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Introduction to Life Cycle Assessment, LCA

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IRCADA – USYS TdLab – IfU-ESD workshop

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Amman, Jordan

Outline

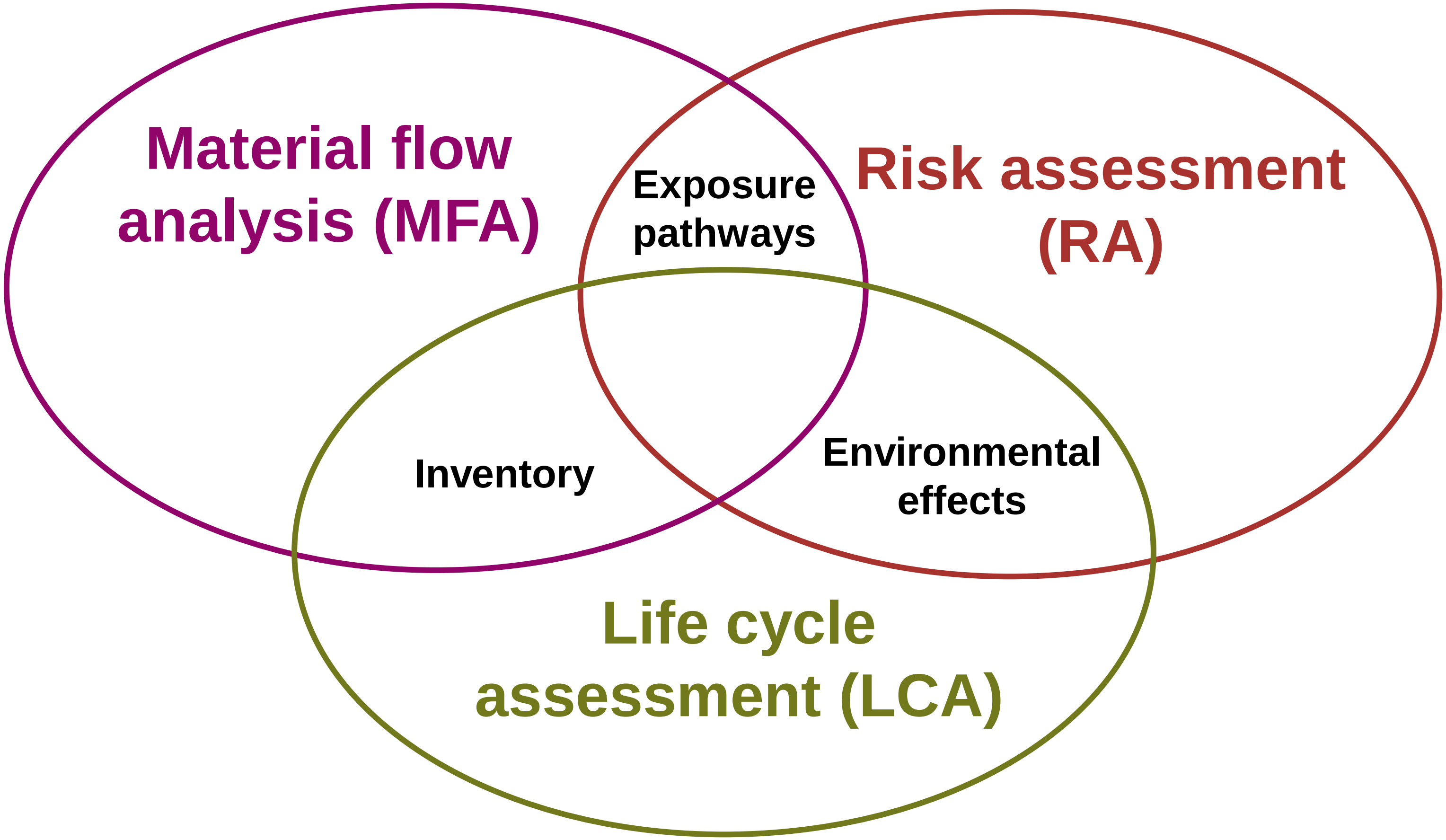
- Introduction
  - Environmental assessment
  - Overview Life Cycle Assessment (LCA)
- LCA
  - Goal and scope deifnition
    - Functional unit
    - System boundaries
  - Inventory (LCI)
    - Accounting principles
    - Inventory analysis
  - Impact assessment (LCIA)
  - Interpretation of results

Learning goals

To get a first overview of…

- What (the purpose of) LCA is
- How a LCA is performed
- How to identify critical aspects in the supply chain
- How to interpret and critically assess a LCA study

Environmental assessment tools / approaches

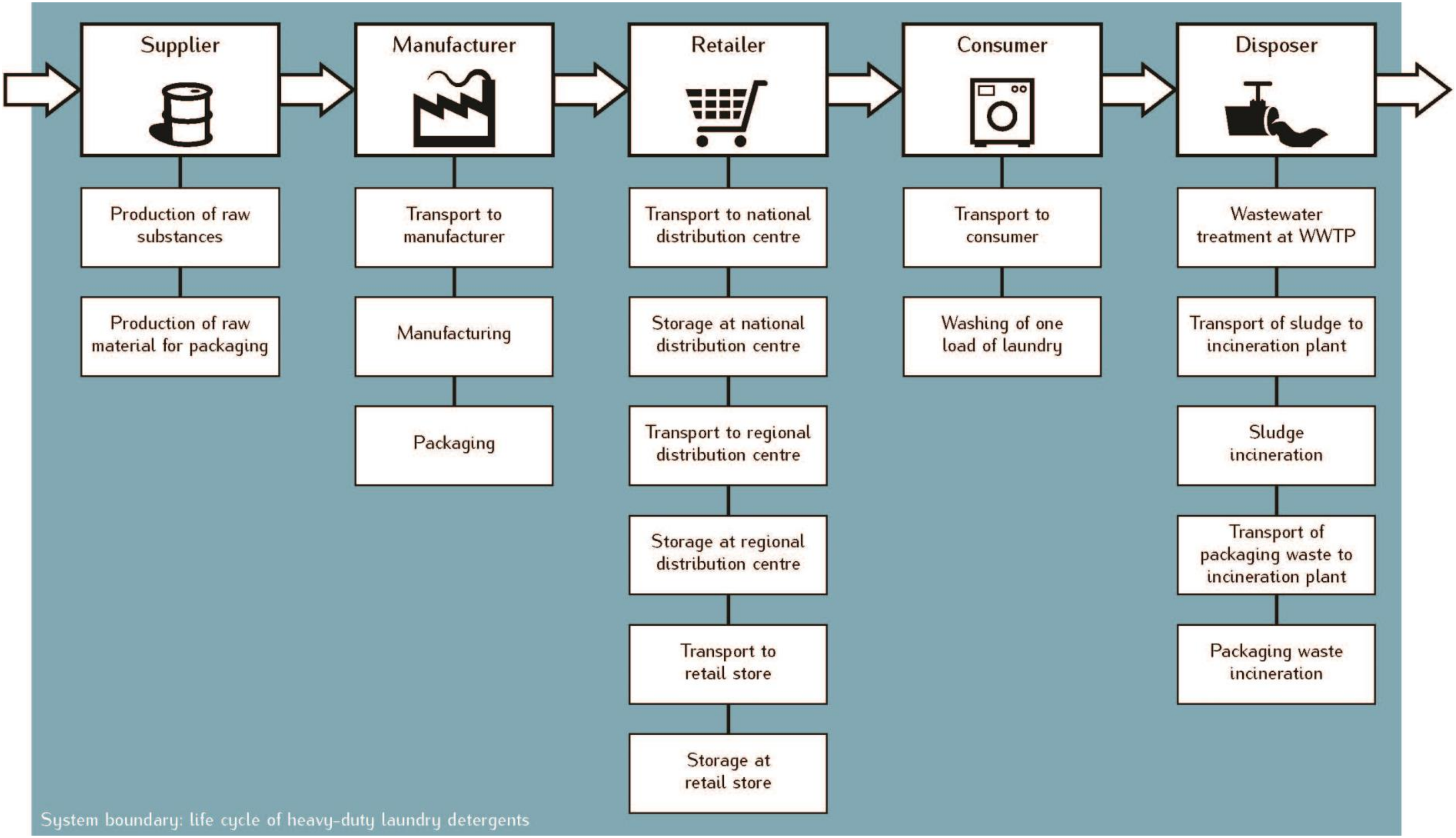


➡ **Approaches are complementary**

LCA is a systematic method for analyzing environmental impacts of products, processes, and services over their entire life cycles

Picture source: Science 344, p. 1109-1112

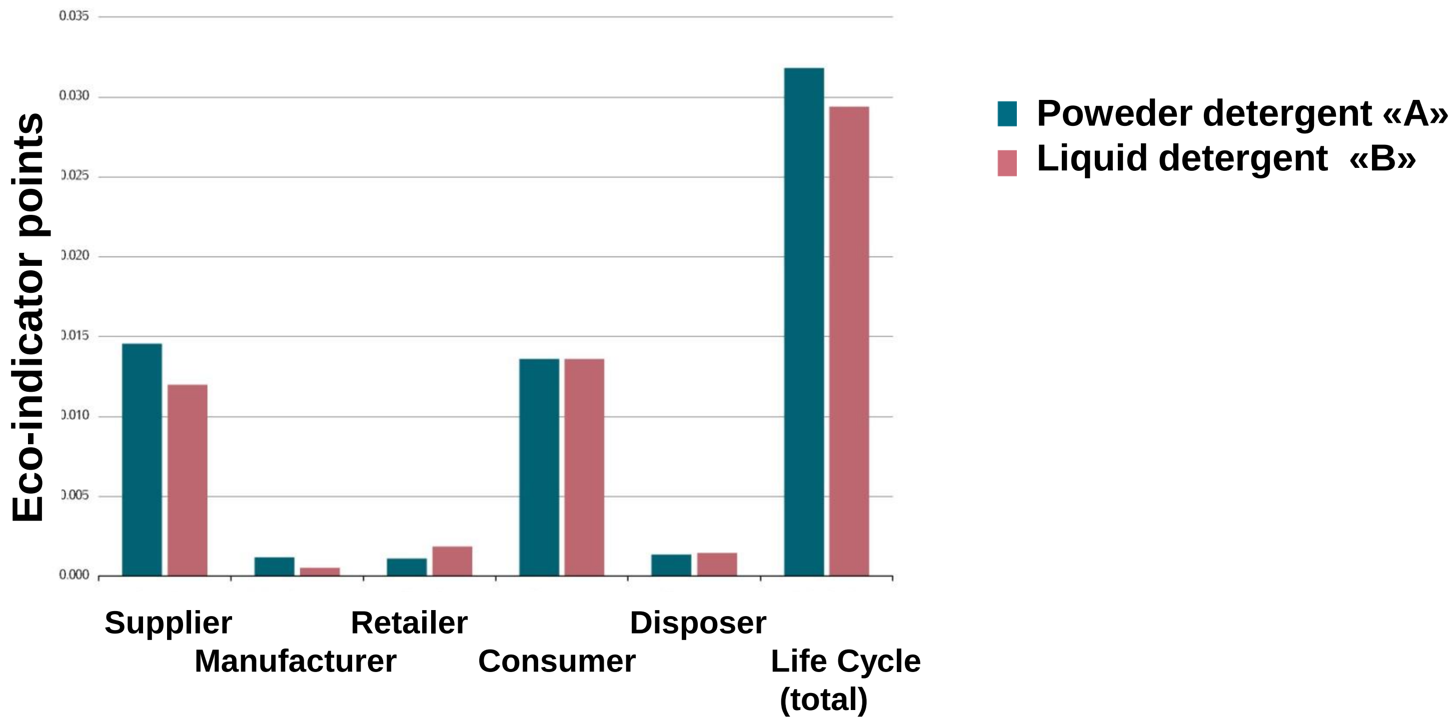
Example LCA of detergent (for washing machine)



Results – detergent example

Typical question in LCA study:

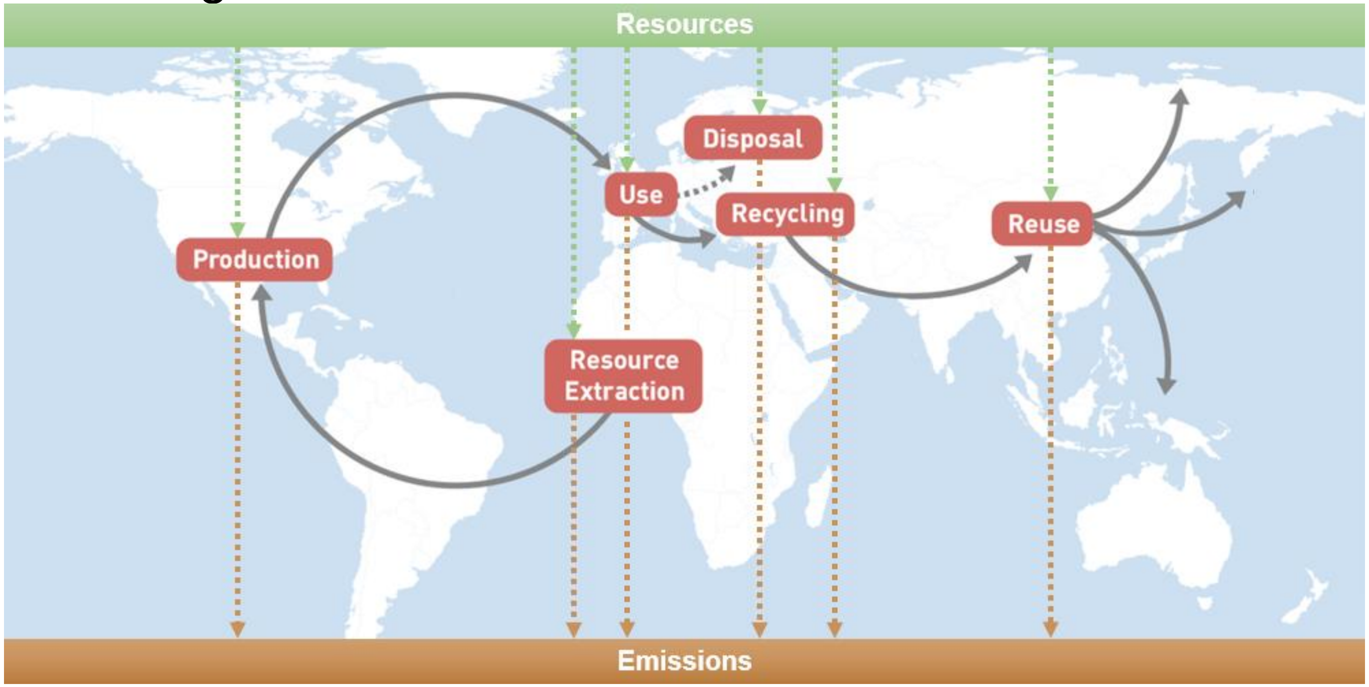
- Which alternative has the lowest overall envrionmental impacts?



Which product is the better choice?

Global value chains

- International value chains increase in complexity and have global environmental impacts
- LCA aims to track these impacts and assess them from a systems perspective
- The goal is to identify decisions or strategies for improvement without burden shifting



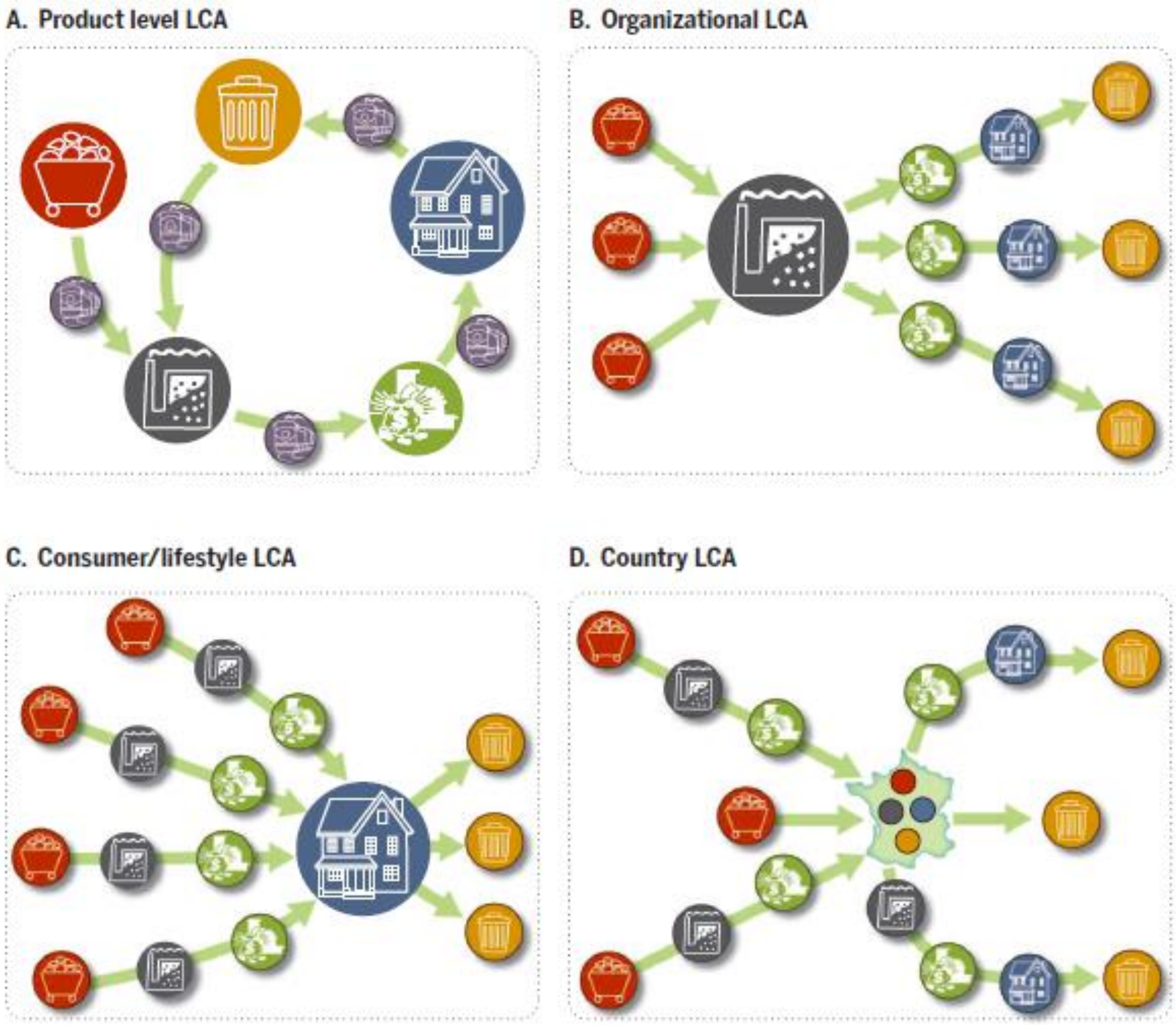
Purposes for LCA

a) To find improvement potential within life cycle of a product (not just production)
→ Product design / process analysis

b) Comparison of different options with the same functionality (same service)
→ Support decisions (ecolabels, 'green marketing')

c) Comparison of scenarios (in combination with Input output-analysis)
→ Political policies and decisions

Applications of LCA *(Hellweg & Milà i Canals 2014)*



Picture source: Science 344, p. 1109-1112

No or limited use of LCA for…

a) Assessment of disasters / accidents

b) Evaluation of best location for facilities
-> environmental impact assessment *(in German: UVP)*

c) Environmental management practices of companies
-> ISO 14001 norms

International standard on LCA – ISO 14044:2006

- Guidance on **procedure**:
  - Goal and scope definition
  - Inventory analysis
  - Impact assessment
  - Interpretation

- No specific method, tool or data basis prescribed

1. Definition of goal and scope
- What is the purpose of the LCA?
- Who is the intended audience?
- What are the systems under study and what are their functions?
- What are the underlying assumptions / limitations?

2. Inventory analysis
- What are the relevant emissions and resources the system(s) produce or consume?
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3. Impact assessment
- Which impact categories are considered and which models are used?
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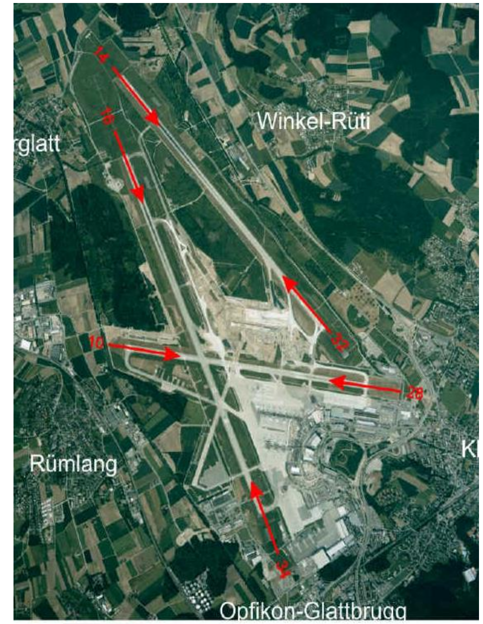
4. Interpretation
- What are the conclusions?
- How reliable and sensitive are the results?
- What are the re-commendations?

ISO 14044:2006

Goal & scope: main points (I)

- Purpose of study
  - For comparison, ecodesign, internal or external communication, marketing claims, ecolabelling, *etc.*
- Define «functional unit» of study:
  - What is the function of the system / service to the consumer?
  - Example: packing 1 liter of milk

Example: Functional unit of air transport, e.g. 1‘000 person-km transport



1‘000 pkm Transport

Source: Frischknecht, Handouts in Umweltverträgliche Technologien

Goal & scope: main points (II)

- Draw system boundaries
  - What environmental aspects are included
  - Which processes are excluded -> why?
- Define time, geographical and technological coverage
  - For what situation is the study valid?
- Critical review and other procedural aspects
  - Critical review by independent expert or panel of interested parties required for LCA studies «*where the results are intended to be used to support a comparative assertion intended to be disclosed to the public*» (ISO 14044:2006)

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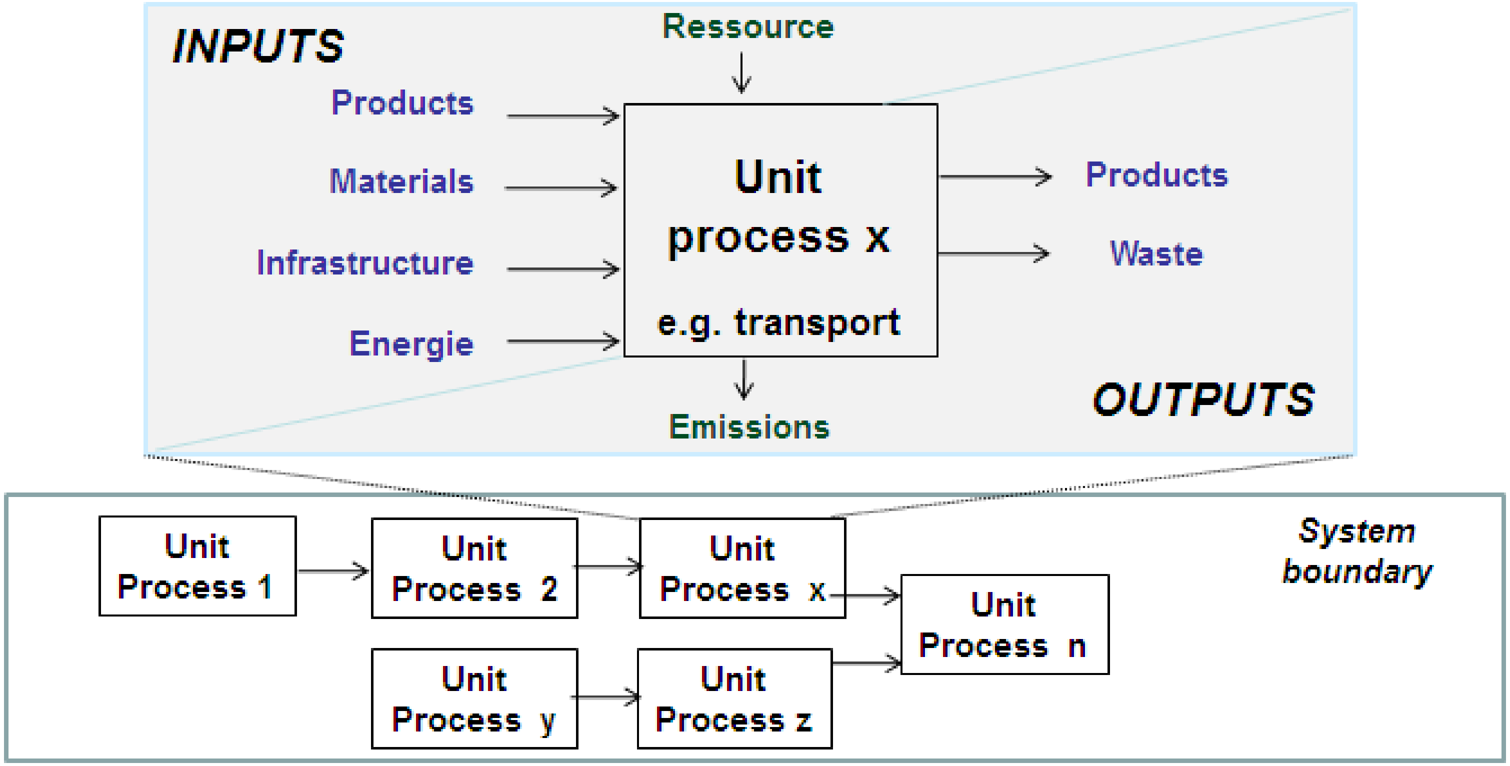
Life cycle inventory (LCI) analyis

Data collection of environmentally-relevant flows for unit processes (parts of the life cycle);

→Unit processes within flowchart



Inventory analyis – required data

- Unit processes
- Materials
- Energy use
- Consumables
- Transports
- Information on product use
- Waste disposal

Exchanges within technosphere (products / services of other processes)
-> **technosphere flows**

- Resource uses
- Emissions

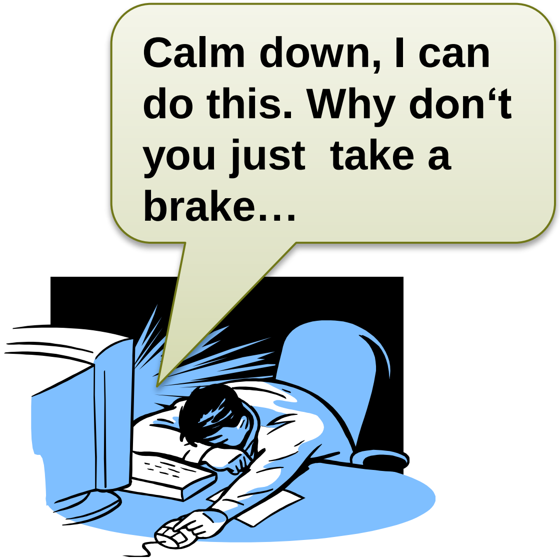
Exchanges with the environment
(environmental flows)

Handling data gaps

- Specific data should be collected for primary processes (foreground system) and high quality representative data for others (background system, e.g. electricity generation)
- If no data can be found, conservative estimates should be used!
  - If relevant in assessment: improve data (iterative process)

Inventory database developments

Inventory databases contain inventory data on a large number of basic processes, e.g. electricity generation or production of steel, cement, chemicals, etc. etc., thereby greatly facilitating LCA studies



ecoinvent

AusLCI The Australian Life Cycle Inventory Database Initiative

European Platform on LCA

JEMAI

…

Life cycle impact assessment (LCIA)

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From LCI to LCIA

Inventory Analysis

Emission/ Resource	Unit	Compar- tement	Amount per funct. unit
CO_2	kg	Air	0.5
CH_4	kg	Air	1.5
SO_x	kg	Air	1.0
NO_x	kg	Air	0.5
Cd^{2+}	kg	Water	0.0001
Fe	kg	Soil	0.5
...			

Life Cycle Impact Assessment

Global Warming

Emission	*Characteri- zation factor*	*Ref.unit CO_2-eq.*
CO_2	1	0.5
CH_4	28	42
Sum		42.5

Acidification		*SO_x-eq.*
SO_x	1	1
NO_x	0.7	0.35
Sum		1.35

Human toxicity		*1,4-Dichlor- benzol-eq.*
NO_x	1.4	0.7
Cd^{2+}	23	0.0023
Sum		0.7023

LCIA framework

Environmental interventions	Impact categories	Damage categories	
LCI results	**Midpoints**	**Endpoints**	*Areas of Protection*

LCI results

- Emissions (air, water and soil)
- Resource extraction

Midpoints

- Climate change
- Ozone depletion
- Photochemical ozone creation
- Human toxic effects
- *Ecotoxic effects*
- *Eutrophication*
- *Acidification*
- *Land stress*
- *Water stress*
- Resource depletion

Endpoints

Human Health

Ecosystem Quality

Resource Depletion

Impact category 'climate change' = carbon footprint

Characterization factors (CF) based on IPCC 2013 factors; 3 time horizons

Greenhouse gas (GHG)	**Global warming potential (GWP) 20 years** [kg CO_2-eq]	**Global warming potential (GWP) 100 years** [kg CO_2-eq.]	**Global warming potential (GWP) 500 years** [kg CO_2-eq.]
Carbon dioxide (CO_2)	1	1	1
Methane (CH_4)	62	28	8
Nitrious oxide (N_2O)	264	265	131
Sulfur hexafluoride (SF_6)	17'500	23'507	31'510
HFC-134a	3'710	1'301	371

100 years is typically recommended

Standard elements of impact assessment

Mandatory elements

Selection impact categories and LCIA methods (characterization models)

↓

Classification (grouping emissions/resource use in impact categories)

↓

Characterization (quantification of environmental impacts)

↓

Results of impact categories -> interpretation or:

↓

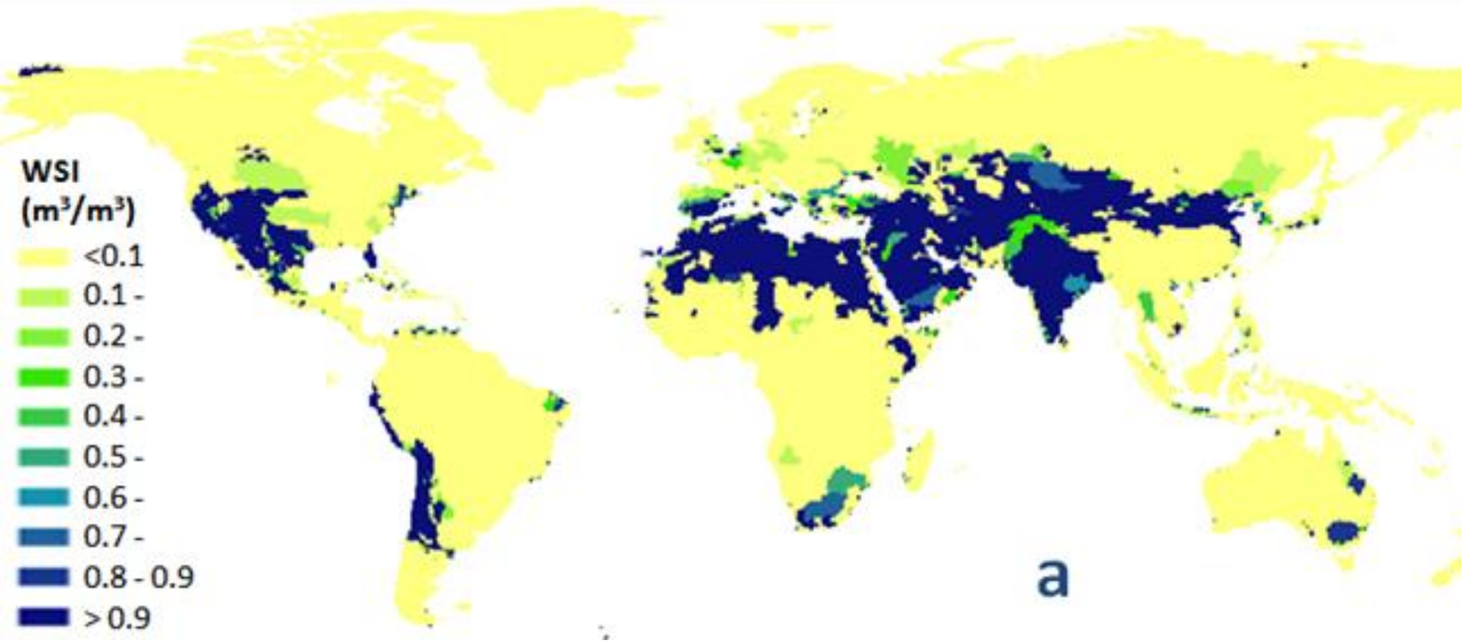
Optional elements
Normalization, Grouping, Weighting

Source: ISO 14044:2006

Regional aspects in LCA

- Regionalization relevant in, for example, land use/water consumption and biodiversity
- Not implemented in standard LCA softwares
  - Data in google earth available from www.esdmaps.ethz.ch/

e.g. Midpoint indicator: Water Stress Index (WSI)



→ **takes into account water availability, use, and variation in precipitation**

Pfister et al. 2009

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The LCA methodology – an iterative process

- Results should be used to refine the model concerning relevant processes and emissions
- Analyze the contribution of processes and emissions
- Understand the underlying reasons for the results
  - Is it realistic or maybe an artefact?
  - Is it robust?

Uncertainties

- LCA results are highly uncertain
  - Assumptions
  - Uncertainty of inventory data
  - Uncertainty in characterization models
  - Uncertainty in weighting schemes

- Careful consideration is required for proper conlusions
  (typically a factor 2 is not highly significant)

- Results should be considered relative to other options

Example: assessing uncertainty in carbon footprints: natural gas *versus* biogas in car

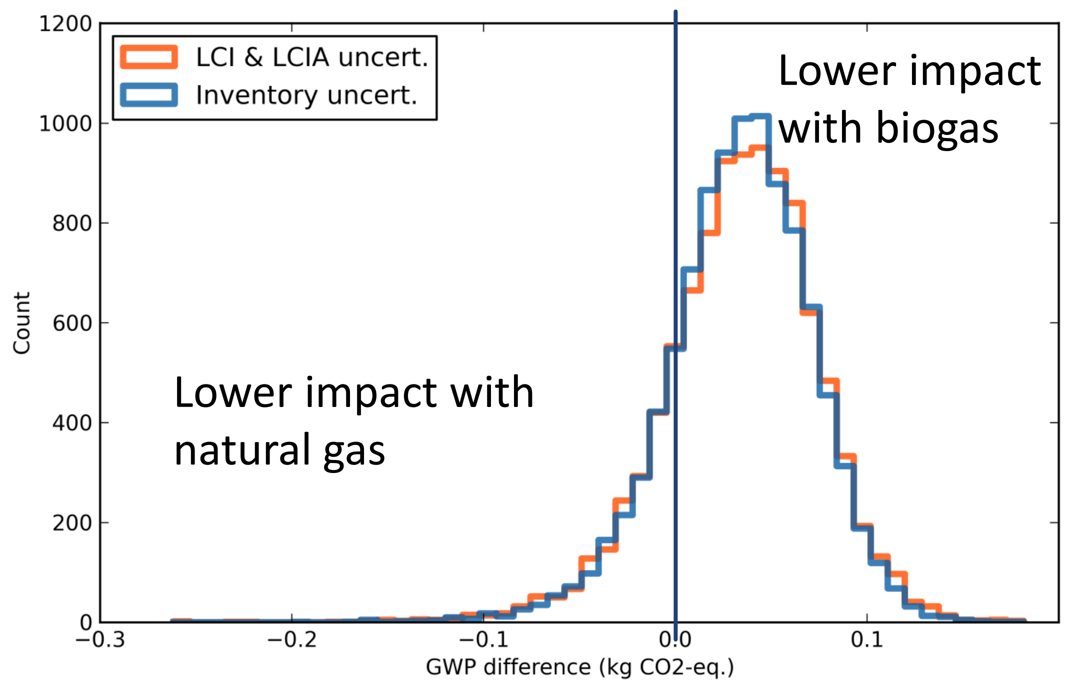
Impacts natural gas car: 0.16 kg CO_2-eq. / person-km
Impacts methane (biogas) car 0.12 kg CO_2-eq. / person-km

→ biogas impact < 75% of natural gas

But uncertainties?

19% chance that biogas performs worse!

10'000 Monte Carlo runs



A few illustrative examples…

- Life Cycle Inventory and Carbon and Water FoodPrint of Fruits and Vegetables (Stoessel et al. 2012)
- Carbon footprint per person and year in a Swiss municipality (PhD thesis of Dominik Saner)
- Spatially explicit impacts from phosphorus emissions in agriculture (Scherer & Pfister 2015)

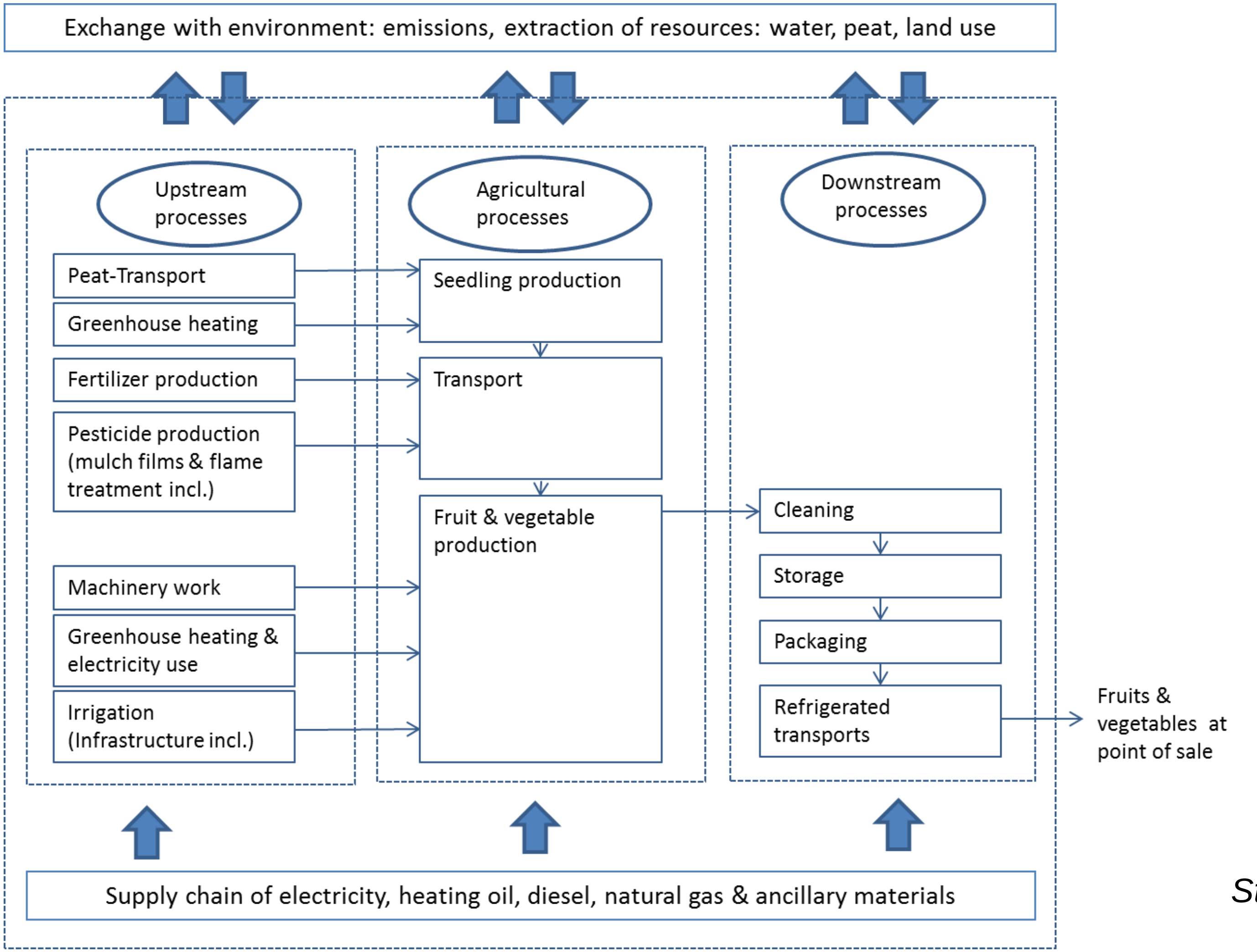
Scope

Image source: National Institutes of Health, United States Department of Health and Human Services

- Study performed for major Swiss food retailer
- 28 vegetables and fruits
- 29 countries of origin
- Open-field and greenhouse production
- Background data for transport, energy, fertilizer, pesticide production etc. from ecoinvent v2.01 / SimaPro 7
- Functional unit: 1 kg of vegetable or fruit (as fresh matter) at the point of sale

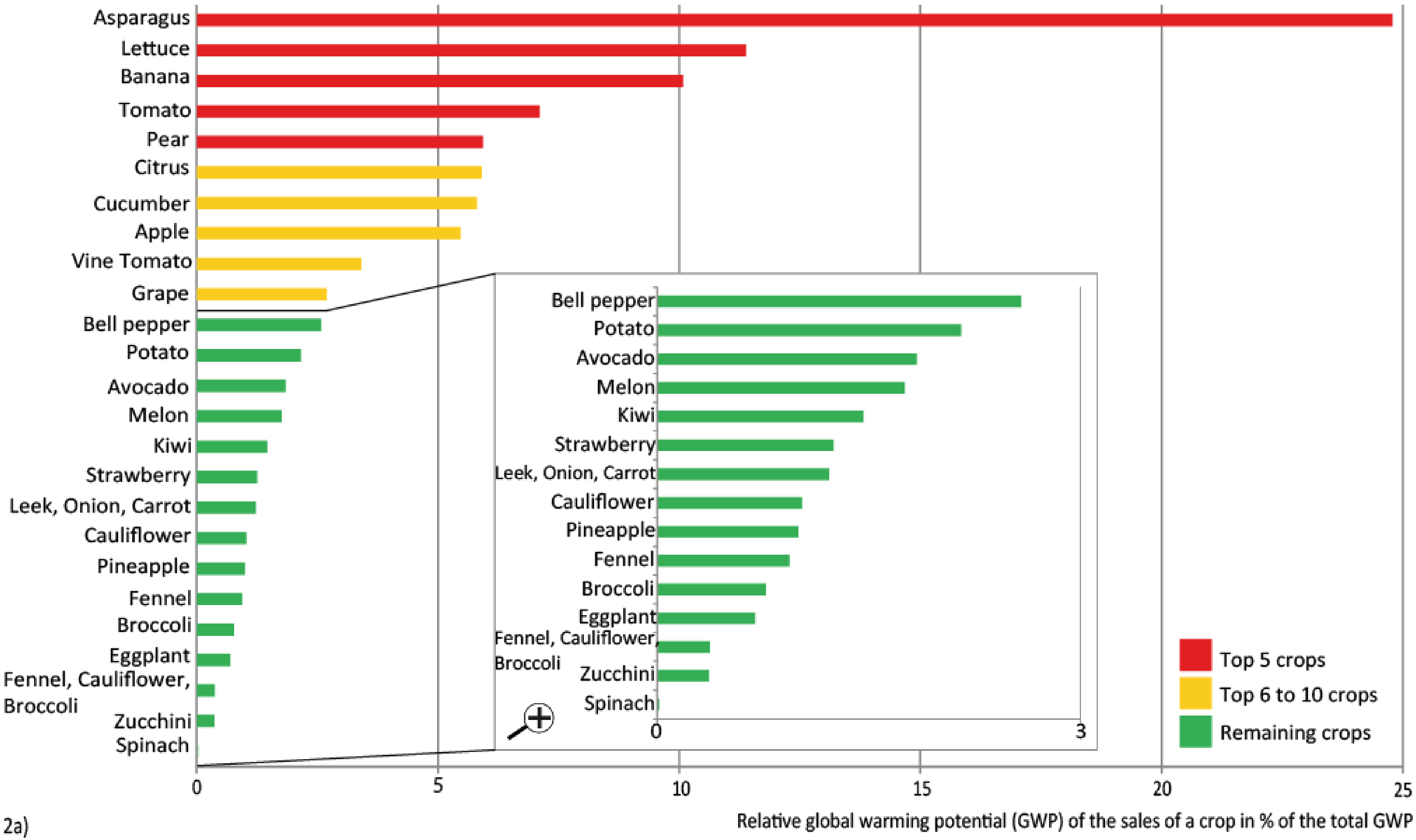
Stössel F, Juraske R, Pfister S; Hellweg S, Life Cycle Inventory and Carbon and Water FoodPrint of Fruits and Vegetables: Application to a Swiss Retailer, Environ. Sci. Technol. , 3253-3262, 2012

System boundaries



Stössel et al (2012)

Carbon Footprint of vegetables/fruits (as total annual sales)



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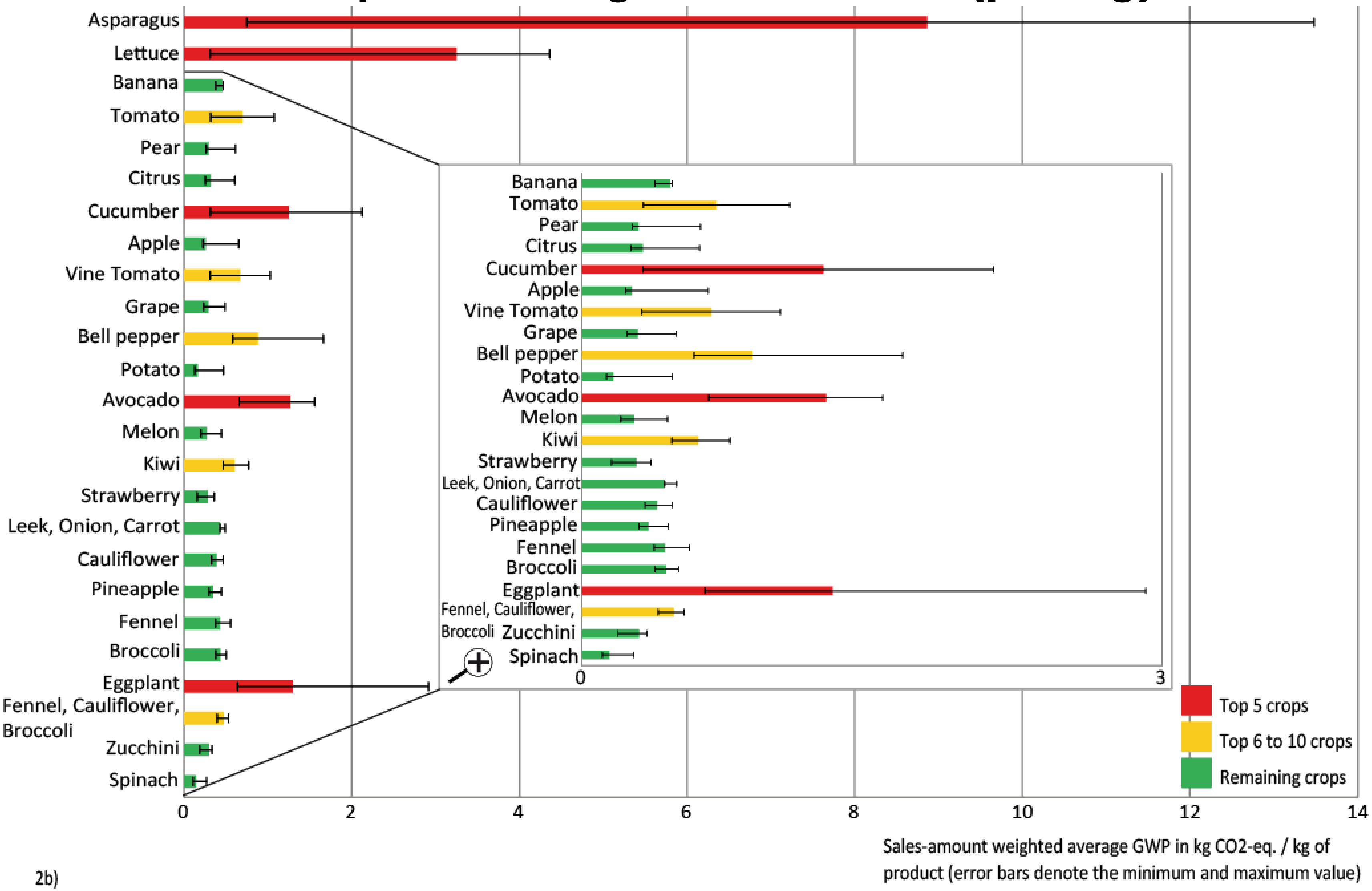
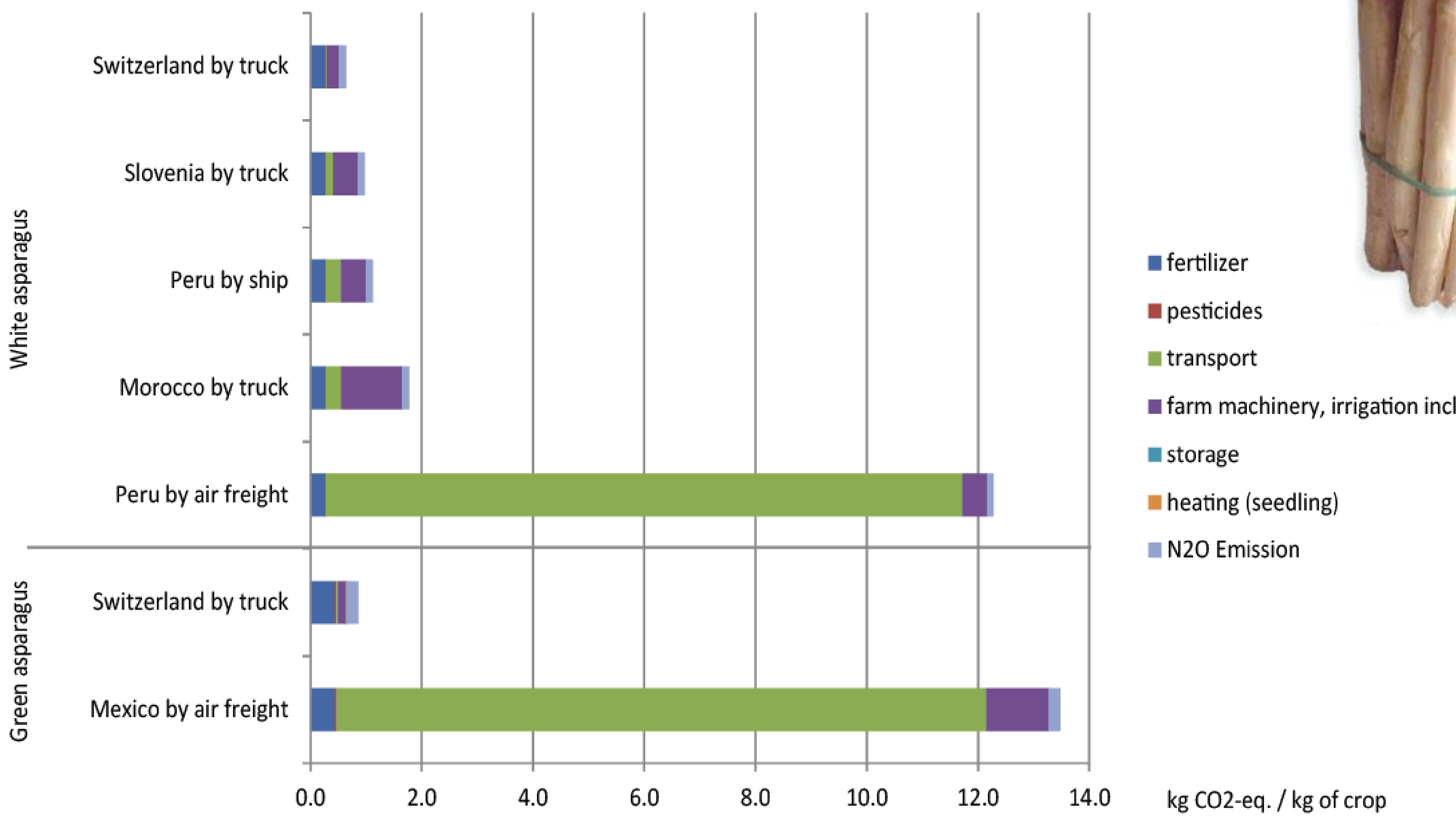
Carbon Footprint of vegetables/fruits (per kg)



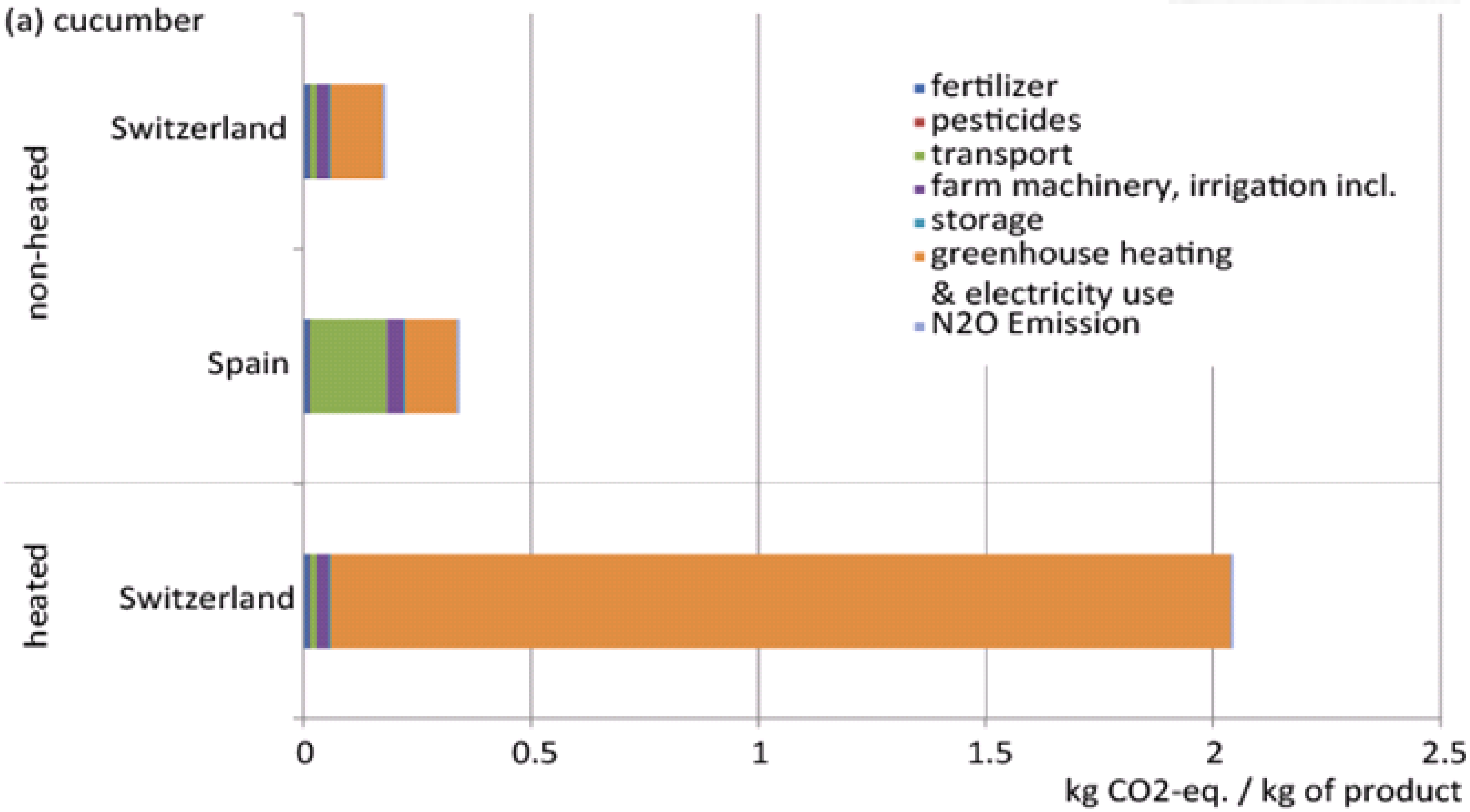
Stössel F, Juraske R, Pfister S; Hellweg S, Life Cycle Inventory and Carbon and Water FoodPrint of Fruits and Vegetables: Application to a Swiss Retailer, Environ. Sci. Technol. , 3253-3262, 2012

Carbon footprint of asparagus



Stössel et al, (2012)

Carbon footprint of cucumbers



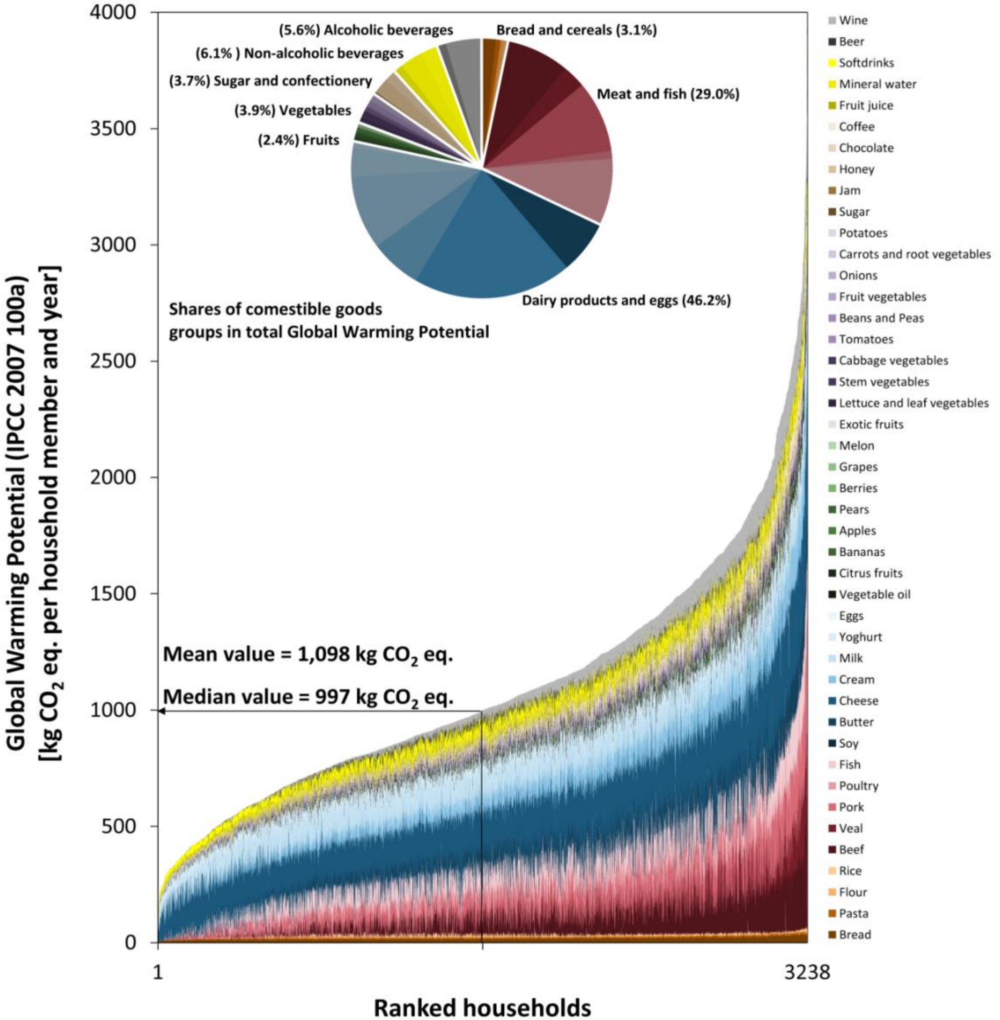
Stössel et al, submitted

Lowering the carbon footprint of vegetables

1. Avoid air transport
2. Prefer non-heated production over heated greenhouses
   - But tradeoff with water impacts (typically water scarce areas)!
3. As little truck transport as necessary

Carbon footprint per person and year in a Swiss municipality

→ consumption of meat and dairy products decisive



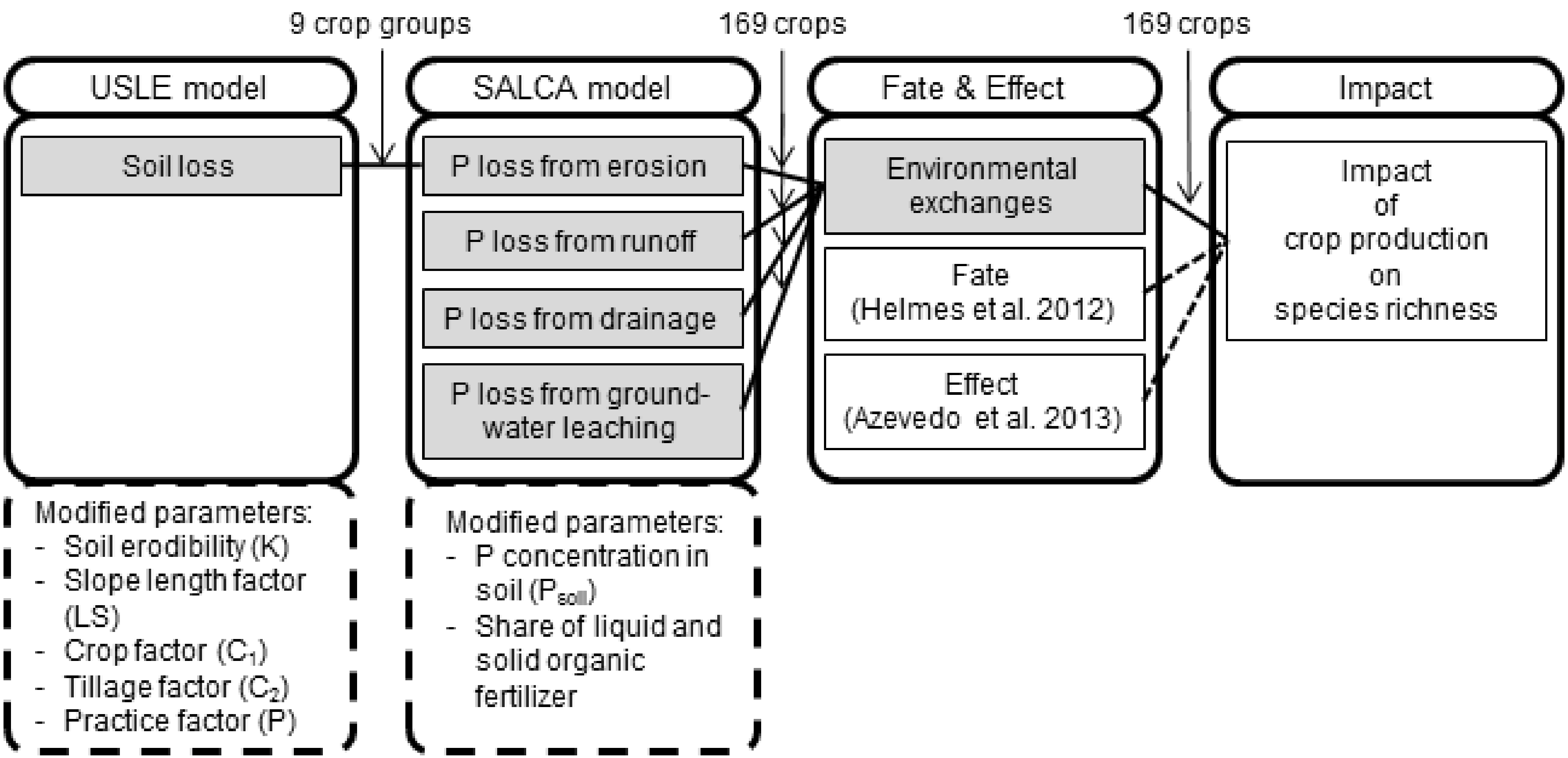
Source Dominik Saner, ETH Zürich

Spatially explicit impacts from phosphorus emissions in agriculture

Motivation:

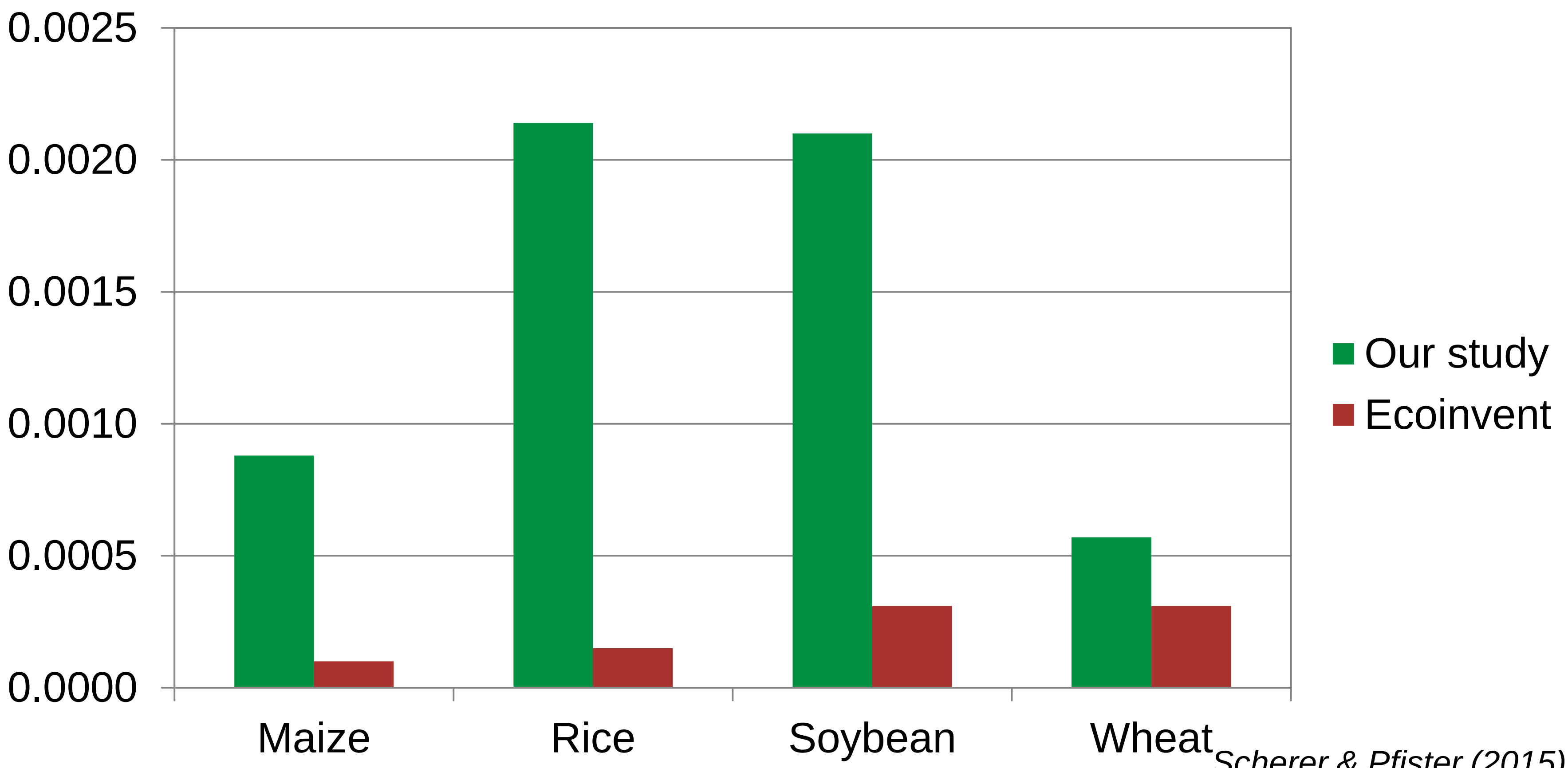
- Aquatic eutrophication threatens biodiversity
- Phosphorus emissions are the chief cause for freshwater eutrophication
- Agriculture is the major non-point source
- Emissions are likely to increase
- Previous assessments were limited to a few countries, a few crops and/or were too simplified

Coupling of models



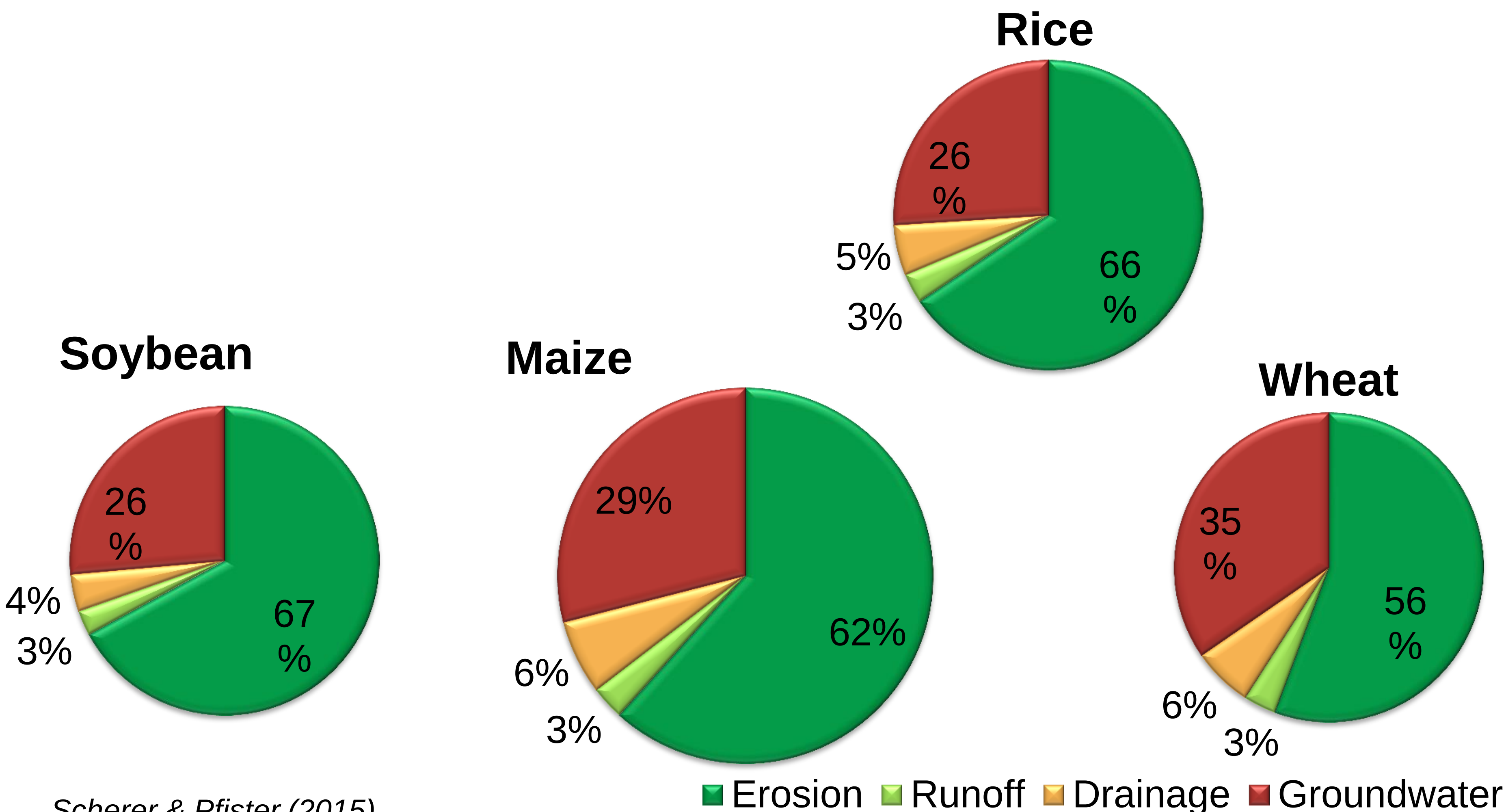
Scherer & Pfister (2015)

Results: Global average phosphorus emissions (kg P / kg crop)



Scherer & Pfister (2015)

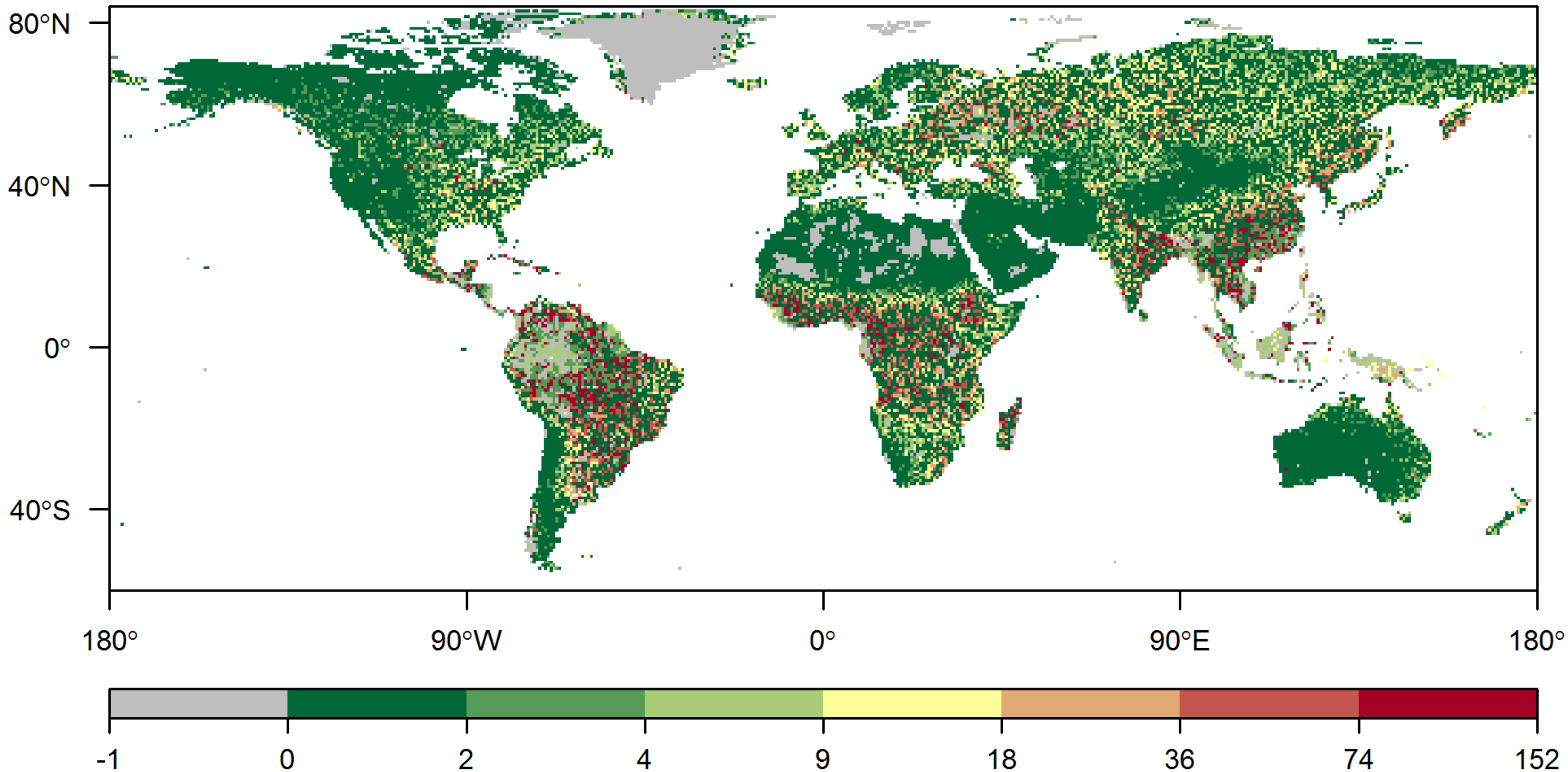
Dominant processes of phosphorus emissions



Scherer & Pfister (2015)

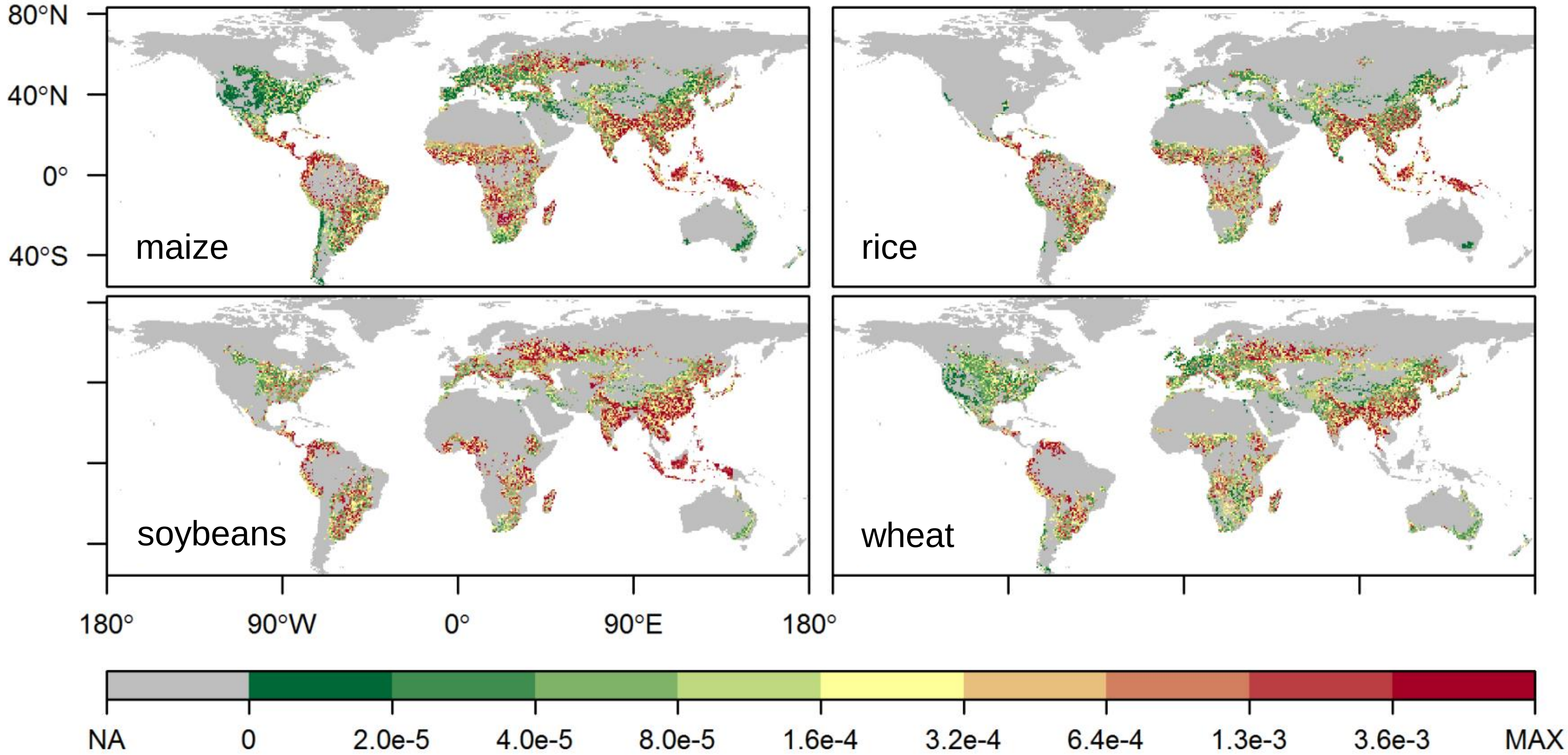
www.esd.ifu.ethz.ch/

Erosion loss per cropland use



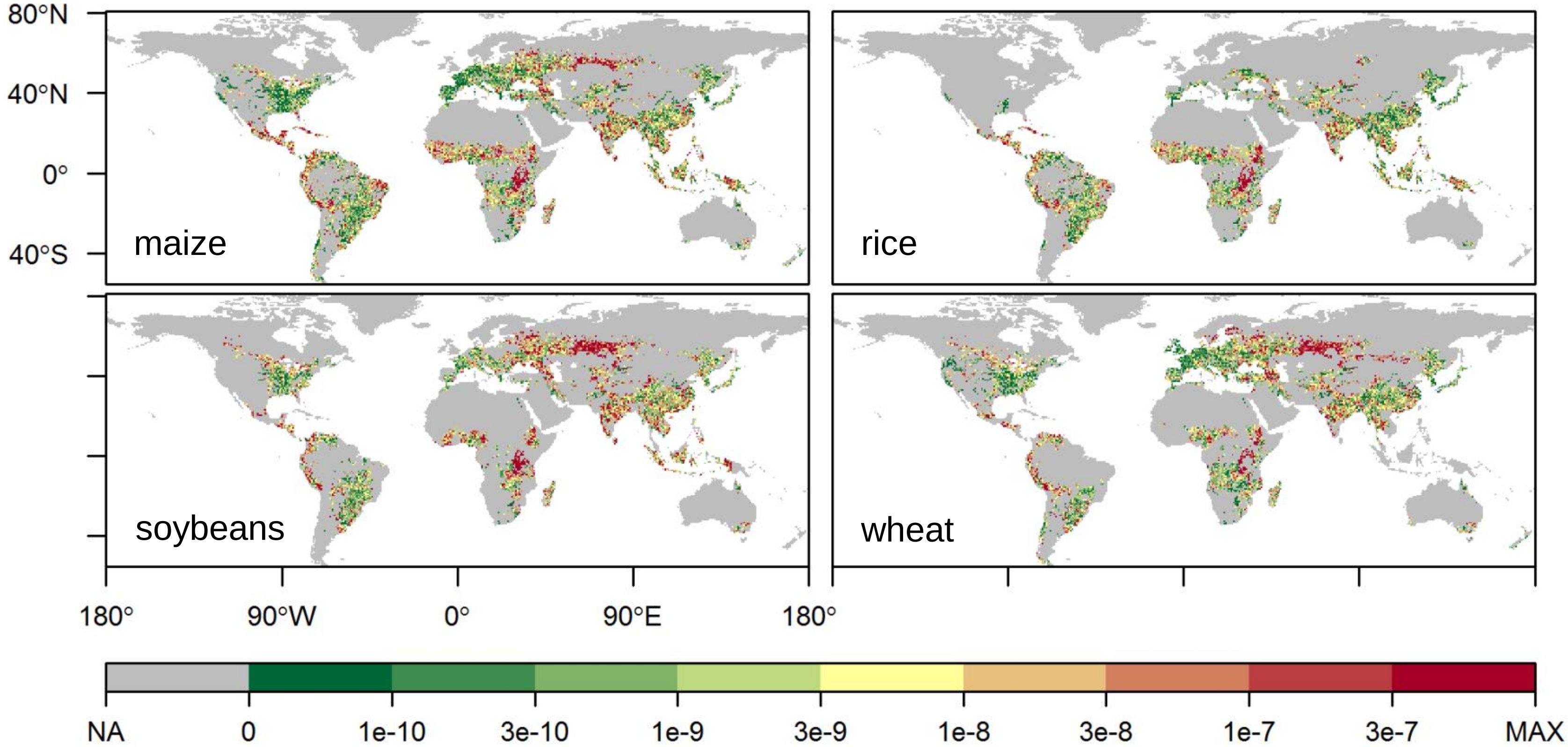
Ton soil / (ha yr)

Phosphorus emissions (kg P / kg crop)



Scherer & Pfister (2015)

Impacts on biodiversity (days m^3 / kg crop)



Scherer & Pfister (2015)

Conclusions

- Detailed erosion model for different crops with high spatial resolution
- Improvement of modelling scheme of phosphorus emissions
- Underestimation of phosphorus emissions in ecoinvent
- Importance of regionalising both inventory results and characterisation factors
- Major limitations
  - Management factors effect on erosion (factor 16)
  - Bioavailability of phosphorus
  - Soil erodibility
  - No crop specific fertilization
  - Interactions with nitrogen

Scherer & Pfister (2015)

Introduction to LCA – wrap-up

Summary LCA

- LCA is a comprehensive assessment of very complex systems
- Tries to avoid burden shifting (e.g. from GHG emissions to radioactive waste)
- Features high uncertainties
- Is most valuable for understanding the system and not for reporting absolute numbers
- Is still a growing research field with many gaps

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Thank you for your attention!

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References

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Introduction to SimaPro LCA software

A really small case… PET vs. Glass bottle