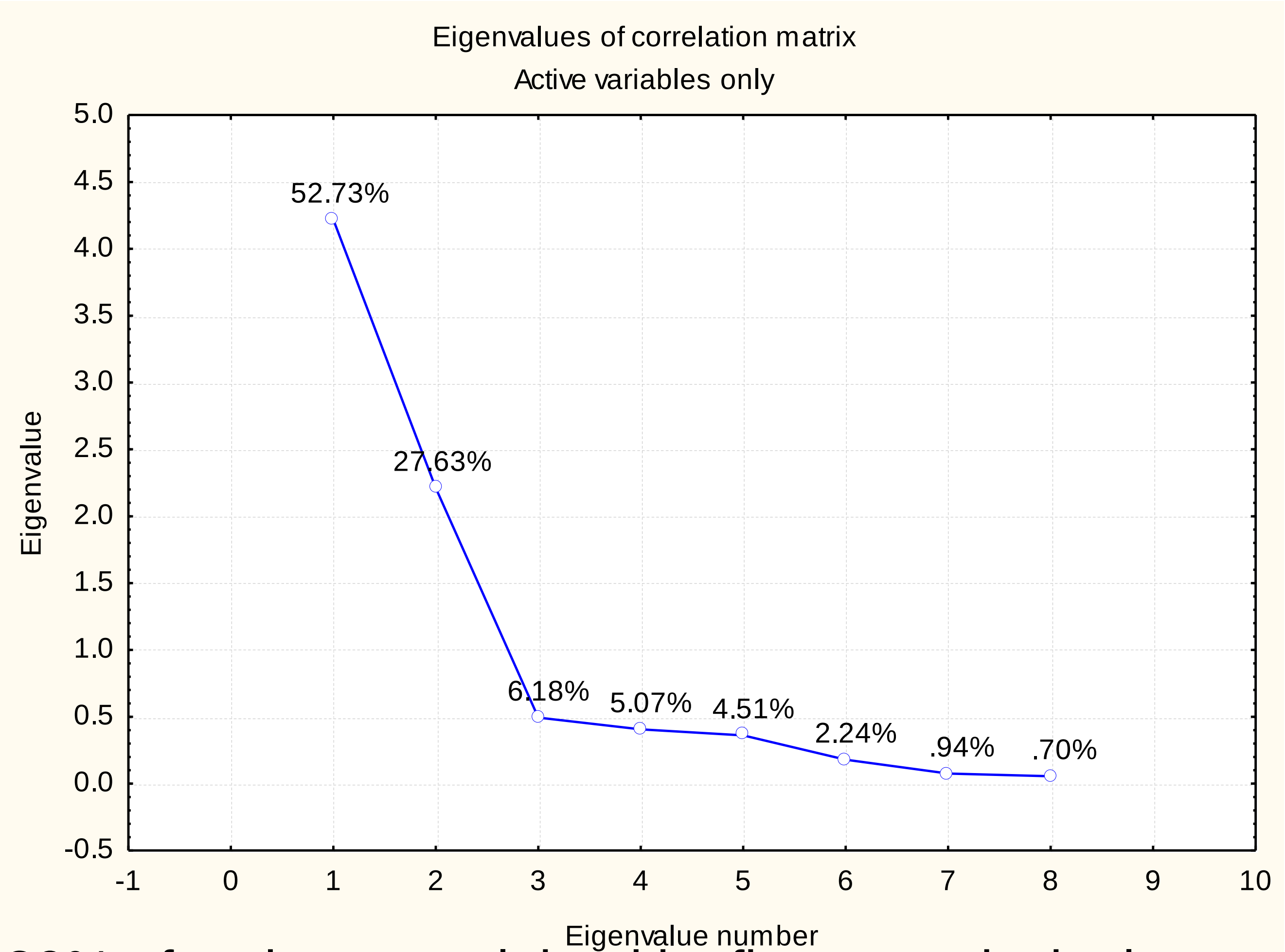
Variability of environmental impacts: GWP of wheat from literature



Potential use of multivariate statistics in LCA to explain variability

- To select proxies, we have to identify similar datasets
- Multivariate statistics (like principal component analysis, PCA) can be used to show similarities between environmental impacts
- It can be also used to group environmental profiles, e.g. of crops
- Analysis based on a set of midpoint LCIA indicators
- In the study applied to crop inventories from SALCA (Switzerland) and ecoinvent (global)

Principal component analysis of SALCA inventories



80% of variance explained by first two principal components

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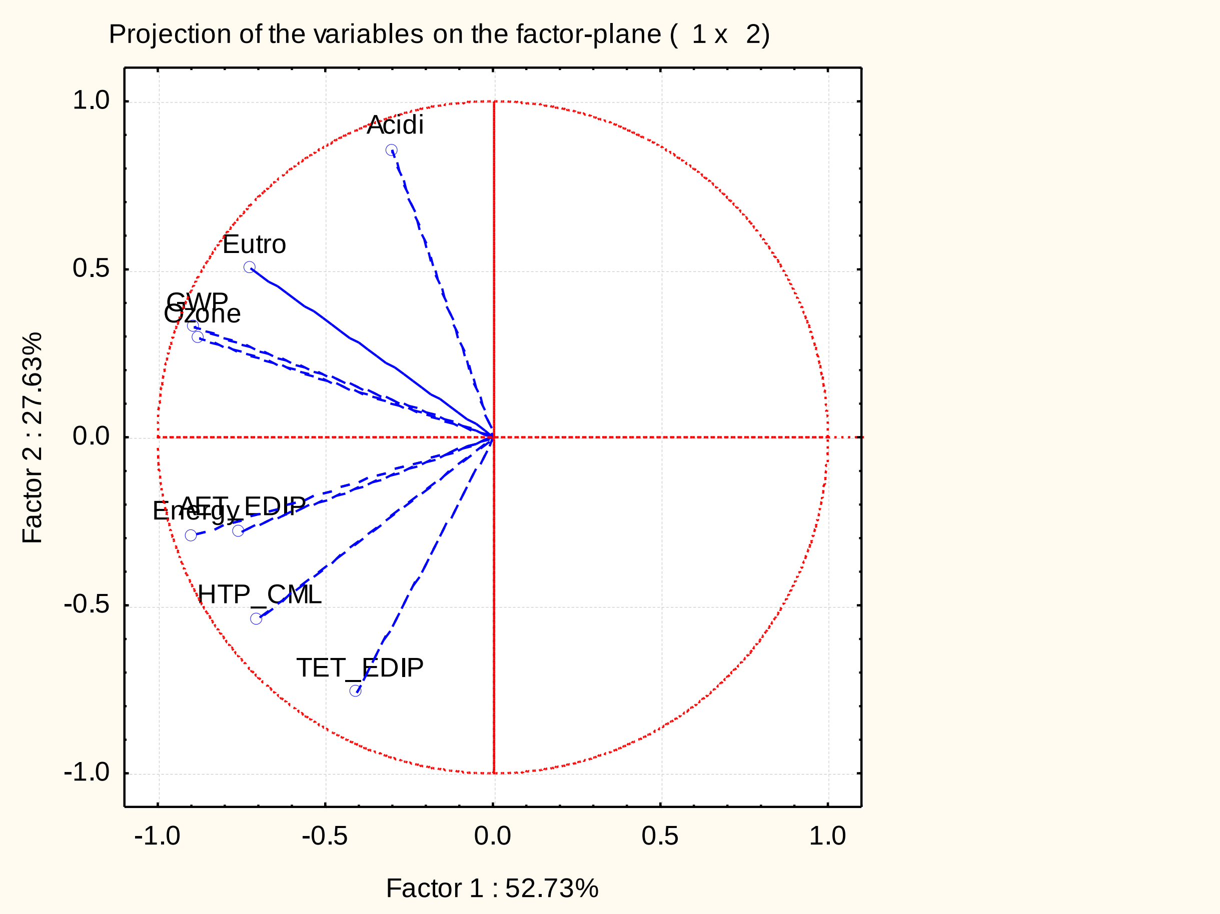
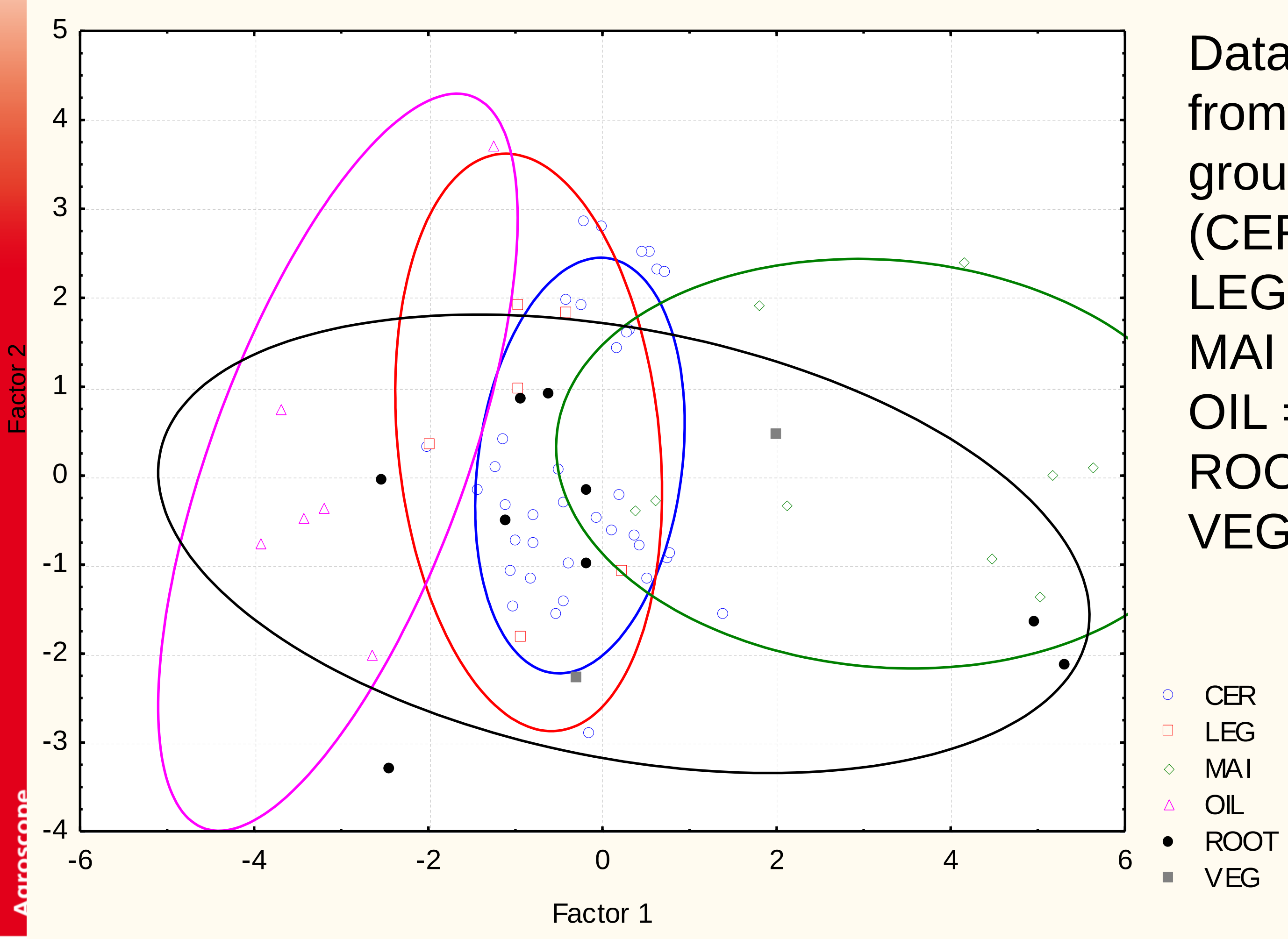
Principal component analysis of SALCA inventories



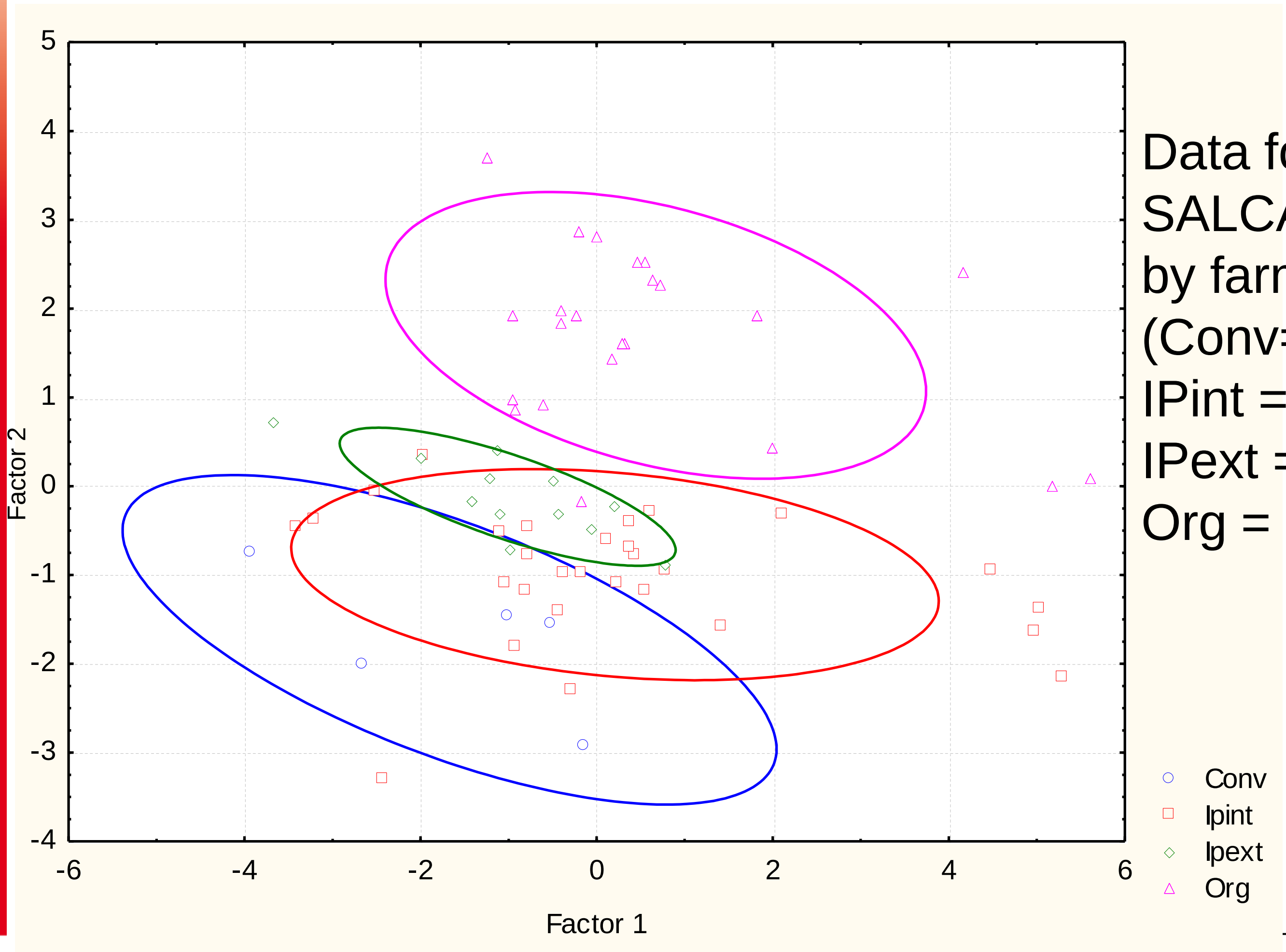
Relationship between impact indicators and factors 1 and 2

Factor 1:
- can group crops
- related to the yield



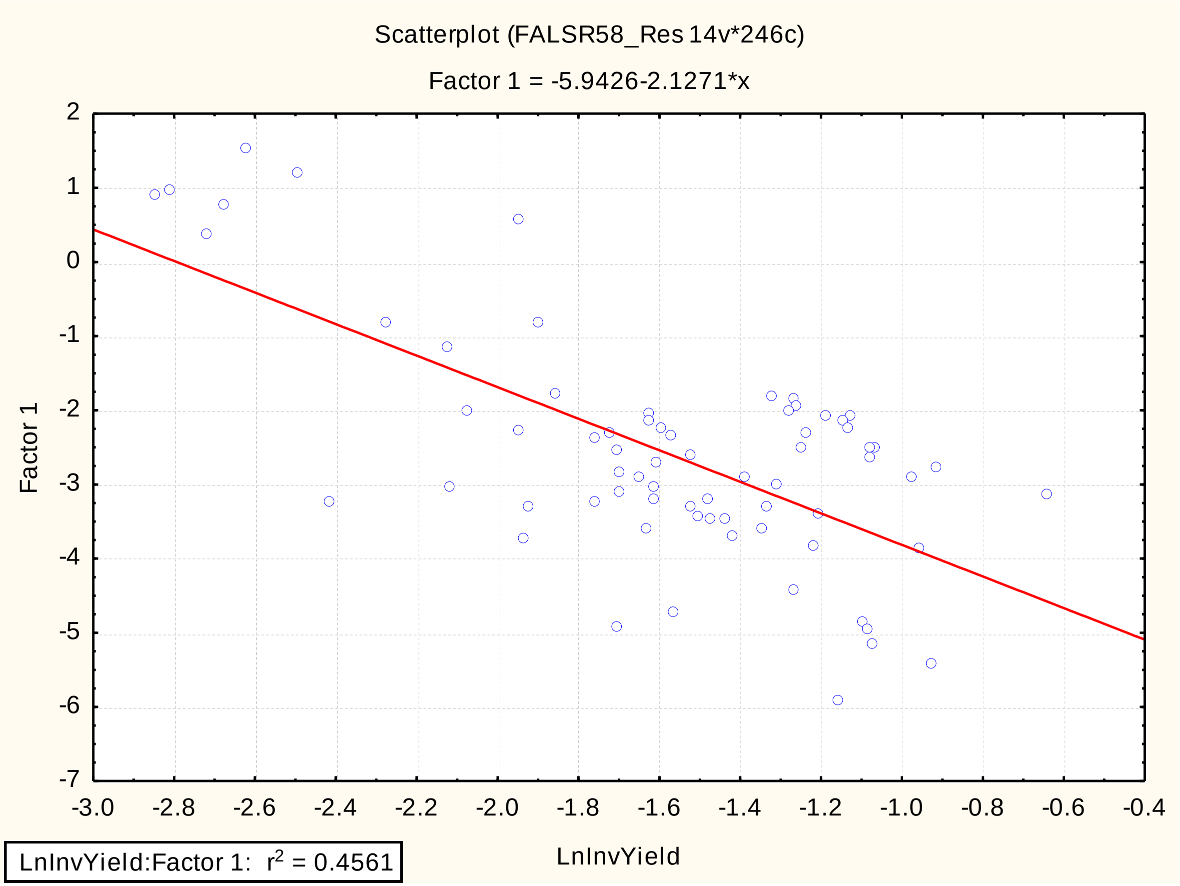
Data for Swiss crops from SALCA database: grouping by crop group (CER = cereals, LEG = legumes, MAI = maize, OIL = oil crops, ROOT = root crops, VEG = vegetables).

Factor 2:
- related to the farming system and the intensity



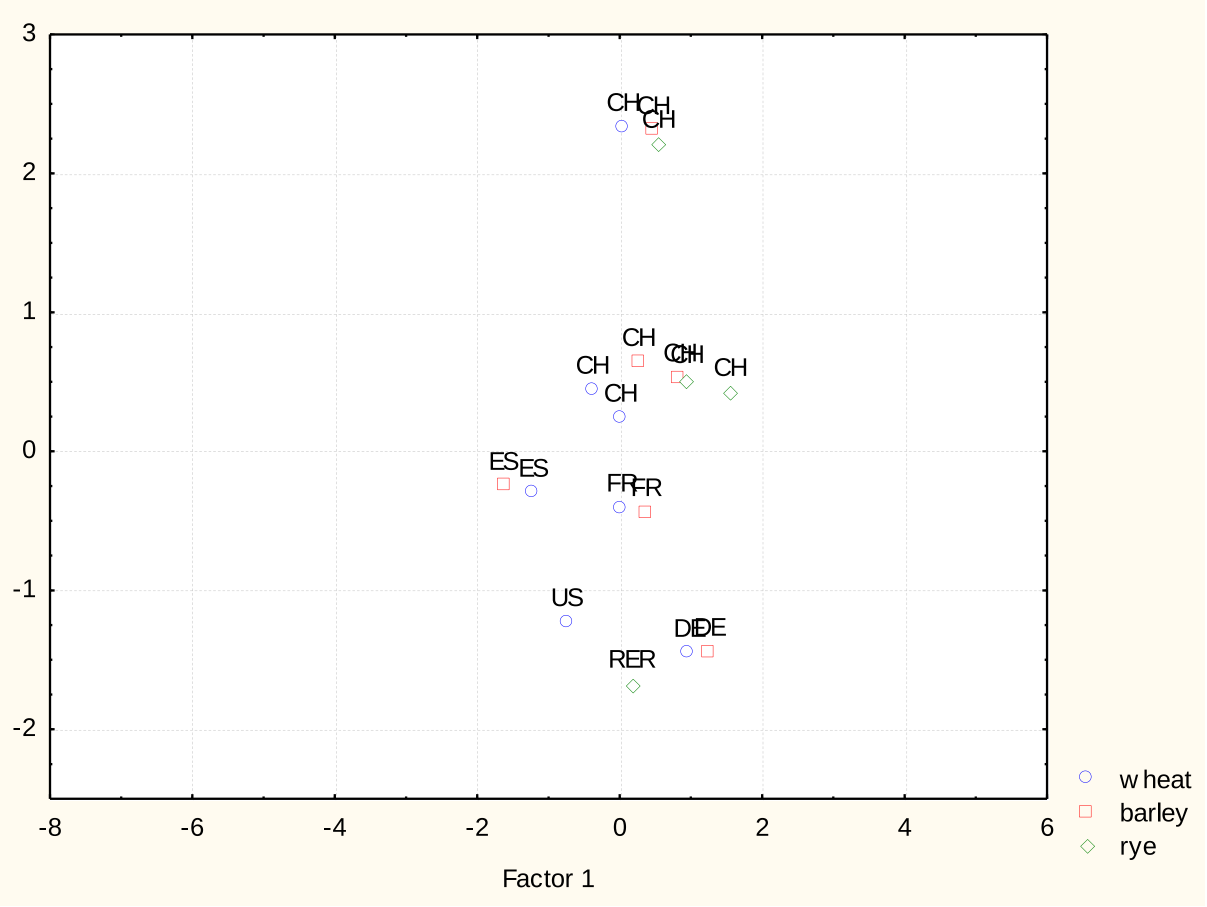
Data for Swiss crops from SALCA database: grouping by farming system (Conv=conventional, IPint = integrated intensive, IPext = integrated extensive, Org = organic).

Principal component analysis of SALCA inventories



Yield is a key factor

Principal component analysis of ecoinvent inventories



Cereals in different countries

Potential use of multivariate statistics in LCA to explain variability

- Between 76 and 80% of the variability could be explained by the first two principal components.
- Factor 1 → crop (group) and yield
- Factor 2 → farming system (conventional, integrated, extensive, organic)
- More data are needed for more systematic analyses

- The analysis helps to
  - show similarities and differences between environmental profiles
  - to find suitable proxies
  - to derive simplified methods for extrapolations and approximations

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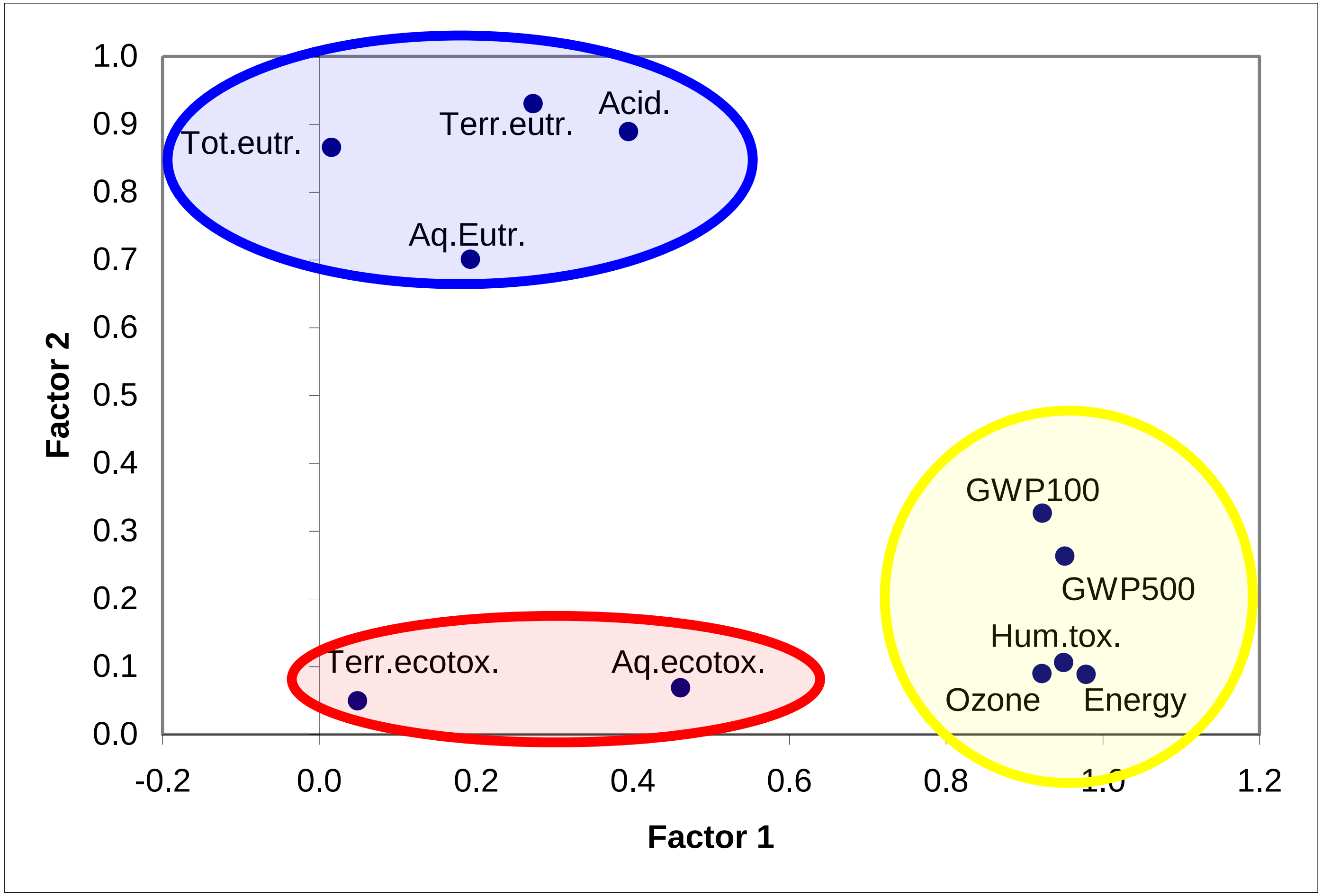
Methodology example 1: Factor analysis Milk production in 35 farms



Source: Rossier & Gaillard (2001)

Methodology example 2: Principal component analysis (PCA)

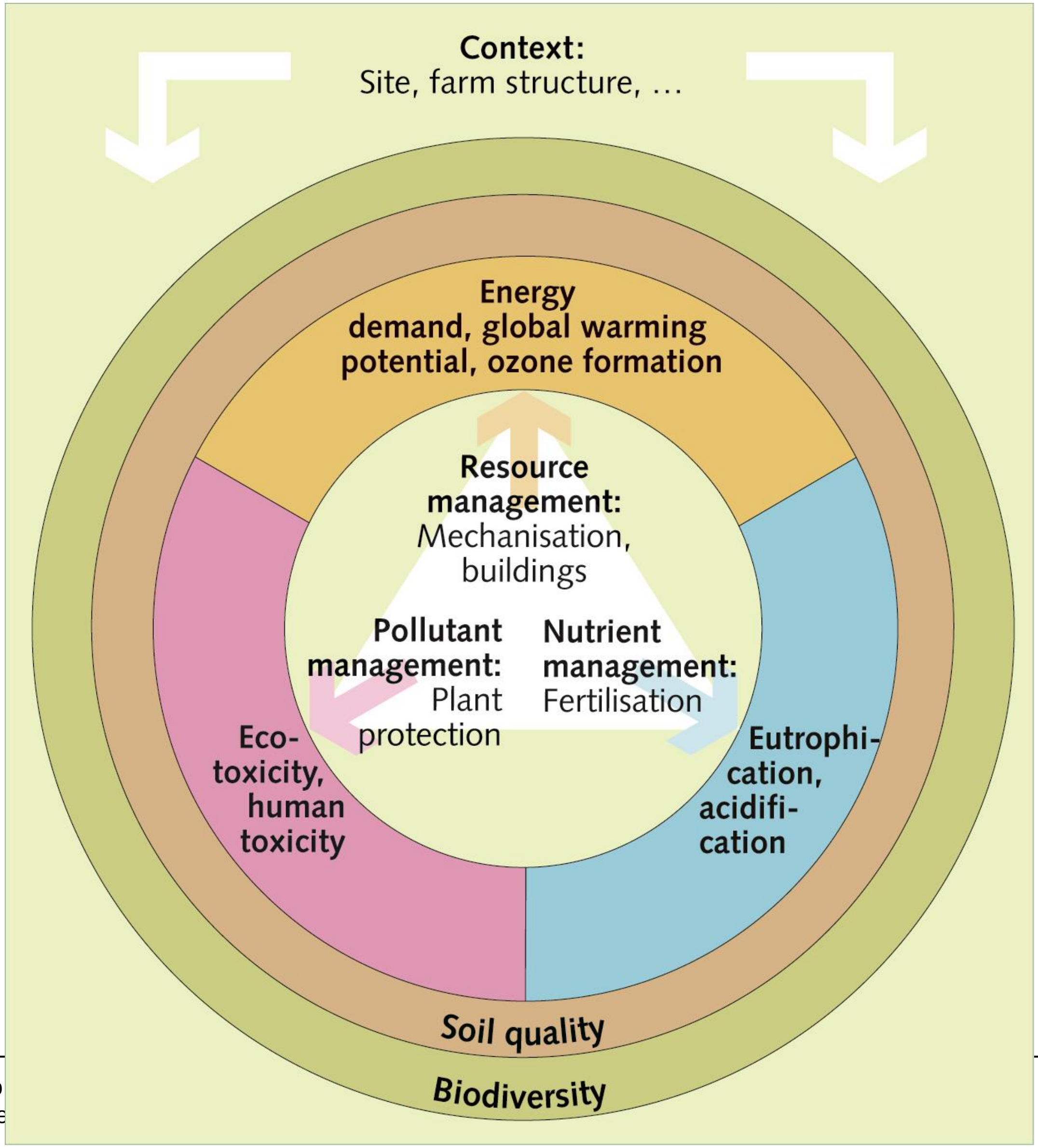
445 apple orchards, Switzerland, 1997-2000

No.	Impact categories	Component 1	Component 2	Component 3
1	Energy use (GJ eq. ha^{-1})	**0.95**	-0.03	0.06
2	Global warming potential for 100 years (t CO_2 eq. ha^{-1})	**0.95**	-0.01	0.20
3	Ozone formation (kg C_2H_4 eq. ha^{-1})	**0.94**	-0.04	-0.01
4	Aquatic ecotoxicity (kg Zn eq. ha^{-1})	0.00	**0.93**	0.07
5	Terrestrial ecotoxicity (kg Zn eq. ha^{-1})	0.07	**0.93**	0.00
6	Aquatic eutrophication (kg PO_4 eq. ha^{-1})	0.19	0.05	**0.98**
7	Terrestrial eutrophication (kg PO_4 eq. ha^{-1})	**0.90**	0.13	0.16
8	Acidification (kg SO_2 eq. ha^{-1})	**0.94**	0.13	0.16
	Total variance explained			
	Initial eigenvalues	4.58	1.76	0.89
	Variance explained (% of variance)	57.19	22.00	11.17

N = 445; loadings exceeding 0.8 are in bold print.

Source: Mouron *et al*. (2006)

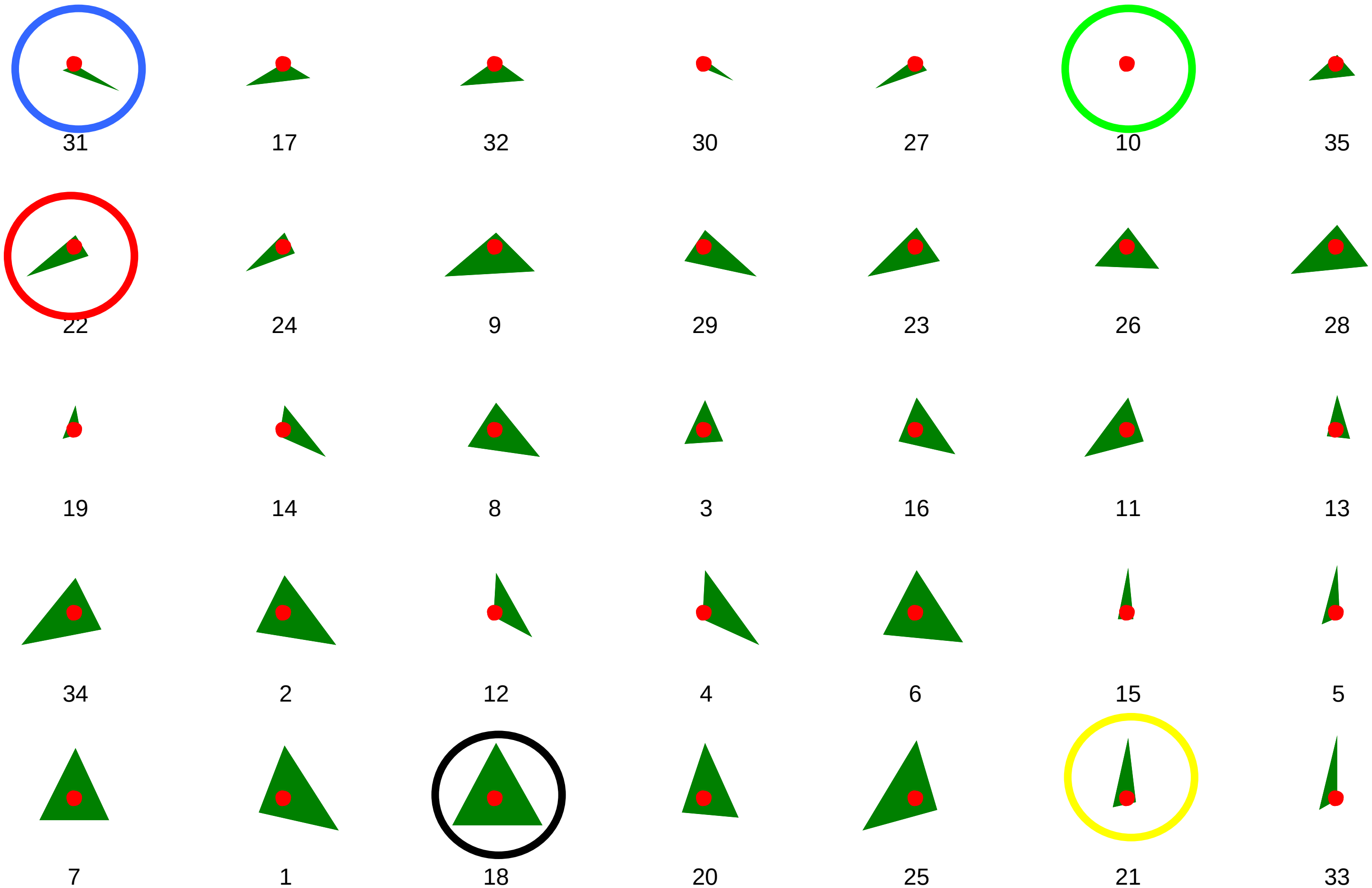
Result: The Management triangle

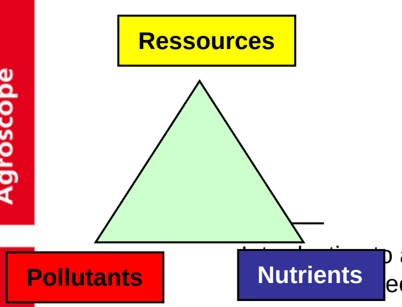


Application of the management triangle to the environmental management of farms

Example for 35 milk producers, impacts per kg milk

Small area = favourable for the environment



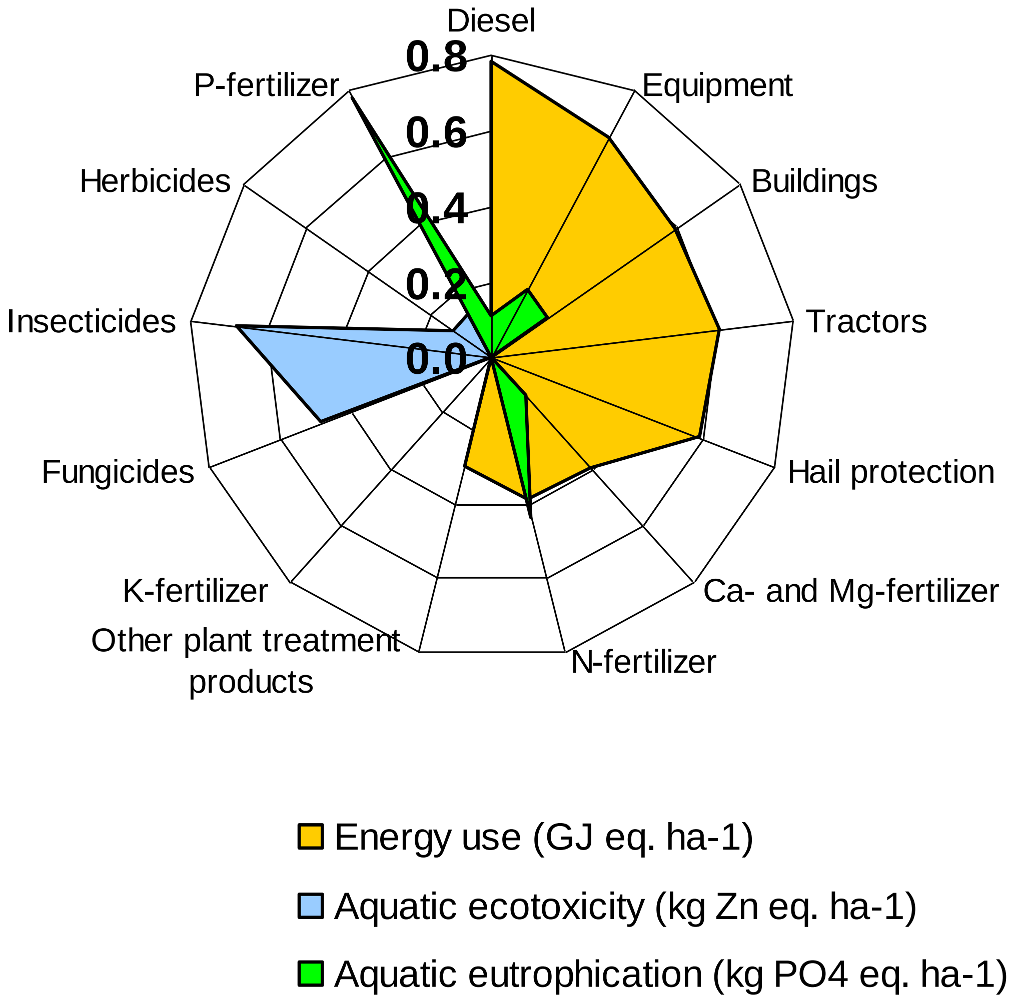


Source: Rossier D. & Gaillard G., 2001. Bilan écologique de l'exploitation agricole: Méthode et application à 50 entre-prises. Rapport SRVA et FAL, 105 pp. et annexes.

Environmental management of apple orchards

Input-impact-map: correlations between selected impacts and input groups

445 apple orchards, Switzerland, 1997-2000; Pearson correlation (r)



Energy demand correlated to 8 of 13 inputs.

Aq. ecotox. determined by insecticides (0.7) and fungicides (0.5).

Aq. eutrophication depends on P-fertiliser (0.8) and N-fertiliser (0.4).

Source: Mouron *et al*. (2006)

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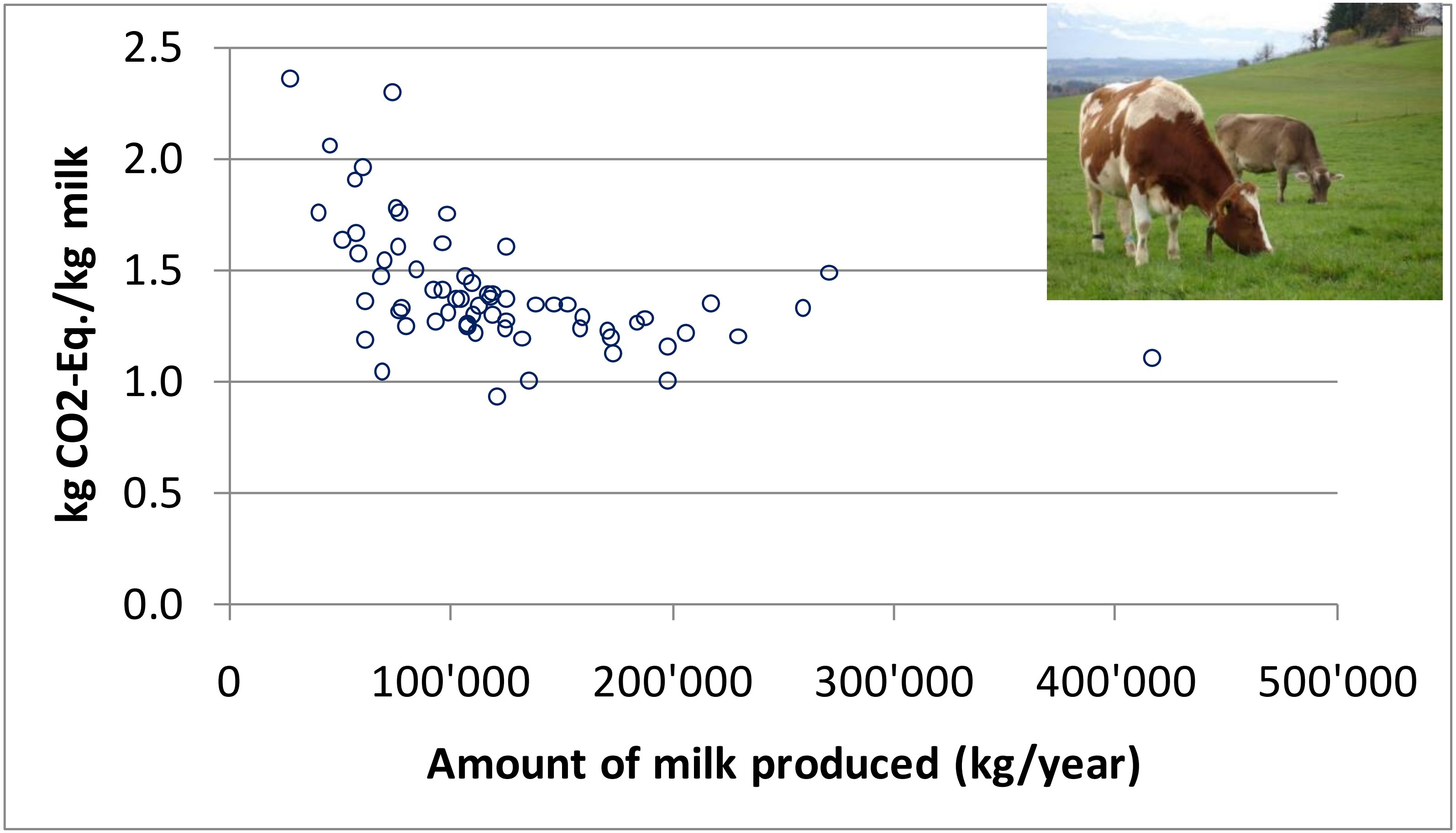
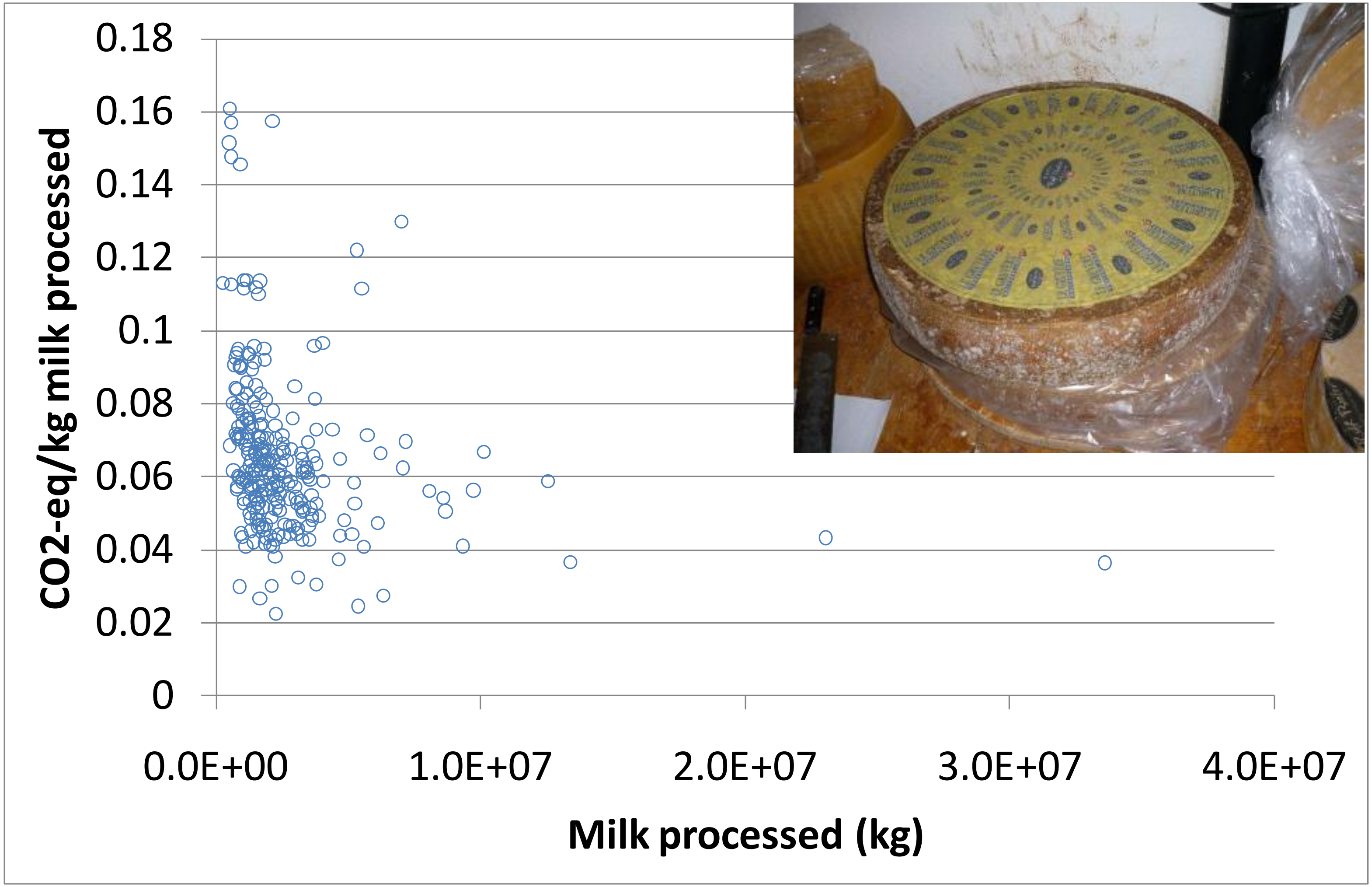
Conclusions multivariate analysis

- Midpoint impact indicators can be grouped by multivariate statistical methods
- Three dimensions were derived for farming systems:
  - Resource management
  - Nutrient management
  - Pollutant management
- Related to
  - Different environmental impacts
  - Different management options
  - Different time scales
- Enables improved management and communication

Global warming potential of dairy farms and amount of milk produced



GWP of milk processed in dairies



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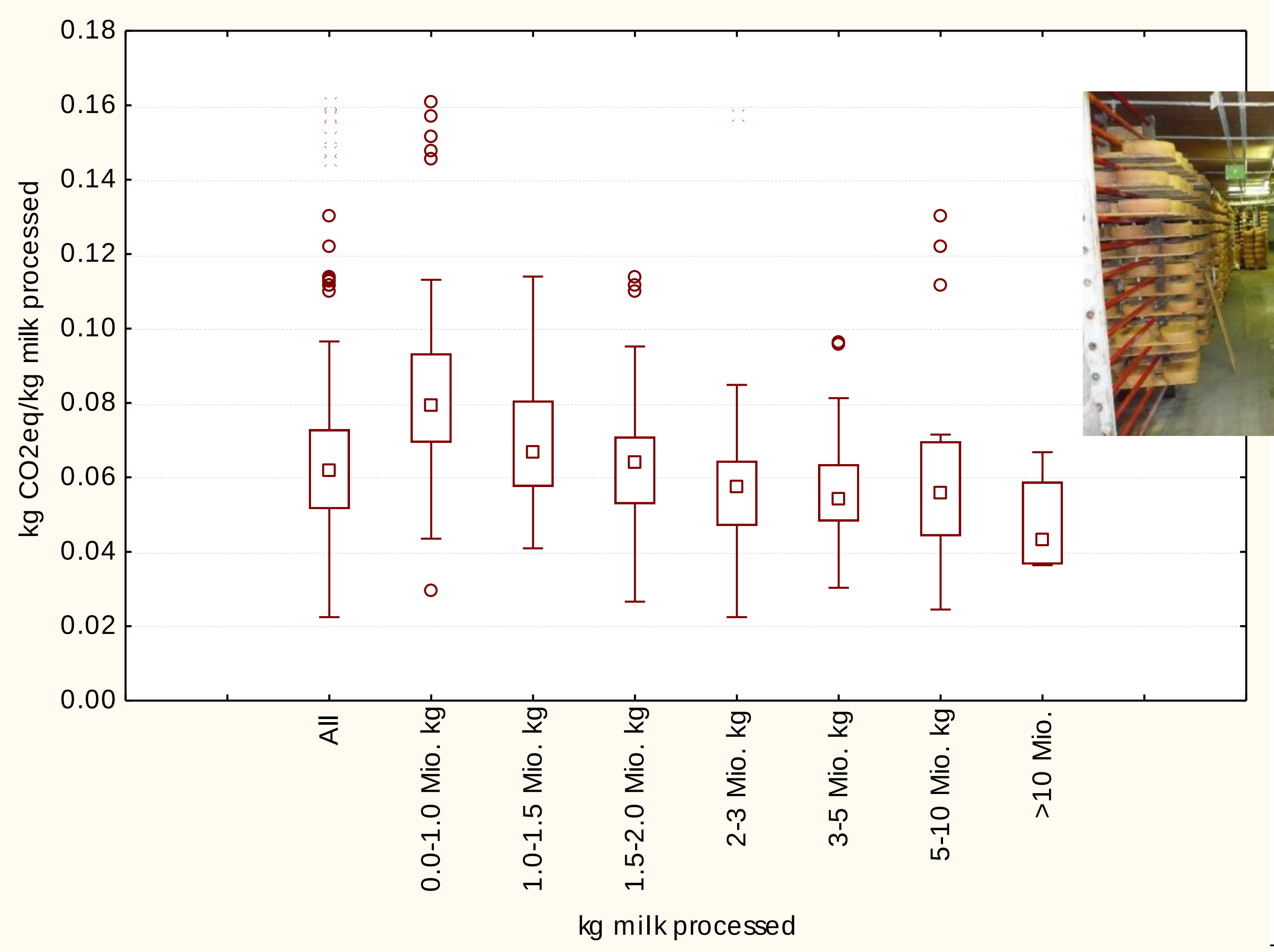
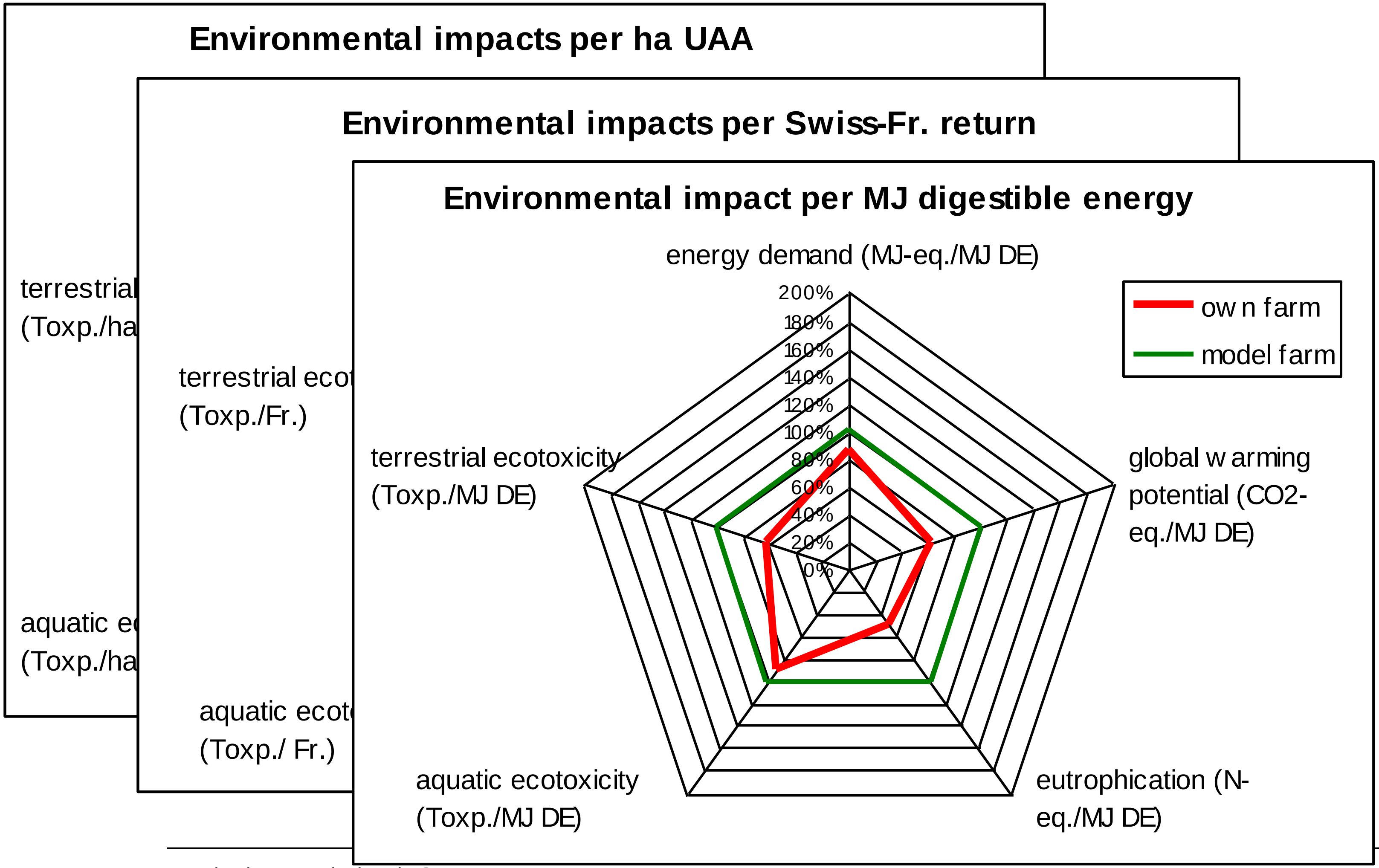
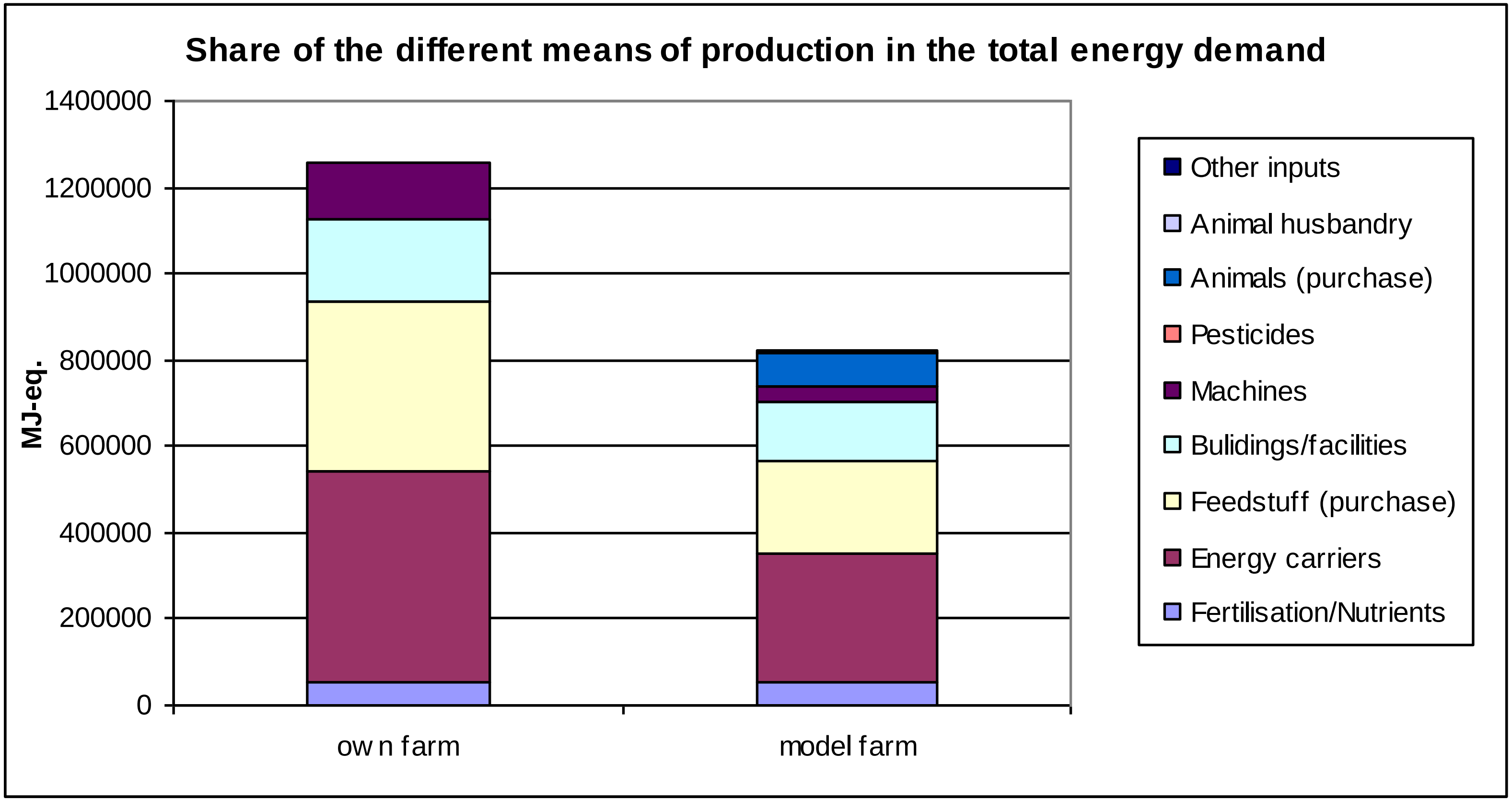
GWP and dairy size



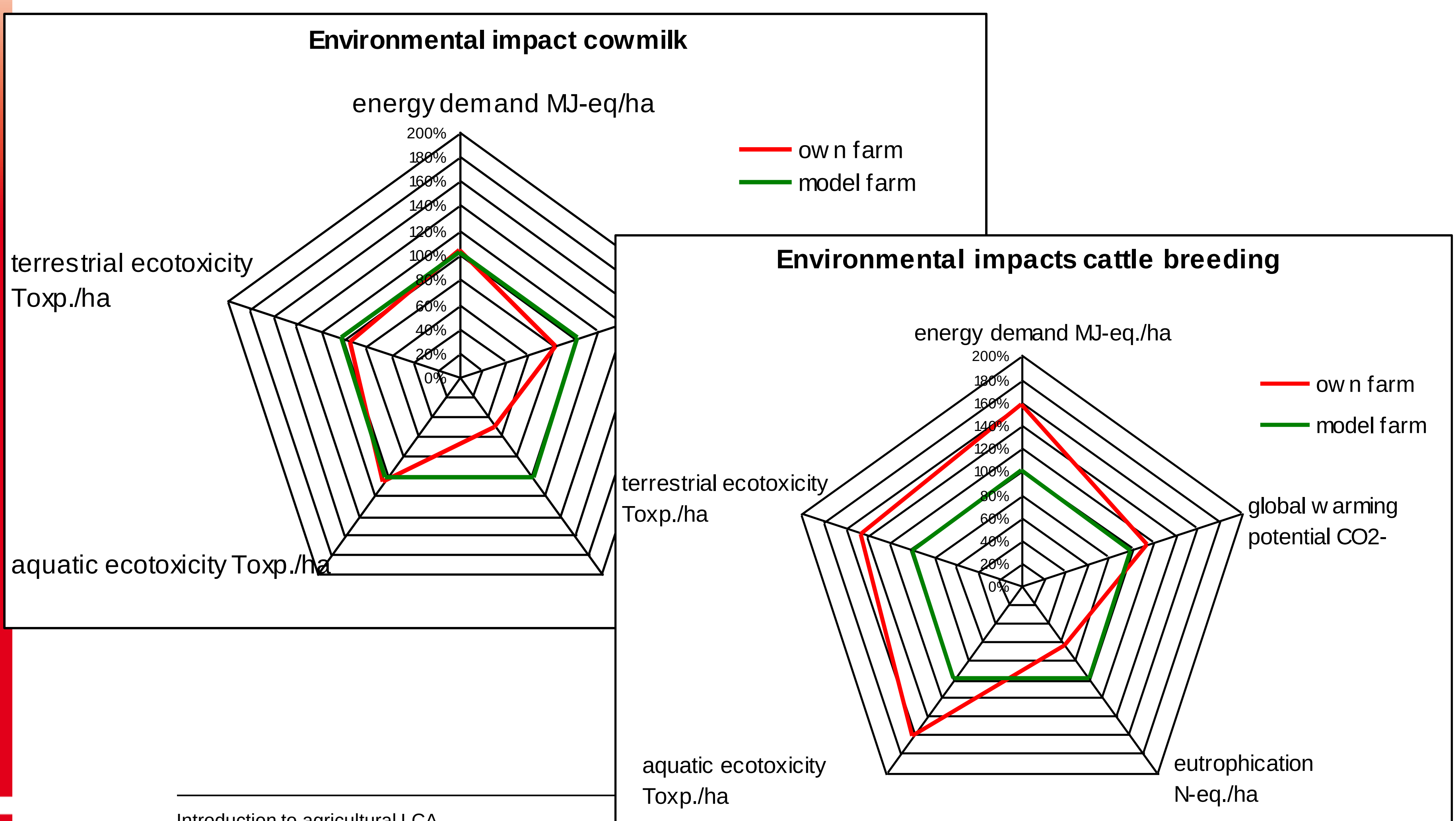
Communication of results to farmers
Overview of environmental impacts



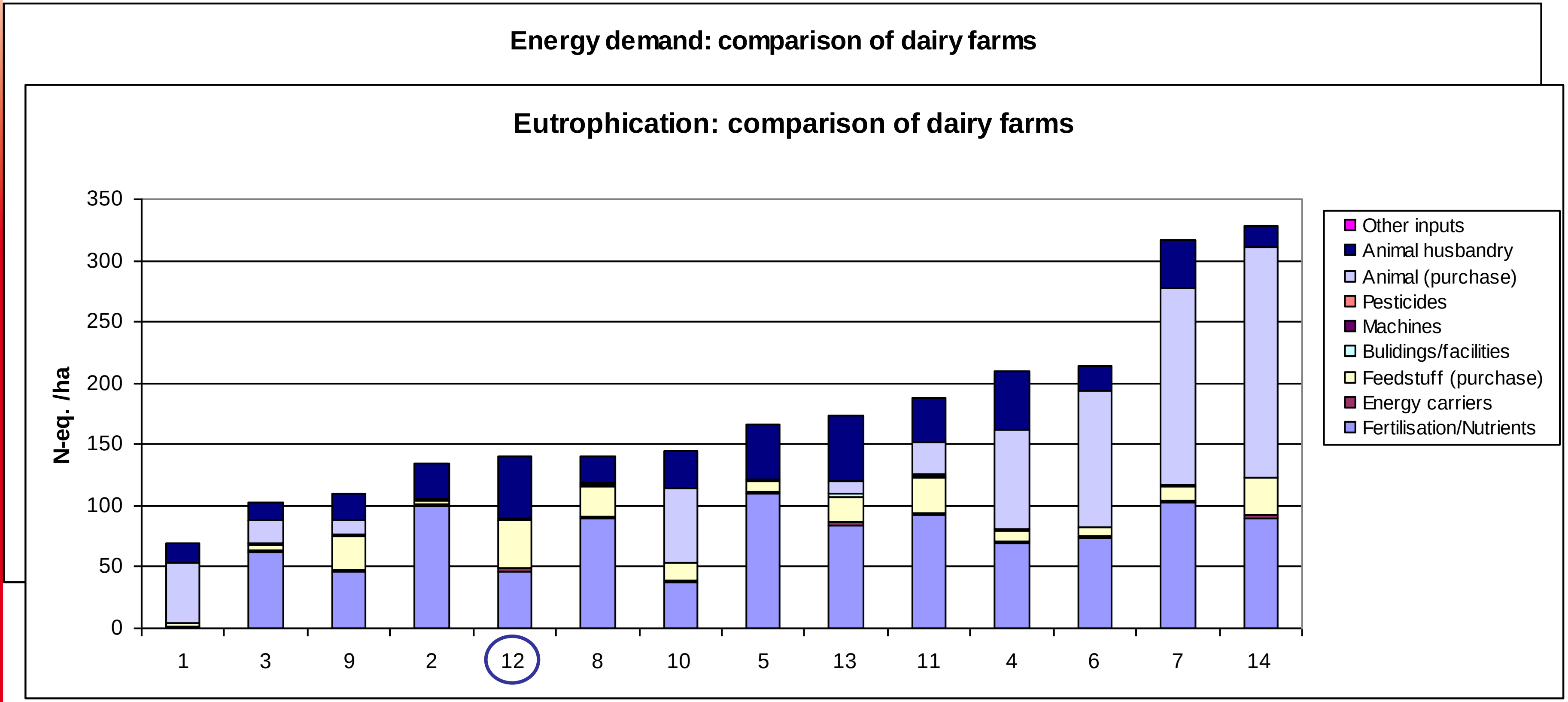
Communication of results to farmers Detailed environmental impacts



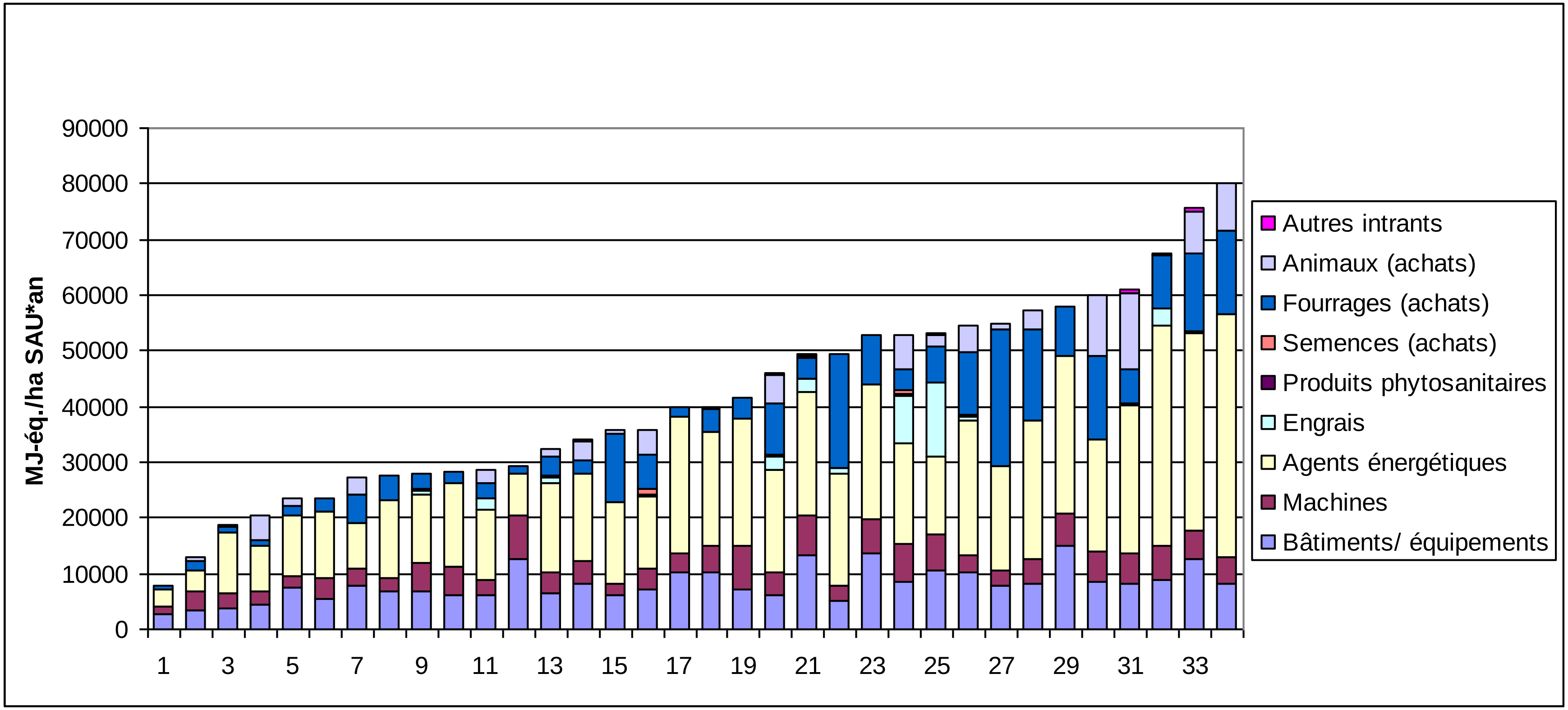
Communication of results to farmers
Environmental impacts by product group



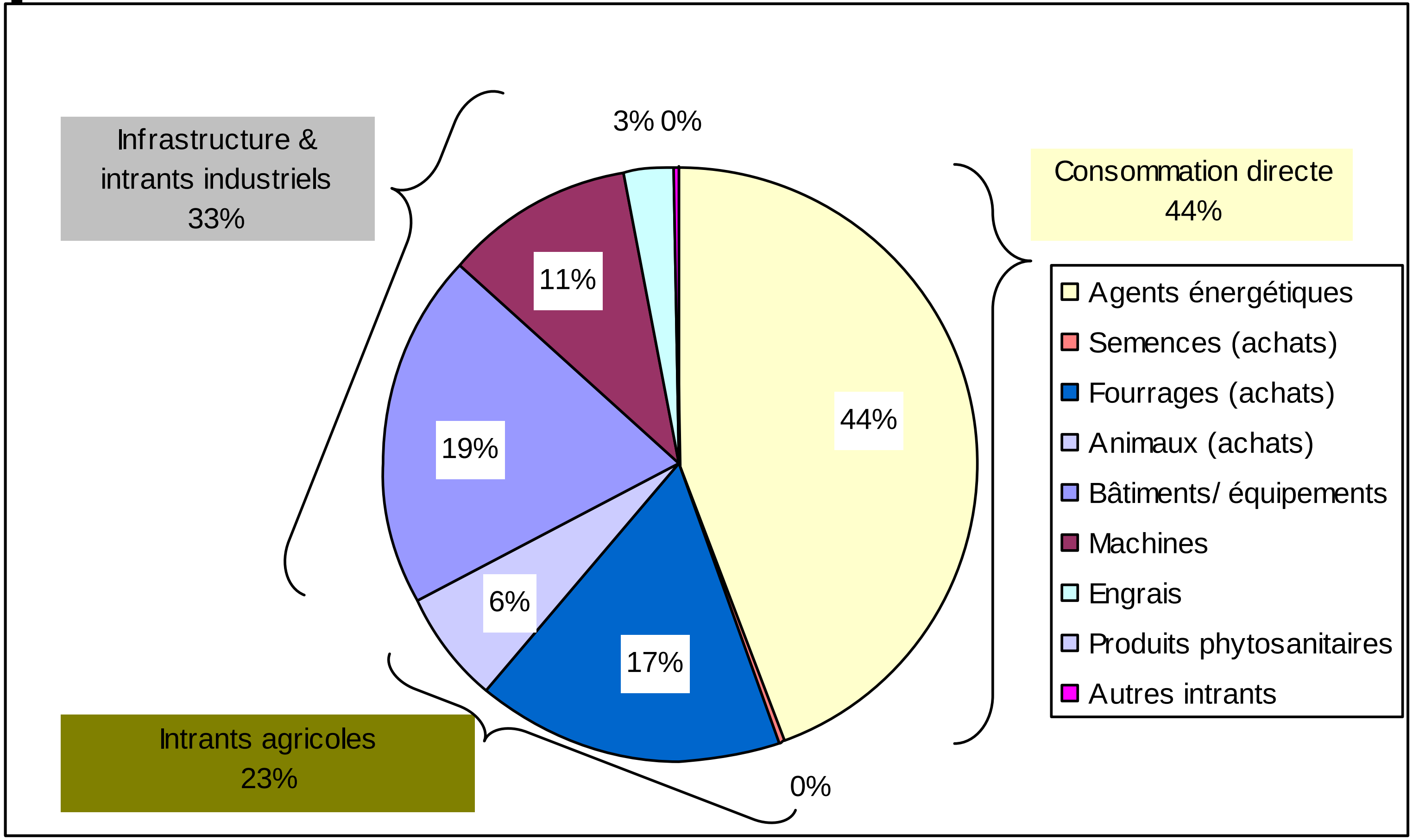
Communication of results to farmers
Comparison to similar farms



Milk production
Energy demand of specialised milk production farms



Milk production
Energy demand of specialised milk production farms



Conclusions

- The environmental impacts of agriculture and the food sector are considerable
- Agriculture has a number of specific aspects that need to be considered
- LCA provides good insights into the behaviour of the systems
- For this a close collaboration between agronomists, environmental scientists and local experts is required

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