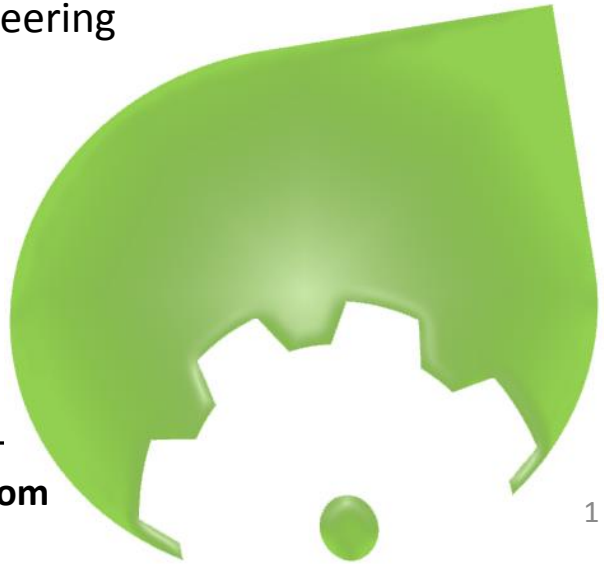
LIFE CYCLE ASSESSMENT (LCA) OF BIOENERGY AND RELEVANCE OF REGIONALISATION

Dr. Stephan Pfister

ETH Zurich, Institute for Environmental Engineering
Ecological Systems Design Group

Email: pfister@ifu.baug.ethz.ch



Introduction

- Bioenergy has gained importance in energy supply
- LCA of first generation biofuels (e.g. Zah et al. 2007):
  - even for carbon footprint might not be favorable
  - add additional impacts on ecosystems.
  - waste has been identified as a good resource by LCA
    - alternative uses exist (e.g. of animal feed)
- Feedstock production is of main importance
  - Regionalized assessments required

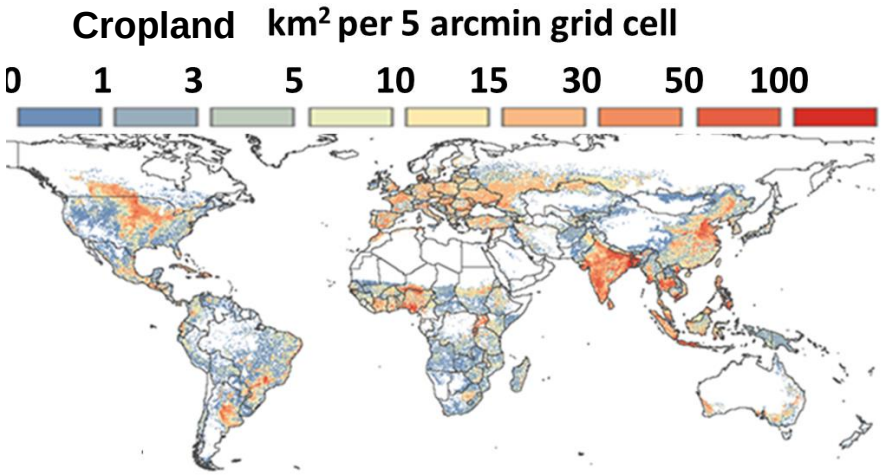
LCA of feedstock production

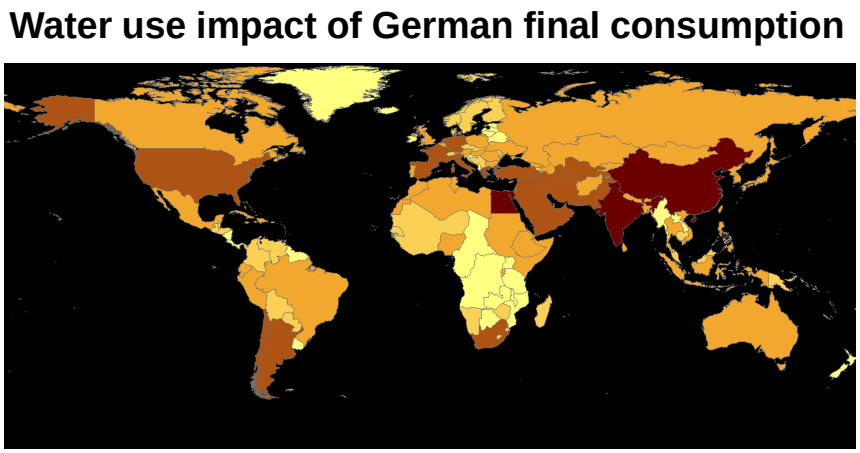
Global assessments are needed to compare bioenergy of different origins

-> Consistent, simplified model approaches for land, water and fertilizer use

-> Transport typically not relvant

-> Highly globalized market





Issues Inventory and Characterization

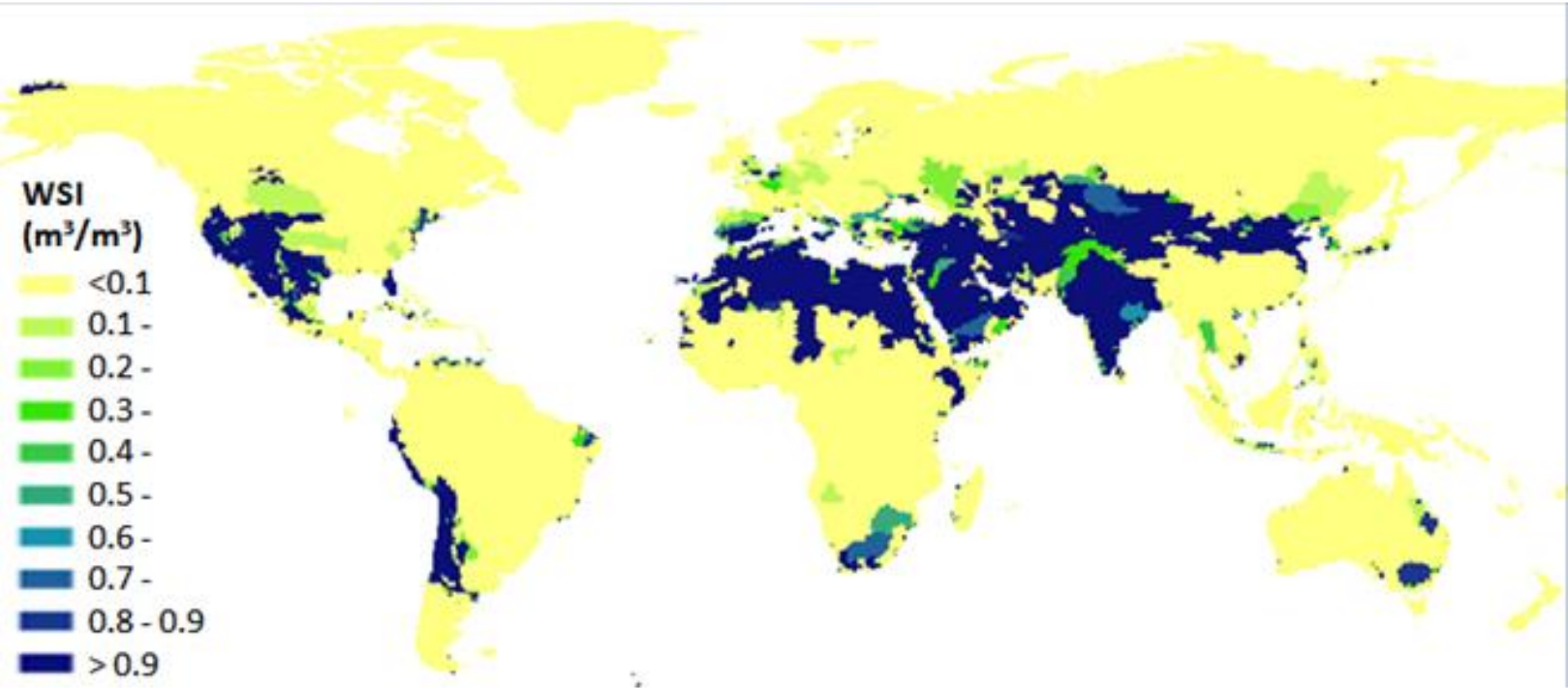
- Inventory data is so far very limited
  - Few datasets for specific locations
  - Can be collected for individual cases

- Characterization models often global
  - High level of details for water, land, eutrophication and acidifcation
  - Not yet for toxic emissions
  - Cannot be easily adjusted

IMPACTS

Water stress index (WSI)

Midpoint characterization factor
-> based on use-to-availability ratio

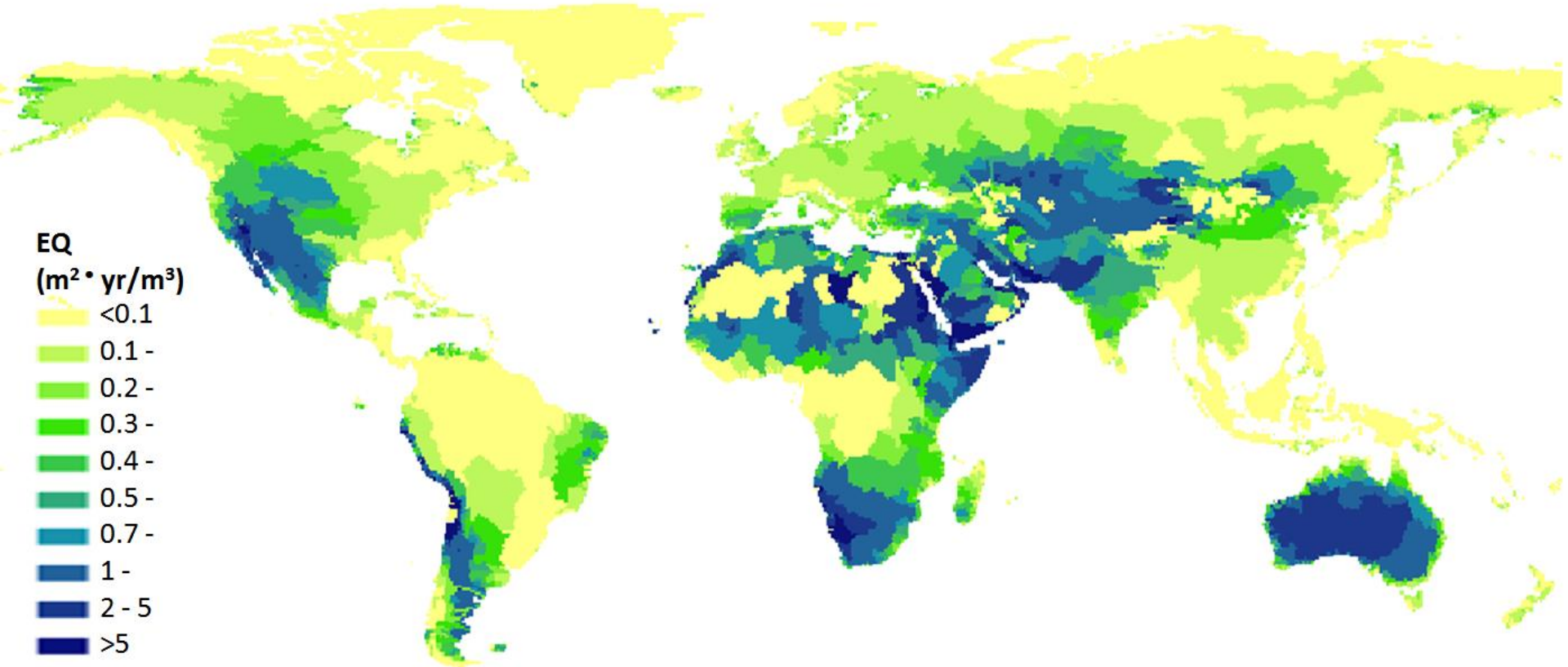


Pfister et al. 2009

Impacts on ecosystem Quality

Loss of ecosystem quality (PDF m2 yr /m3), according to EI99

-> Based on precipitation and water limited NPP

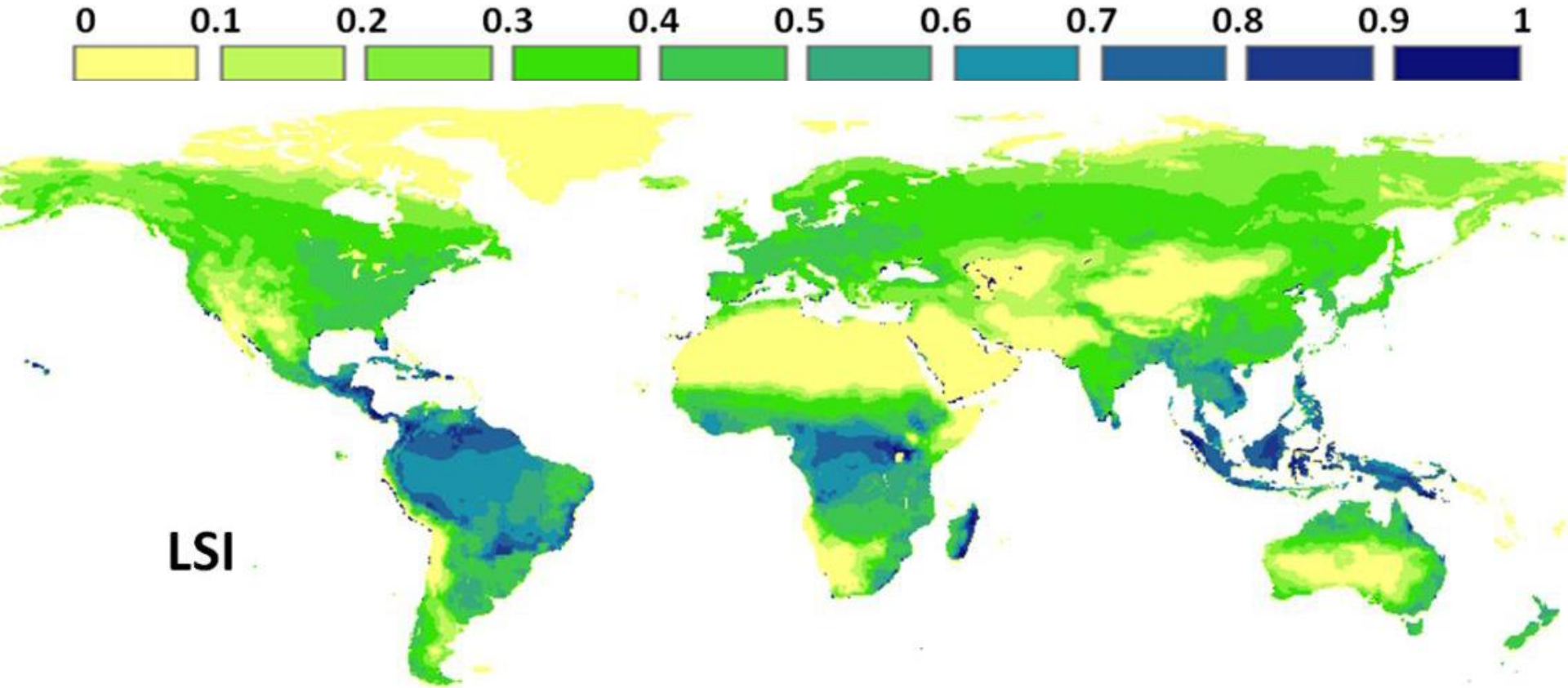


Compatible with impacts from pollution impacts

-> also comparable to land use impacts

Land stress indicator (midpoint CF)

Based on productivity (NPP) of Land as limiting factor

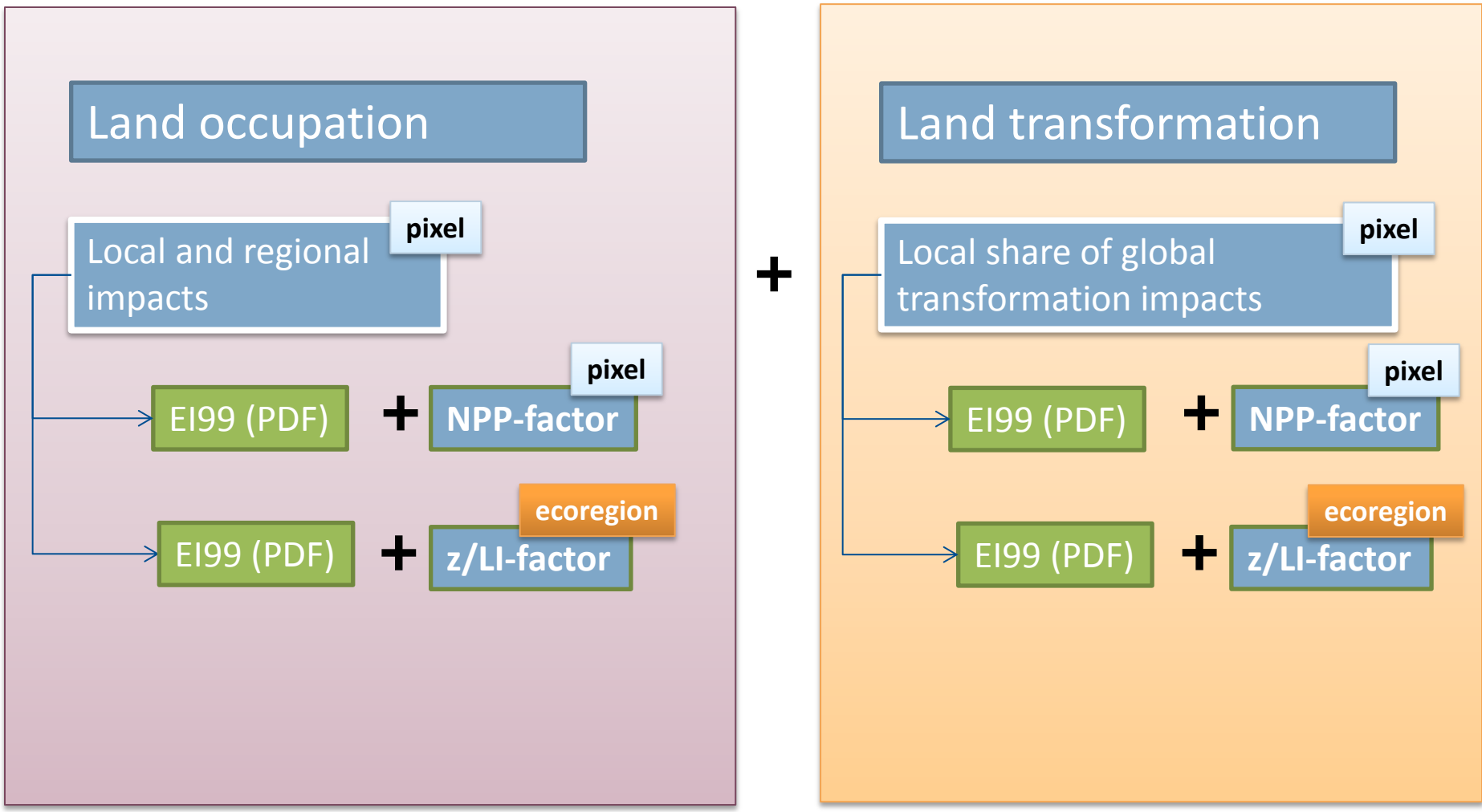


Pfister et al. 2011

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

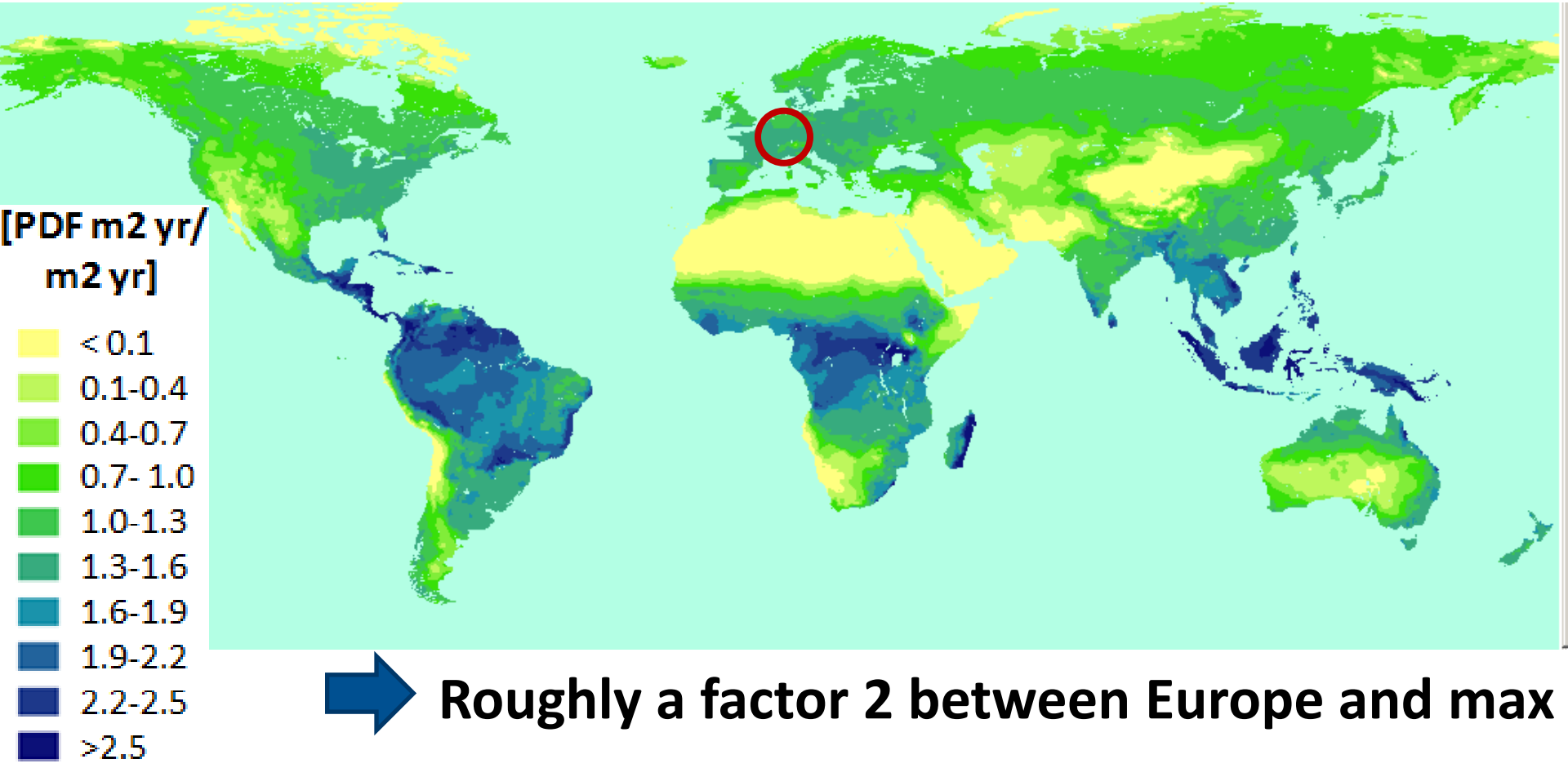
ESD
ecological systems design

Land use endpoint CF (based on EI99)



Land use endpoint CF (based on EI99)

Includes indirect land use change based on average cropland increase (~0.4% per year)



Roughly a factor 2 between Europe and max

Pfister et al. 2010

Current crop production

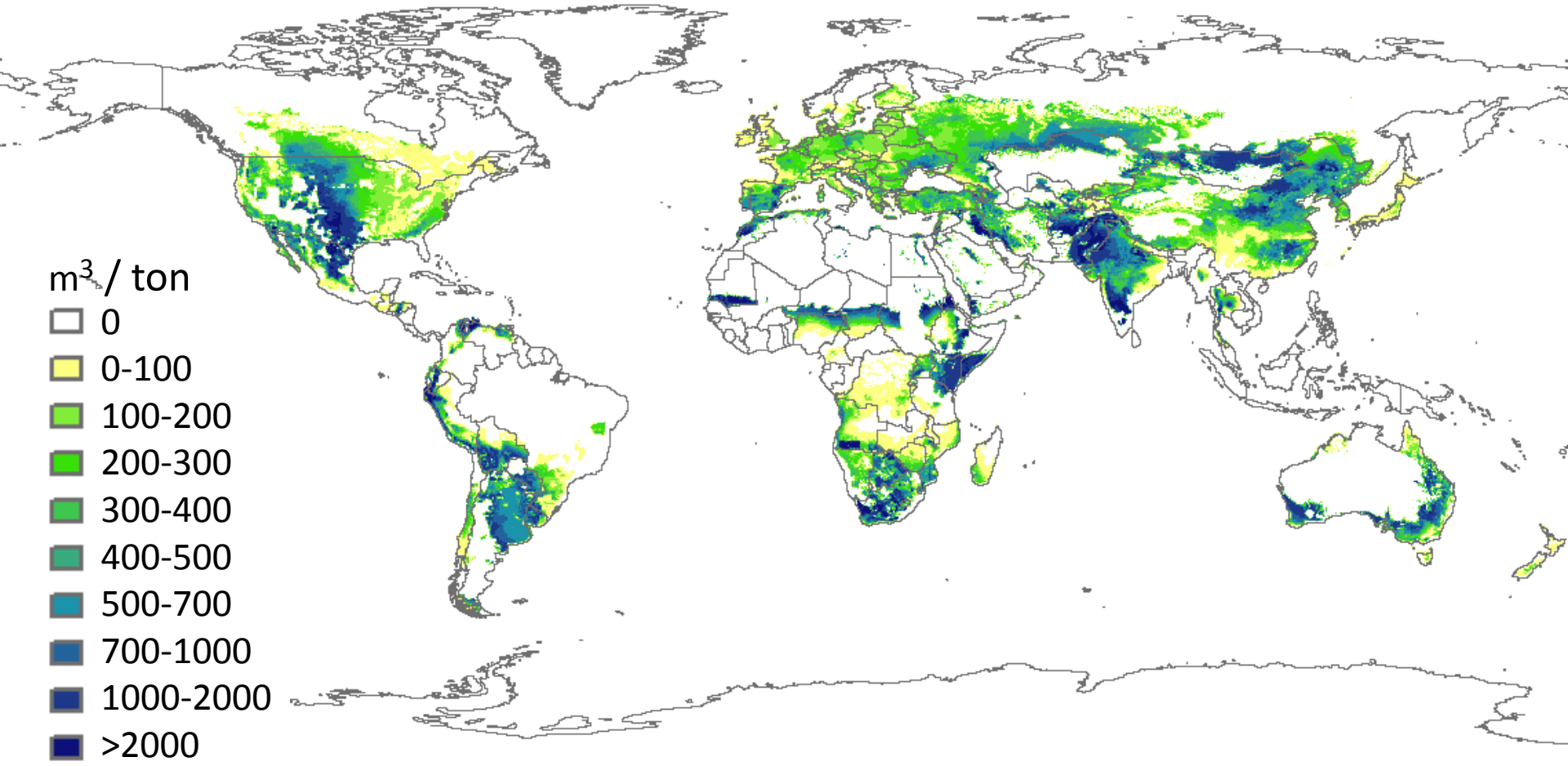
Agriculture

- Crop production on high spatial resolution
  - < 10 km resolution
  - Water consumption and related impacts
  - Land use and related impacts

- Not included:
  eutrophication, fuels etc.

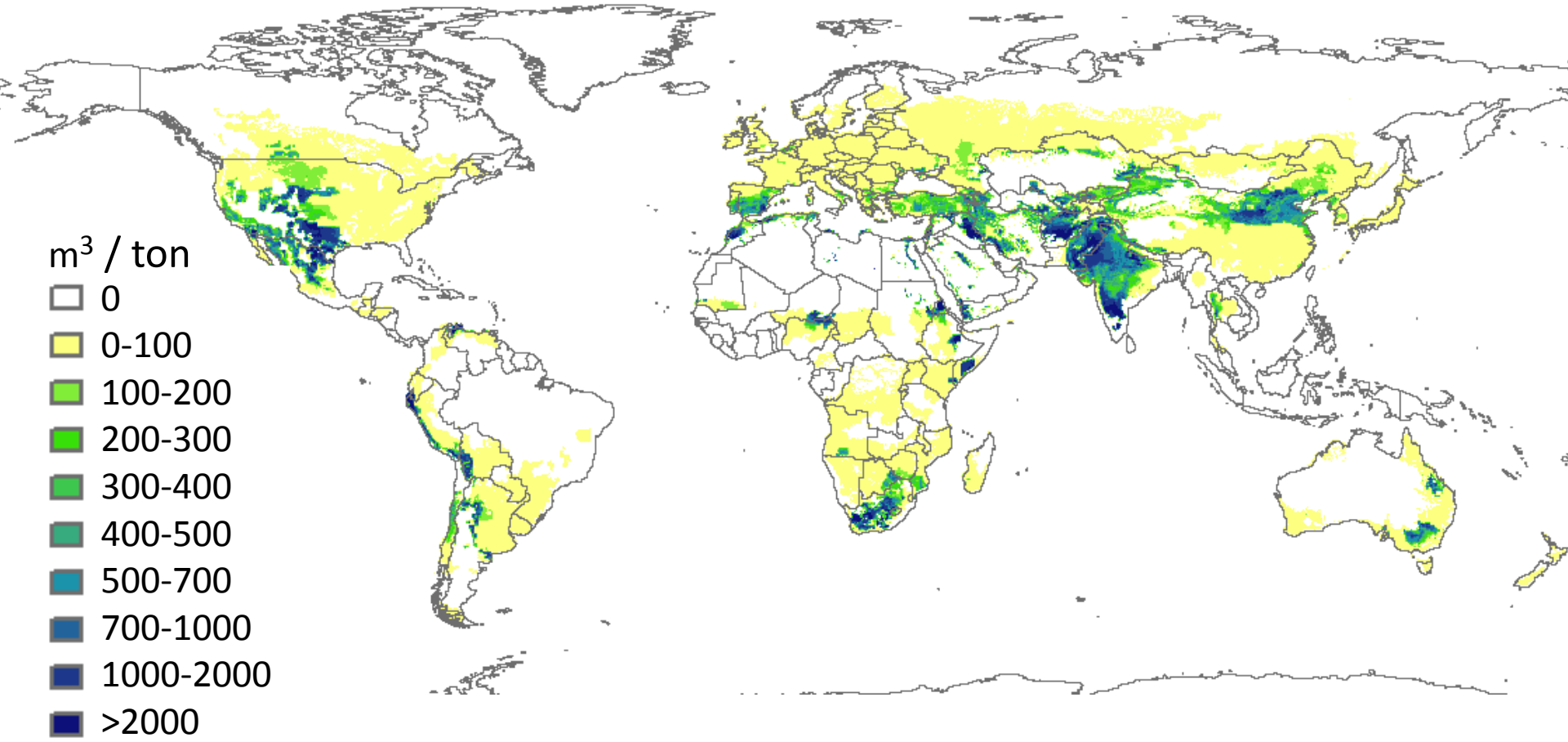
Irrigation water consumption of wheat cultivation

[Volume/output]



Water midpoint impact from wheat cultivation

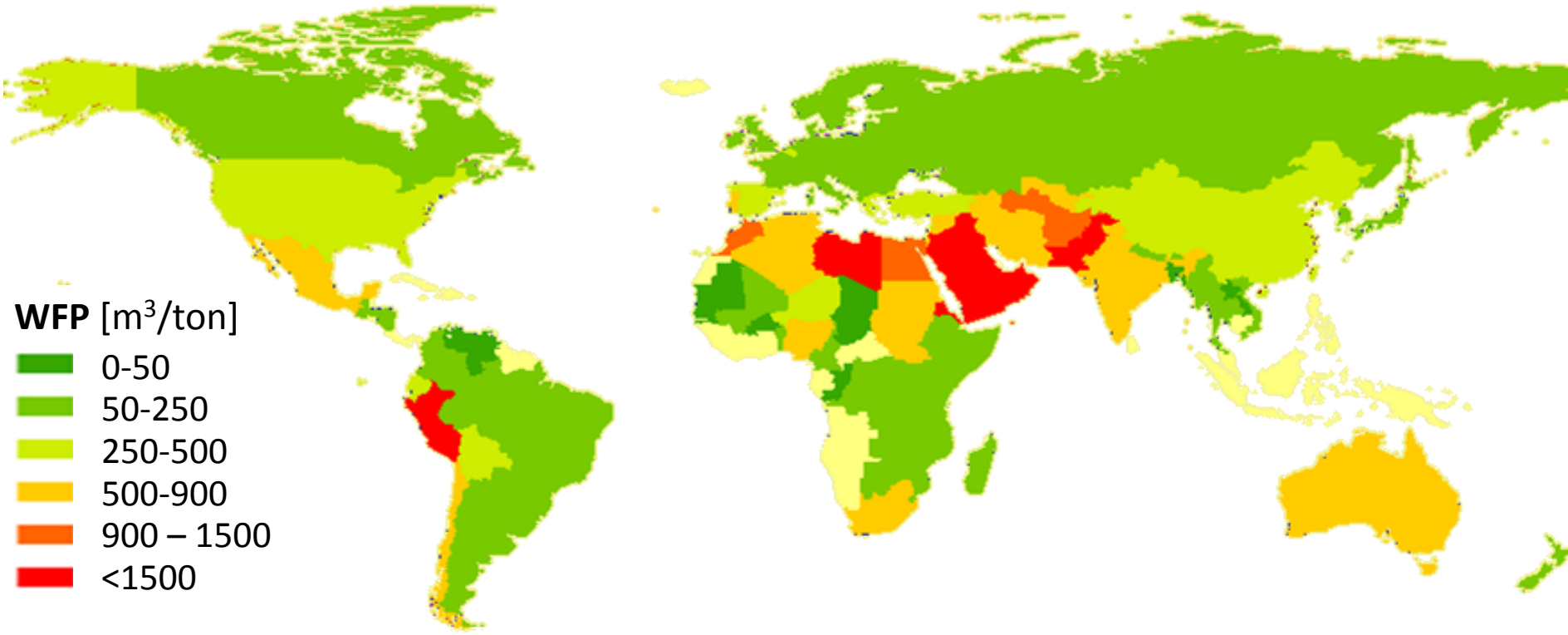
[WSI-weighted volume/output]



Aggregation on country level

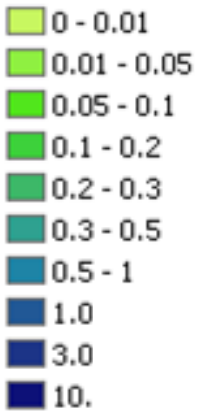
Wheat's water impact for background processes

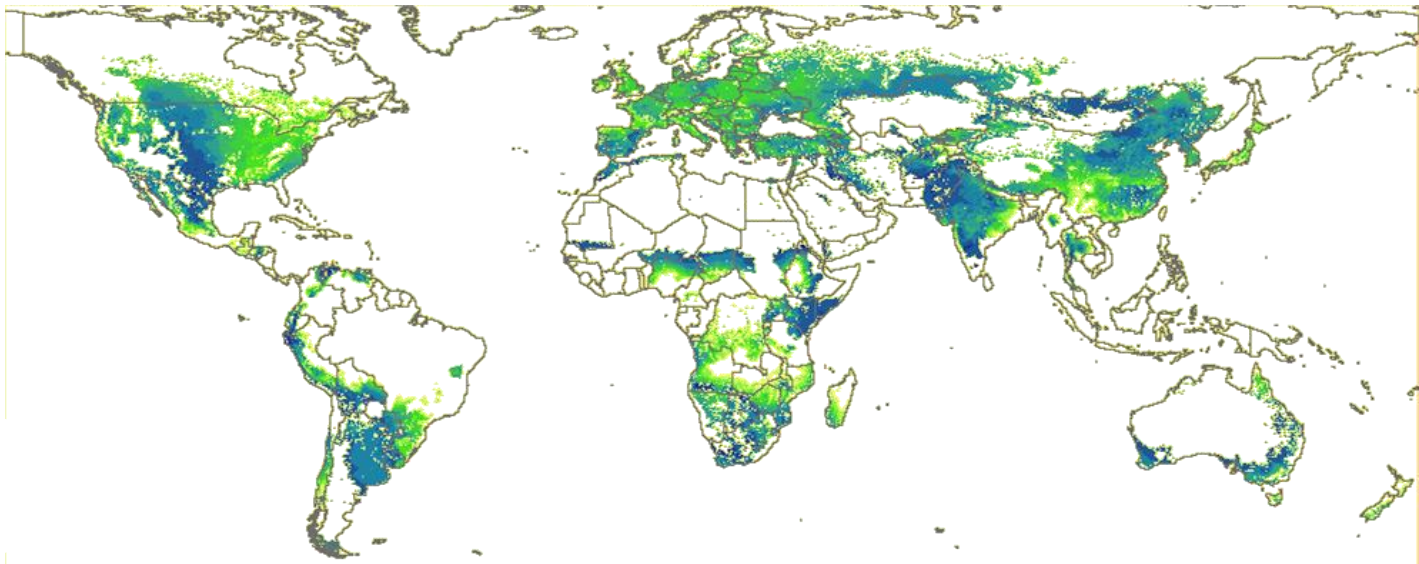
-> can be coupled with trade data for unspecific origins



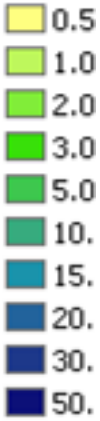
Wheat inventory: water and land use

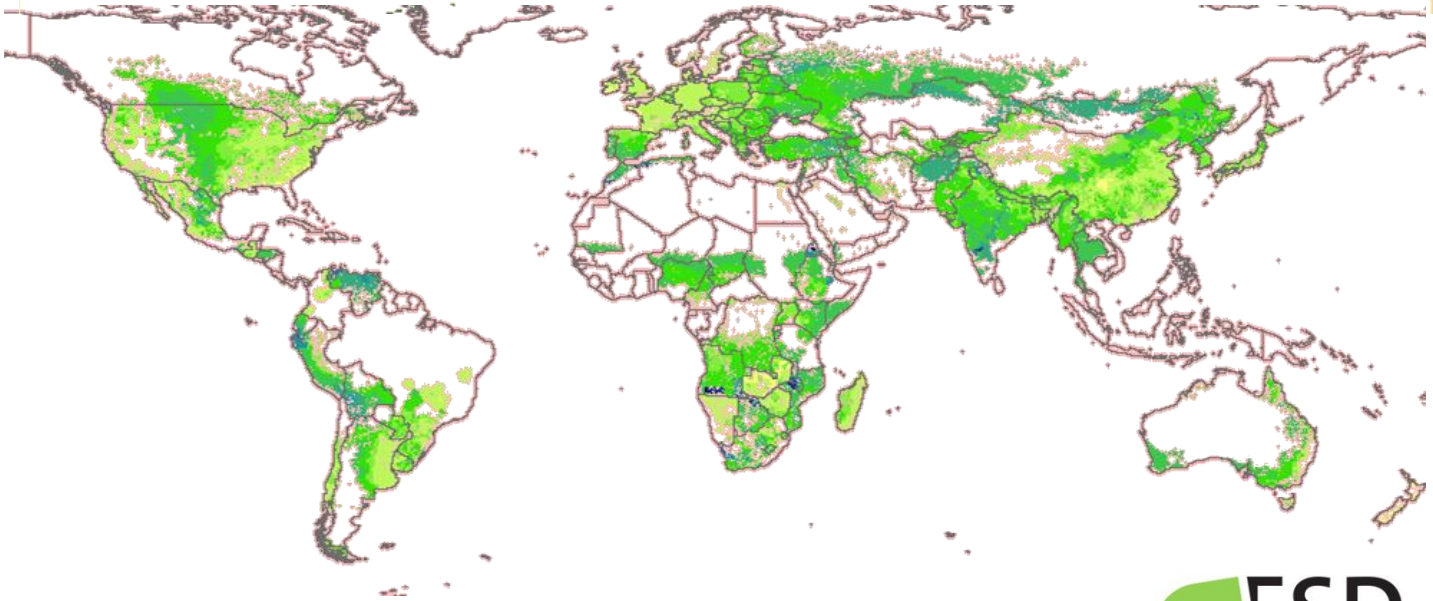
Water consumption
[m³/kg]





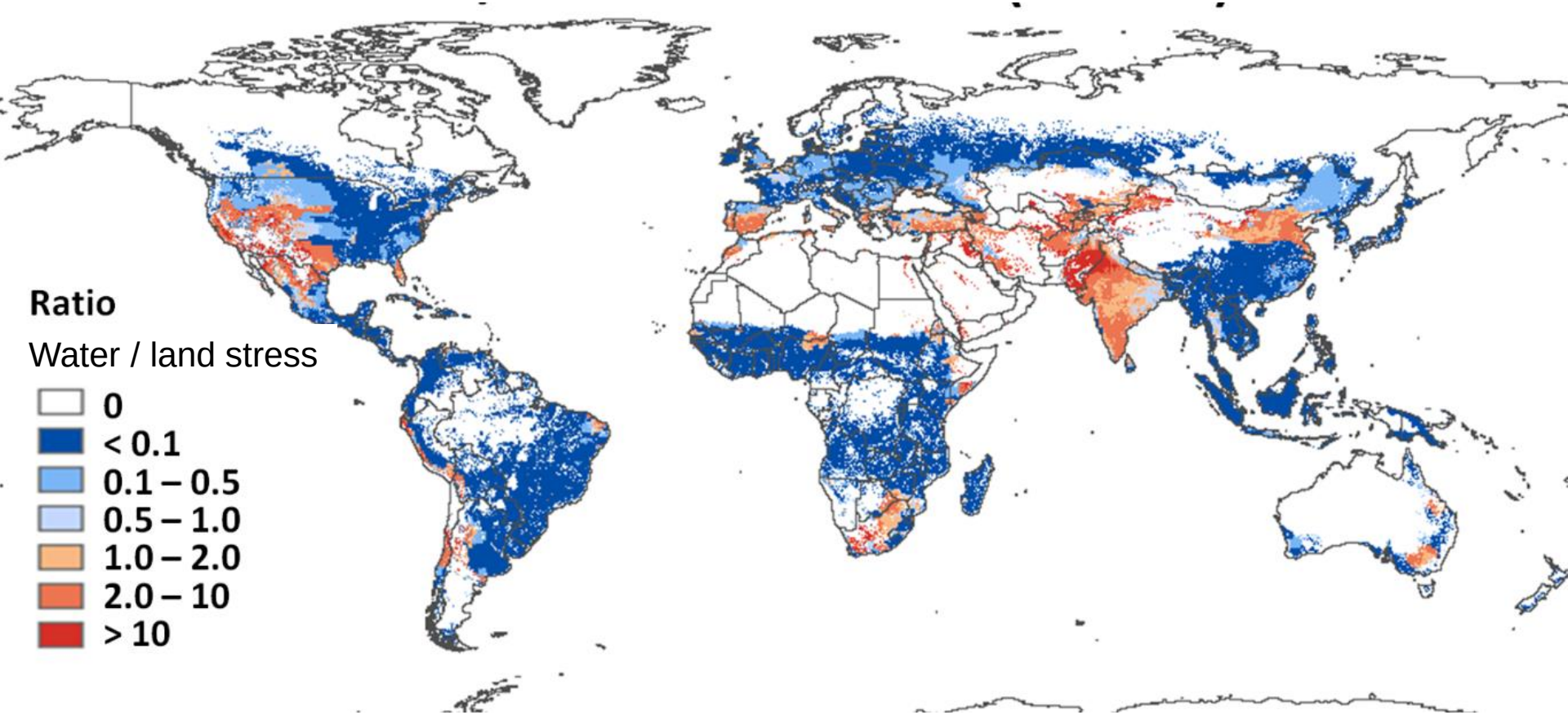
Land occupation
[m²yr/kg]





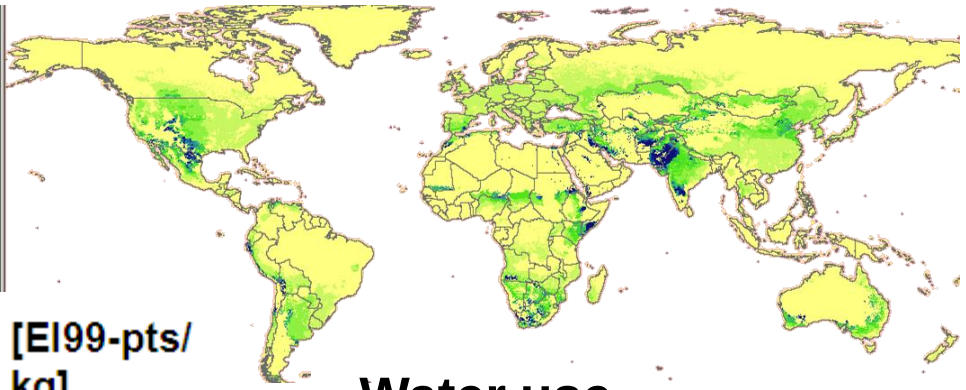
Land-Water tradeoffs wheat cultivation

-> relative relevance compared to global impact



Pfister et al. 201

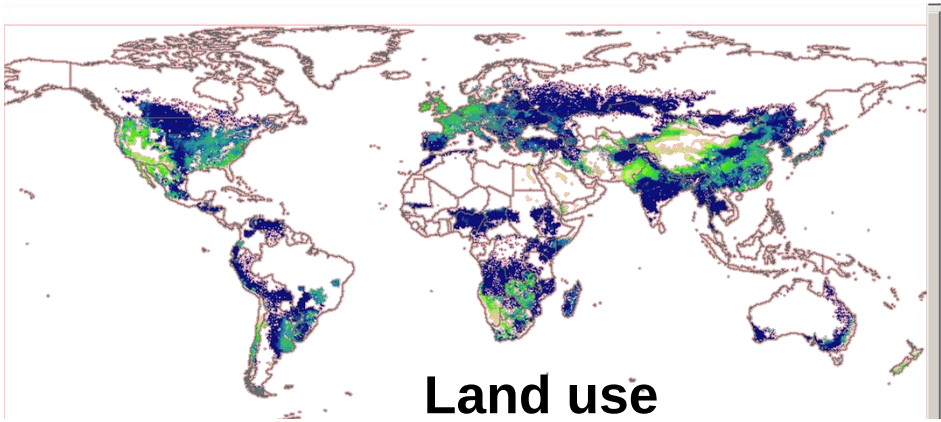
Endpoint impacts of wheat production



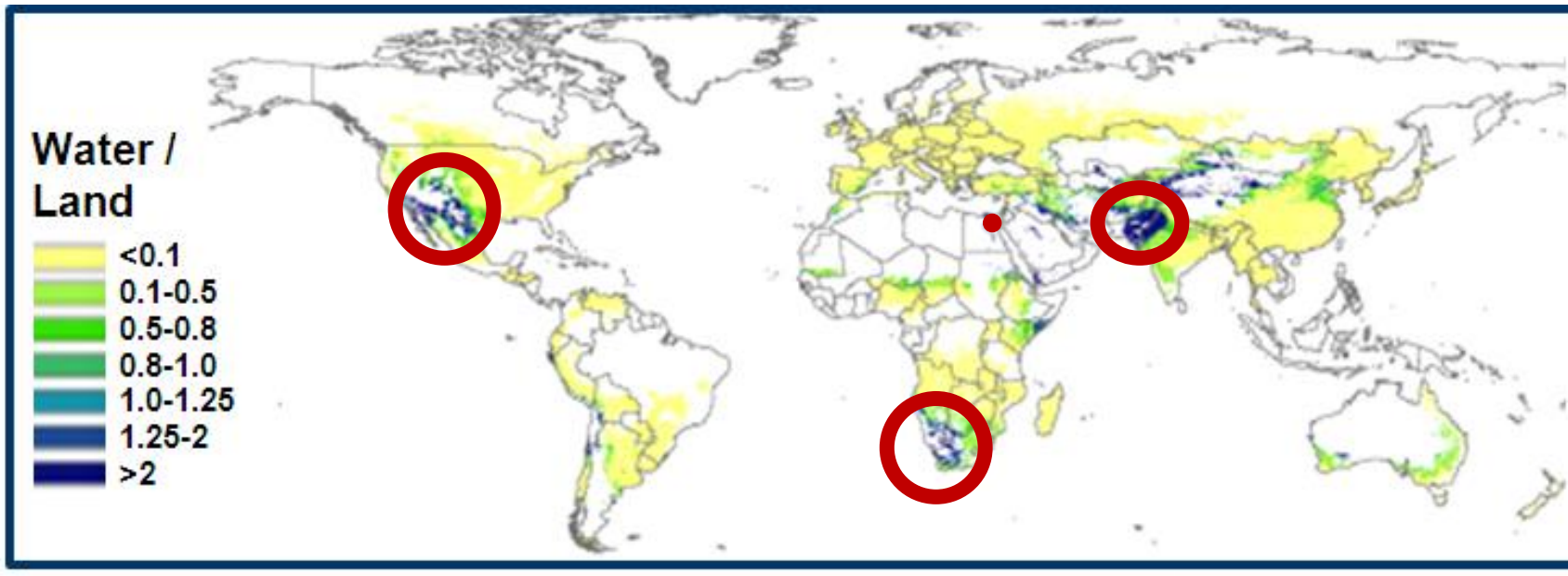
[EI99-pts/kg]

0
<0.01
<0.05
<0.1
<0.15
<0.2
<0.25
<0.3
<0.35
<0.4
>0.4

Water use



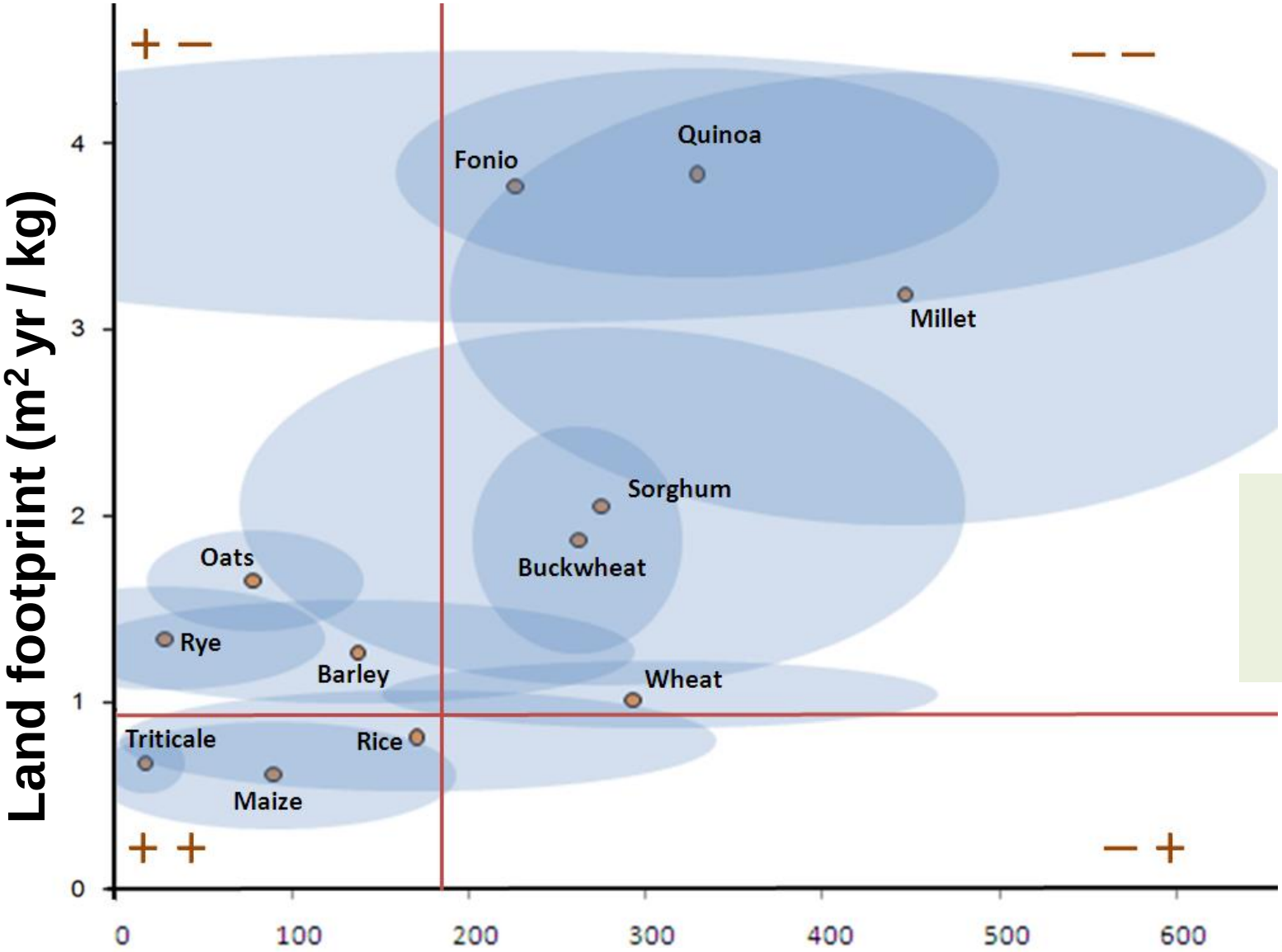
Land use



Water / Land

<0.1
0.1-0.5
0.5-0.8
0.8-1.0
1.0-1.25
1.25-2
>2

Land-Water tradeoffs & Variability cereals



Range:
0.5 std of individual results

Pfister et al. 201

Eidgen
Swiss F

ESD

Land and water impacts of biofuel

- Better drive than dress with biomass

Feed-stock	Feedstock Origin	Net fossil fuel offset of crops* ($GJ\ Mg^{-1}$)	Water Stress of fossil fuel offset ($m^3_{eq}\ GJ^{-1}$)	Land stress per fossil fuel offset ($m^2yr_{eq}\ GJ^{-1}$)
Cotton	global mix	15.6	84.3*	101*
Maize	USA	4.10	10.4	83
	global mix		21.8†	151†
Sugar cane	Brazil	2.02	0.54	45
	global mix		16.9†	40†
Palm oil	Malaysia	10.6	0.06	37
	global mix		0.35†	51†
Soy bean	USA	6.98	12.7	158
	global mix		20.4†	160†
Rape-seed	Switzerland	11.2	0.85	102
	global mix		36.0†	159†

Future of bioenergy

- Food demand is increasing by ~50% by 2050
- Increases land and water stress
- Priority on replacing oil burned for heat (incl. thermal power)
  - cellulosic biomass: generally lower impacts per MJ

Irrigation for 2 Scenarios in 2050

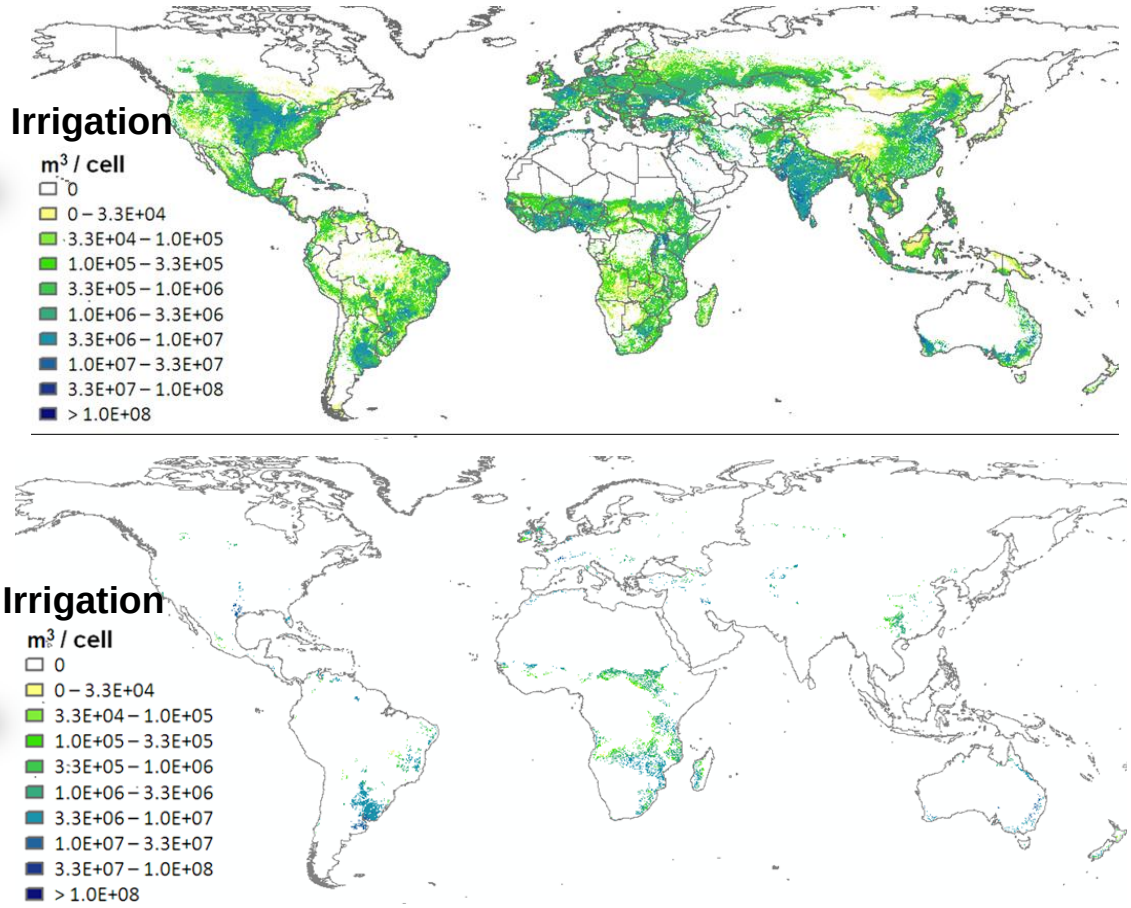
Strategies:

- Intensification & Waste reduction

Irrigation:
+ 1125 km³ (64%)

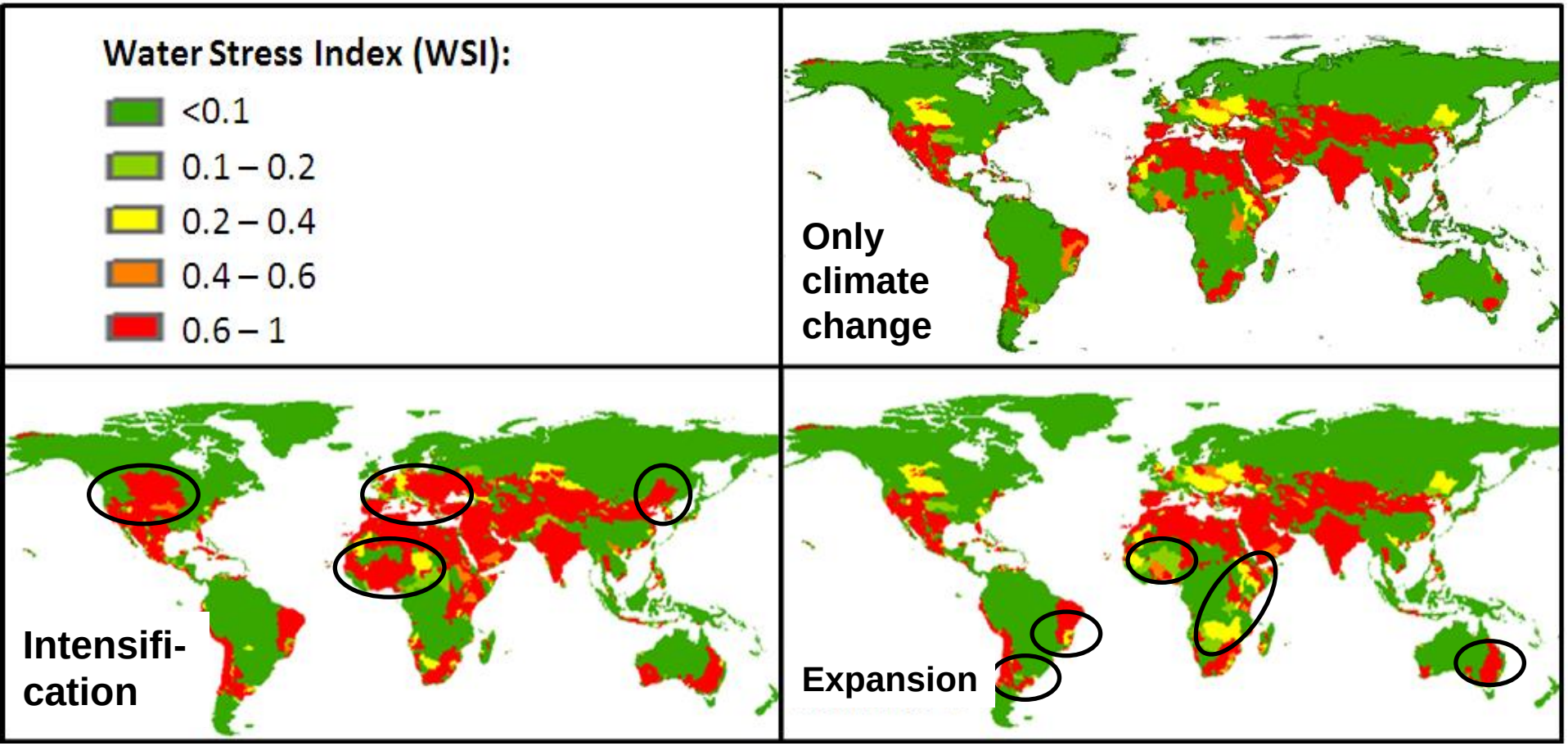
- Expansion on pastures

Irrigation:
+169 km³ (10%)



Water Stress Index in 2050

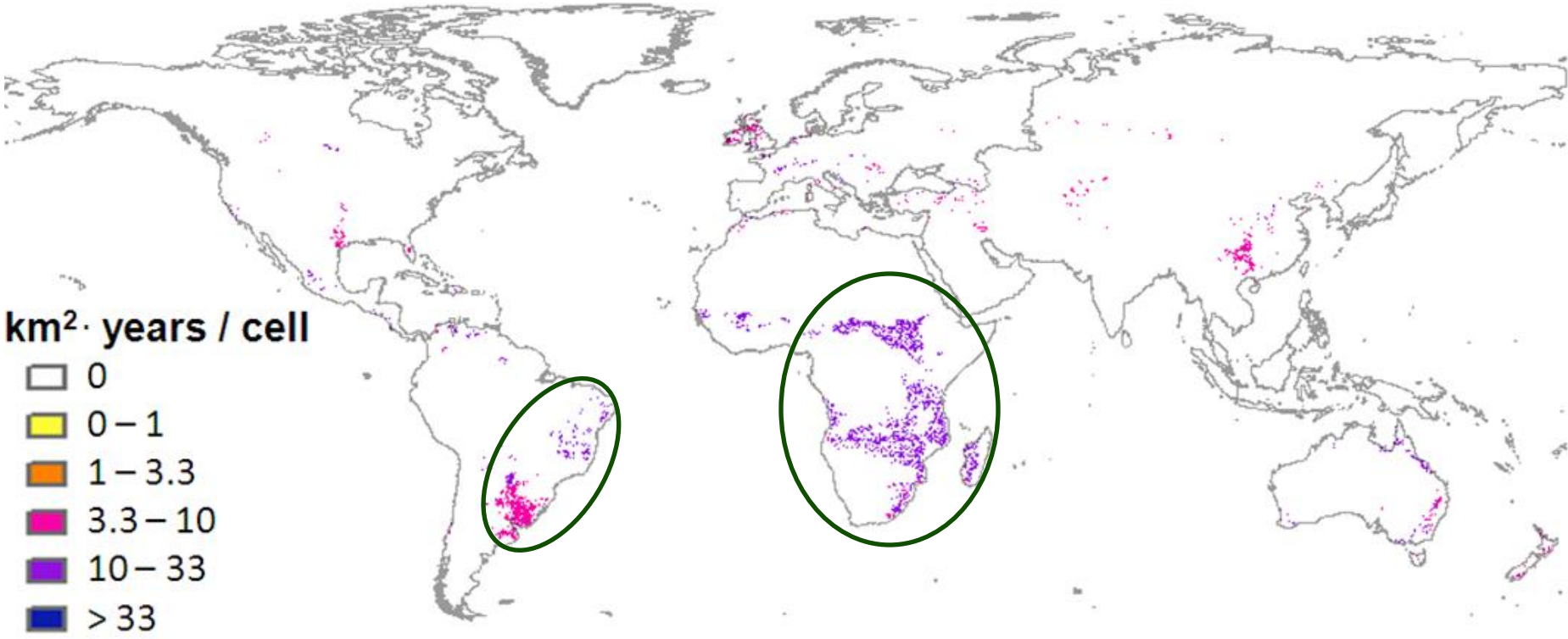
- Water Stress Change for food only



Additional Land stress in expansion scenario

- In Africa (ca. 2/3)
- In South America (ca. 1/4)

Global Stress: +14%



Conclusion

Conclusions

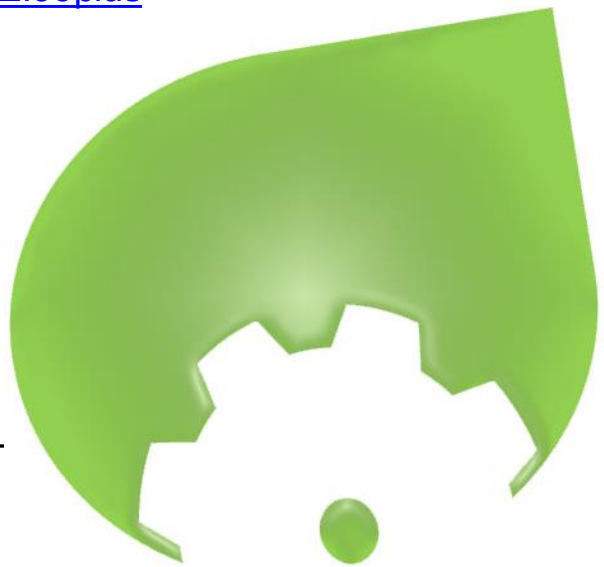
- Imported biomass from cereals typically higher water impats r
- Oil-based biofuels have typically large land use impacts
  - palm oil as marginal production)
- Impacts on land and water resource increase with increasing demand for crops and bioenergy
- National perspective is not a proper spatial boundary
- Proper level of regionalization (high spatial resolution)
  - Country level is not enough (inventory and CF)
  - AGGREGATE after Impact Assessment! (if at all)
- Communicate with caution
  - Address complexity of impacts (LOW QUALITY OF GLOBAL MODELS)
  - Include uncertainty assessment (also in GHG emissions)

THANKS FOR YOUR ATTENTION!

pfister@ifu.baug.ethz.ch

Data sources:

- Water accounting (crops and electricity): http://www.ifu.ethz.ch/ESD/downloads/WATER_DATA
- Impact assessment land/water: http://www.ifu.ethz.ch/ESD/downloads/EI99plus



BACKUP SLIDES

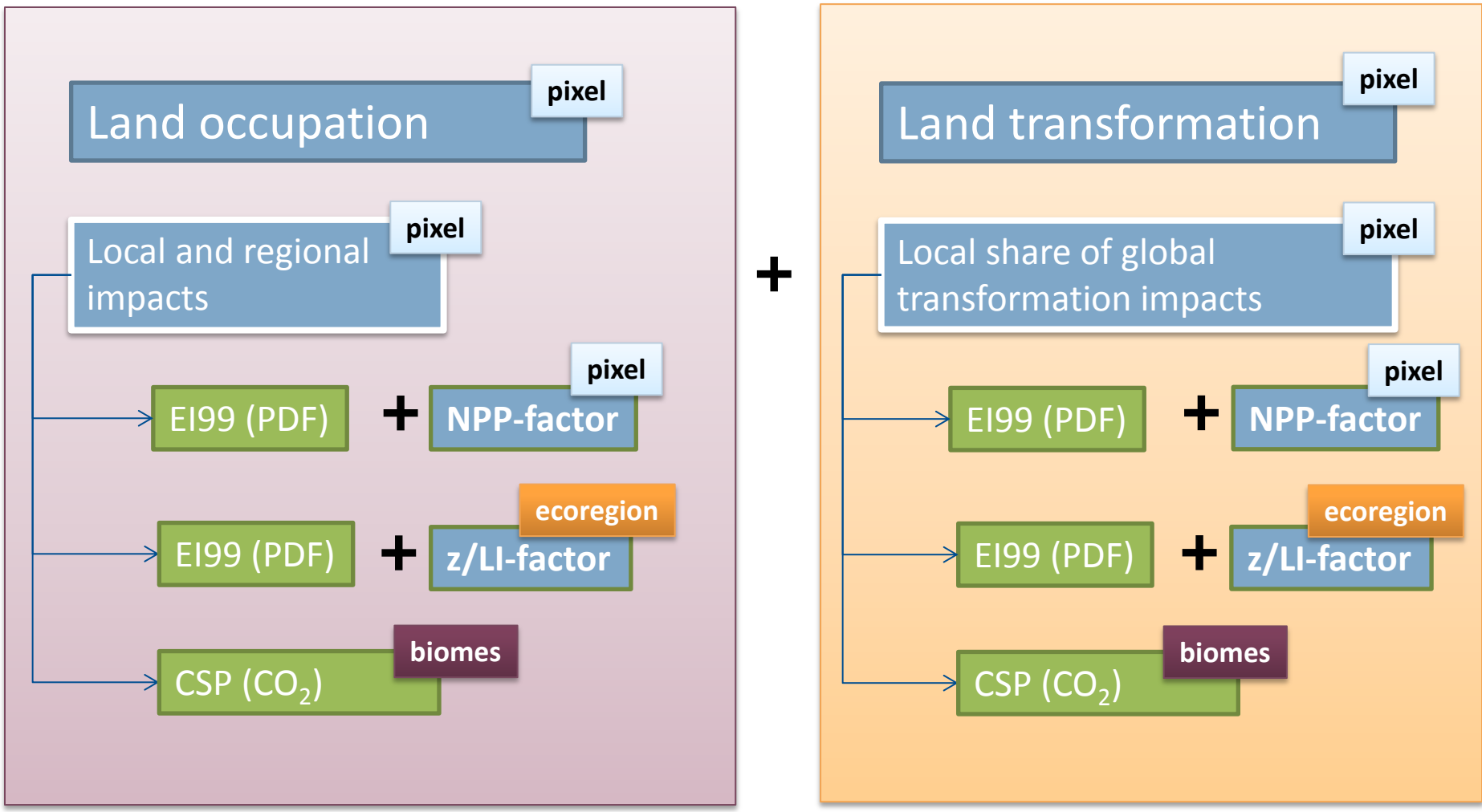
Land use impact assessment

According to EI99HA:

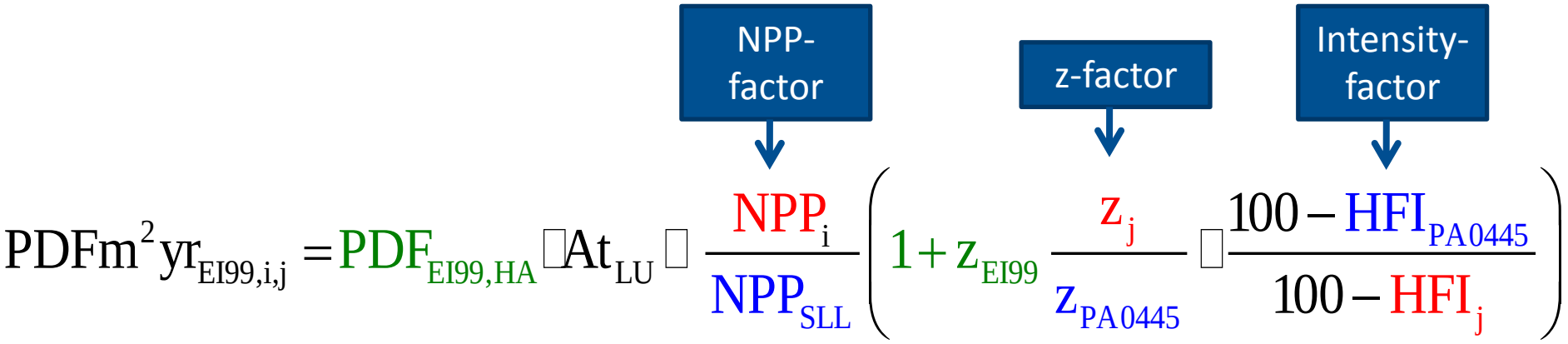
- Ecosystem quality (EQ):
  - Based on Köllner (2001): plant species richness, z-factor
  - Include ecosystem scarcity & vulnerablity (Weidema & Lindeijer 2001, Schmidt 2008)

- Carbon sequestration potential (CSP)
  - Based on Müller-Wenk & Brandao 2010
  - Apply EI99HA impact factors for GHG emissions

Impact assessment scheme



Regionalized ecosystem quality impacts



NPP_{SLL} = Reference NPP of Swiss lowlands **= 650g/m²yr**

z_{PA0445} = z factor of ecoregion PA0445 (Swiss lowlands)

HFI_{PA0445} = Human footprint index of PA0445 **= 31.5**

NPP-factor pixelwise **i** / vulnerability factor ecoregion-based **j**

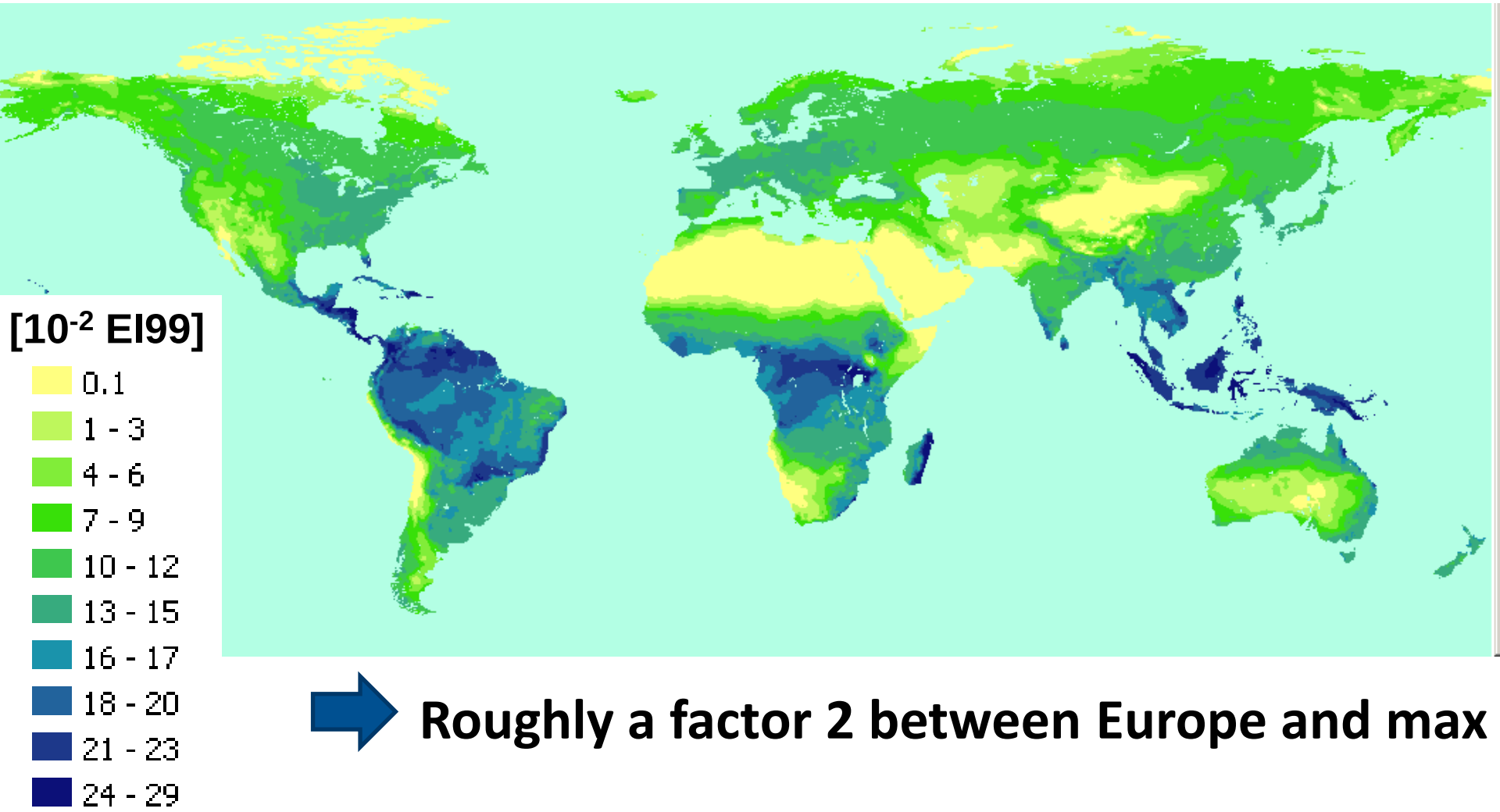
Transformation inclusion

- Occupation / Transformation
  - Transformation often very high (e.g. ~25% for German and Swiss rapeseed production according to ecoinvent)
  - Restoration time based on Schmidt (2008) and Weidema et al. (2001)

$$CF_{transformation,\,i} = \frac{IMPACT_{Global,year}}{area_{agri.year}} \square \frac{NPP_{0,i}}{NPP_{0,global}}$$

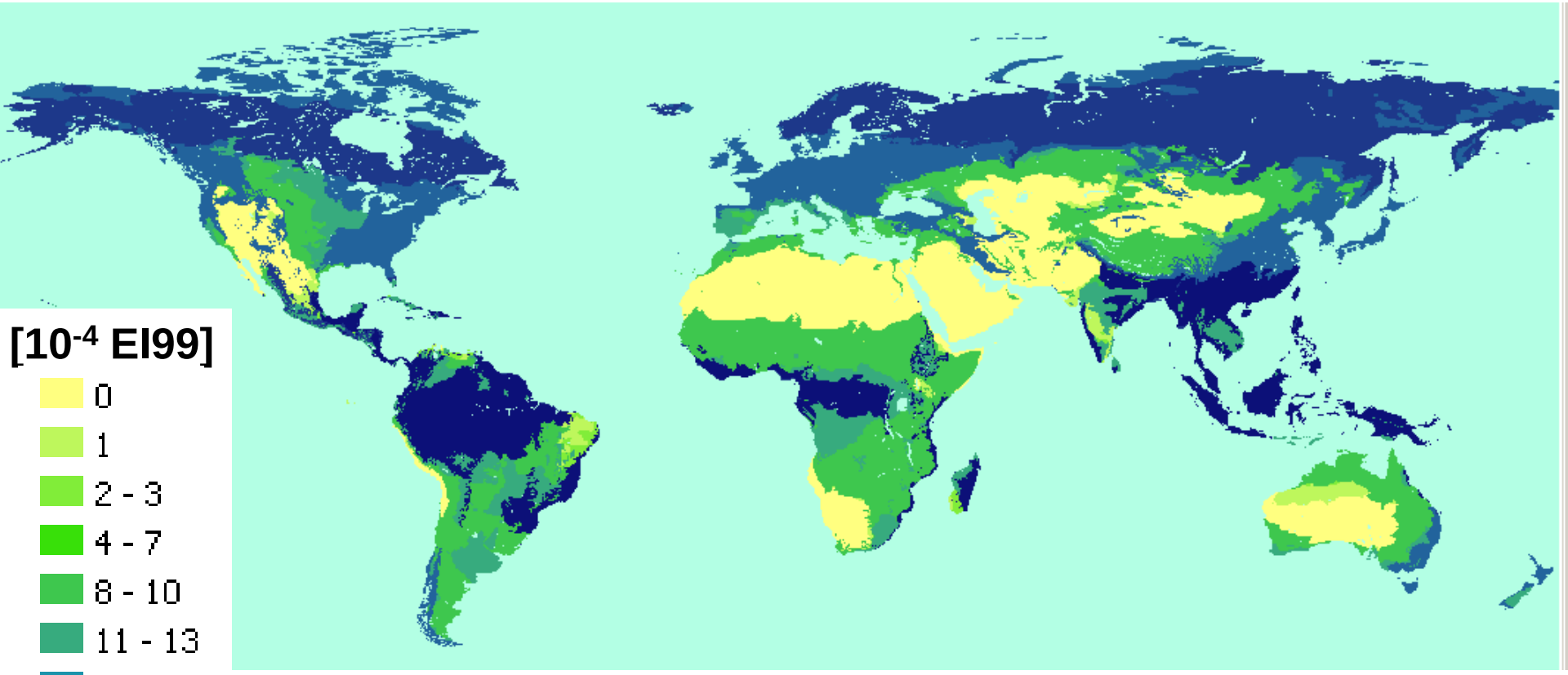
  - 0.41% transformation rate (based on past 20 and 100 year LU change assessment)

Ecosystem Quality impacts



Roughly a factor 2 between Europe and max

Climate change impacts

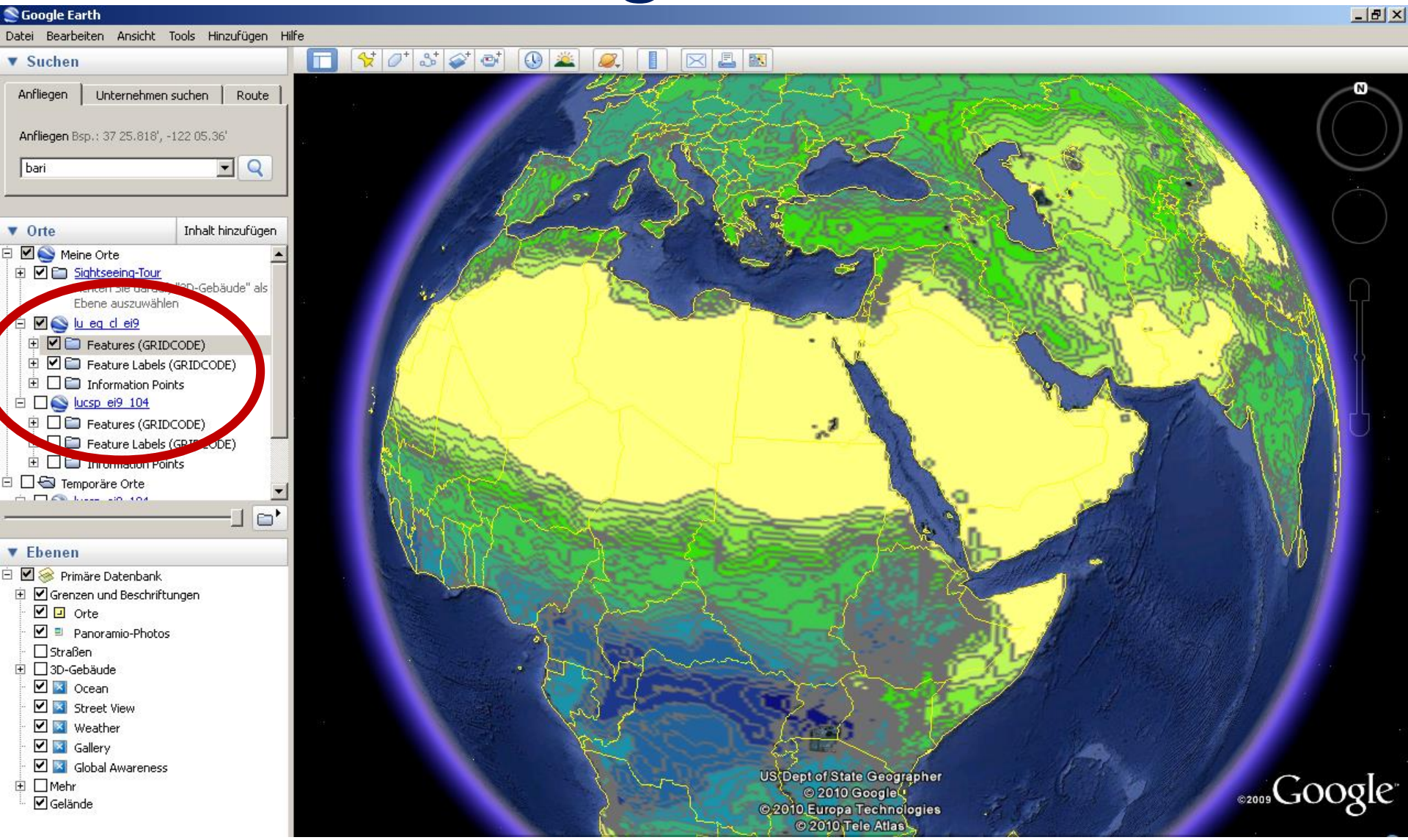


- CSP roughly 100 times lower than EQ
- similar pattern (except forcold climates)

Application of regionalized impact factors

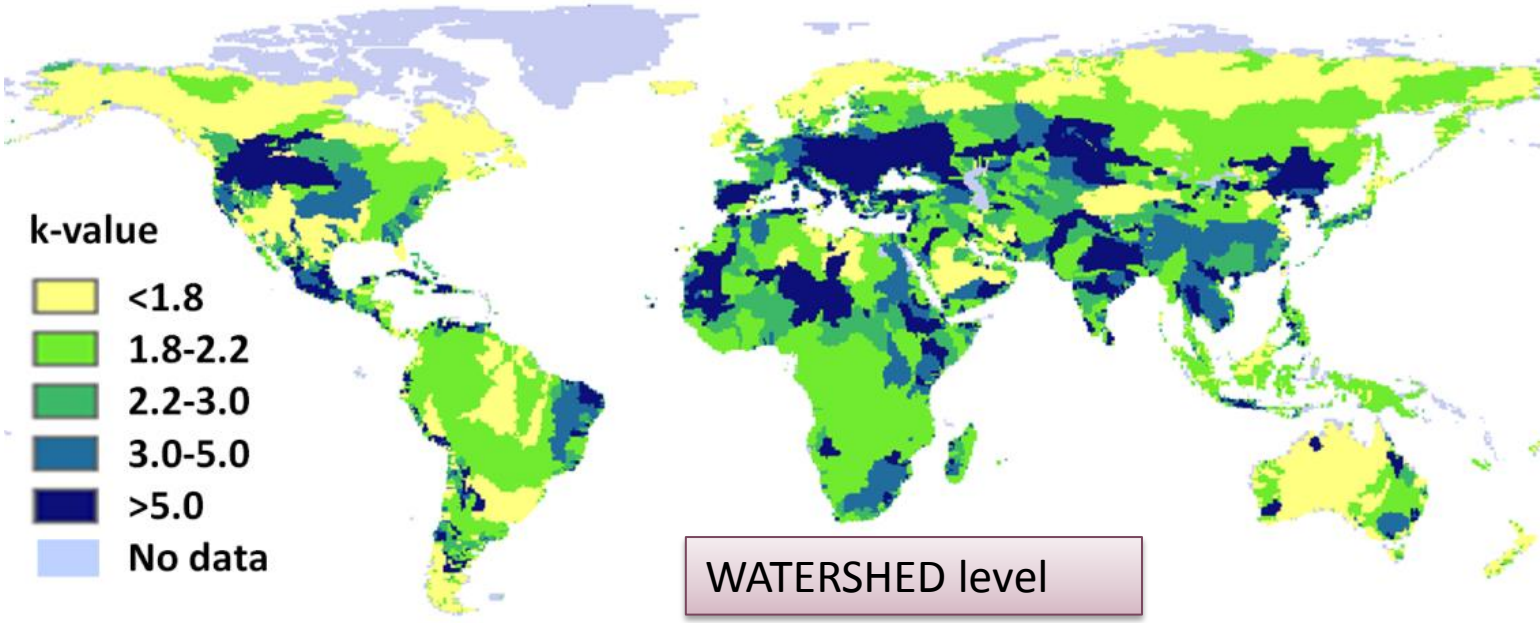
- Google Earth layer: impacts according to **EI99HA method:** www.ifu.ethz.ch/ESD/data
  - Download layer, double-click & read impact factors
  - Apply to inventories
  - Subtract standard land occupation and transformation impacts (including related CO2 emissions)

Google Earth

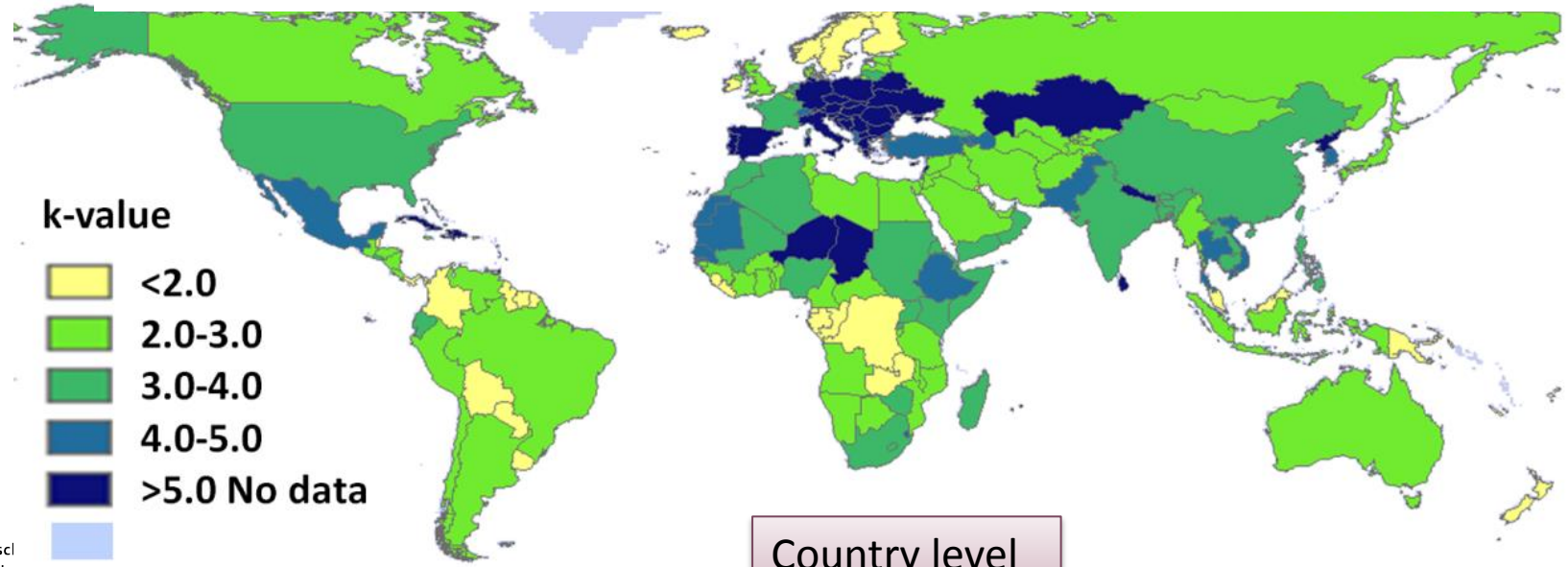


Uncertainty WSI (Pfister & Hellweg 2011)

K-value:
Mean */ k-value includes 95% interval



WATERSHED level



Country level

P emissions

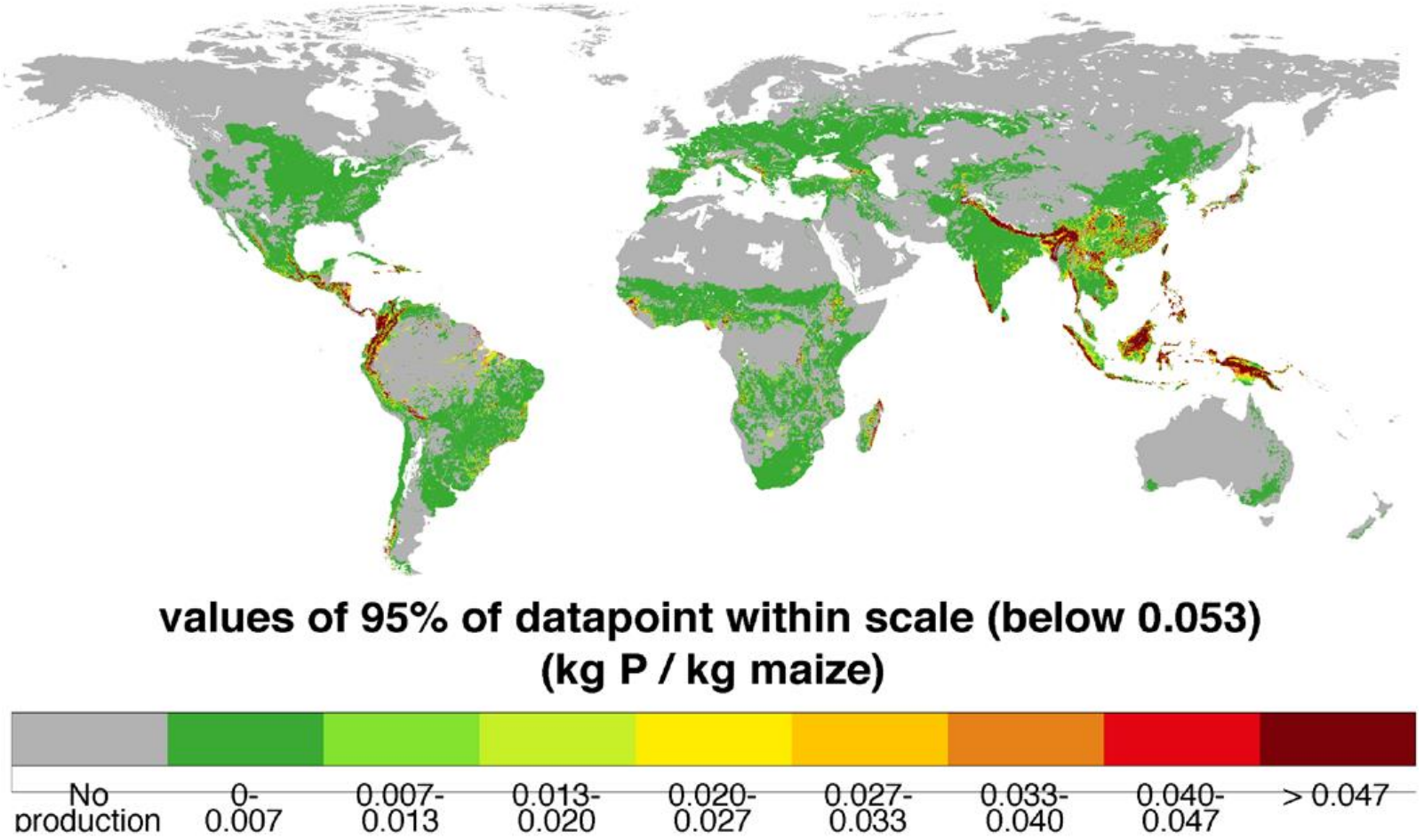
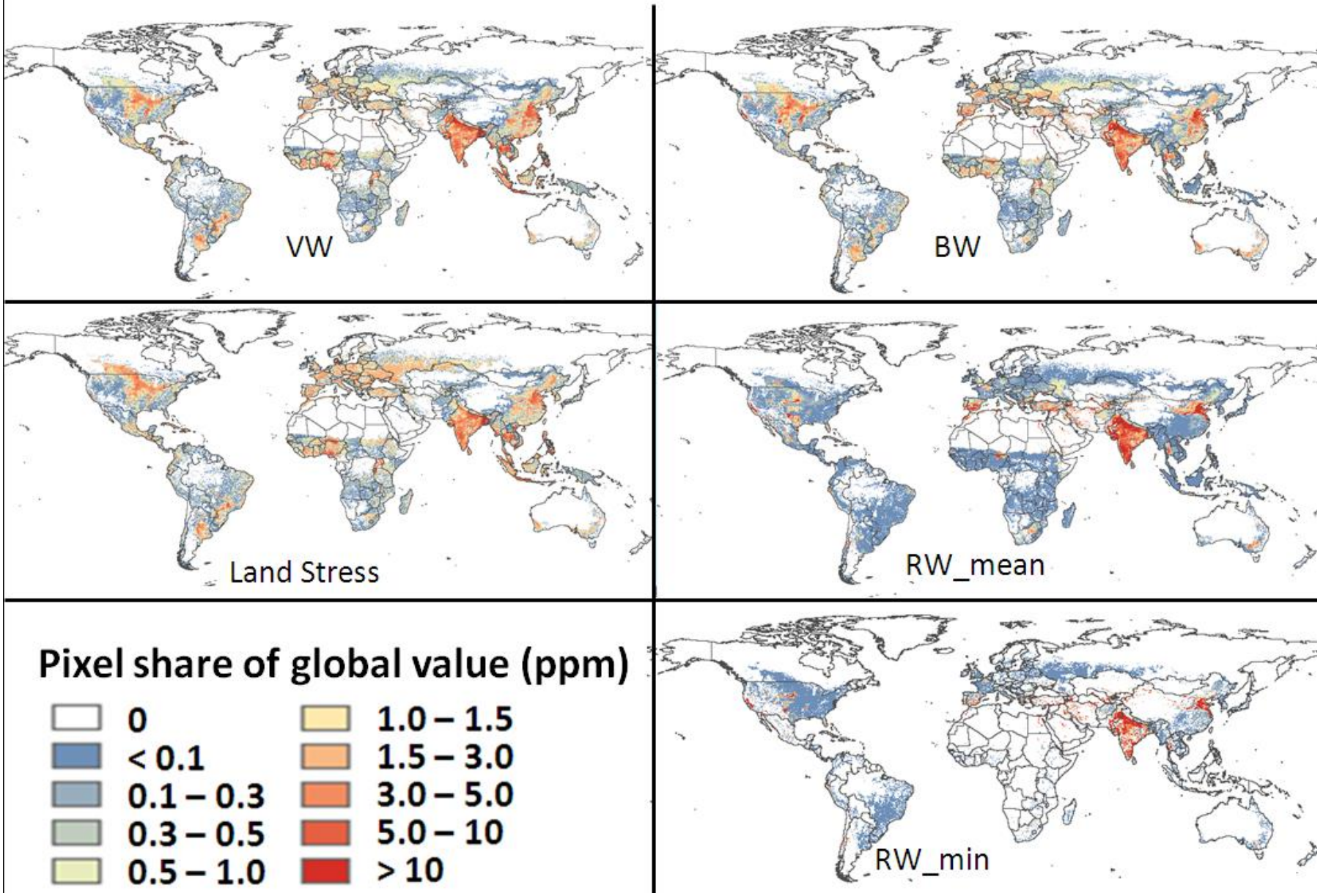


Figure 3. Emission of phosphorous to aquatic environment per kg harvested maize as a result of fertilizer application in agriculture based on Potter et al. (2011)

LCA database: Ecoinvent 3

- >5000 processes included
- Physical water flows are recorded
  - Water input from sea, surface water, groundwater and from air (precipitation)
  - Water output to sea, to surface and ground water and to air (evaporation)
  - Product integration (inputs and outputs)
- Quality issues are addressed by emission to water and resource use from water
- Regional information attached as shapefile information
  - So far **not beyond country level**

Pixel shares of total global values



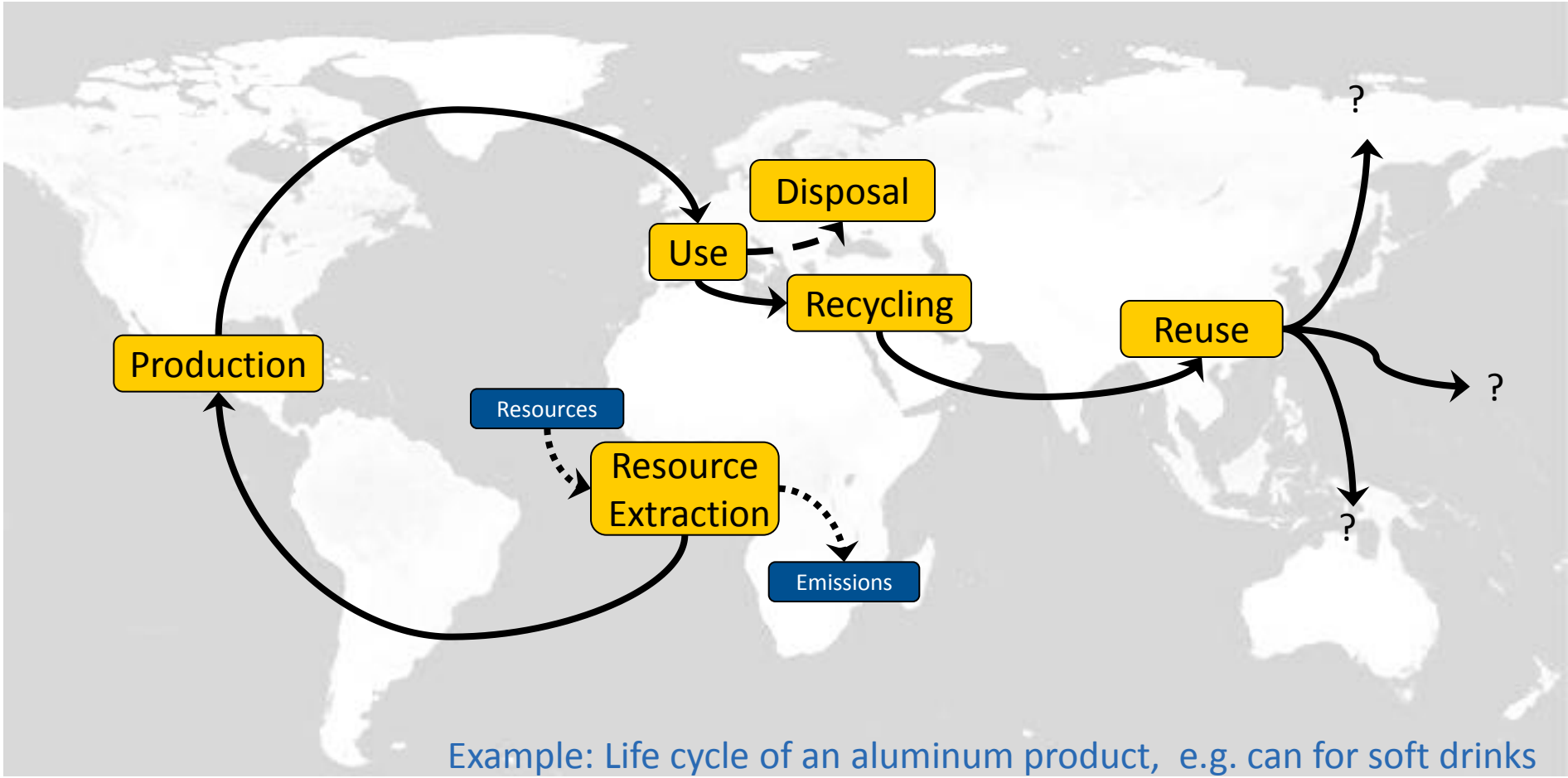
Spatial differentiation of new method from EU project

Impact category	Global level	Country level	Sub-country level
climate change	✓		
ionising radiation	✓		
photochemical ozone depletion	✓	✓	
particular matter formation	✓	✓	
terrestrial acidification	✓	✓	✓
freshwater eutrophication	✓	✓	✓
marine eutrophication	✓	✓	✓
freshwater ecotoxicity	✓		
human toxicity	✓		
marine ecotixicity	✓		
terrestrial ecotoxicity	✓		
land stress	✓	✓	✓
water stress (ecosystems)	✓	✓	✓
water stress (human health)	✓	✓	✓
fossil resources depletion	✓		
metals resources depletion	✓		

LC-IMPACT

Methods available: http://www.lc-impact.eu/downloads

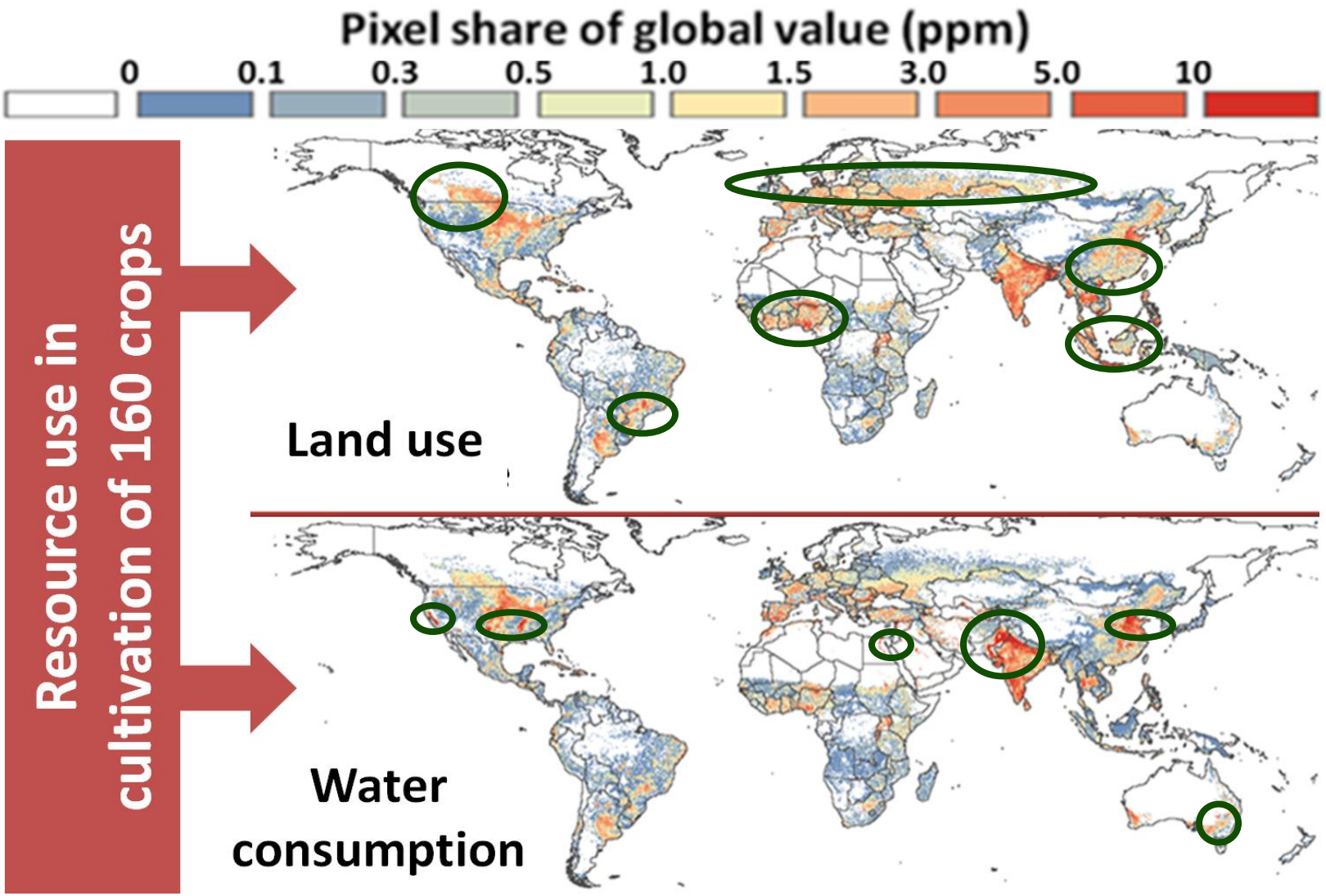
Ökobilanz-Ansatz



Example: Life cycle of an aluminum product, e.g. can for soft drinks

Neu Regionalisierung auf Länder- oder Einzugsgebietsebene

Situation in the year 2000



Germany

Distribution of water consumpiton impacts of final consumption