Food and Gas
is there a sustainable solution?

Picture from Spiegel 2007

August 20, 2008

Rice University

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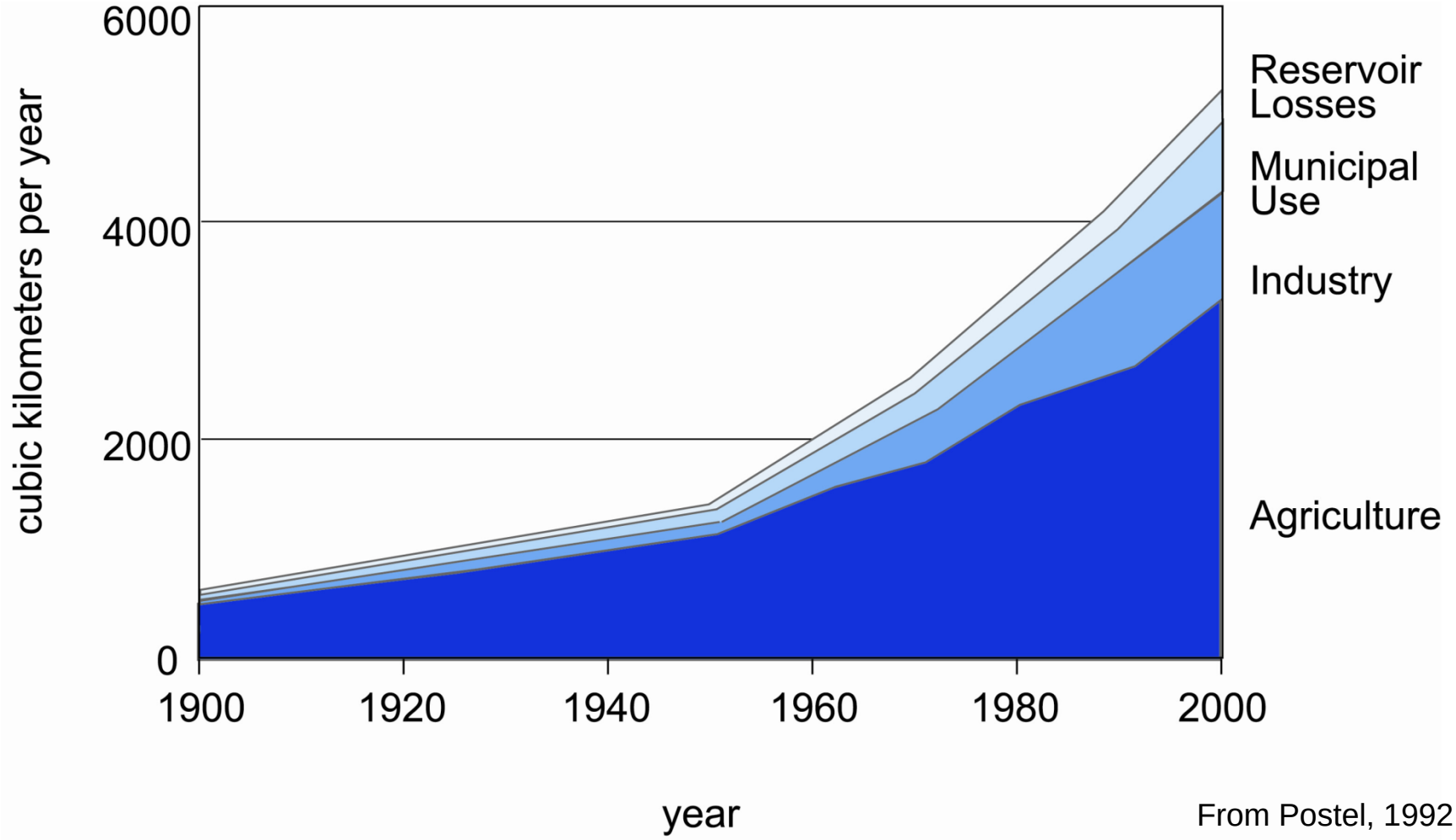
Water Research Institute

Estimated annual world water use total and by sector 1900–2000



From Postel, 1992

Annual water requirement per person

Sufficient	**> 1700 m^3**
Water stress	**1000 - 1700 m^3**
Scarcity	**500 - 1000 m^3**
Extreme scarcity	**< 500 m^3**

From Falkenmark & Widstrand, 1992

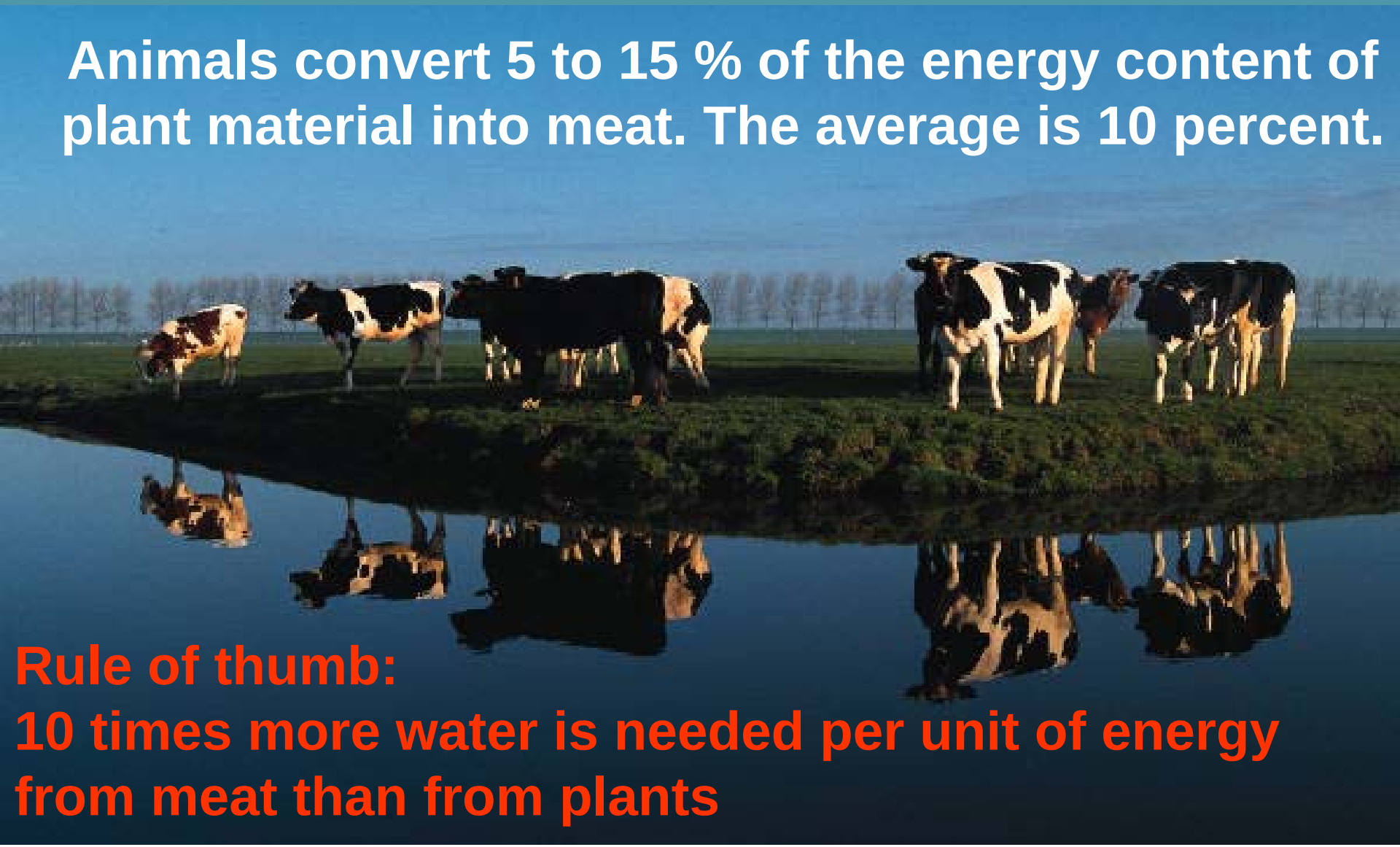
Water needed to produce 1 kg of plant material (dry weight)

Sorghum	250	Liter
Corn	350	Liter
Clover	460	Liter
Wheat	500	Liter
Potatoes	636	Liter
Cucumber	713	Liter
Alfalfa	900	Liter

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

Partially from Muller, 1974

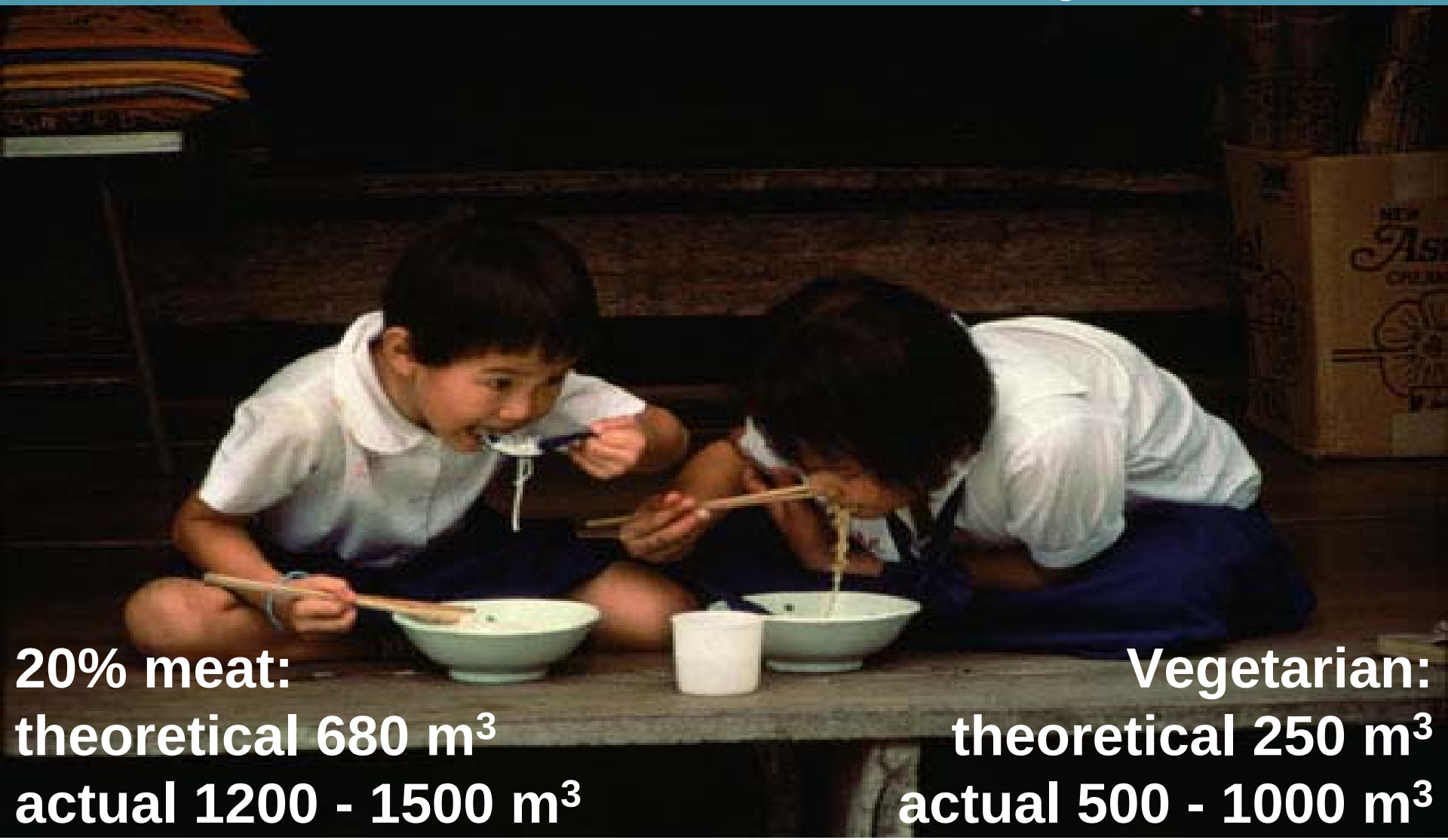
Meat production



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

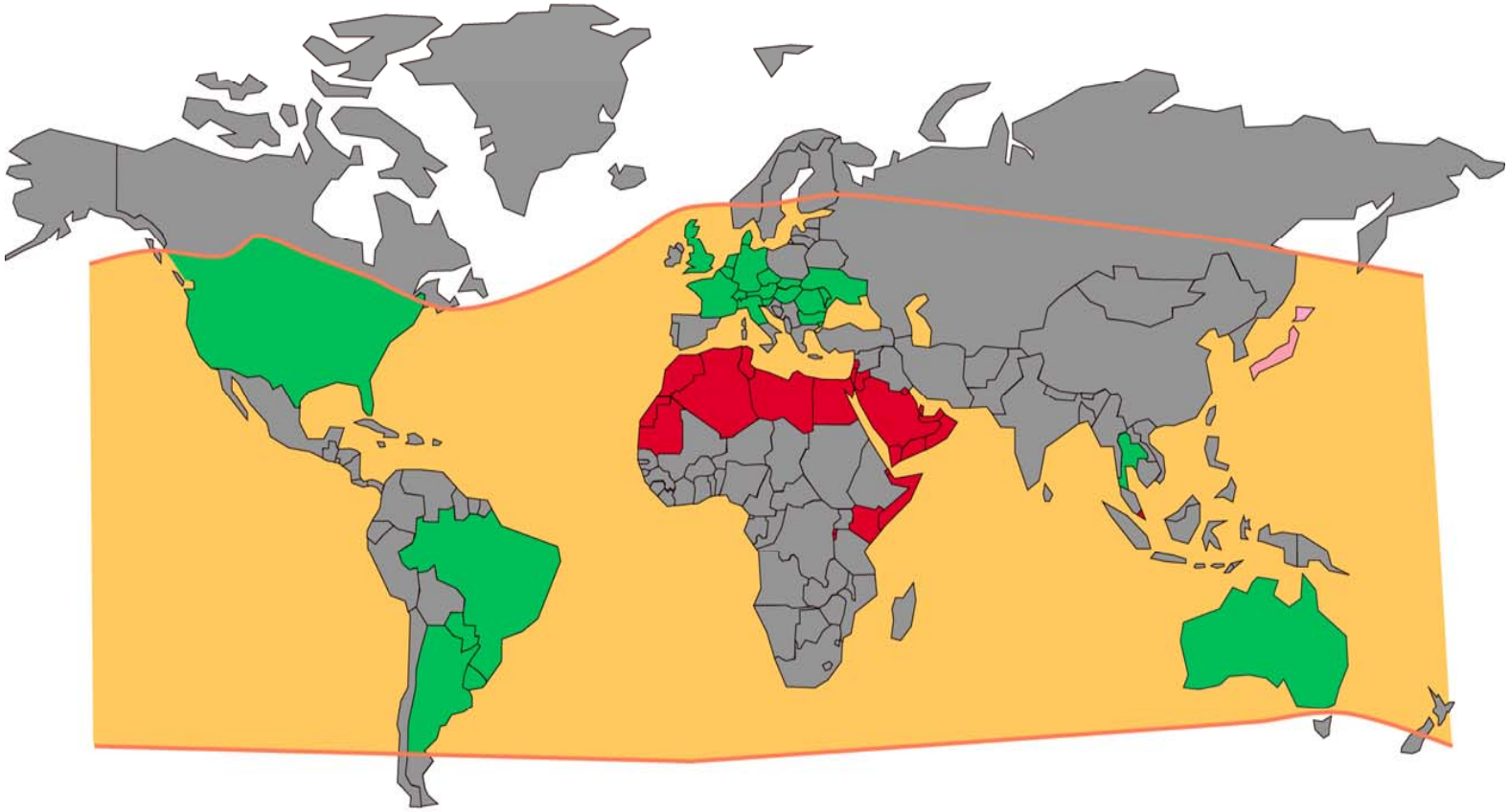
Annual per capita water needs for food to cover 2500 kcal a day



20% meat:
theoretical 680 m^3
actual 1200 - 1500 m^3

Vegetarian:
theoretical 250 m^3
actual 500 - 1000 m^3

Situation 2000



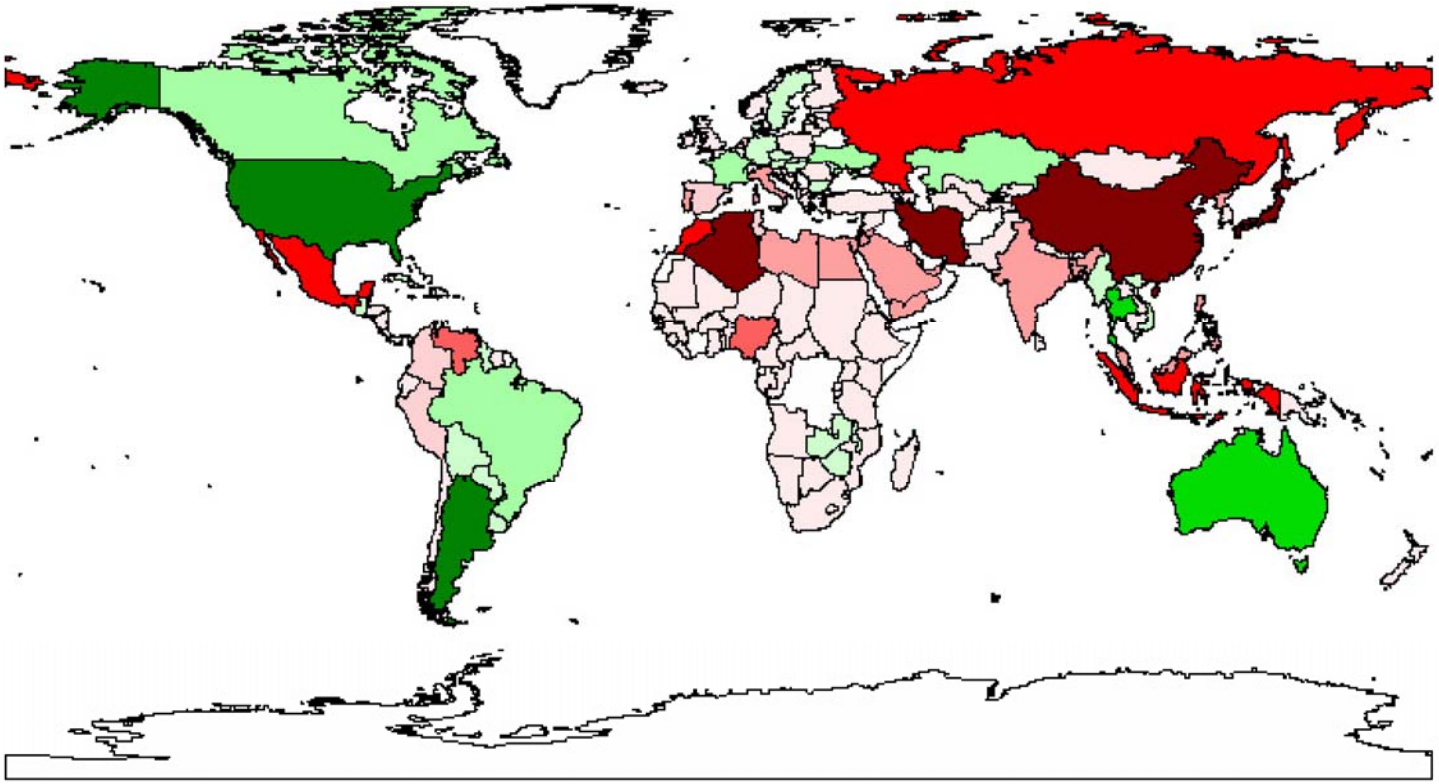
Limits for food production

Lack of water for sufficient food production

Water, soil and climatic conditions allow substantial food production for export

From Zehnder, 2002

Net virtual water trade by country (average over the period 1997–2001)

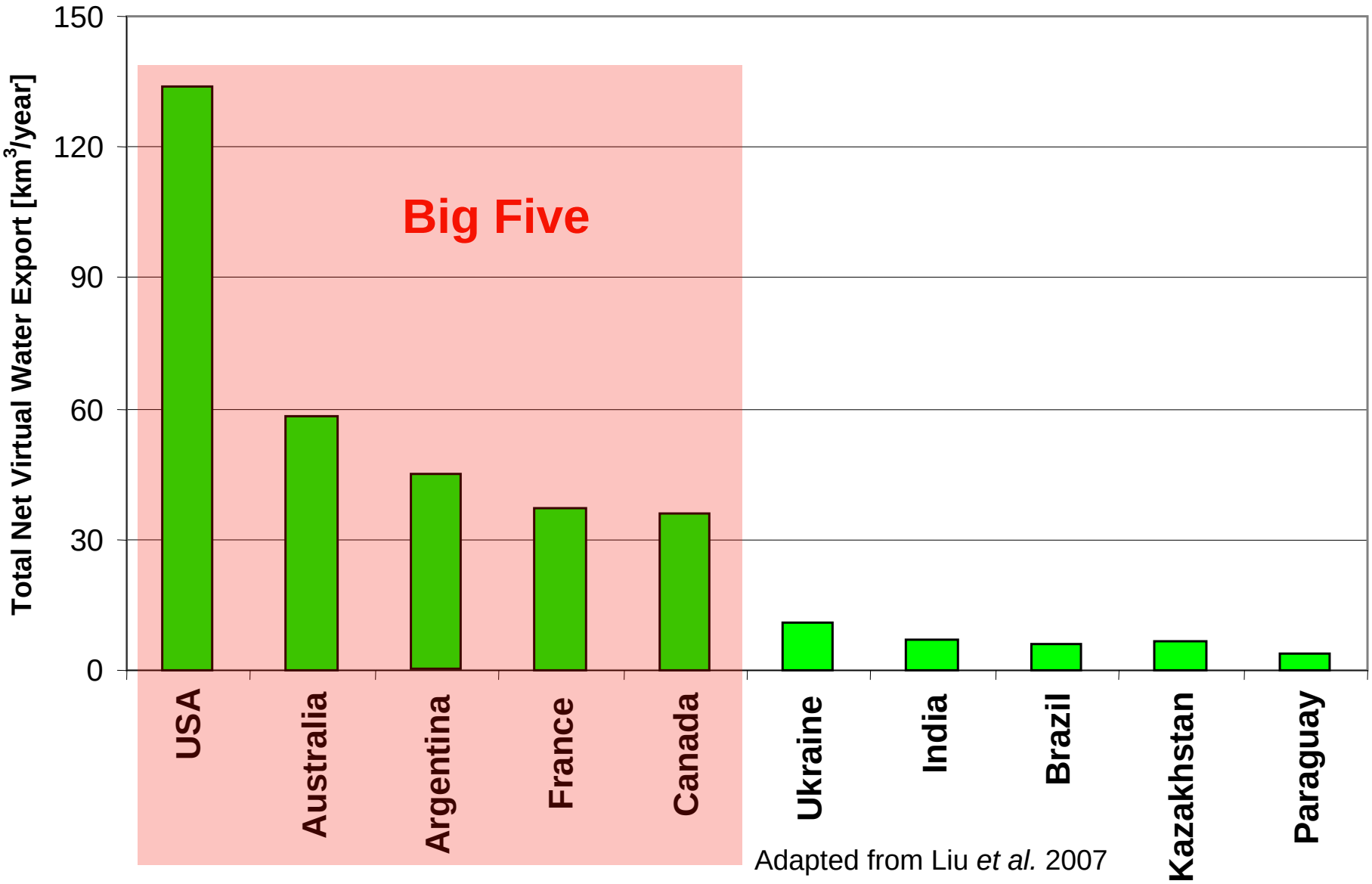


Unit: cubic km

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

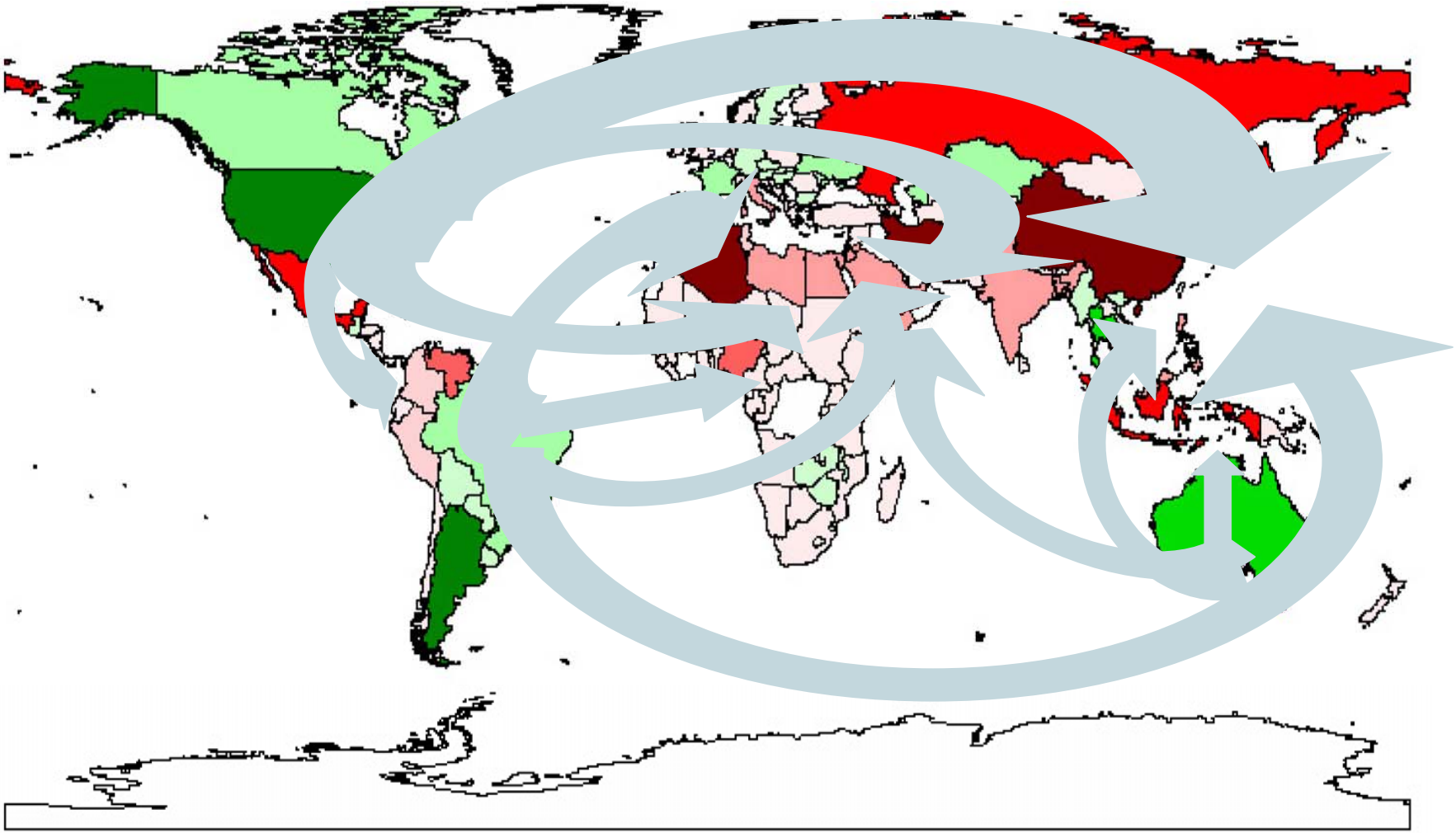
From Yang *et al.* 2007

Main Food Exporting Countries



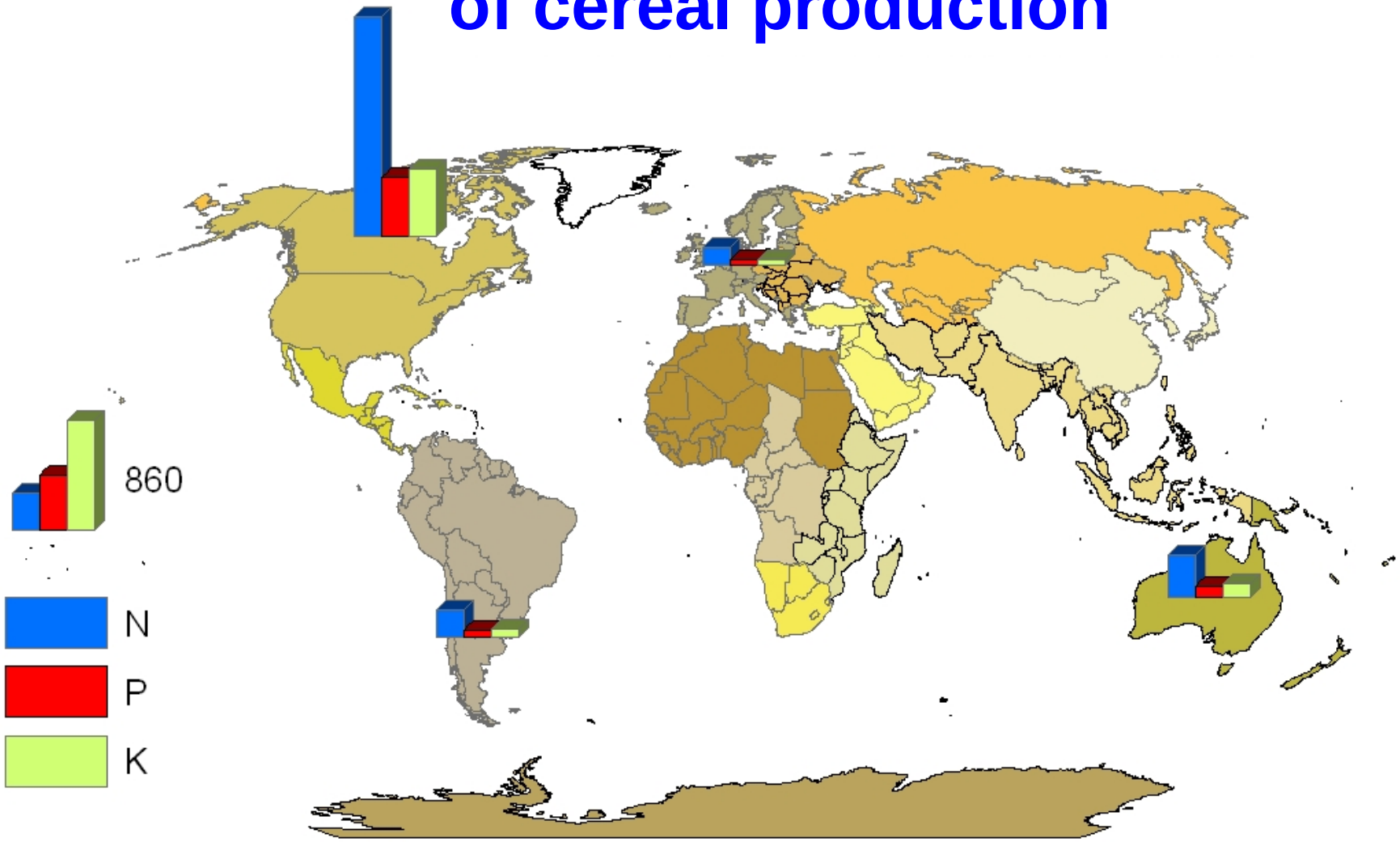
Adapted from Liu *et al.* 2007

Virtual water flows by regions (average over the period 1997–2001)



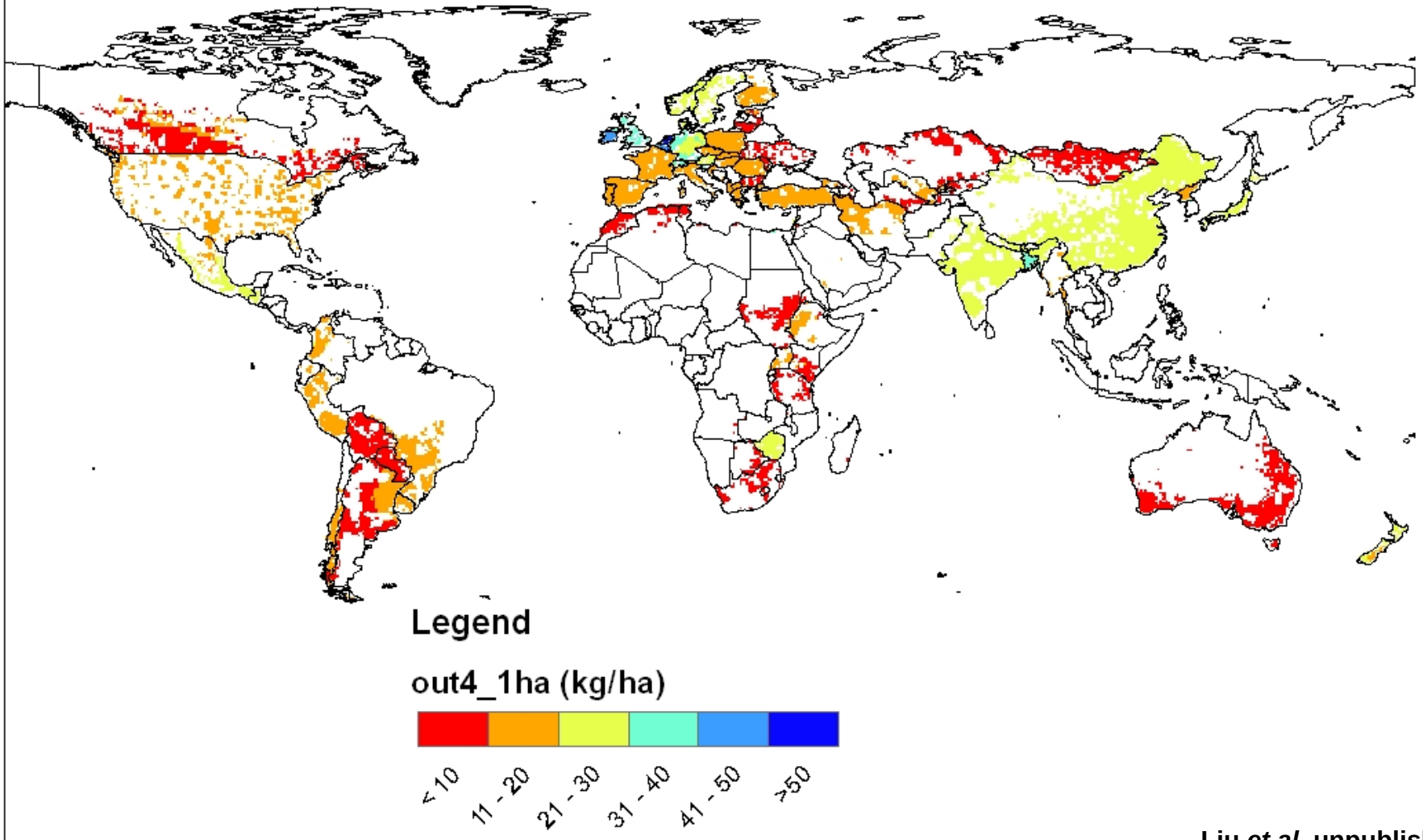
From Yang *et al.* 2006

NPK „pollution“ as a result of cereal production



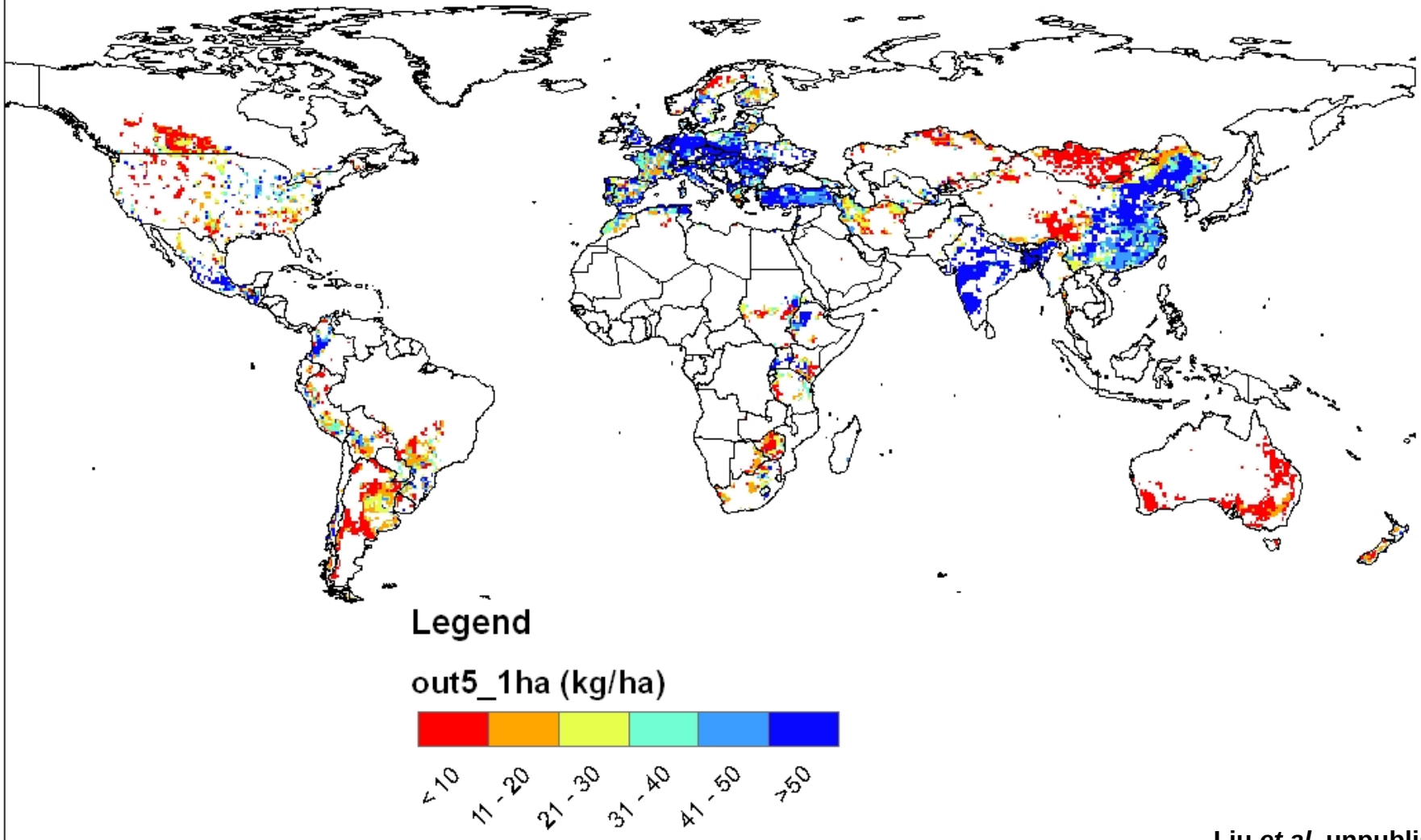
Liu *et al.* unpublished

Nitrogen loss to the atmosphere (wheat)



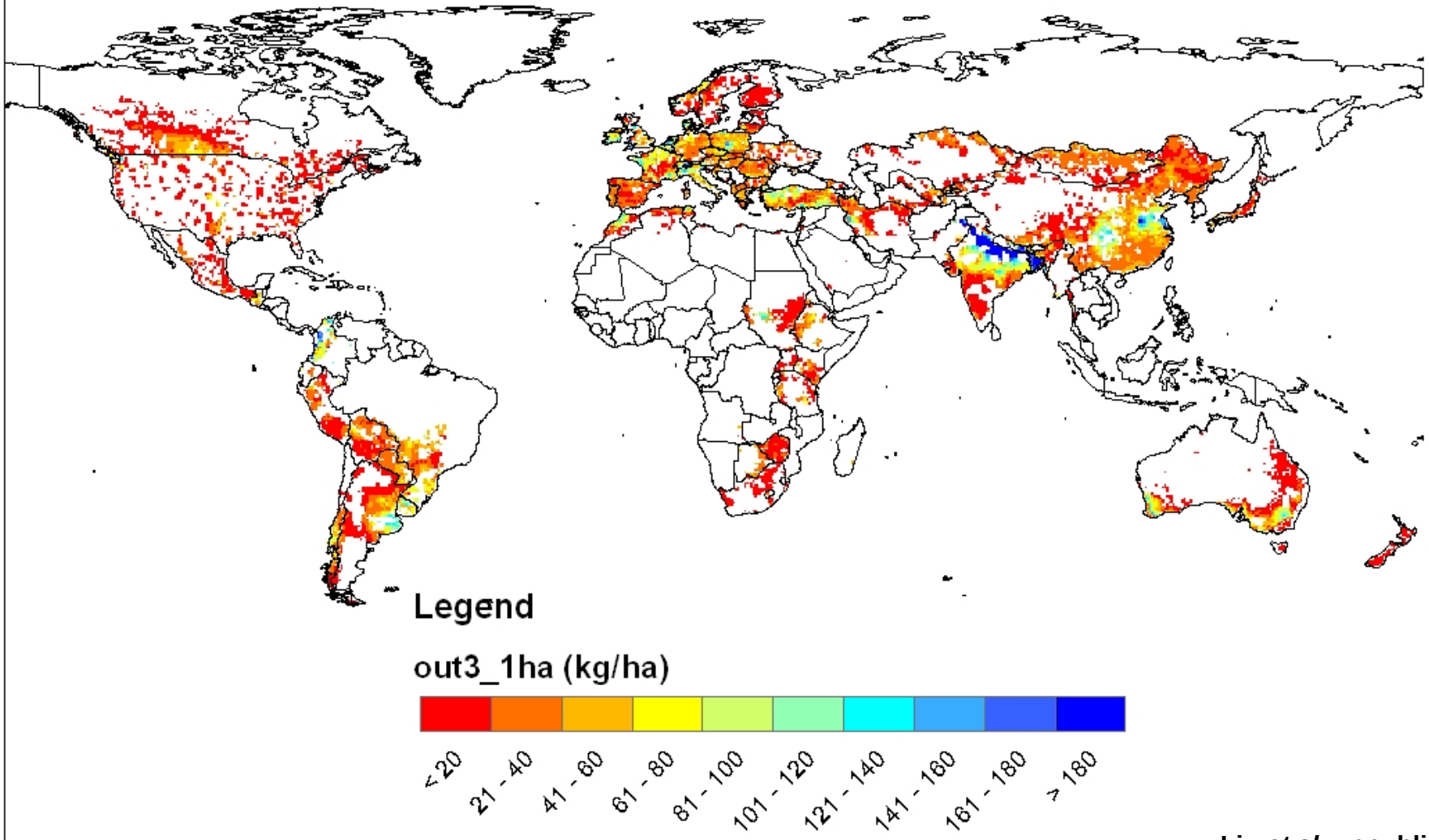
Liu *et al.* unpublished

Nitrogen loss through run-off (wheat)



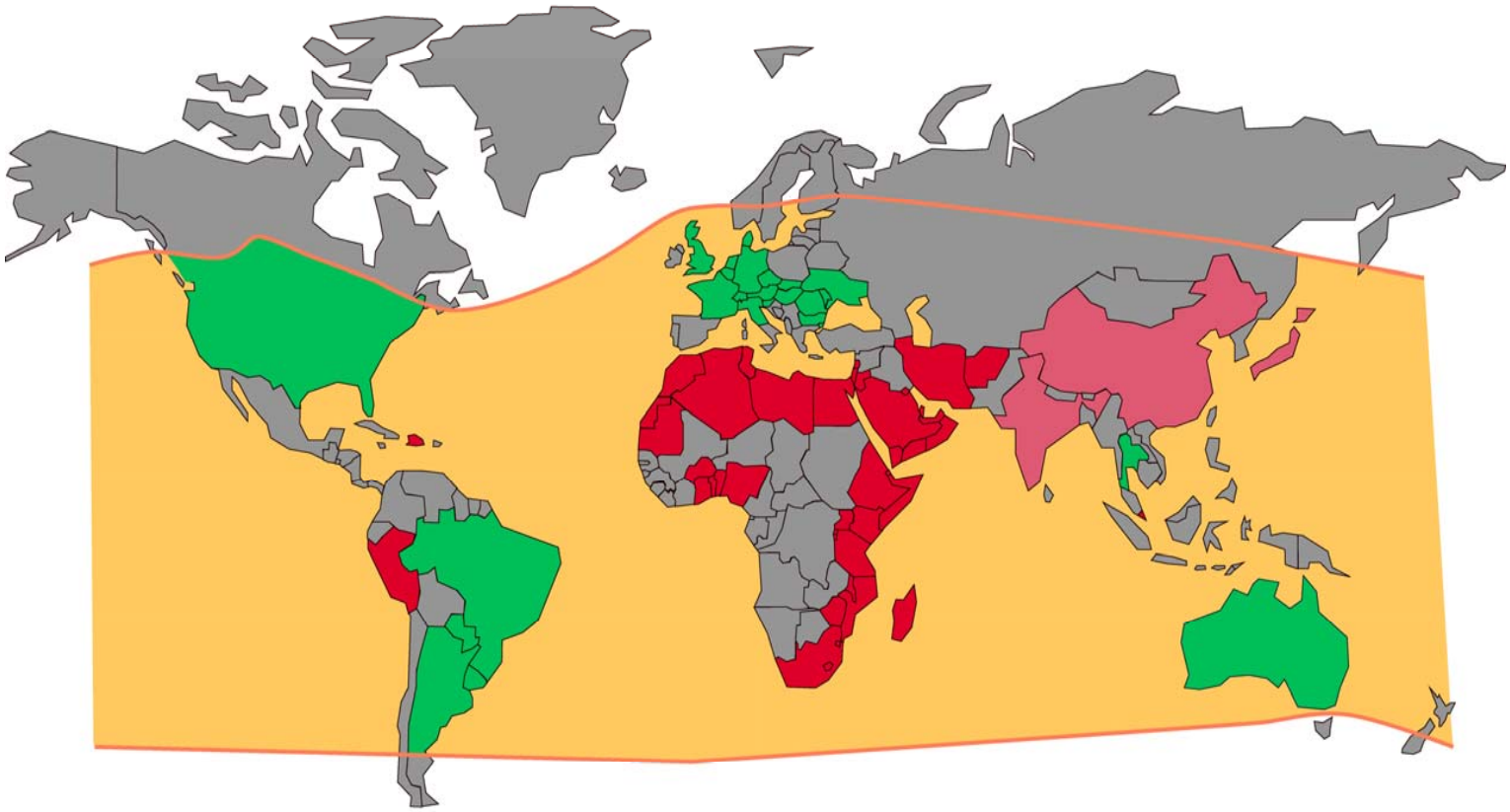
Liu *et al.* unpublished

Nitrogen loss to the groundwater (wheat)



Liu *et al.* unpublished

Situation 2025



Limits for food production

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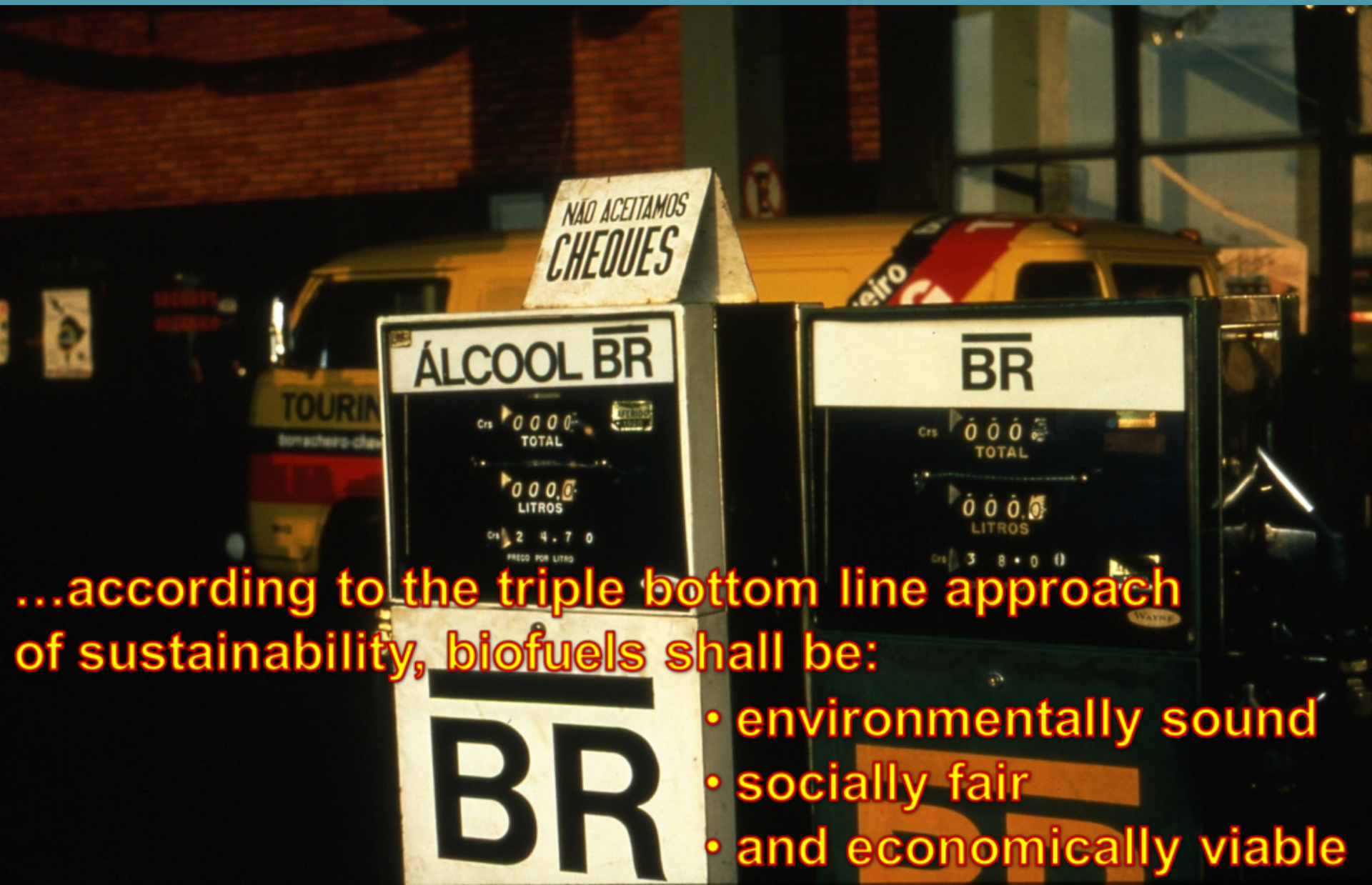
Water, soil and climatic conditions allow substantial food production for export

From Zehnder, 2002

Food and Biofuel is both possible?

Picture from Spiegel 2007

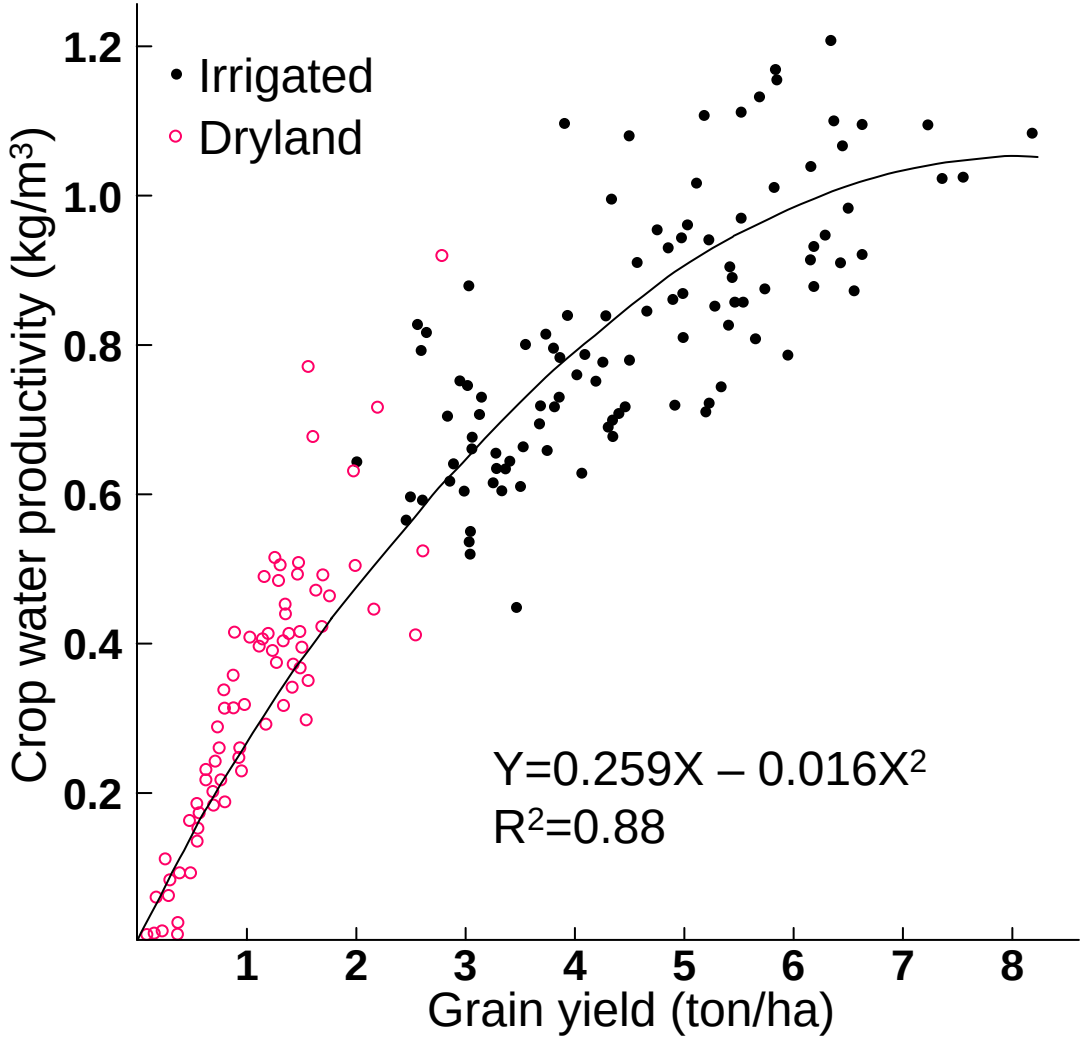
Yes, but…



…according to the triple bottom line approach of sustainability, biofuels shall be:

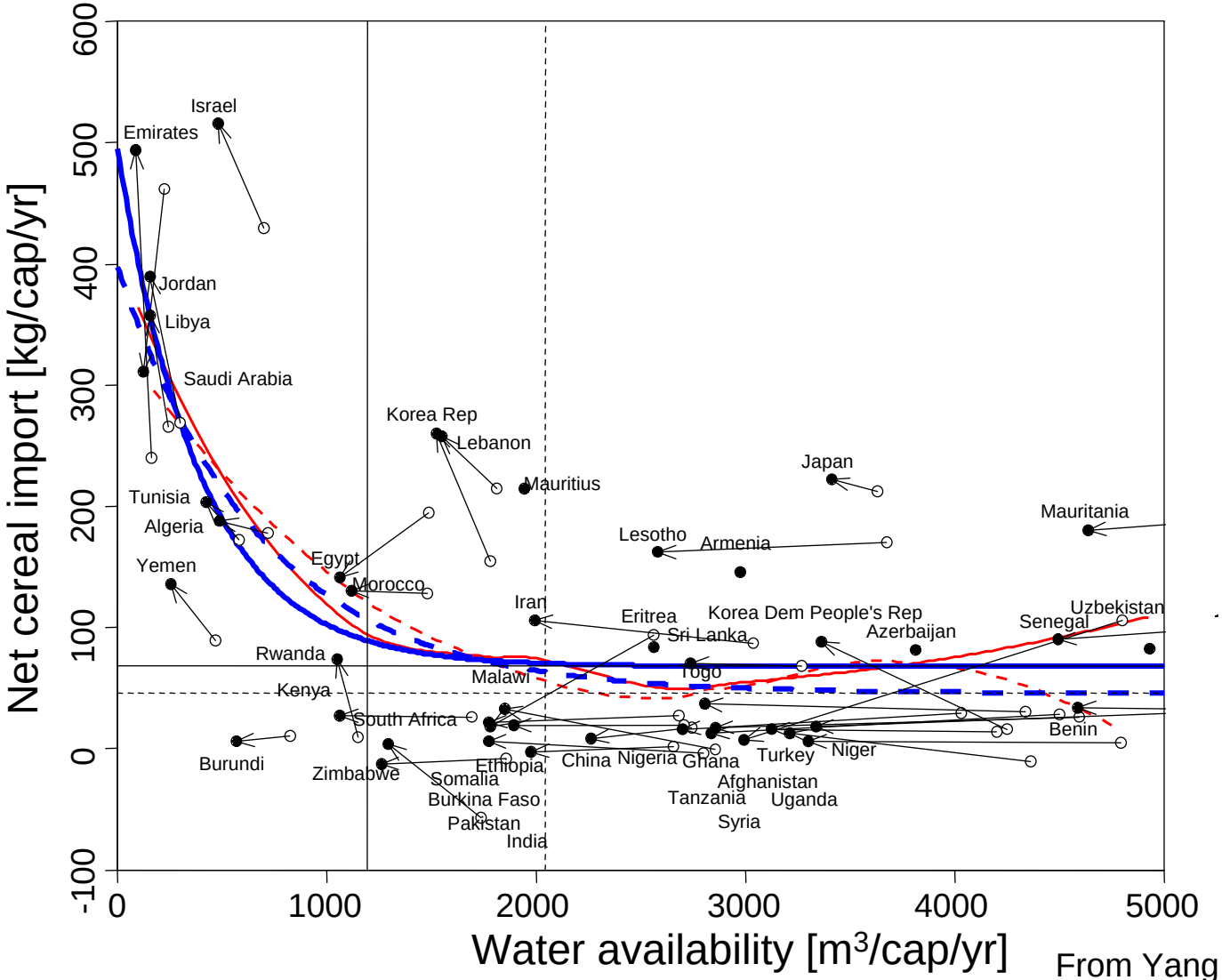
- environmentally sound
- socially fair
- and economically viable

Relationship of crop water productivity (cwp) to grain yield



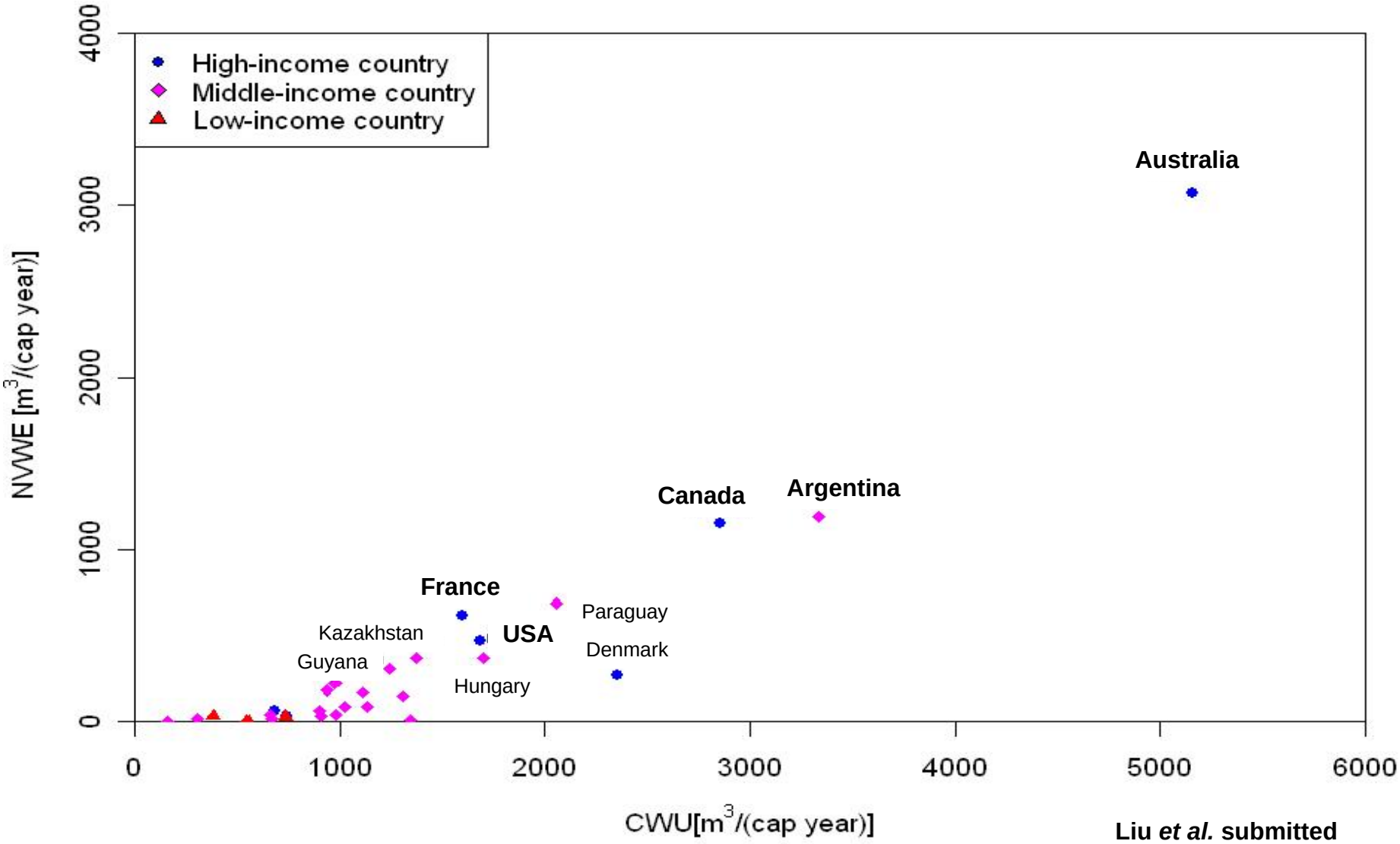
From: Musick *et al.* 1994

Water availability and cereal import comparison between 1980–84 and 1995–99



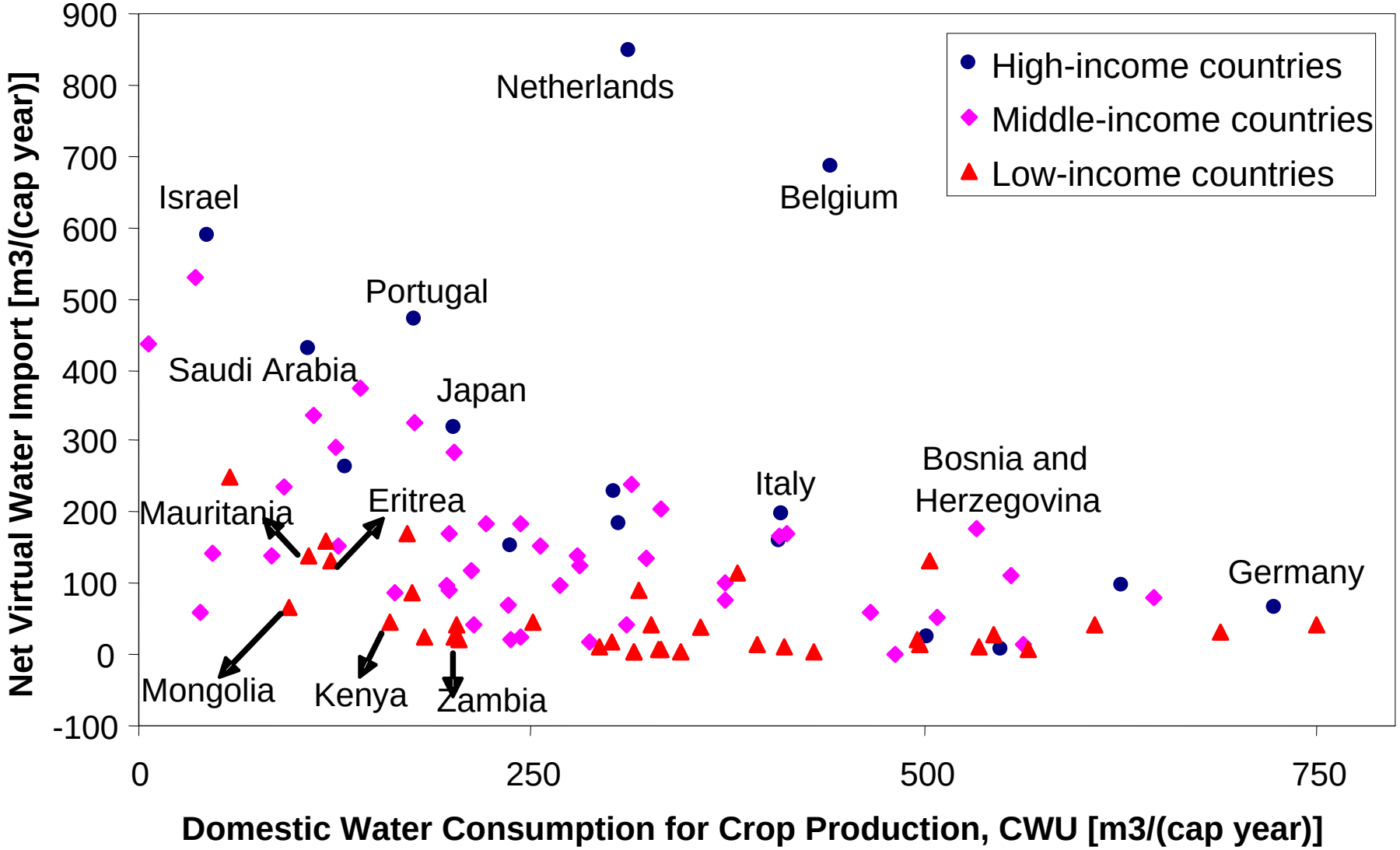
From Yang *et al.* 2003

Consumptive Water Use and Net Virtual Water Export



Liu *et al.* submitted

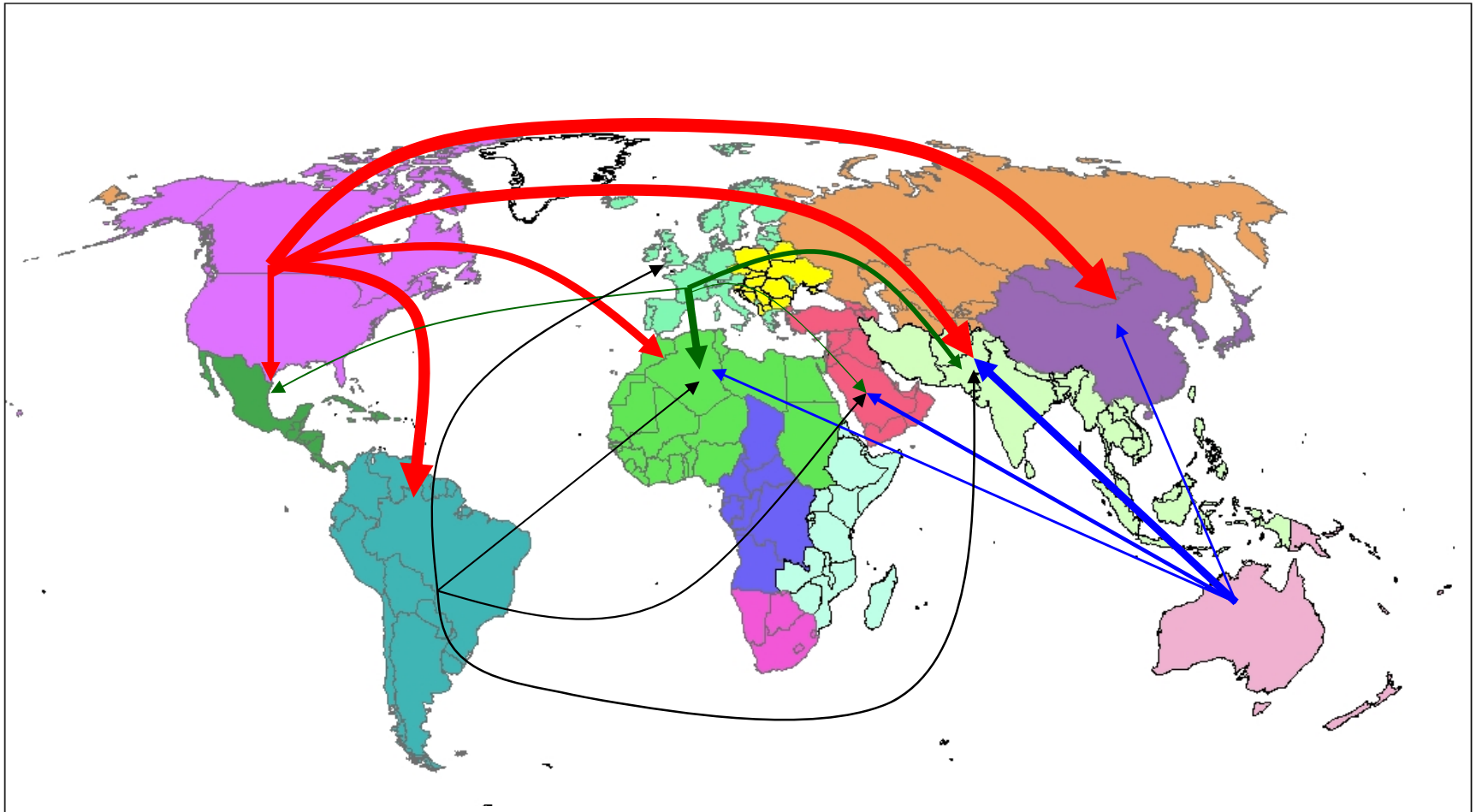
Virtual Water Import (crops only)



From Liu *et al.* 2007

Picture: Bühler AG

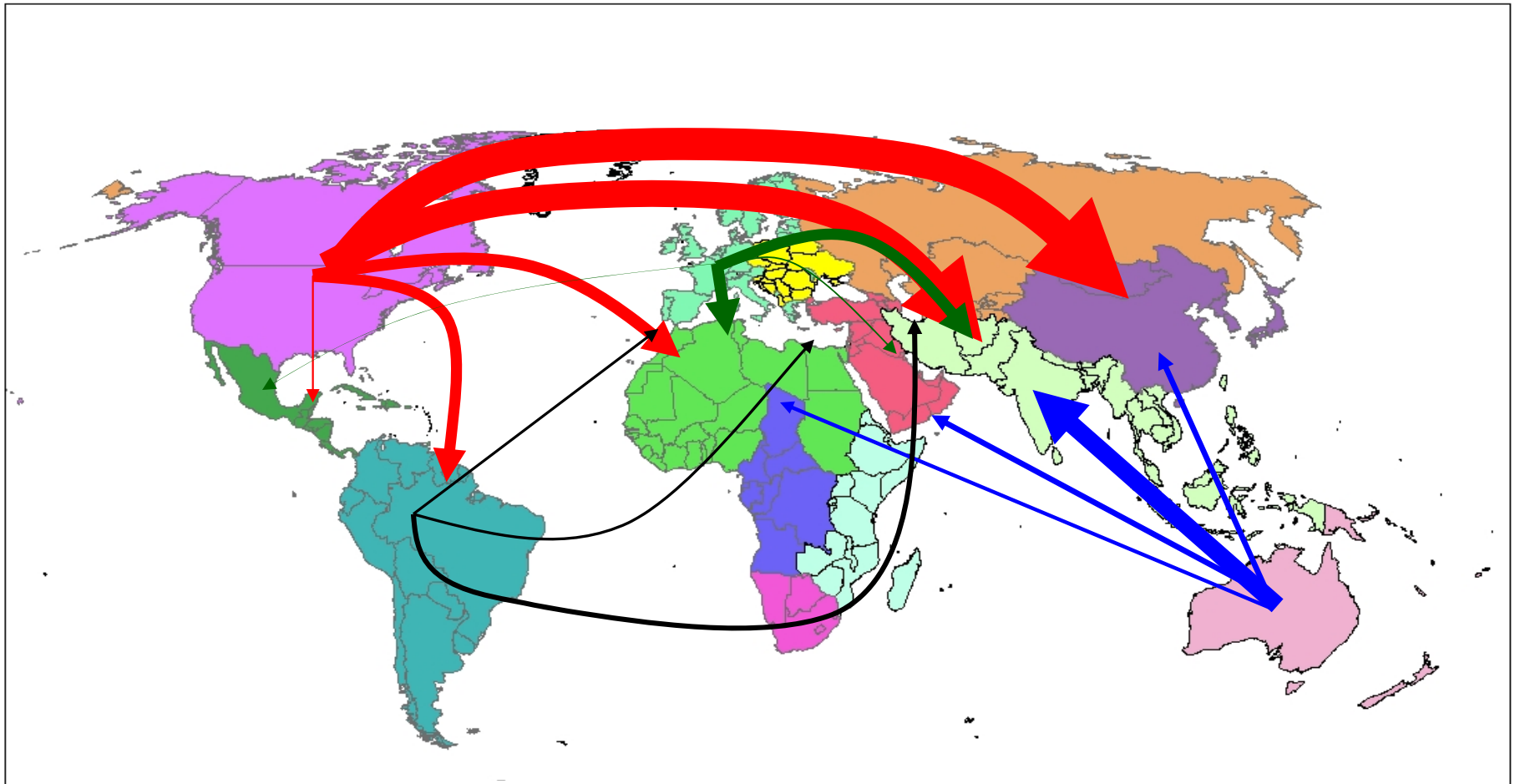
Global net nitrogen flow as a result of cereal trade (2000)



Total annual intercontinental fluxes:
2.2 million tons nitrogen and 0.3 million tons of phosphorus

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