Environmental Impacts of Water Consumption in Global Crop Production

LCA Discussion Forum

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Stephan Pfister, Peter Bayer, Annette Koehler, Stefanie Hellweg

ETH Zurich, Institute for Environmental Engineering,
Ecological Systems Design Group

Motivation

- Agriculture is globally the most important sector concerning water consumption
- LCA increasingly used in decision making, but so far often neglect water-consumption

→ Need for comprehensive tools to assess and improve the environmental impacts of agricultural products

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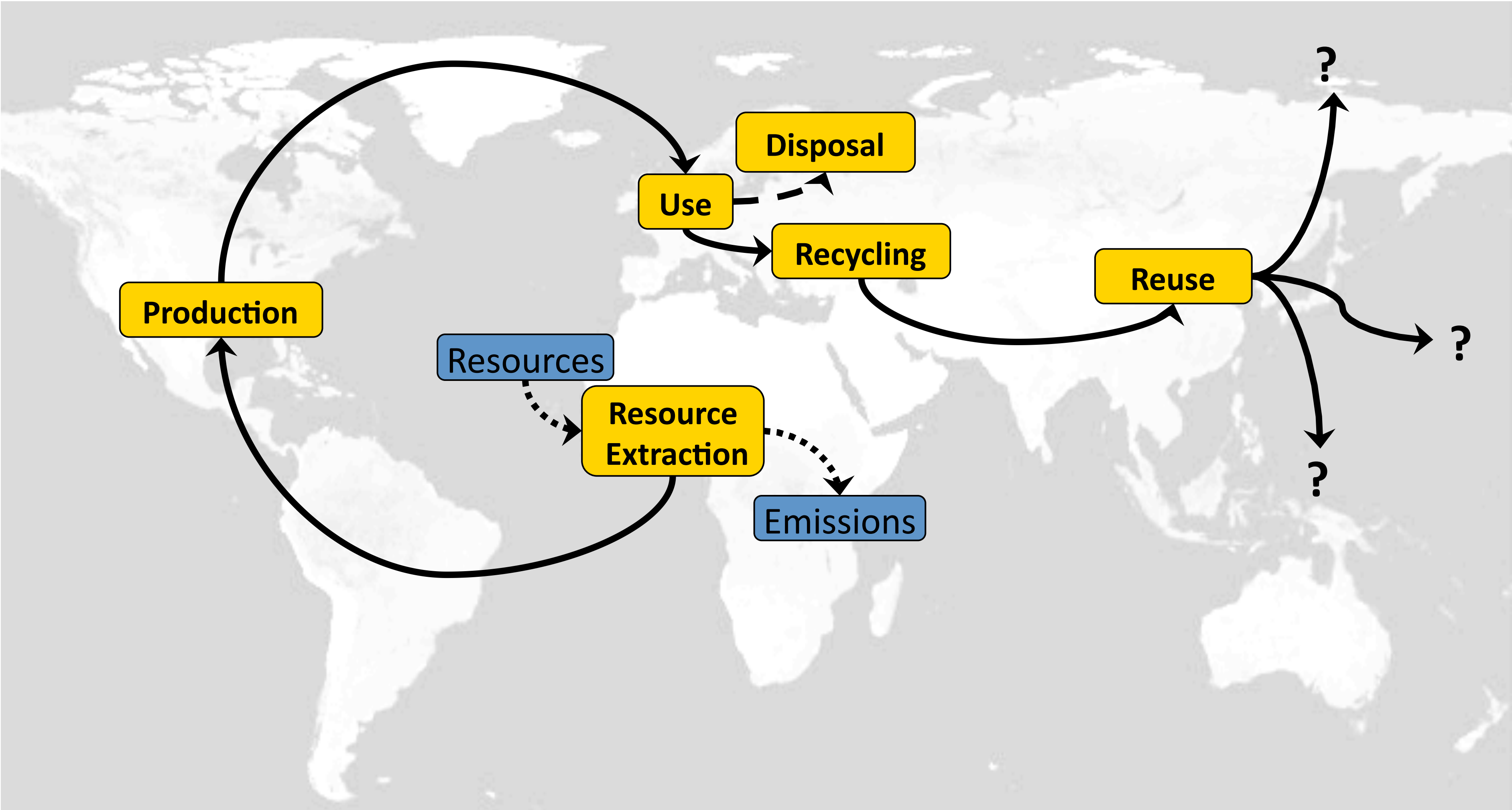
Global value chains

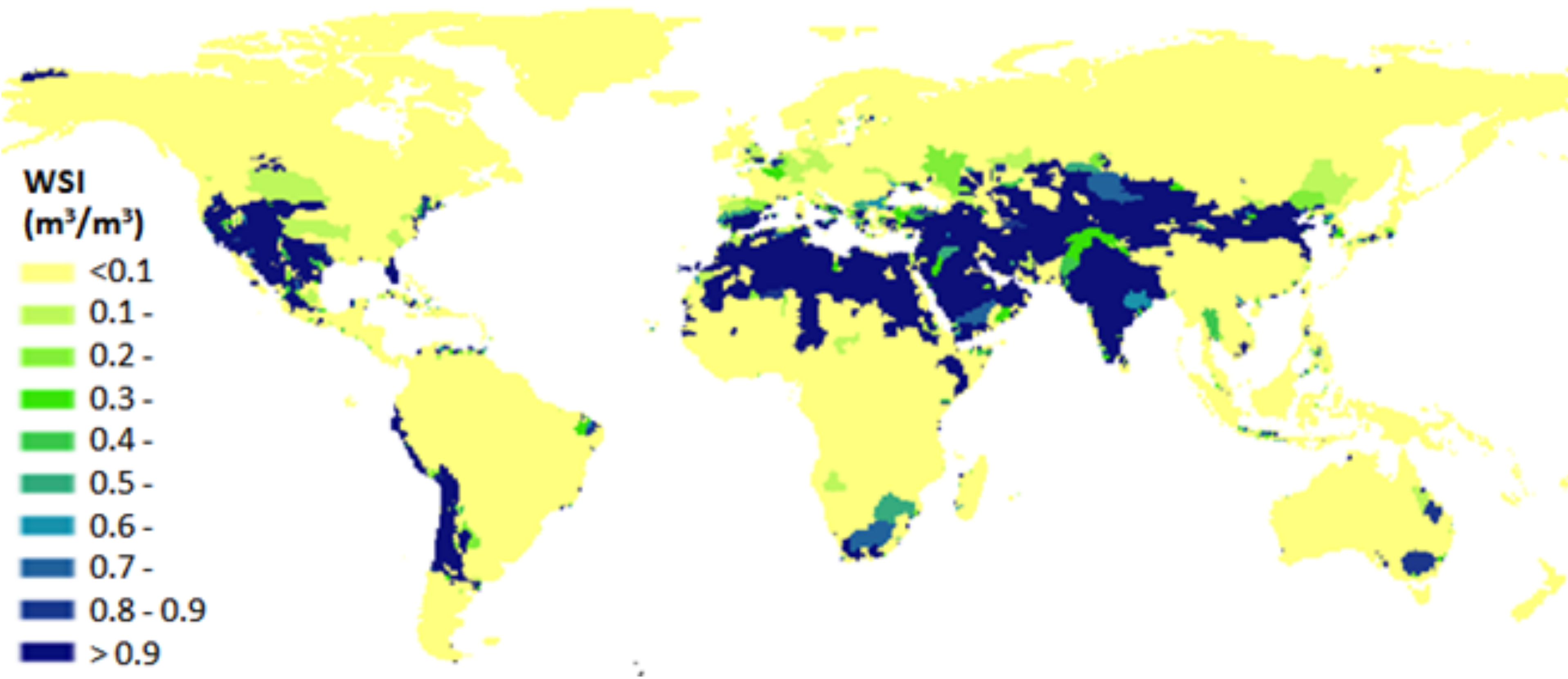


Inventory analysis: Modelling land use and water consumption of crop prodution (160 crops)

- High spatial resolution (~10 km resolution)
  - Crop production in 2000 (Monfreda et al. 2008)
    - Yield and crop cultivation data based on statistics and remote sensing
  - Water consumption:
    - FAO approach and irrigation maps
  - Land use:
    - based on yields and growth periods

Detailed results available for 160 individual crops:
Pfister et al. (2011) **Environmental impacts of water use in global crop production: hotspots and trade-offs with land use**. *ES&T*, online

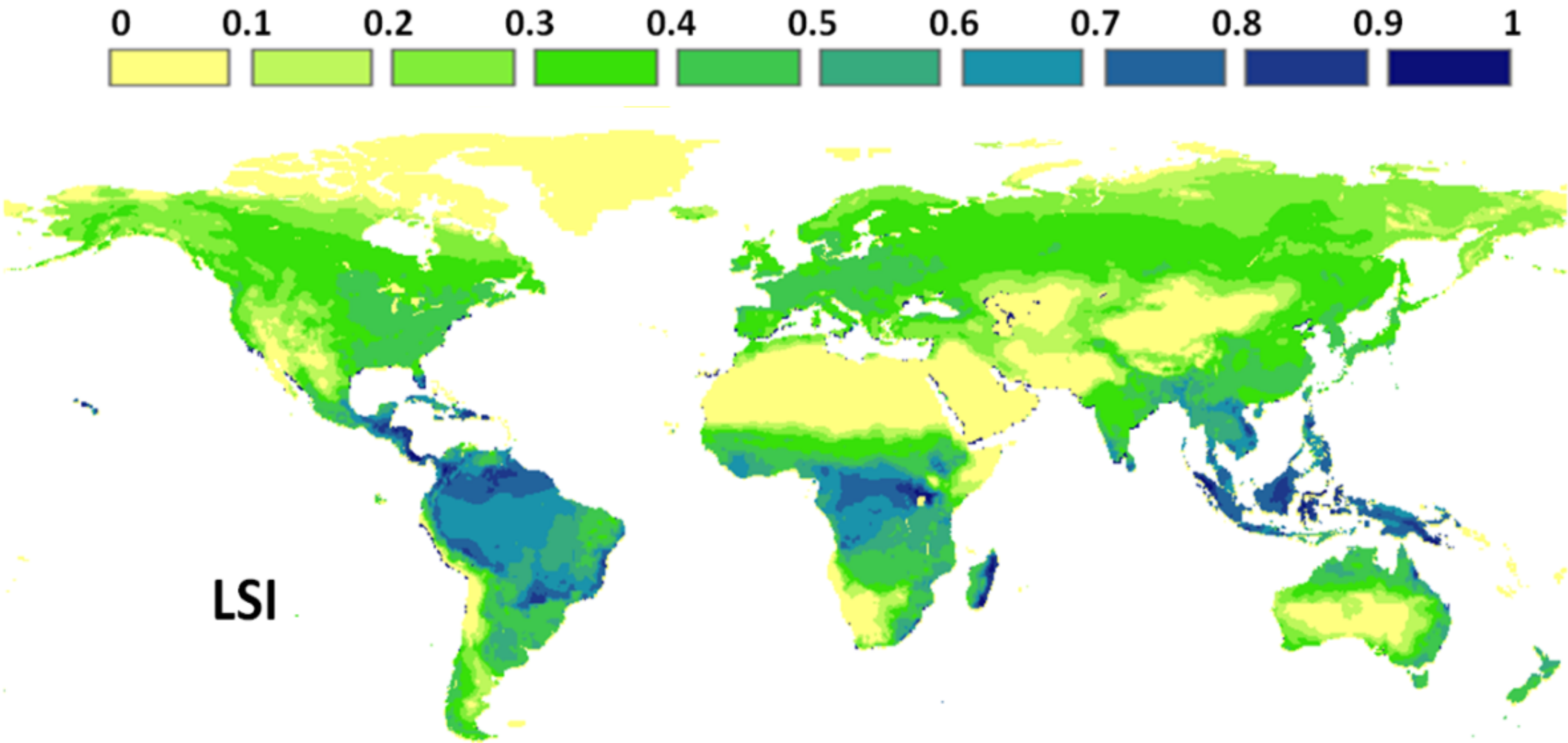
LCIA: Water stress index (WSI)



→ **Takes into account water availability, use, and seasonal/annual variation in precipitation .**

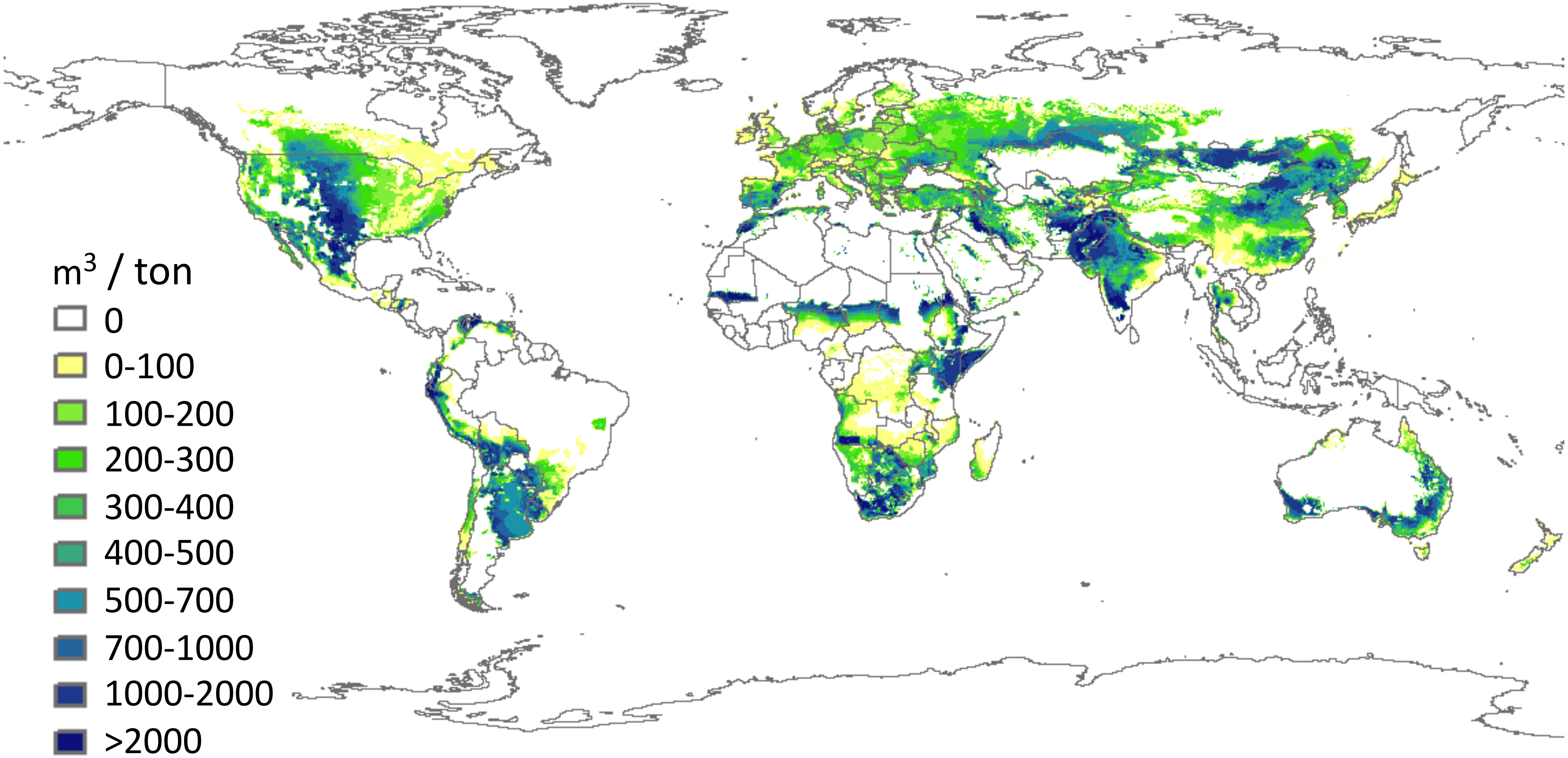
Pfister S, Köhler A, Hellweg S, ES&T 43, 4098 – 4104, 2009 (based on data from Alcamo et al.)

LCIA: Land stress index (LSI)



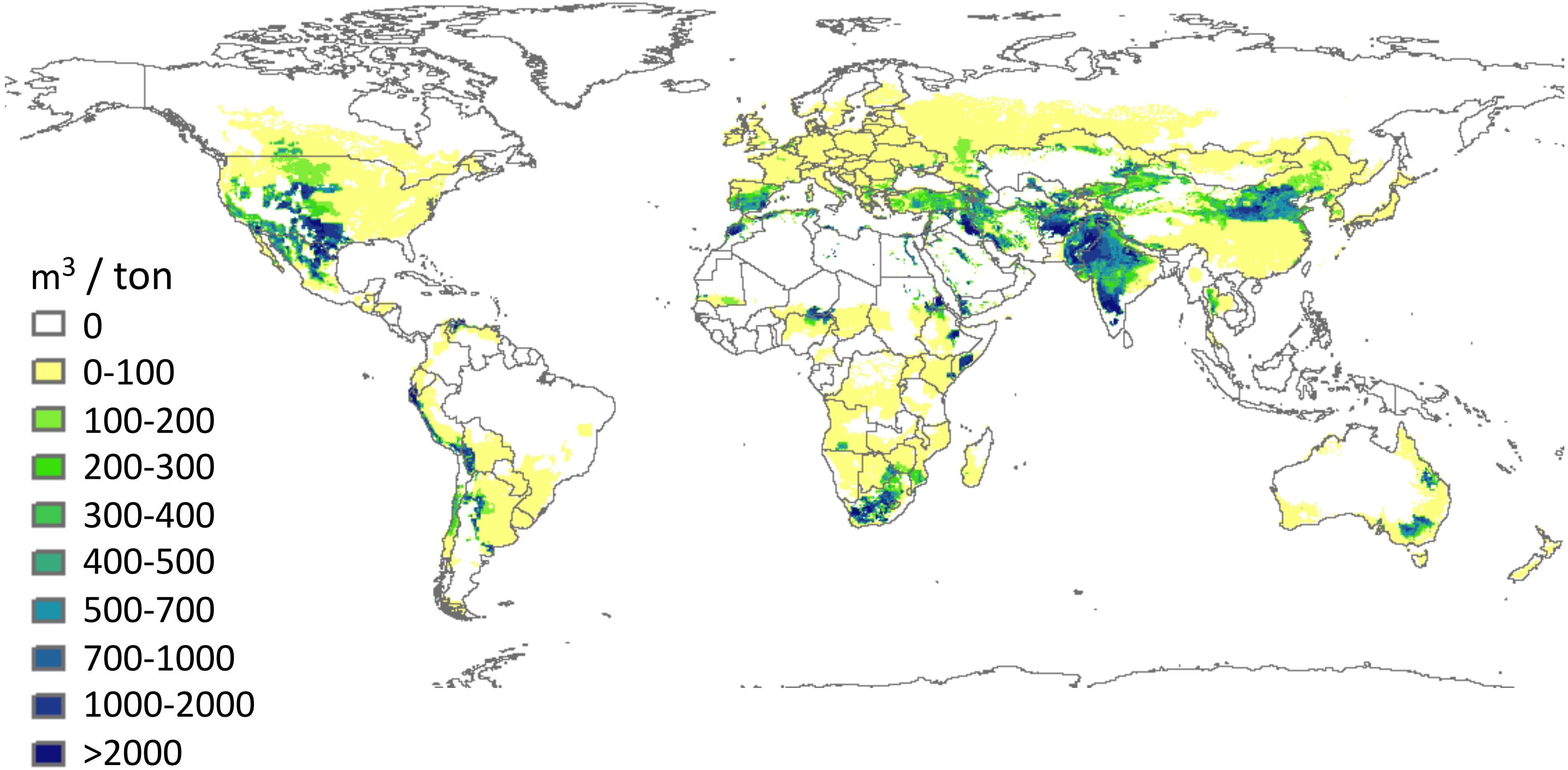
LCI results: Irrigation water consumption of wheat cultivation

[Volume/output]



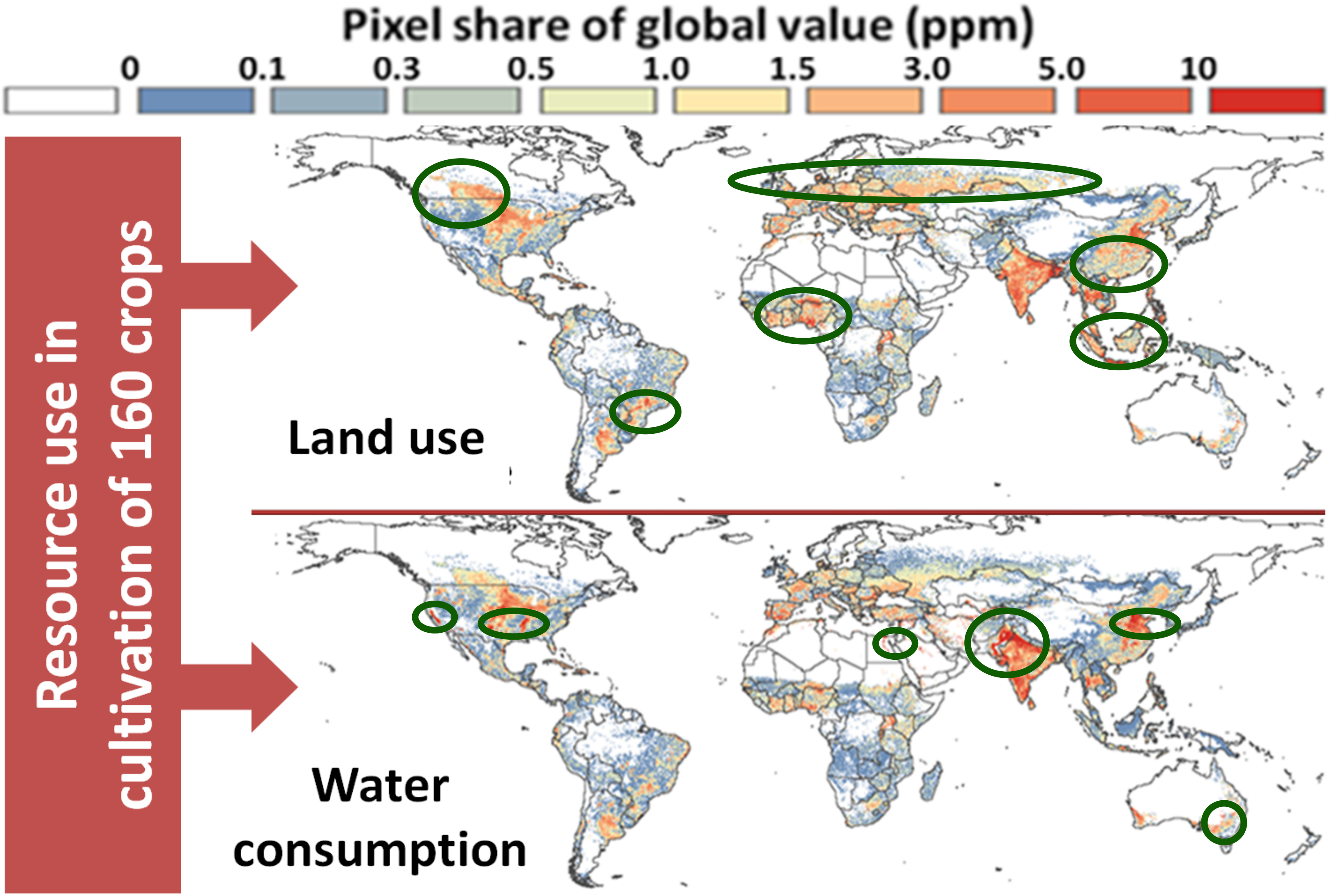
LCIA results: Water deprivation from wheat cultivation

[WSI-weighted volume/output]

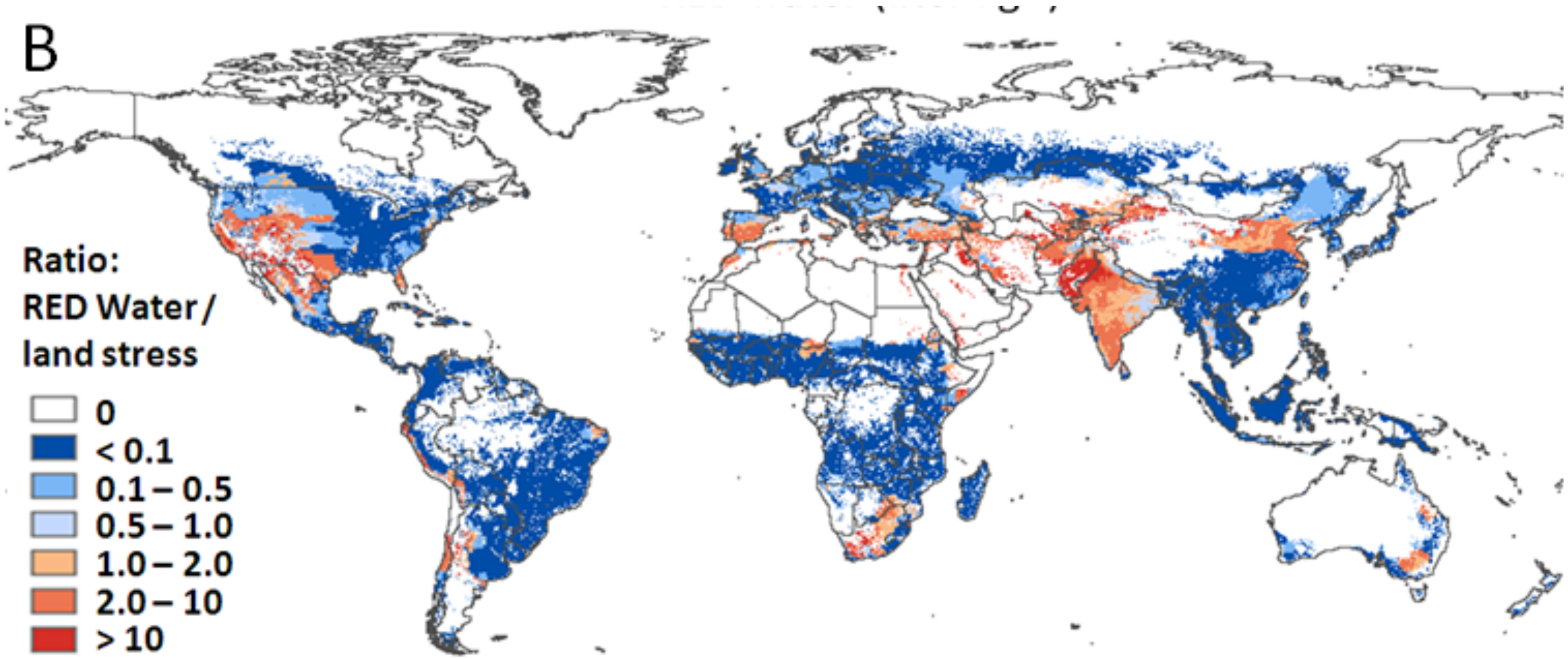


Tradeoff between land and water impacts of wheat cultivation

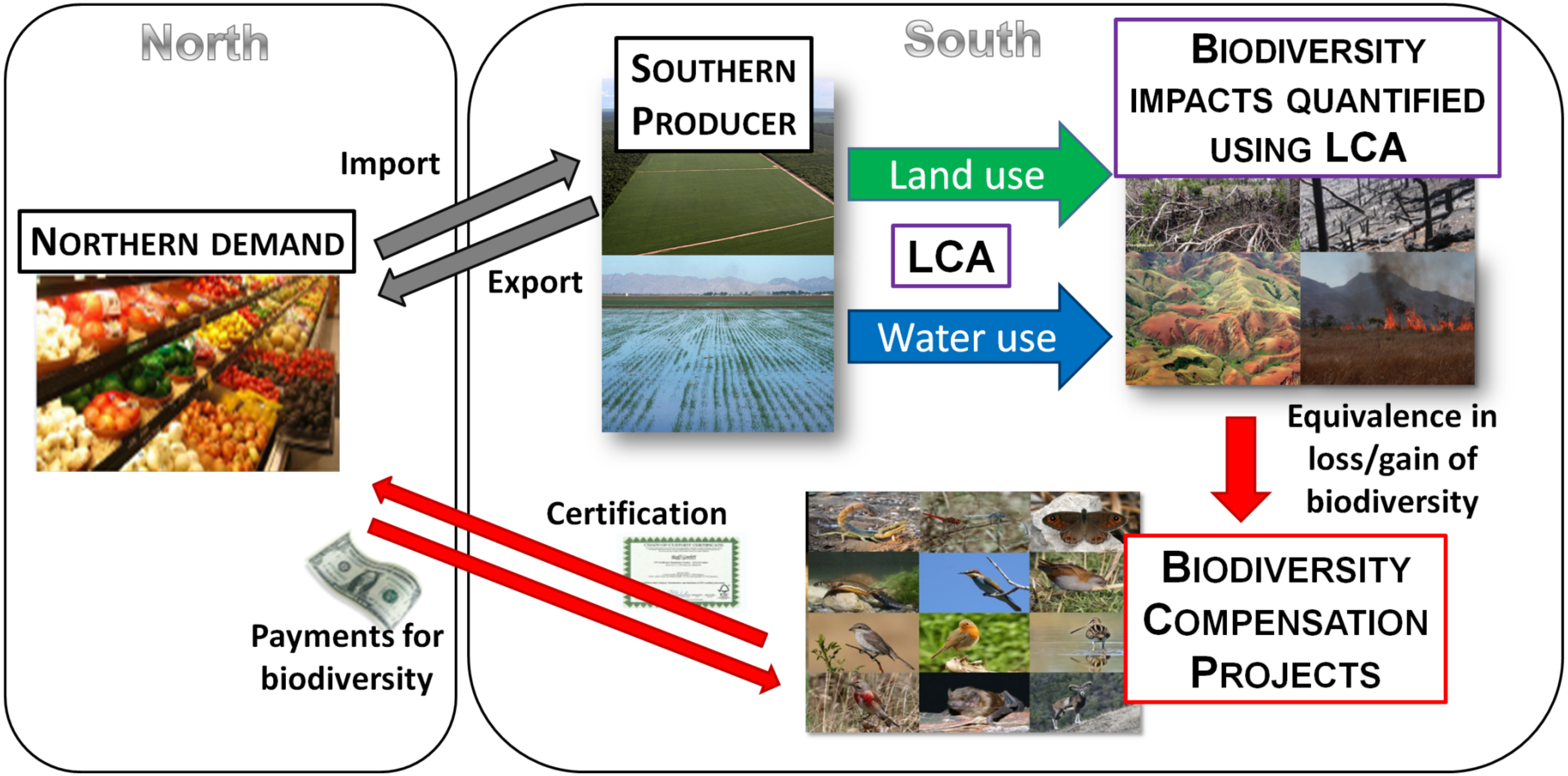
Situation in the year 2000



Tradeoff between Water and Land Use

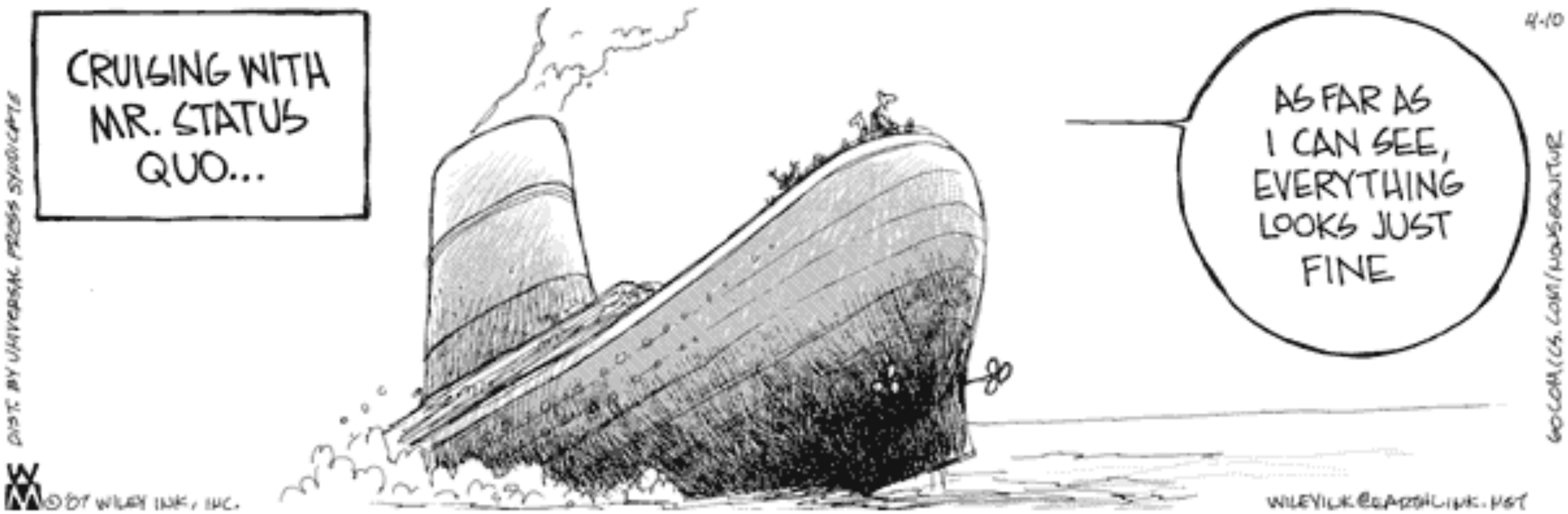


Outlook „myEcosystem“



Ph.D. F. Verones, L. deBaan, M. Curran

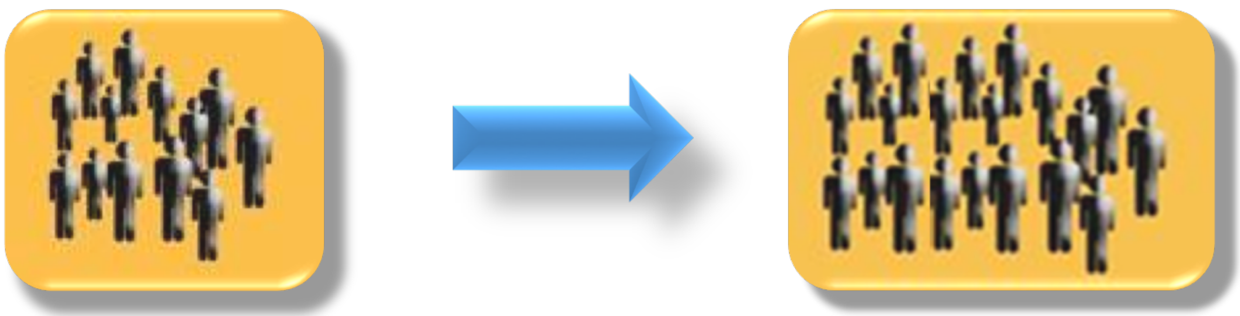
Future scenarios



Future scenarios

IPCC A1B scenario: 9 billion people

2000 **2050**



+50%

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Scenarios 2050

- 60% additional food energy supply
  - Intensification**: Full irrigation** and fertilization & **50% food waste reduction**

Minimal land use

  - Expansion on **suitable area** for rainfed agriculture:
    - Maize and wheat (Fischer et al. 2000)
    - Expansion on pasture

Minimal water consumption

Scenarios 2050

- 60% additional food energy supply
  - Intensification**: Full irrigation** and fert… **…0% food waste reduction**
  - Expansion on **suitable** a…
    - Maize and wheat (…
    - Expansion o… **…al water consumption**

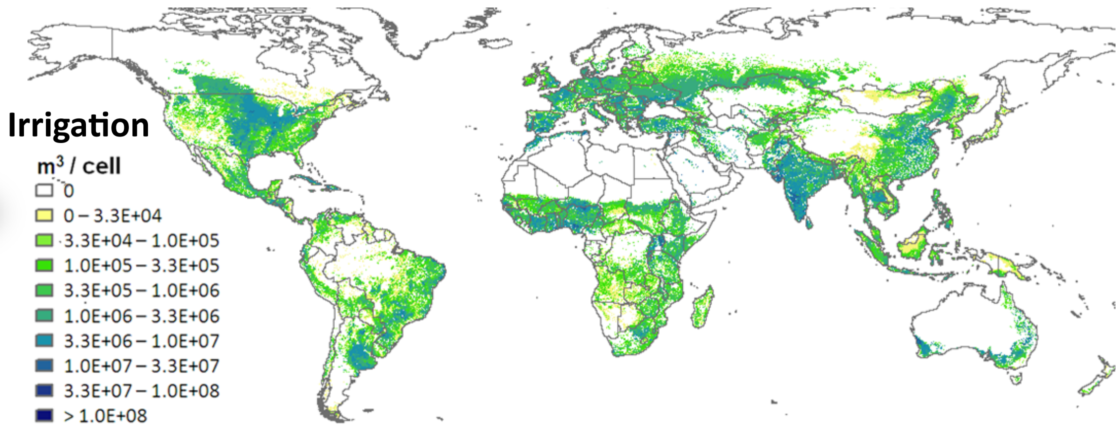
Best practice
&
No market distortions

Results irrigation water consumption

Strategies:

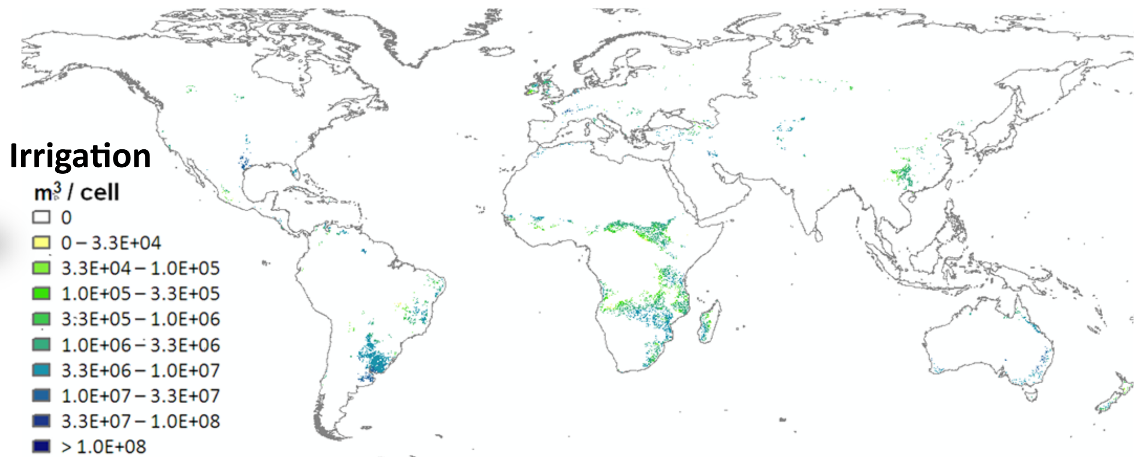
– Intensification & waste reduction

Irrigation:
+ 1125 km³ (64%)



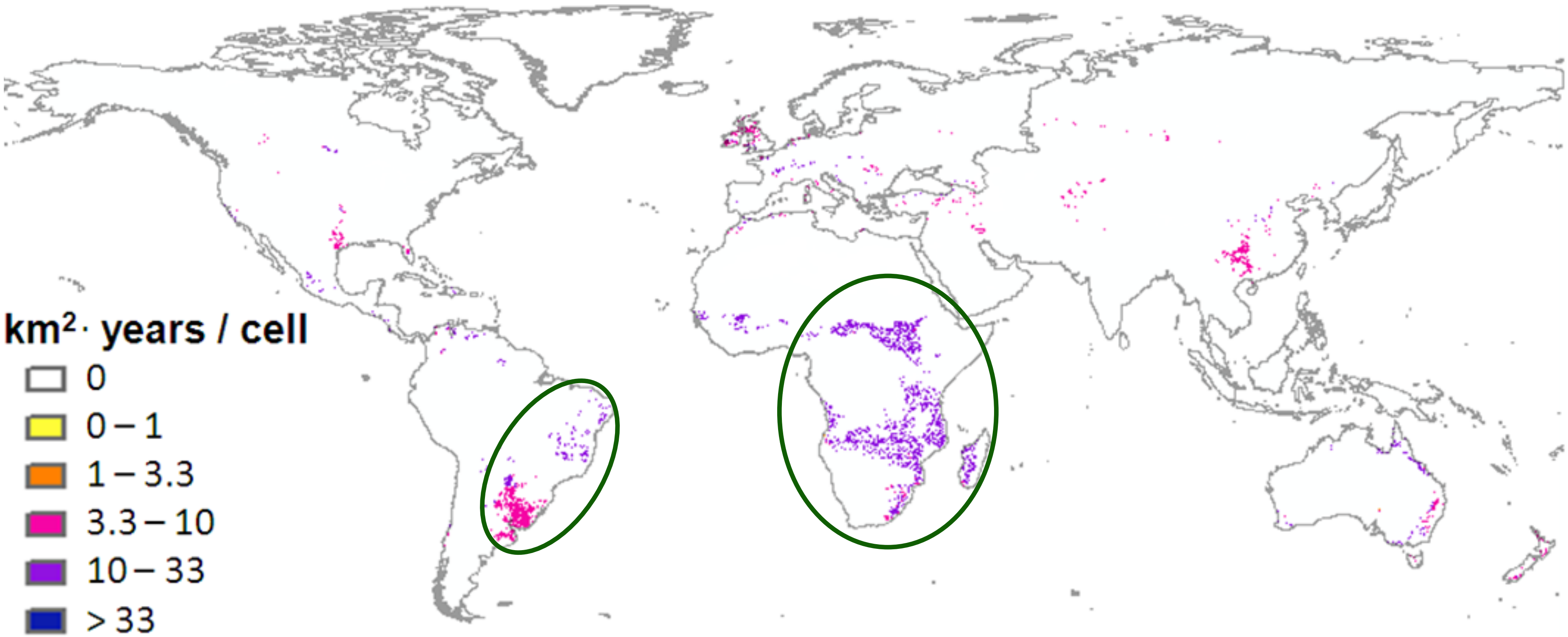
– Expansion on pastures

Irrigation:
+169 km³ (10%)



Expansion: Land stress

- Mainly in Africa (ca. 2/3)
- followed by South America (ca. 1/4)



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Conclusions

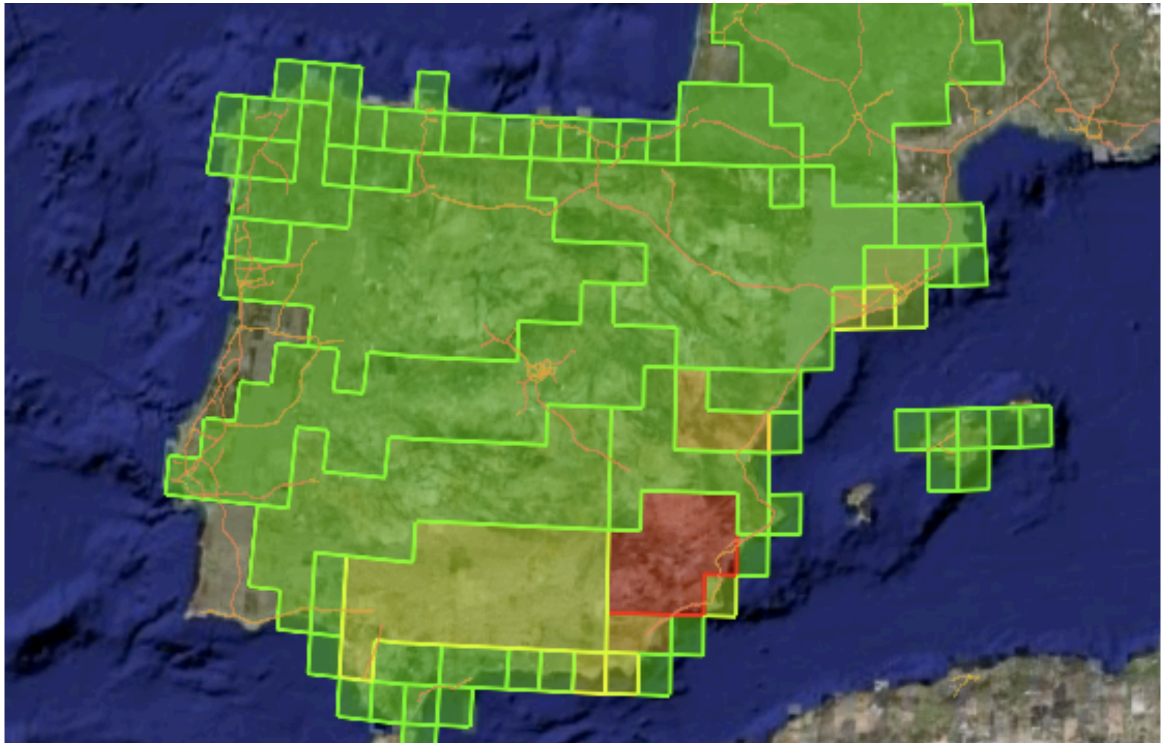
- Pressure on water and land resources is already high in some areas and will be amplified in the future
- Methods for spatially resolved inventory and impact assessment are becoming available for water and land use → facilitates LCA as decision-support tool for product-related decisions of retailers, producers, consumers
- International cooperation is necessary to minimize global environmental impacts

Backup Slides

Results scenarios

	Scenario 1 (efficient intensification)	Scenario 2 (expansion on pastures)	Scenario 3 (rainfed expansion)	Scenario 4 (expansion and intensification)
Total Water (km^3)	1’203 (+22%)	1’088 (+20%)	1’077 (+20%)	2291 (+42%)
Irrigation Water (km^3)	**1’125 (+64%)**	**169 (+10%)**	**142 (+8%)**	**1’294 (+73%)**
Average WSI	0.569	0.484	0.479	0.559
Land stress (1000 km^2*yr)	none	**552 (+14%)**	**534 (+14%)**	**552 (+14%)**
Irrigation water land-stress equivalent (1000 km^2*yr)	450 (+64%)	68 (+10%)	57 (+8%)	518 (+73%)
Total land-stress equivalent (land & water) (1000 km^2*yr)	450 (+10%)	620 (+14%)	591 (+14%)	1070 (+24%)
Total land-stress **equivalent / edible energy produced** (m^2*yr / 1000 kcal)	**0.28 (-13%)**	**0.23 (-29%)**	**0.23 (-29%)**	**0.21 (-33%)**

GIS Integration in a pilot software: example of strawberry production in Spain



Kestenholz 2008

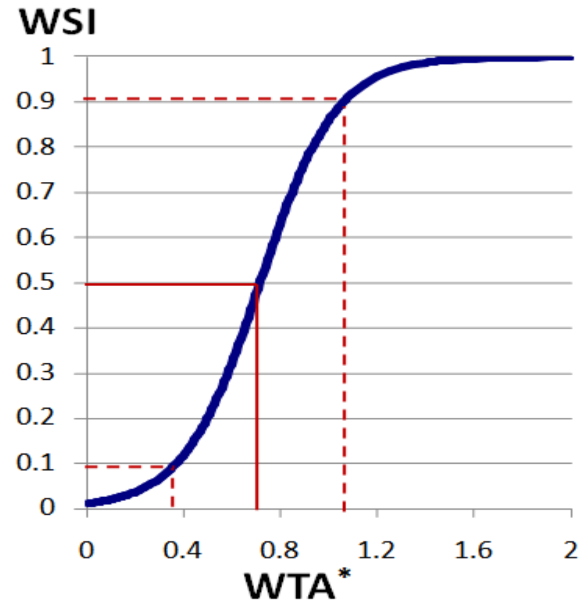
Midpoint CF: Water Stress Index (WSI)

- **Includes**:
  - Withdrawal to availability (WTA)
  - Variability in precipitation (VF)
  - Flow regulation (highly regulated = SRF)

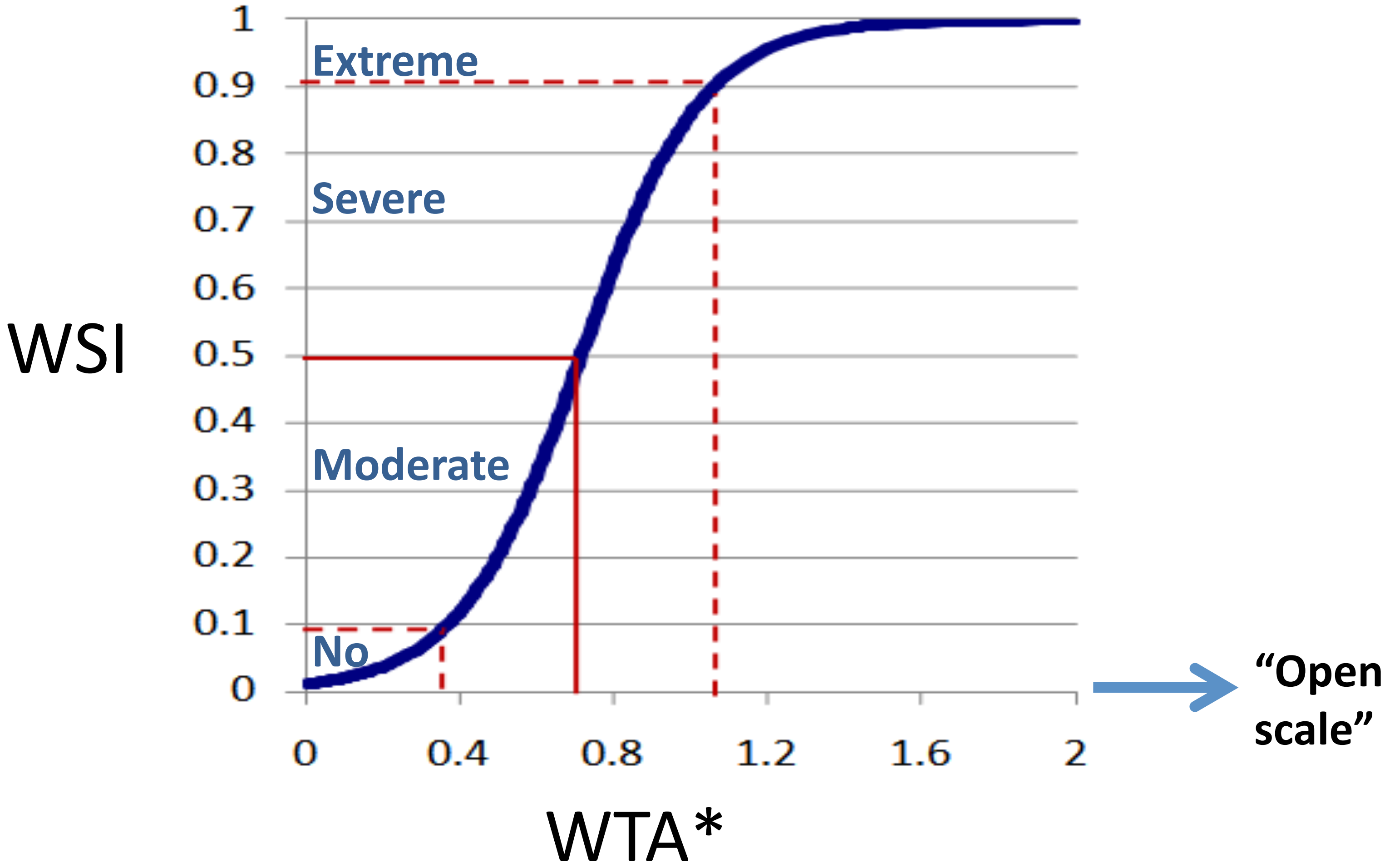
$$WTA^* = \begin{cases} \sqrt{VF} \times WTA & for\ SRF \\ VF \times WTA & for\ non\text{-}SRF \end{cases}$$

- **Index** following logistic function:

$$WSI = \frac{1}{1 + e^{-6.4 \cdot WTA^*} \left(\frac{1}{0.01} - 1\right)}$$



Water stress index (WSI)



Impacts on resources

- Depletion of water stocks: overuse

$$F_{depletion,i} = \begin{cases} \frac{WTA - 1}{WTA} & for \;\; WTA > 1 \\ 0 & for \;\; WTA \leq 1 \end{cases}$$

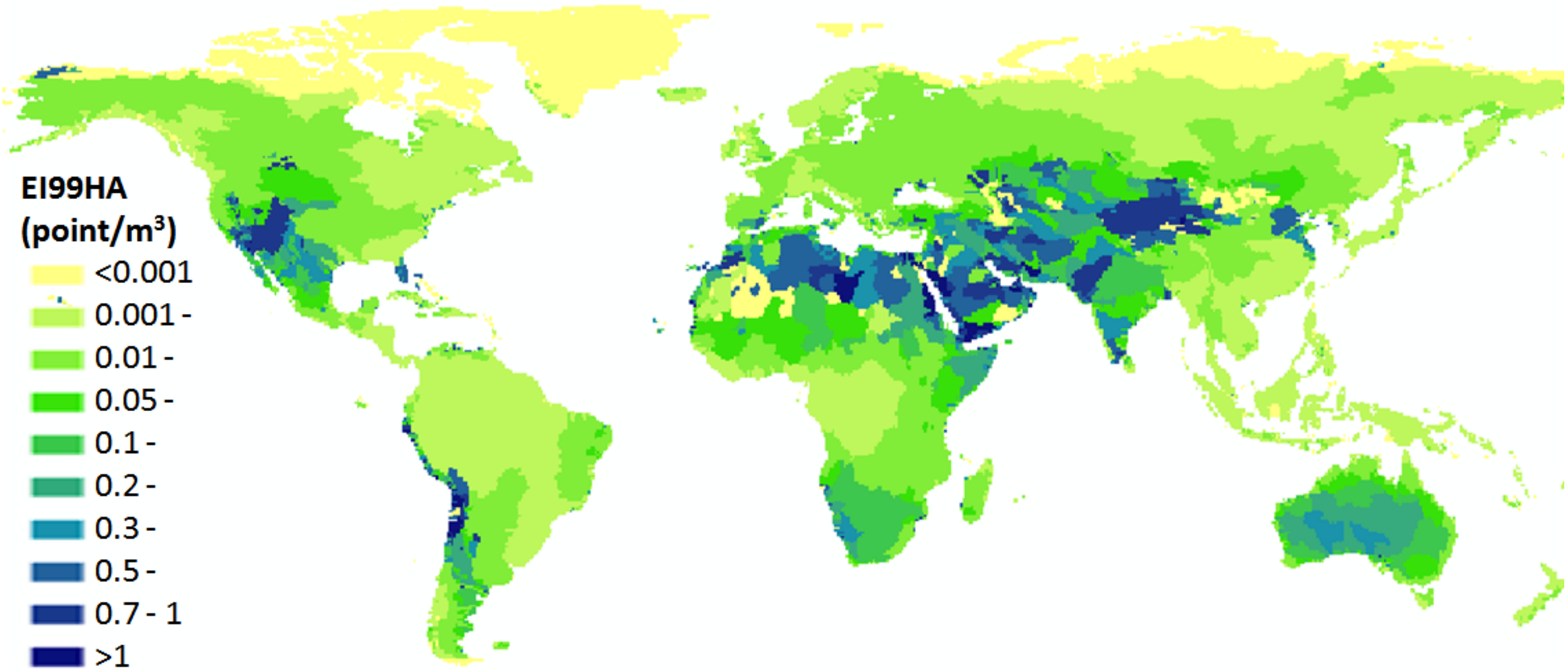
- Desalination as backup technology

$$\Delta RD = F_{depletion} \cdot MJ_{surplus} \cdot WU_{consumptive}$$

Pfister, Koehler & Hellweg (2009), ES&T 43(11): 4098–4104

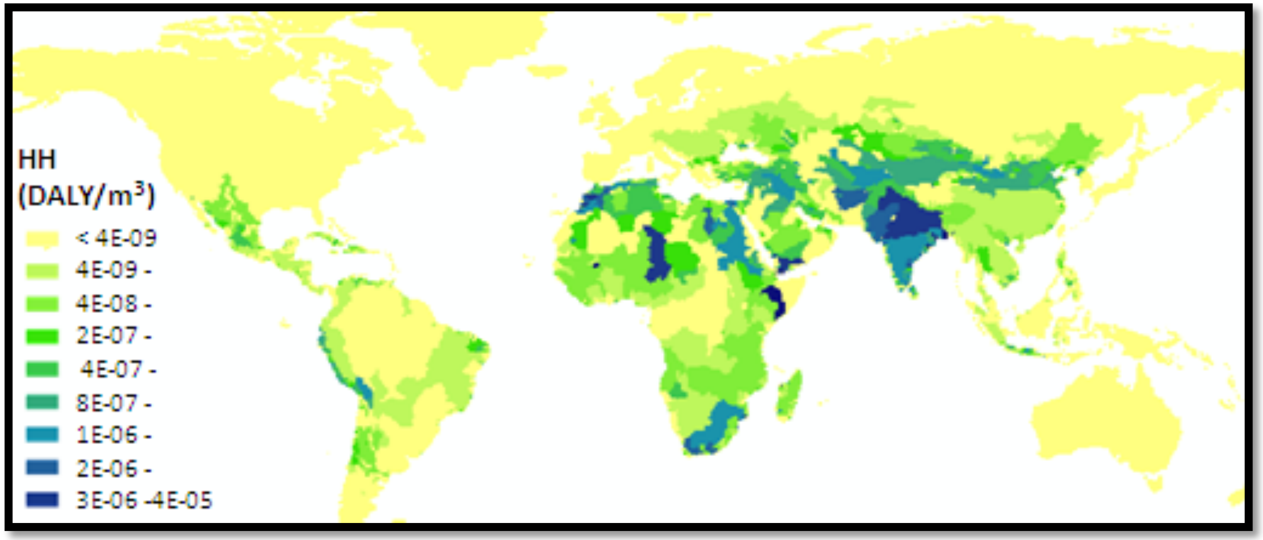
Aggregated damage factors

For comparing overall relevance of water consumption in "ecoindicator 99" method



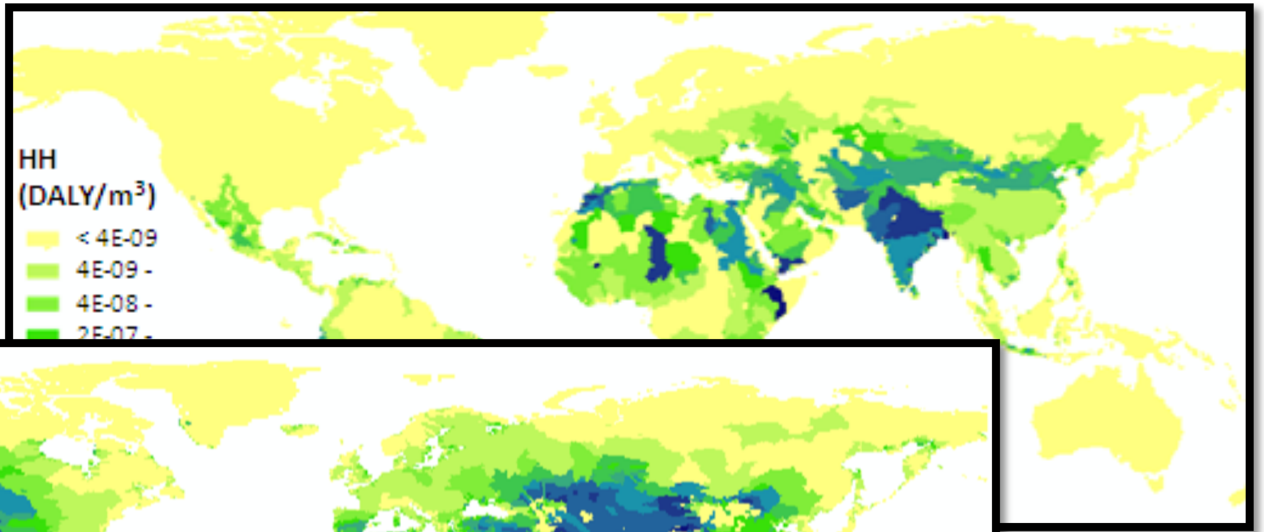
Damage factors

Impacts on human health

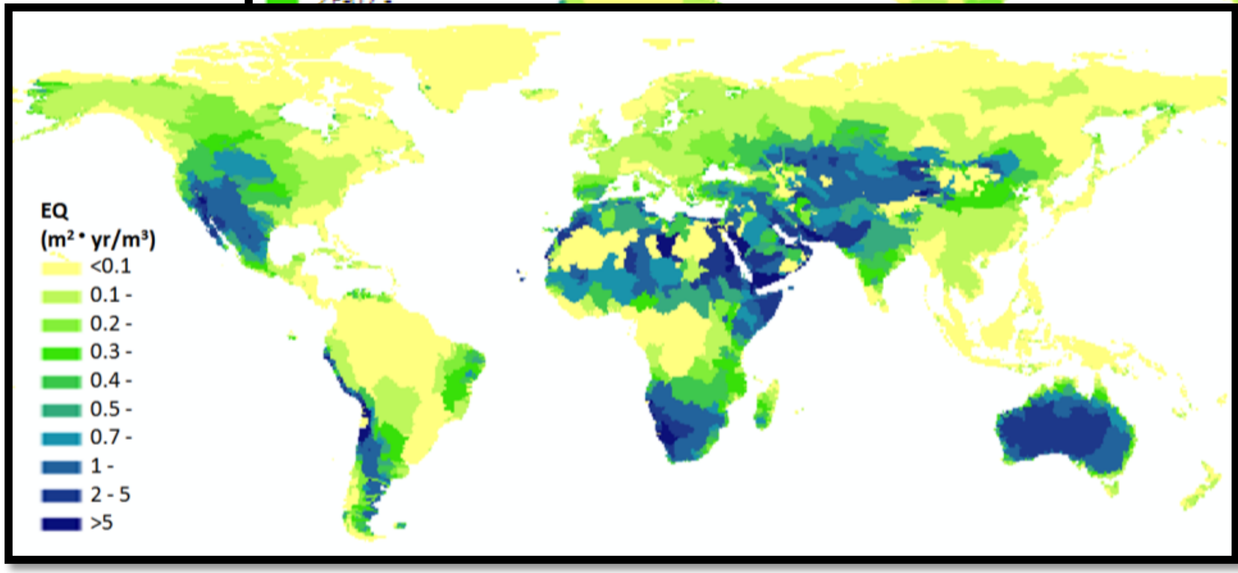


Damage factors

Impacts on human health



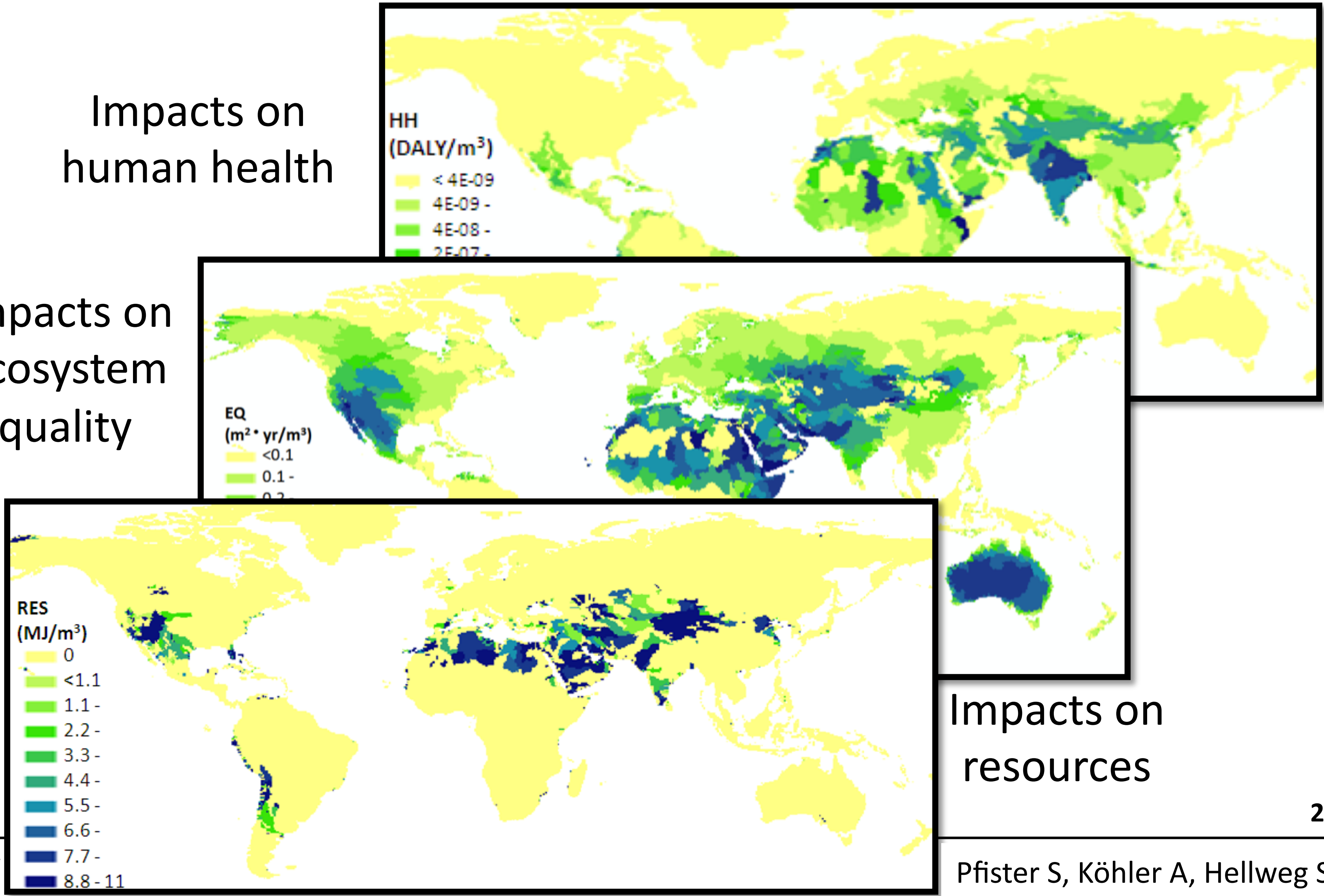
Impacts on ecosystem quality



Damage factors

Impacts on human health

Impacts on ecosystem quality



Impacts on resources

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Pfister S, Köhler A, Hellweg S, ES&T 43, 4098 – 4104, 2009

Application to agriculture: Inventory on high spatial resolution

- Combining global data sets in GIS
  - Climate data
  - Official statistics
  - Remote sensing data

- Calculation of irrigation water requirements (IWR)
  - FAO approach (on 10km*10km resolution)

- Combination with regional characterization factors
  - E.g. midpoint: Water stress index (WSI; Pfister et al. 2009)

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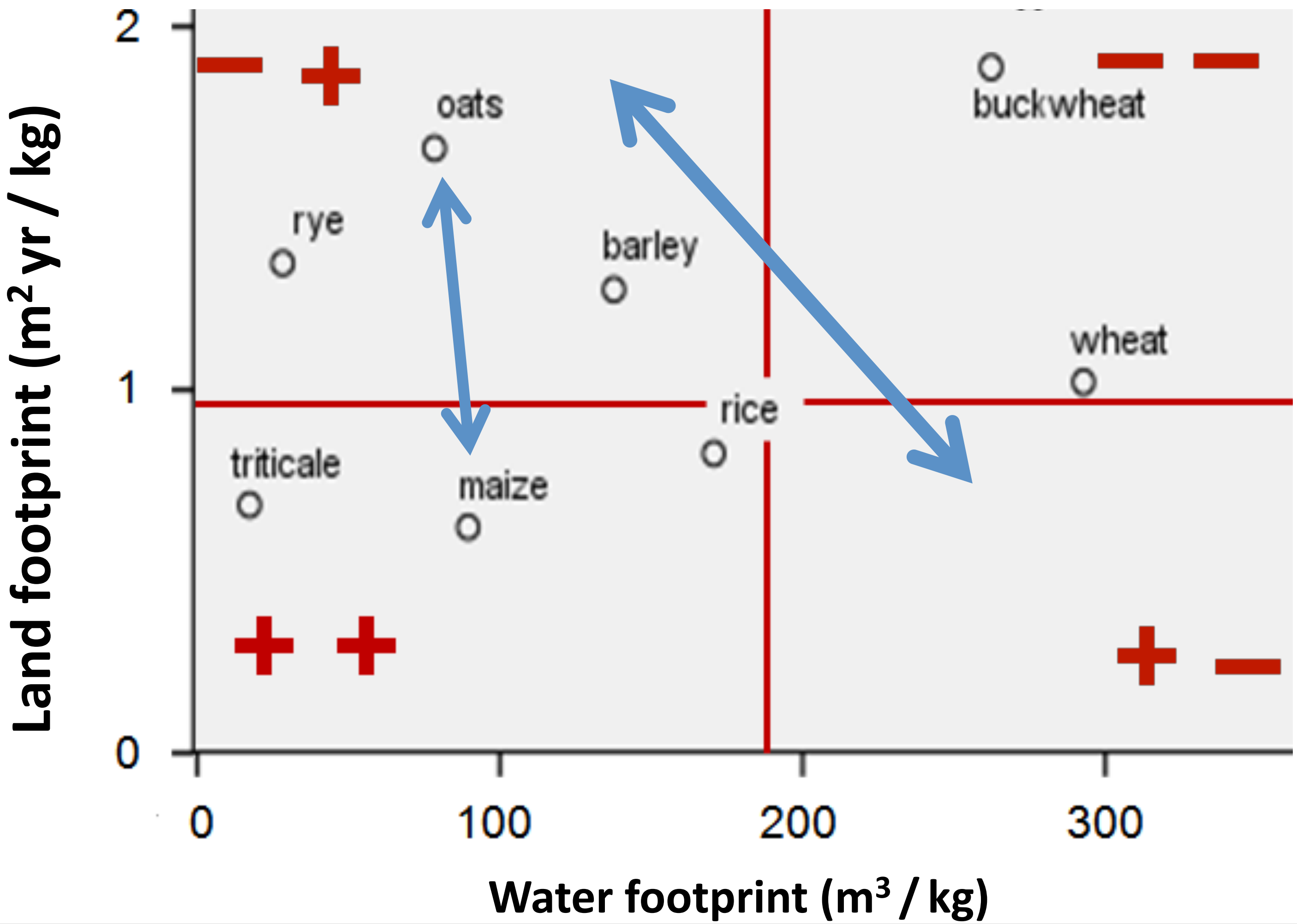
Trade-off water - land



Pasture food losses

- 44% of meat energy from pasture/grassland/ rangeland
- 6% of pasture / natural land change

	pasture output change (NPP0 weighted)	animal feed change (43.9 % pasture)	change food energy (15.1% animal products)
sc2	-6.1%	-2.7%	-0.4%
SC3	-3.7%	-1.6%	-0.2%