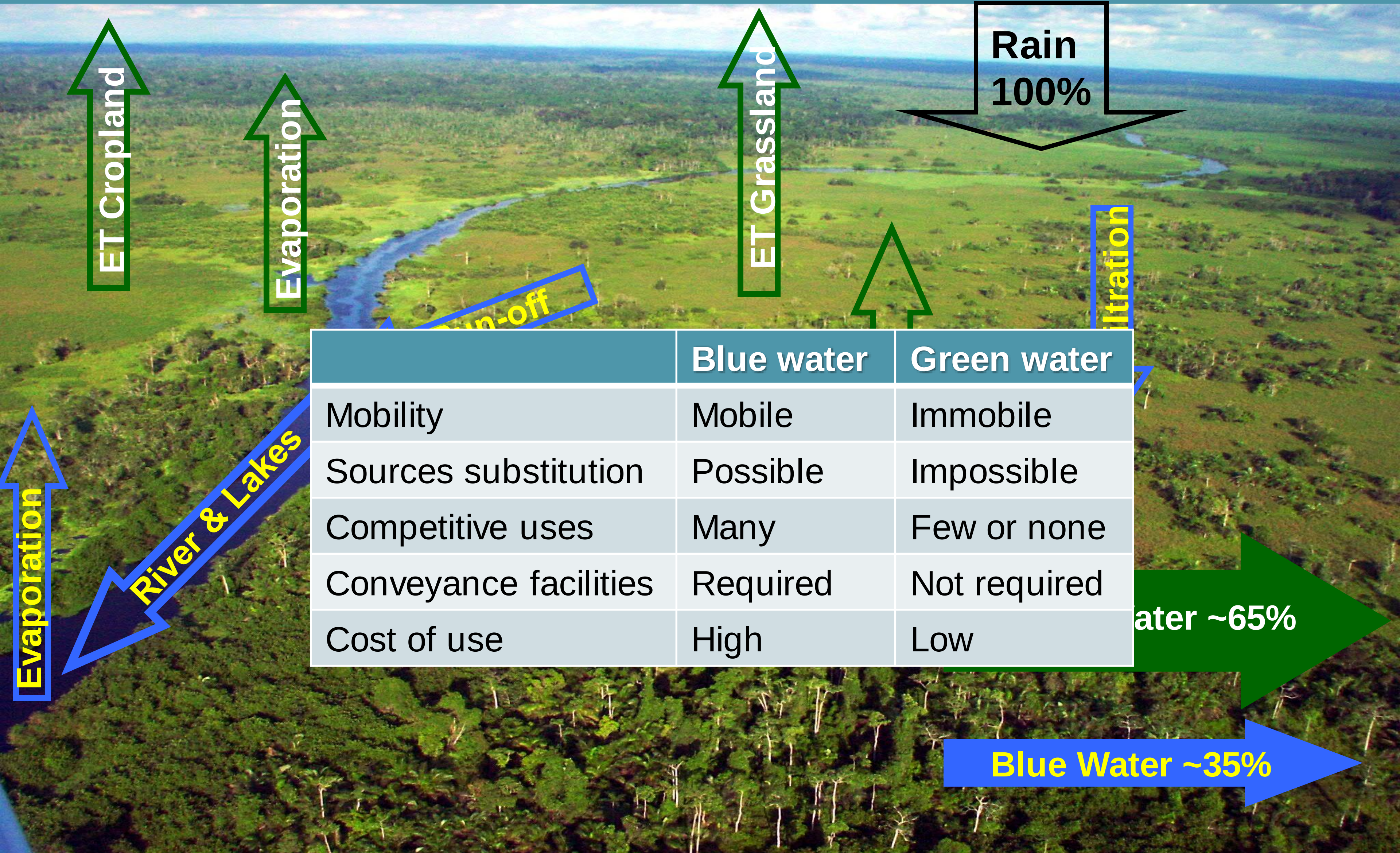
Water-Food-Energy Nexus
Impact on Water Quantity and Quality

Alexander J.B. Zehnder
AI-EES Alberta, Canada, NTU Singapore & Triple Z, Switzerland

Acknowledgements:
Monireh Faramarzi
Georg Hafner
Junguo Liu
Hong Yang

Blue and green water



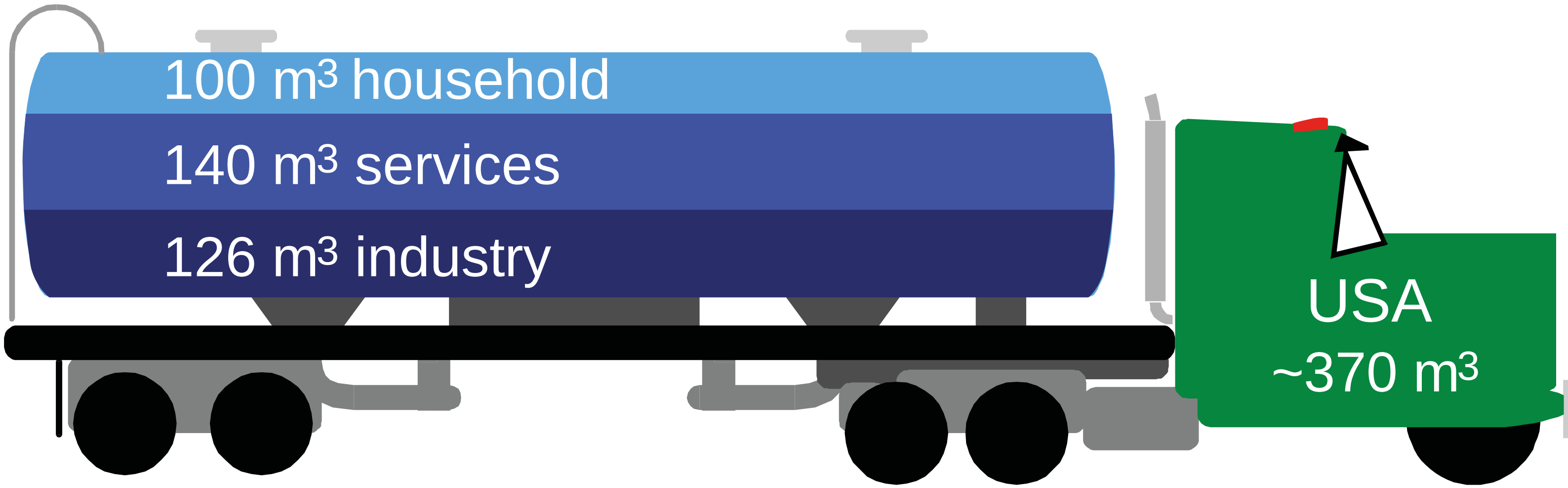
	Blue water	Green water
Mobility	Mobile	Immobile
Sources substitution	Possible	Impossible
Competitive uses	Many	Few or none
Conveyance facilities	Required	Not required
Cost of use	High	Low

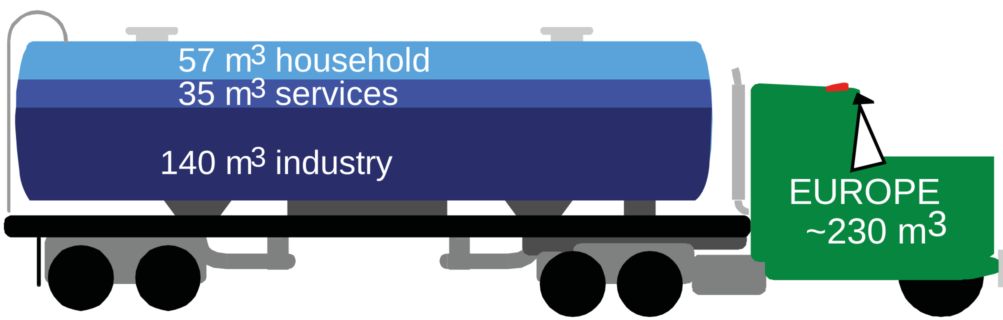
Annual water requirement per person

Sufficient	**> 1700 m³**
Water stress	**1000 - 1700 m³**
Scarcity	**500 - 1000 m³**
Extreme scarcity	**< 500 m³**

From Falkenmark & Widstrand, 1992

Annual water use per capita for household, services, industrial activities





(average 2002–2012)

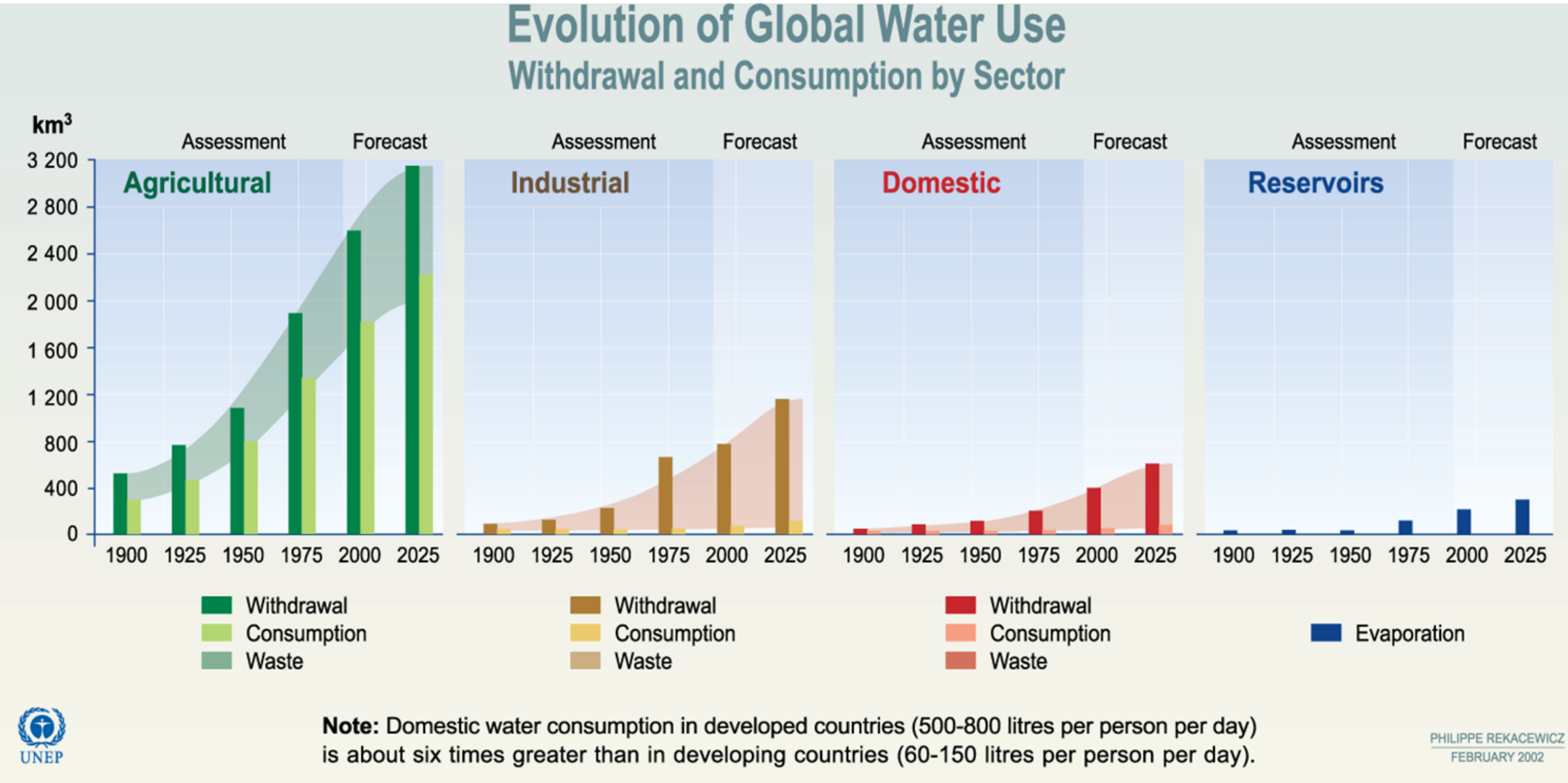
Industry, excl. thermoelectric power

AFRICA

12 m^3 household
8 m^3 services
7 m^3 industry

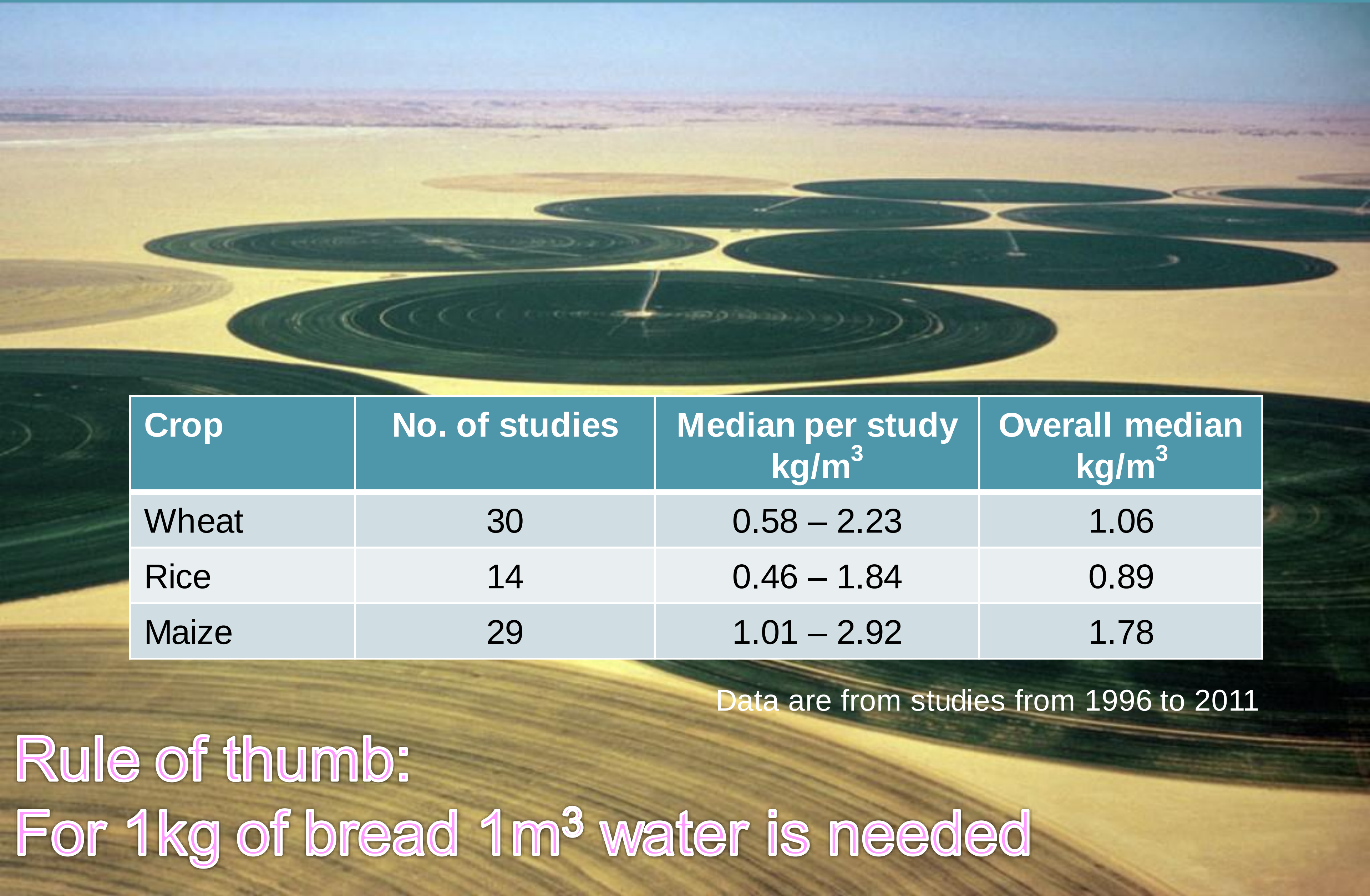
From Aquastat FAO and USGS, 2014

Estimated annual world water use total and by sector 1900–2025



Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultural Organisation (UNESCO, Paris), 1999.

Irrigated crop water productivity

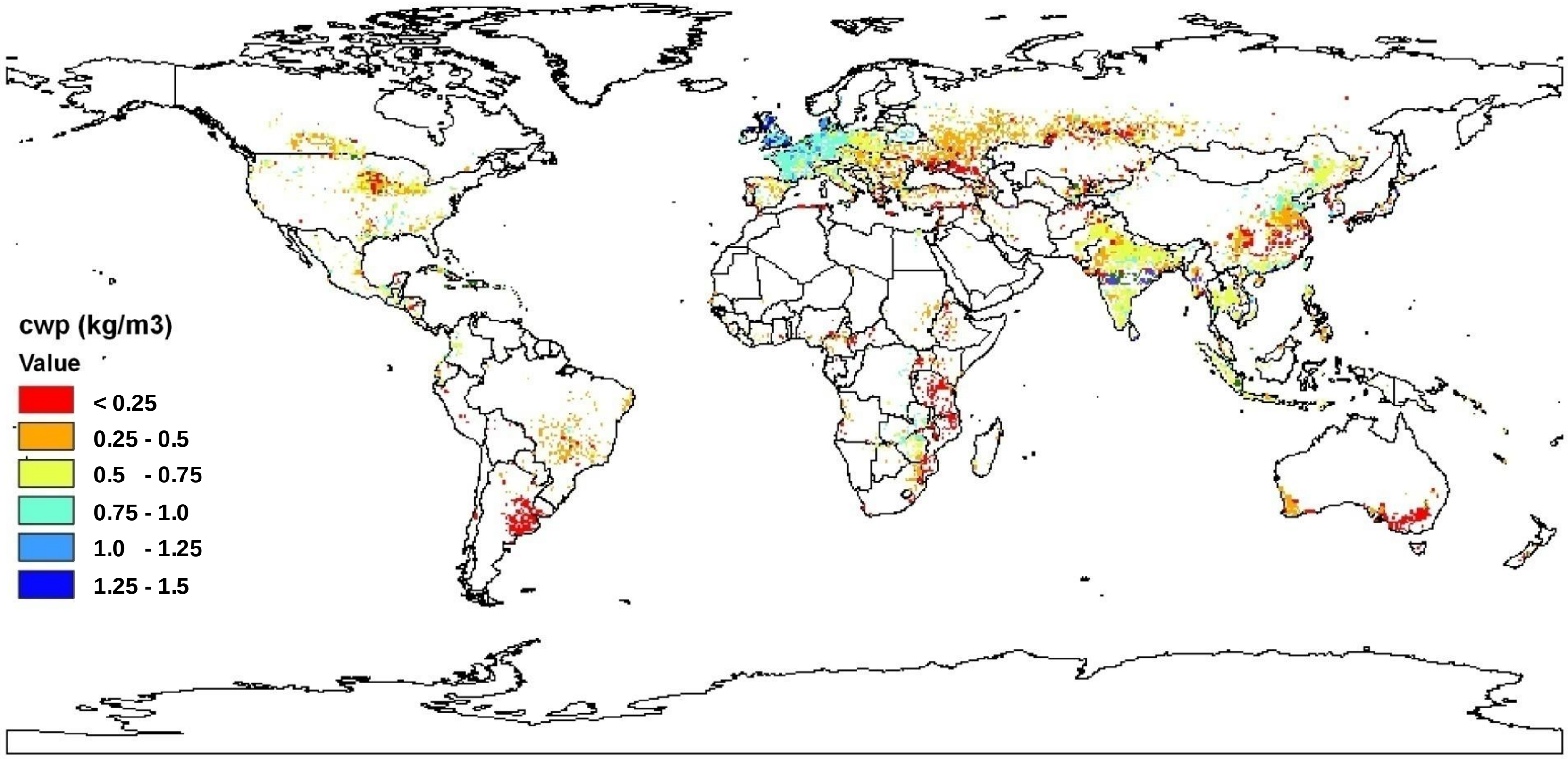


Crop	No. of studies	Median per study kg/m^3	Overall median kg/m^3
Wheat	30	0.58 – 2.23	1.06
Rice	14	0.46 – 1.84	0.89
Maize	29	1.01 – 2.92	1.78

Data are from studies from 1996 to 2011

Rule of thumb:
For 1kg of bread $1m^3$ water is needed

Crop water productivity of wheat (2000)



From Liu *et al*. 2007

Meat production

Animals convert 5 to 15 % of the energy content of plant material into meat. The average is 10 percent.

Rule of thumb:
10 times more water is needed per unit of energy from meat than from plants

Annual per capita water needs for food to cover 2500 kcal a day

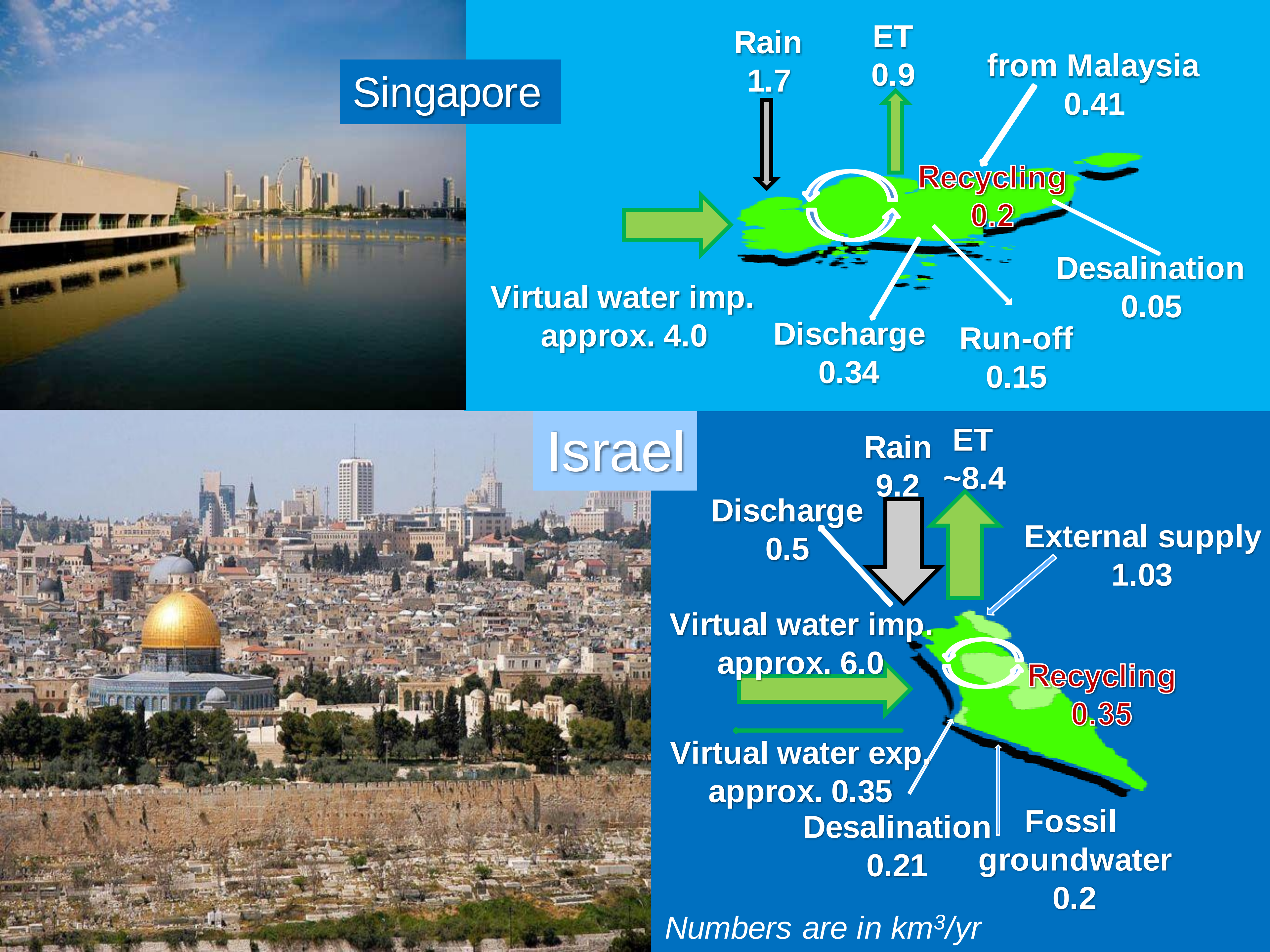
20% meat:
1200 - 1500 m^3

Vegetarian:
600 - 1000 m^3

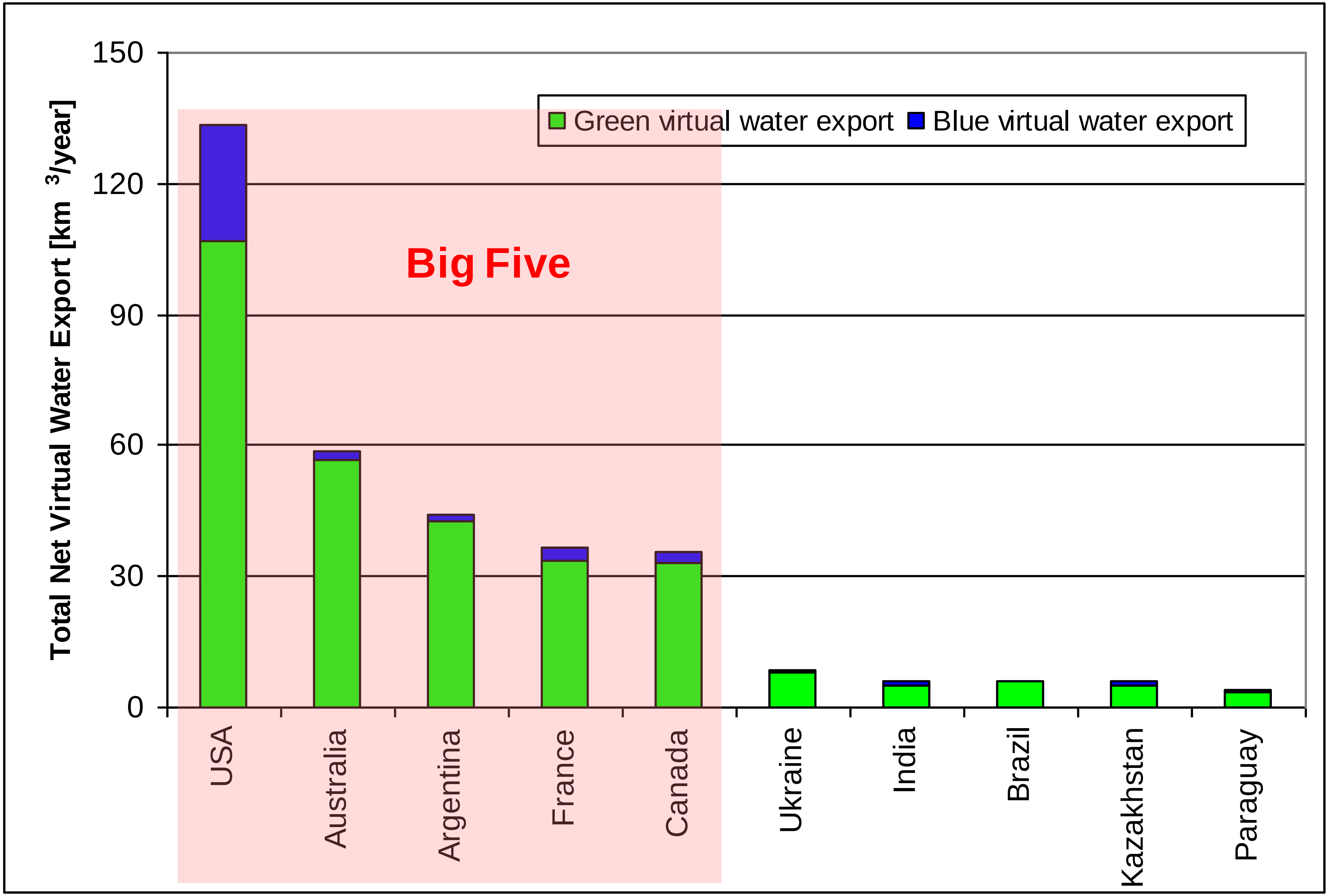
Water availability in Israel in cubic meter per person and year (average 2000–2010)

Internal surface & groundwater	110
Fossil groundwater	26
External surface and groundwater	147
Desalination and recycling	81
Total	**361**
Rain-fed agriculture	**101**
Import of crops	795
Import of meat and dairy products	75
Total virtual water import	**870**
Overall	***1,332***

From: Aquastat FAO, FAOstat WRI, Yang *et al*., 2007 and Liu *et al*., 2009

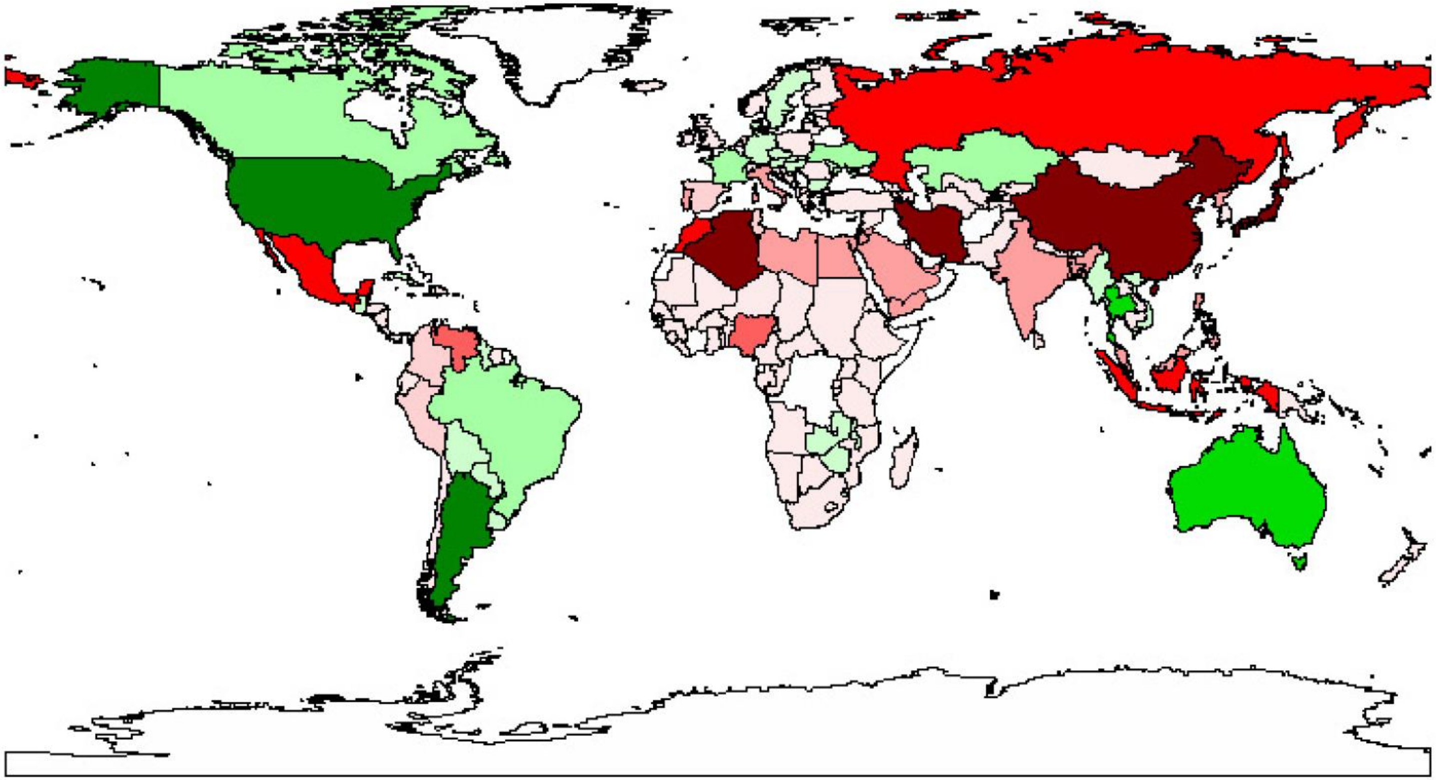

Singapore
Rain 1.7
ET 0.9
from Malaysia 0.41
Recycling 0.2
Desalination 0.05
Virtual water imp. approx. 4.0
Discharge 0.34
Run-off 0.15
Israel
Rain 9.2
ET ~8.4
Discharge 0.5
External supply 1.03
Virtual water imp. approx. 6.0
Recycling 0.35
Virtual water exp. approx. 0.35
Desalination 0.21
Fossil groundwater 0.2
Numbers are in km3/yr

Virtual water export



From Liu *et al.* 2009

Net virtual water trade by country (average over the period 2000–2006)

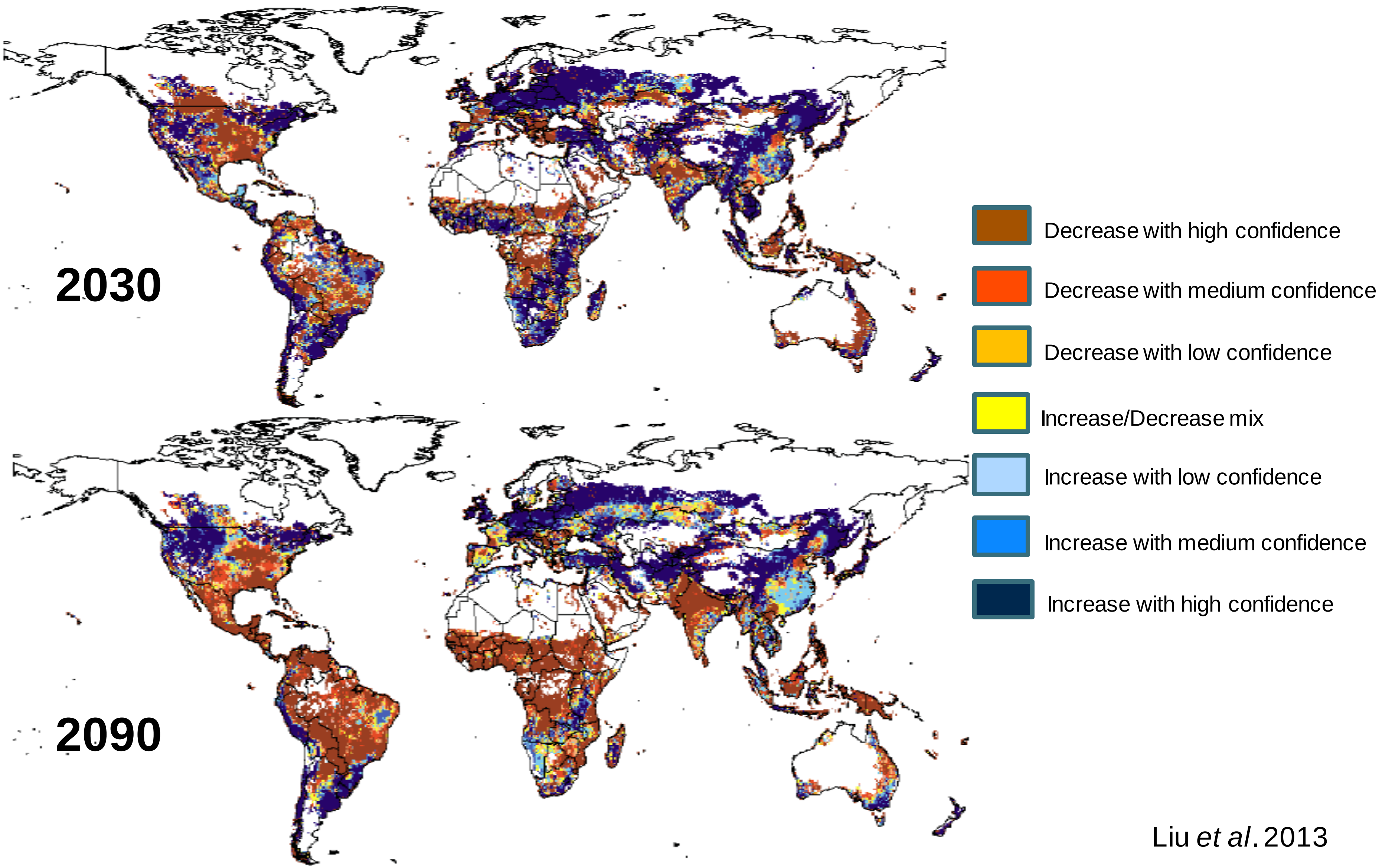


Unit: cubic km

no data	-15 - 0	15 - 20
-100 - -50	0 - 5	20 - 30
-50 - -25	5 - 10	30 - 60
-25 - -15	10 - 15	

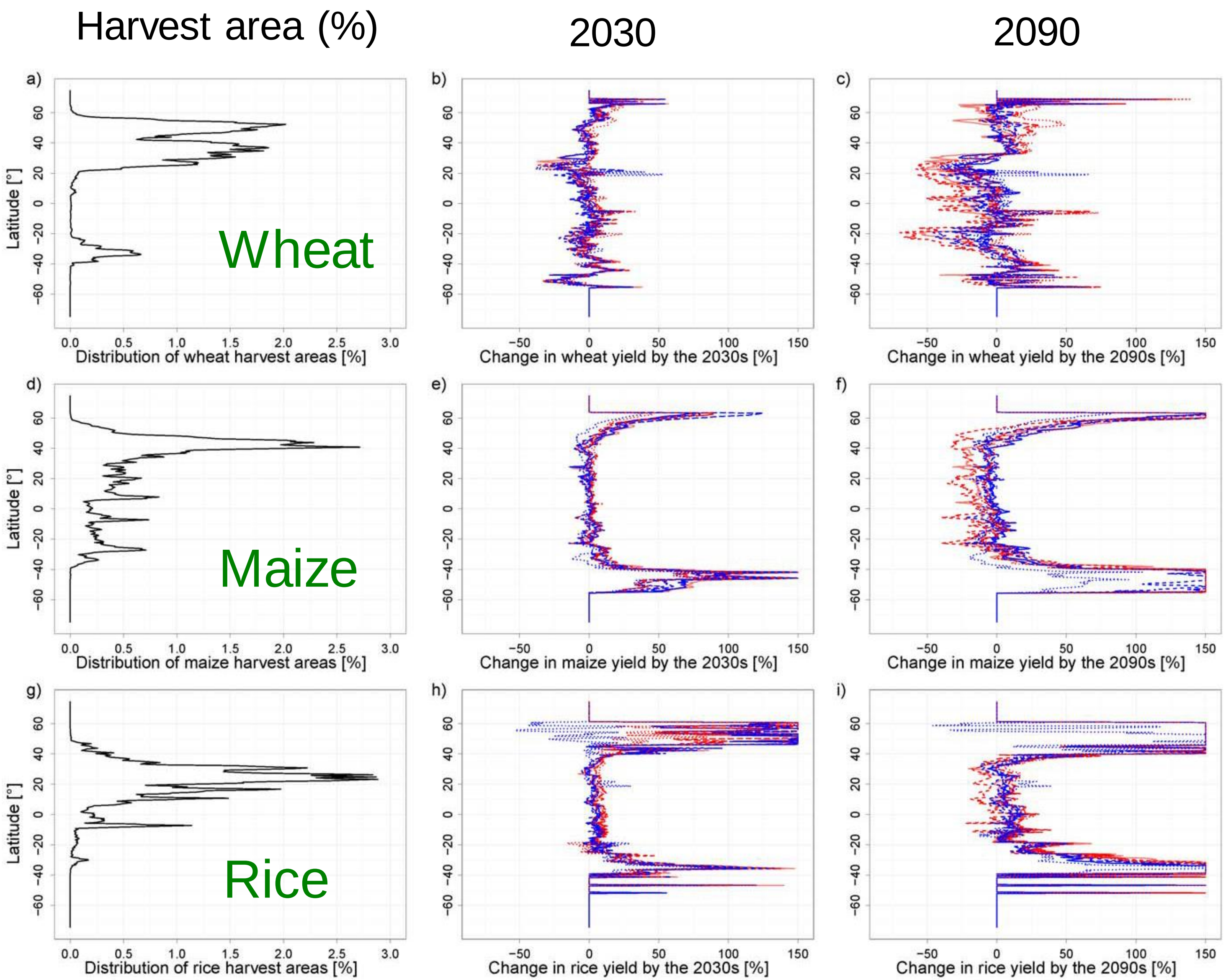
From Yang *et al.* 2007

Impact of climate change on crop production (wheat, maize & rice)



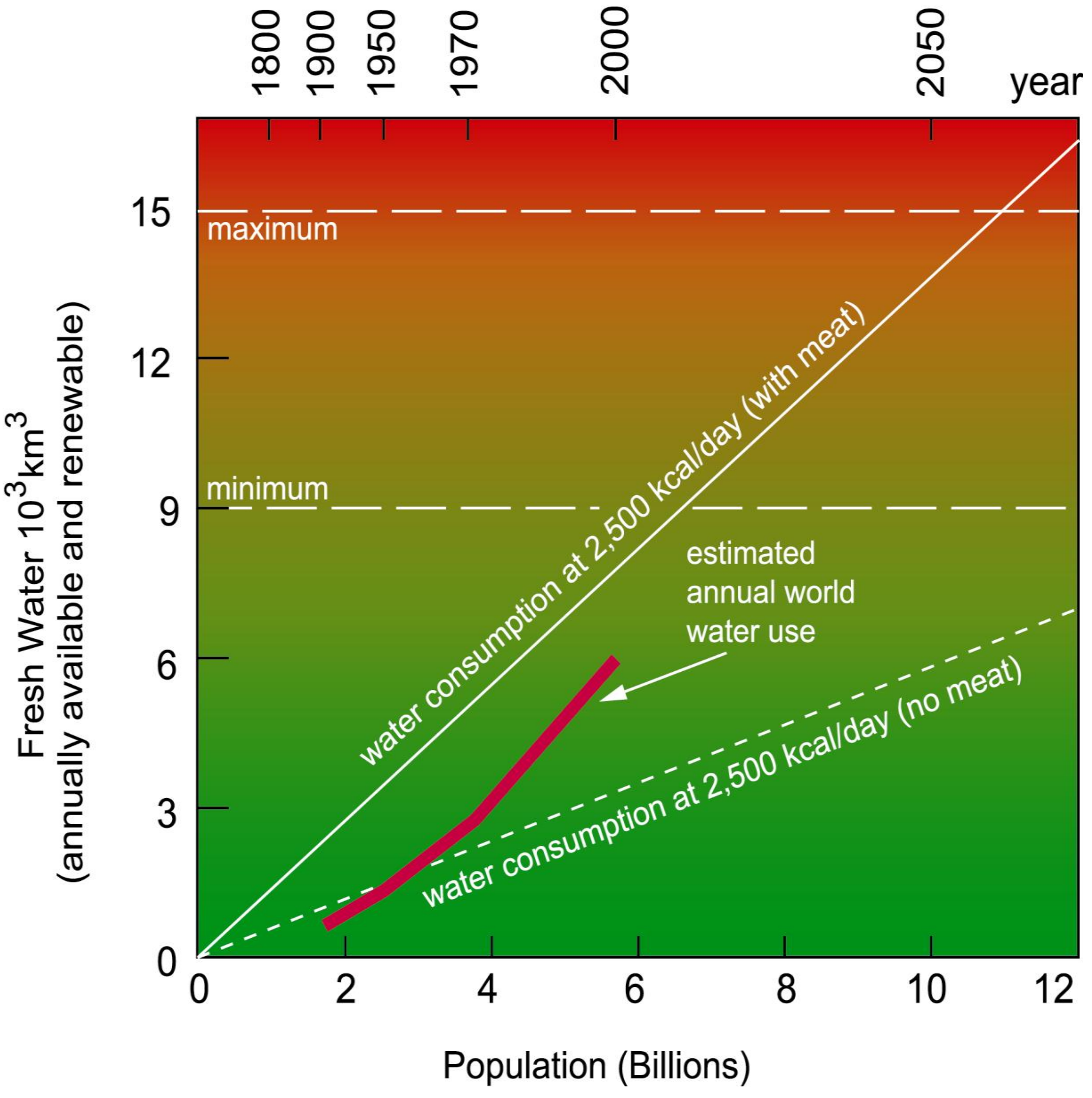
Liu *et al*. 2013

Change in crop yield



Liu *et al*., 2013

Projection of water availability



From Zehnder, 1999

Fate of fertilizer in European agriculture

Fertilizer

100% N and P

Environment

N: 59-72%
P: 82-91%

Crop residue

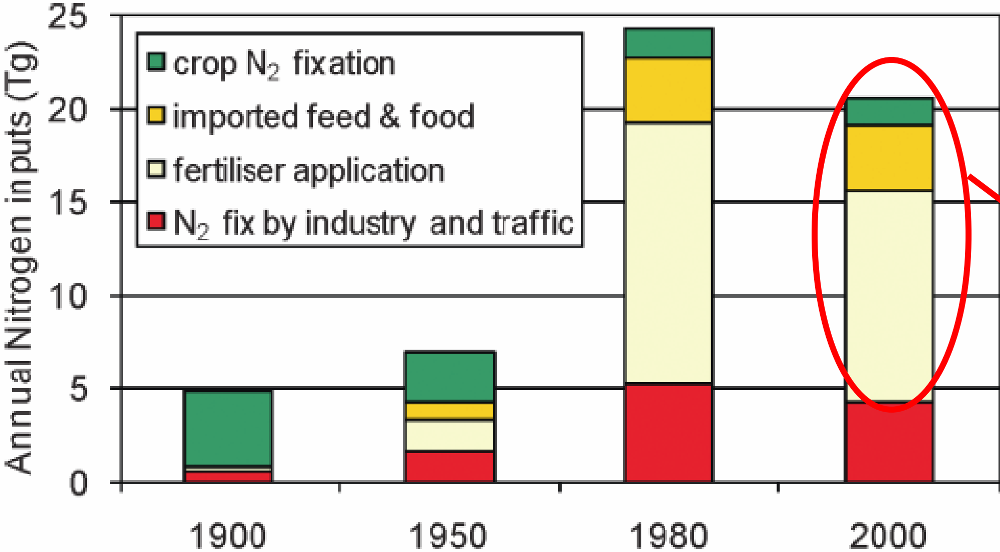
N: 3-6%
P: 1-3%

Crop

N: 25-35%
P: 8-15%

Eutrophication…..and its result

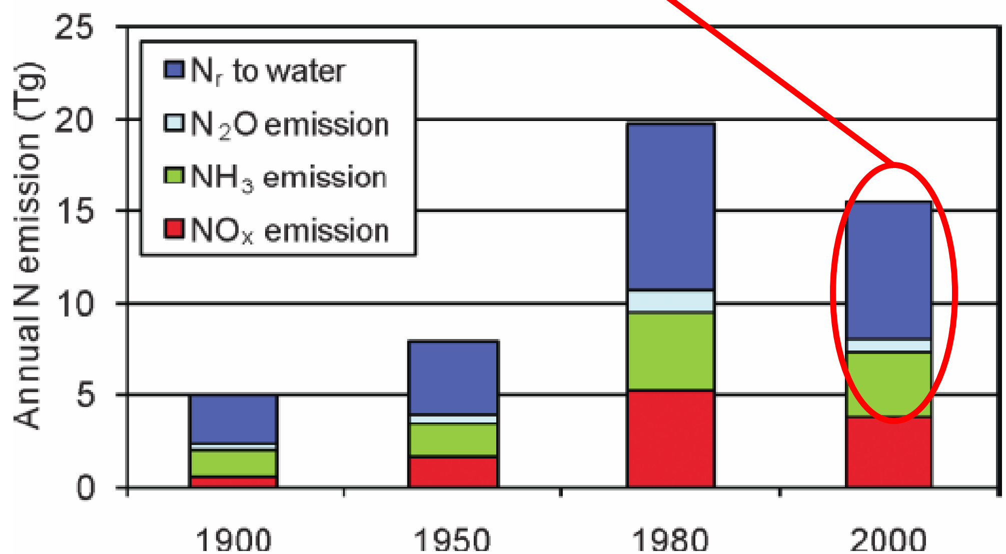
Temporal inputs and losses of nitrogen (EU-27)



Nitrogen Input

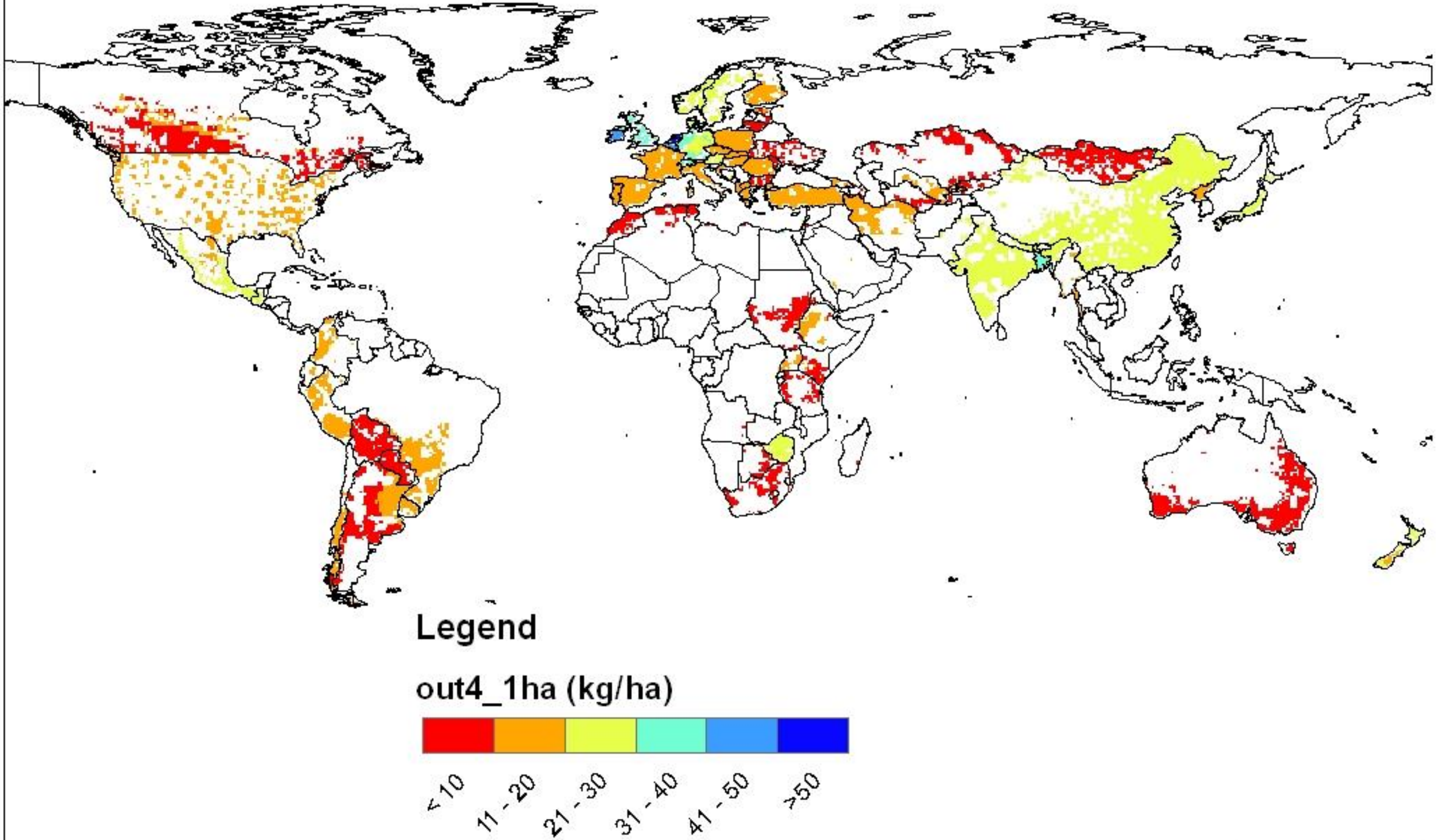
Mainly agriculture

Nitrogen emission



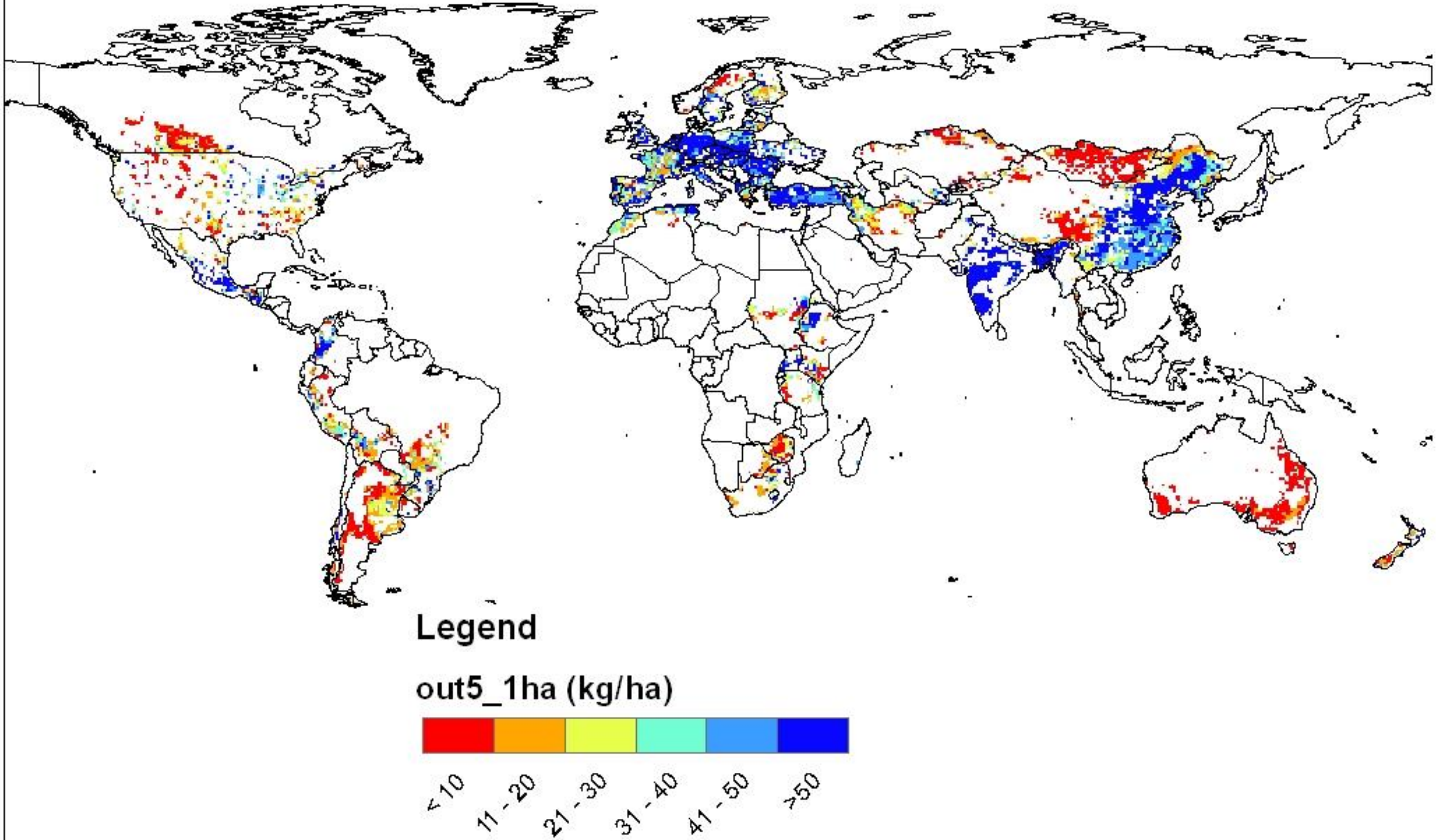
From: Sutton et al. 2011

Nitrogen loss to the atmosphere (wheat)



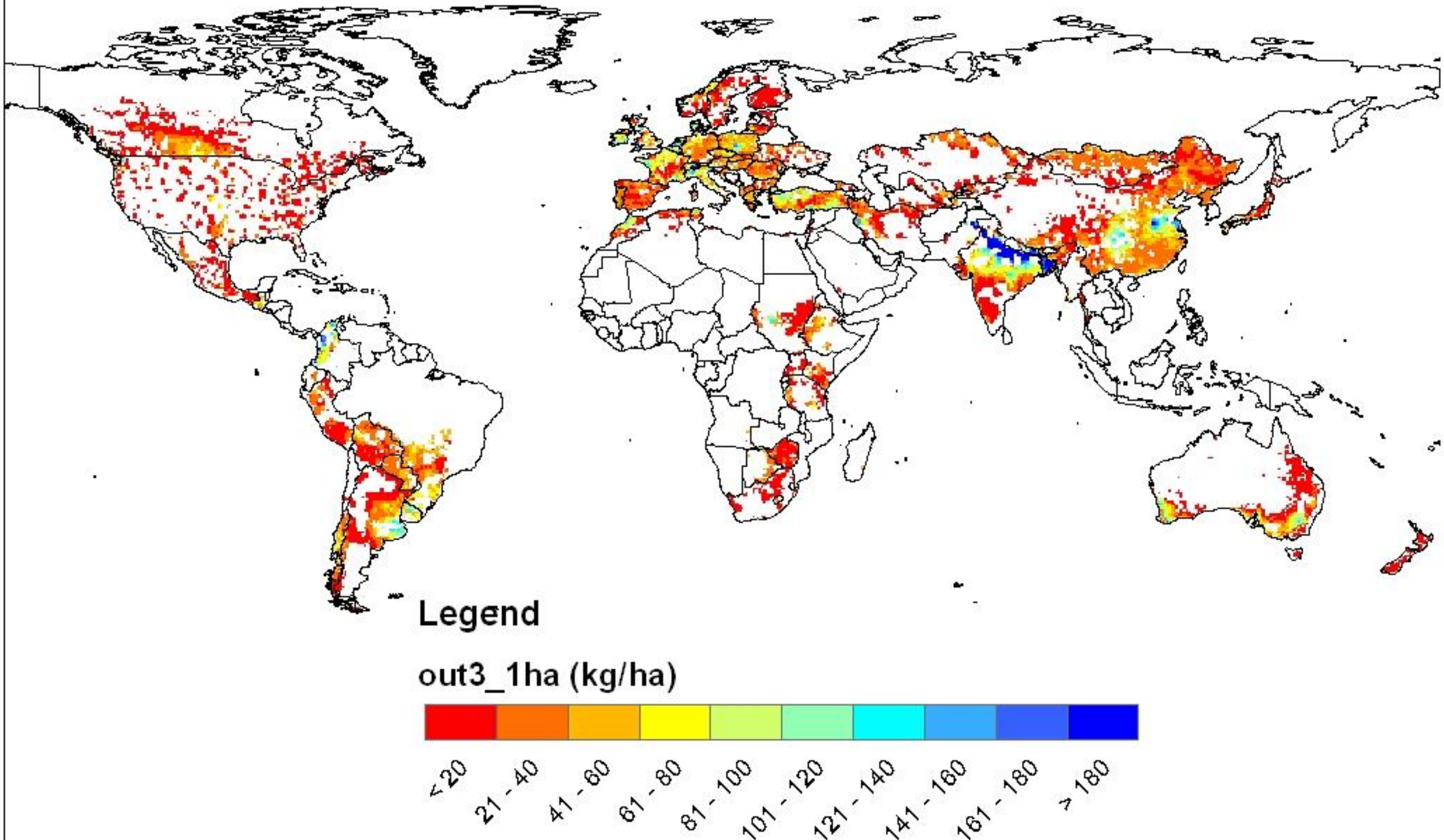
Liu *et al.* unpublished

Nitrogen loss through run-off (wheat)



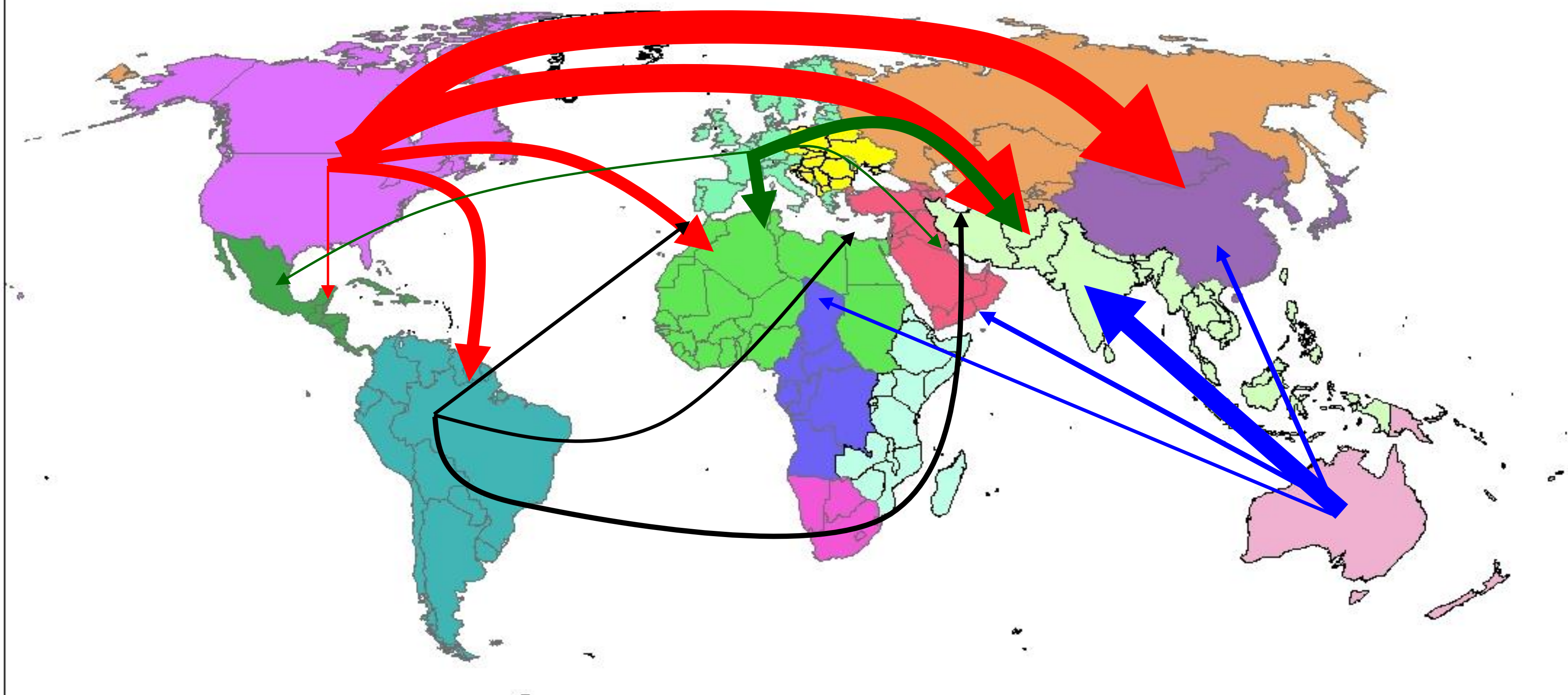
Liu *et al.* unpublished

Nitrogen loss to the groundwater (wheat)



Liu *et al.* unpublished

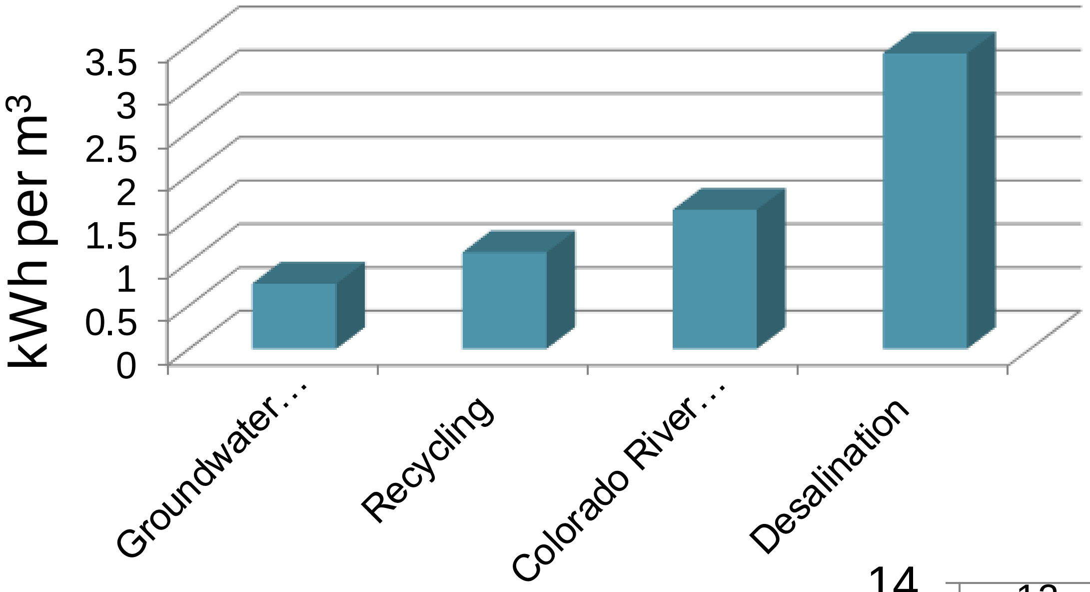
Global net nitrogen flow as a result of cereal trade (2020)



Total annual fluxes:
3.2 million tons nitrogen and 0.45 million tons of phosphorus

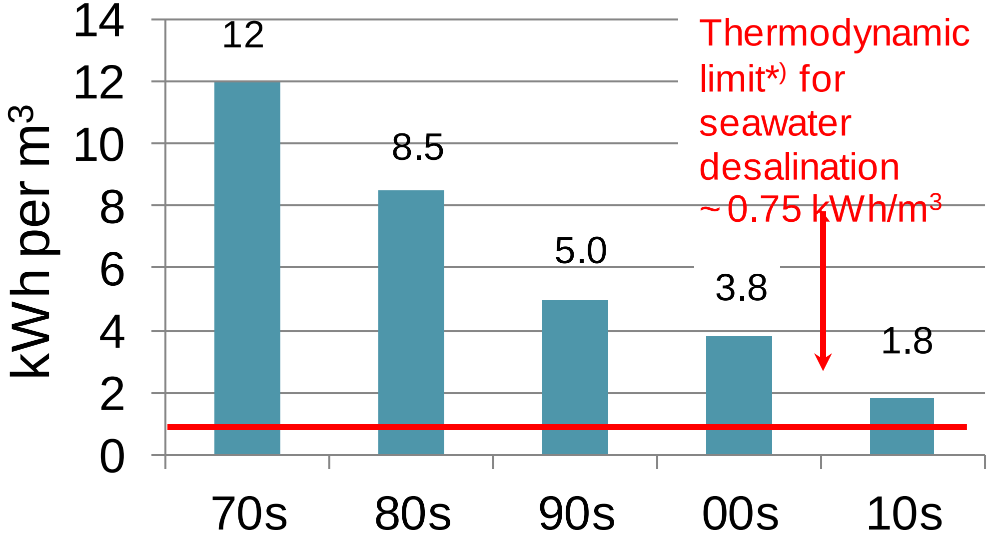
Liu *et al.* unpublished

Energy needs for water supply



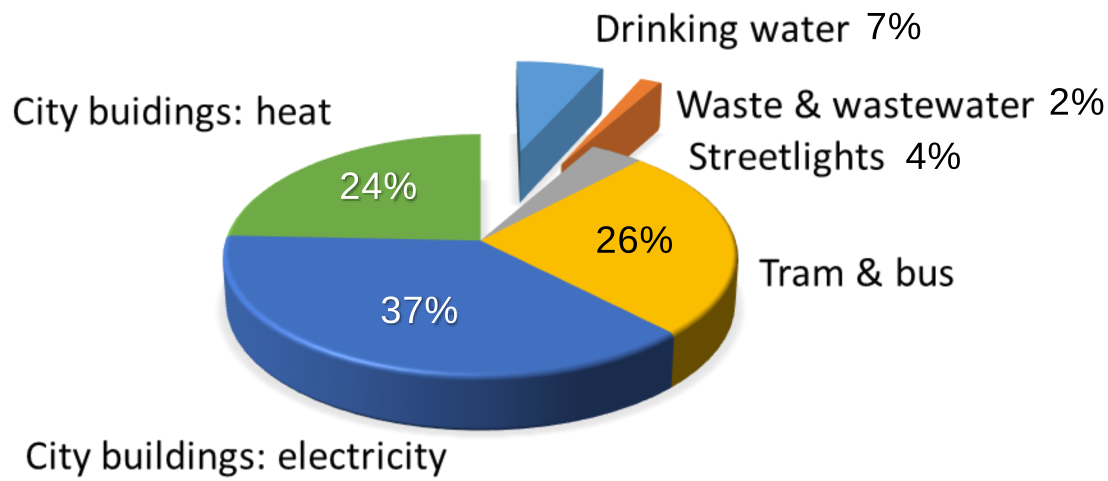
Energy intensities of water supply

Development of the energy consumption in seawater desalination, minimum achieved



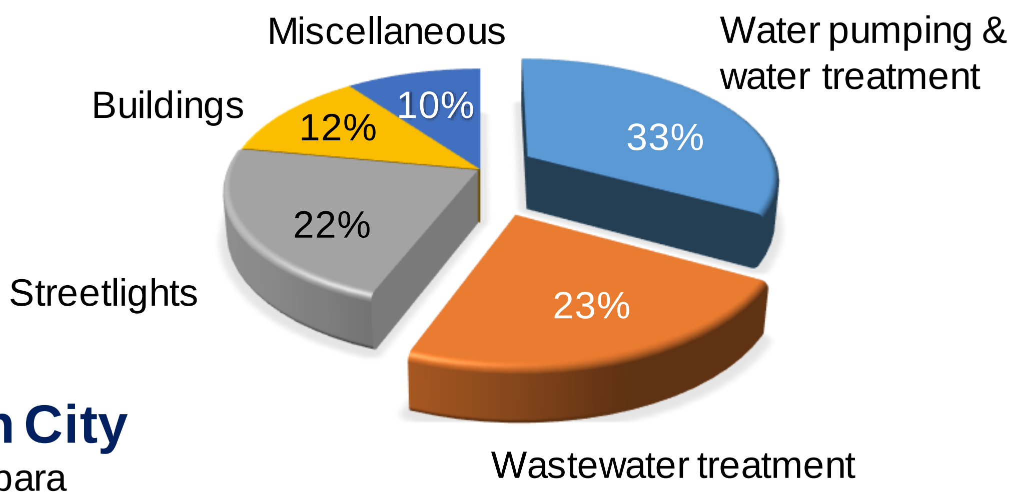
*) for RO with 40% recovery from seawater

Typical energy consumption in a city



City of Zurich Switzerland

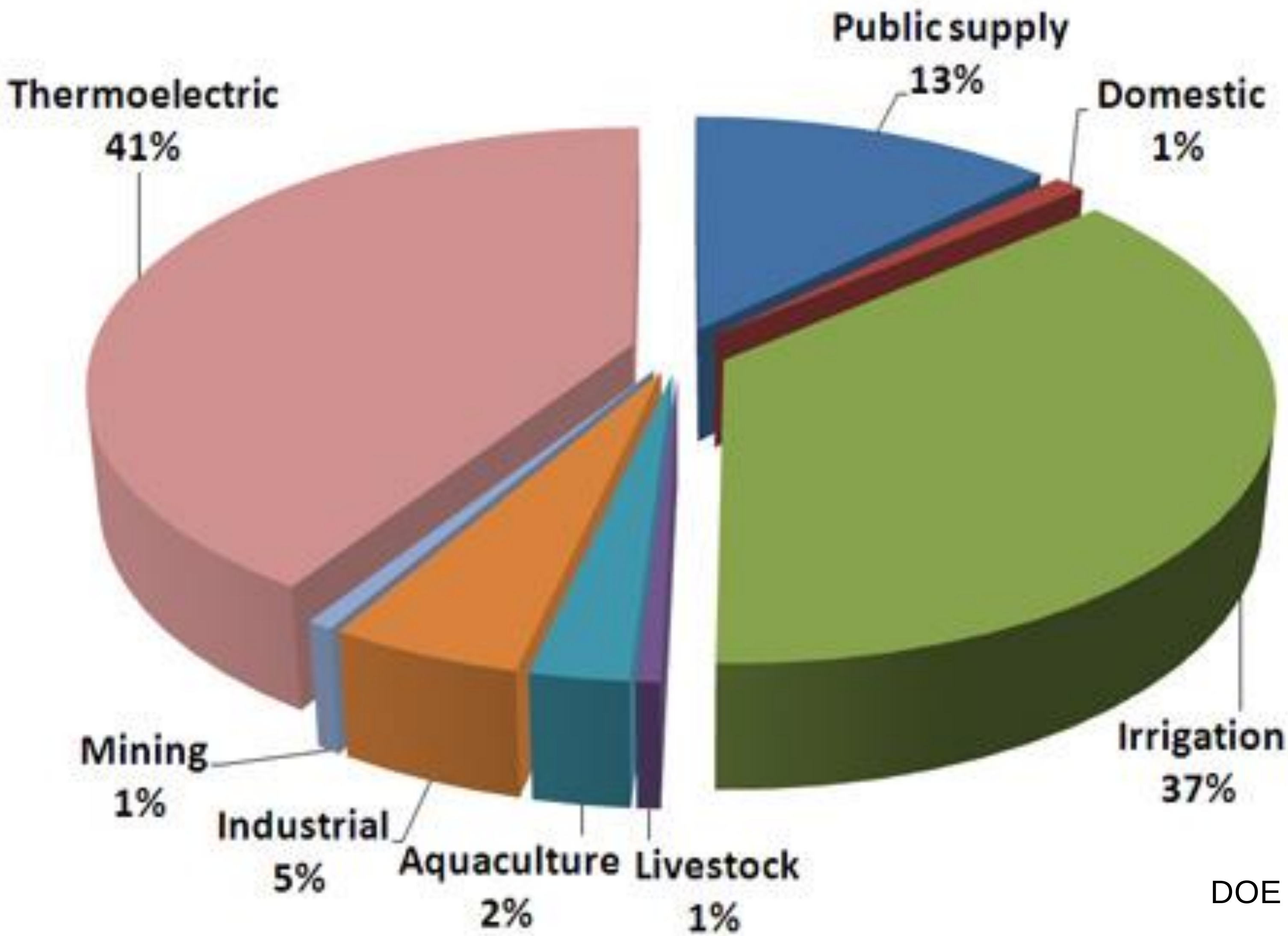
Data from the City of Zurich



Typical Southern Californian City

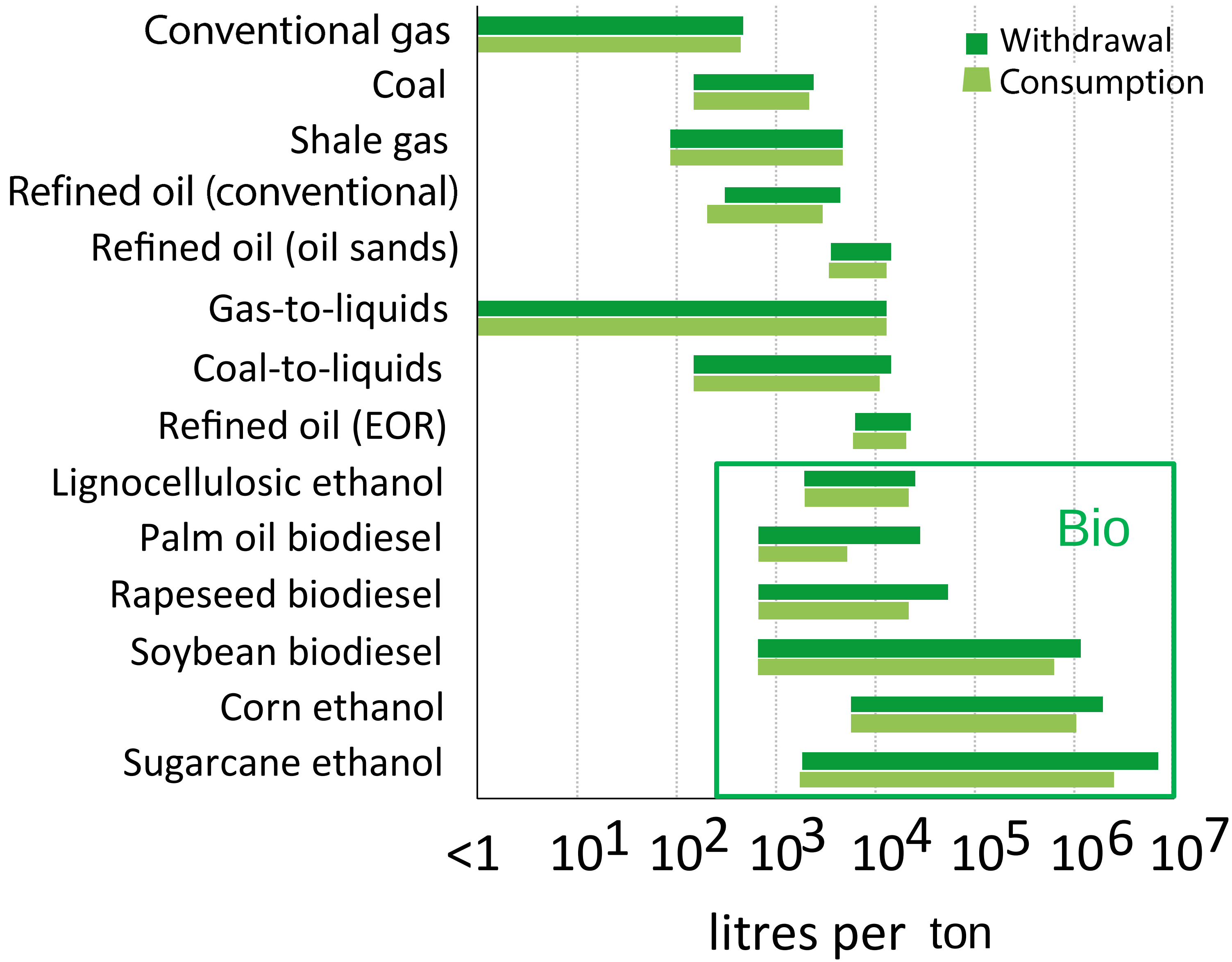
Data from Robert Wilkinson, UC Santa Barbara

US Freshwater withdrawal



DOE 2012

Water-(Food)-Energy Nexus



IEA, 2012

Bioethanol

Picture from Spiegel 2007

Food

or

Gas ?

Can everybody eat and guzzle fuel?

Vegetarian food for one person for a year ……

….equals about 120 liter bioethanol, one tank filling for an off-roader

Conclusions

1. Future demographic trajectories and water scarcity will further accelerate international food trade, global nutrient cycles and adversely impact the environment.

2. Most energy solutions fail without water; but all water solutions fail without energy (*Nick Hodge, in Energy and Capital, June 9th 2008*).

3. Food for fuel is the most unsustainable solution.