Water limits to sustainable food security in global environmental changes scenarios

Maria Cristina Rulli

Politecnico di Milano-Department of Civil and Environmental Engineering

Scenario attuale (2012)

Acqua

900 M senza accesso all’acqua potabile

2.5 B senza infrastrutture idrauliche

Energia

2.5 B senza accesso all’energia

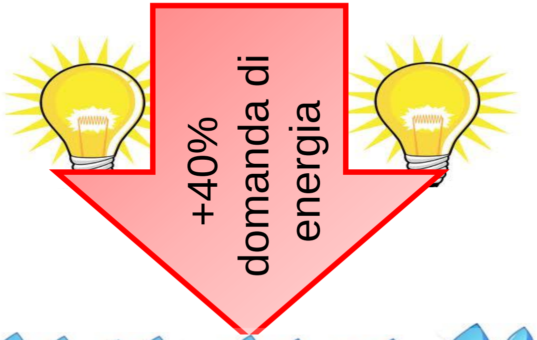
1.5 B seza accesso all’eletricità

Cibo

800 M Malnutrizione

Scenario futuro (2030)

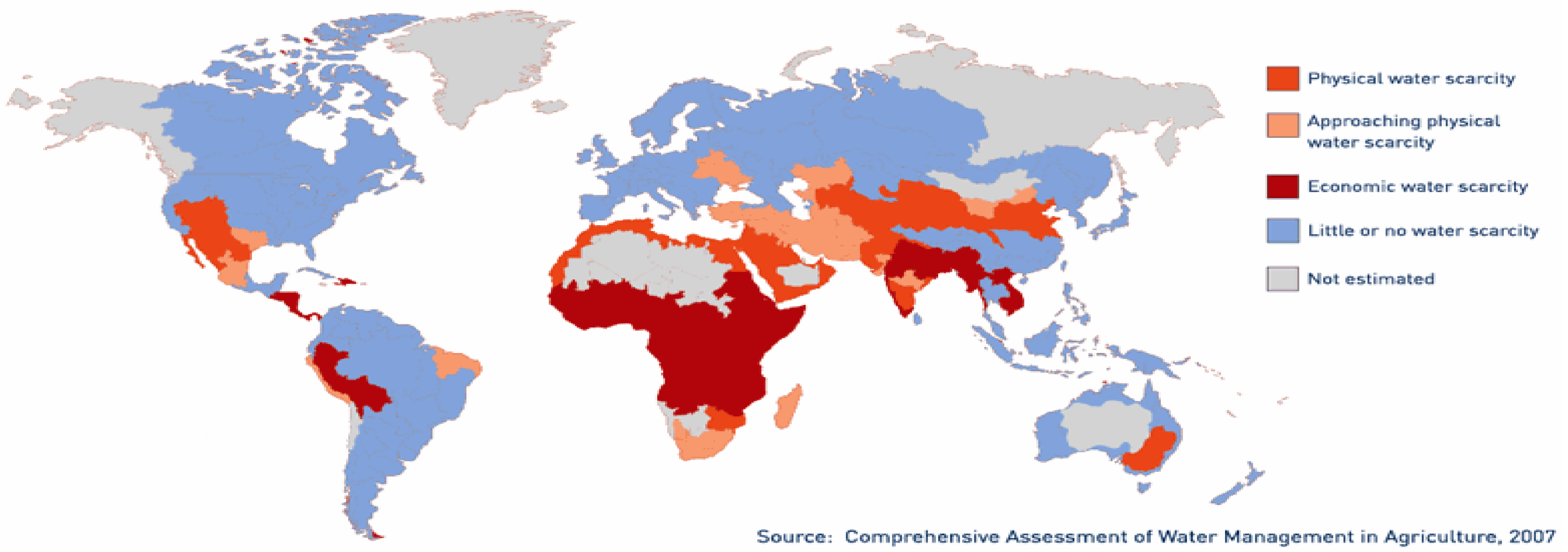
Crescita della popolazione, cambiamenti nella dieta, cambiamenti nelle politiche energetiche …



40% GAP risorse idriche

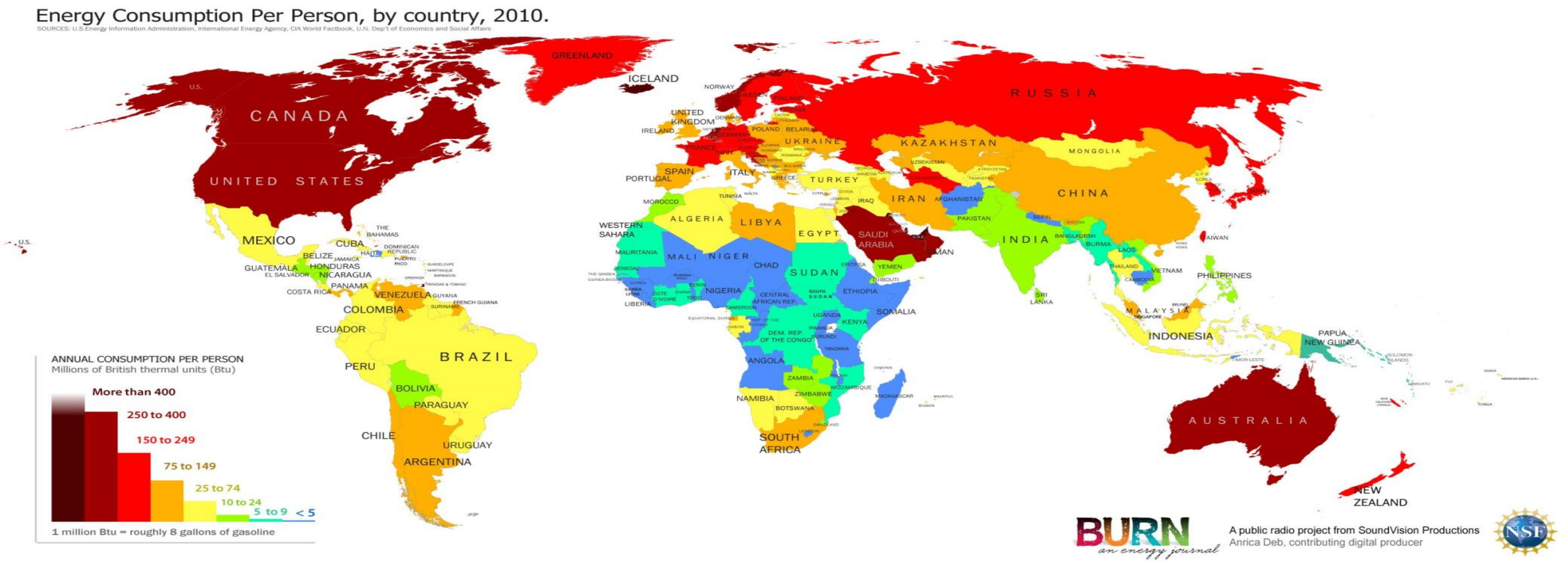
(disponibilità vs domanda)

SCARSITA' IDRICA

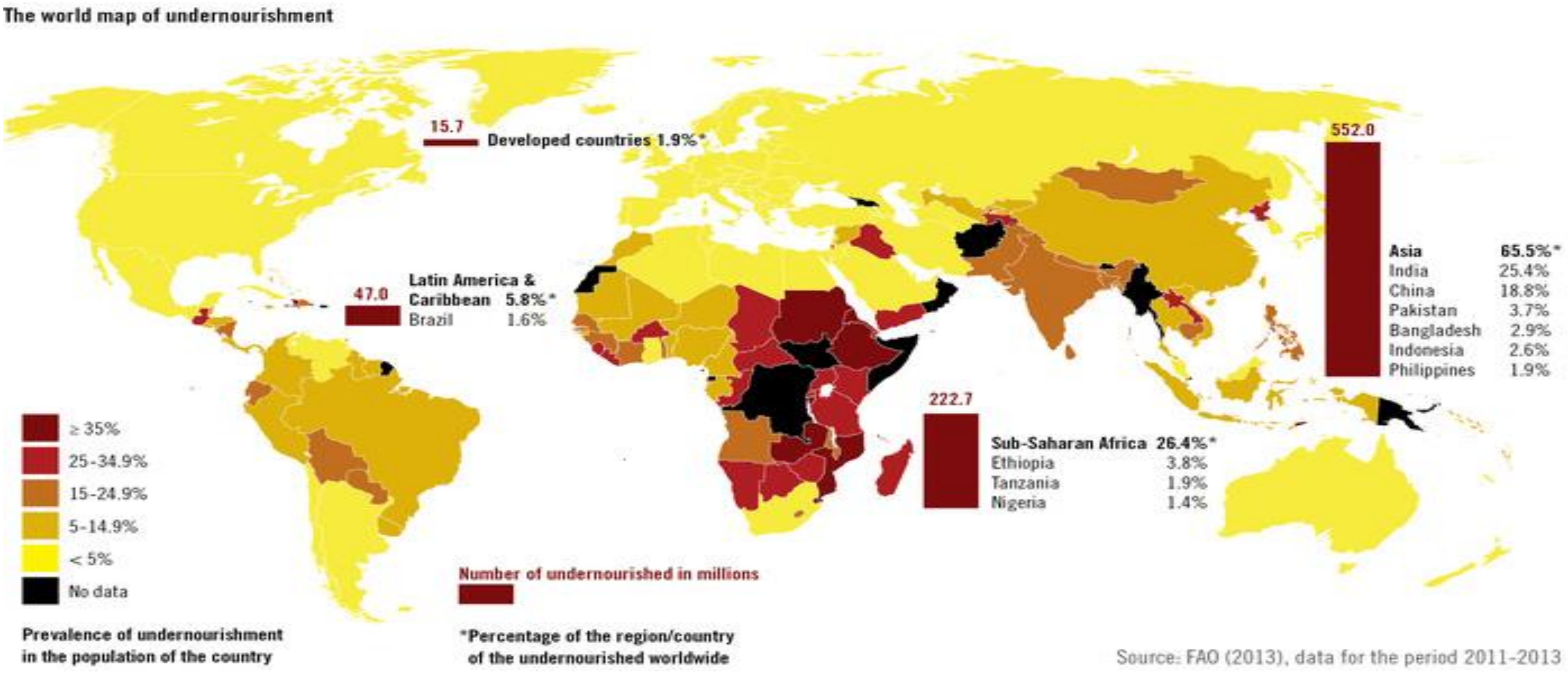


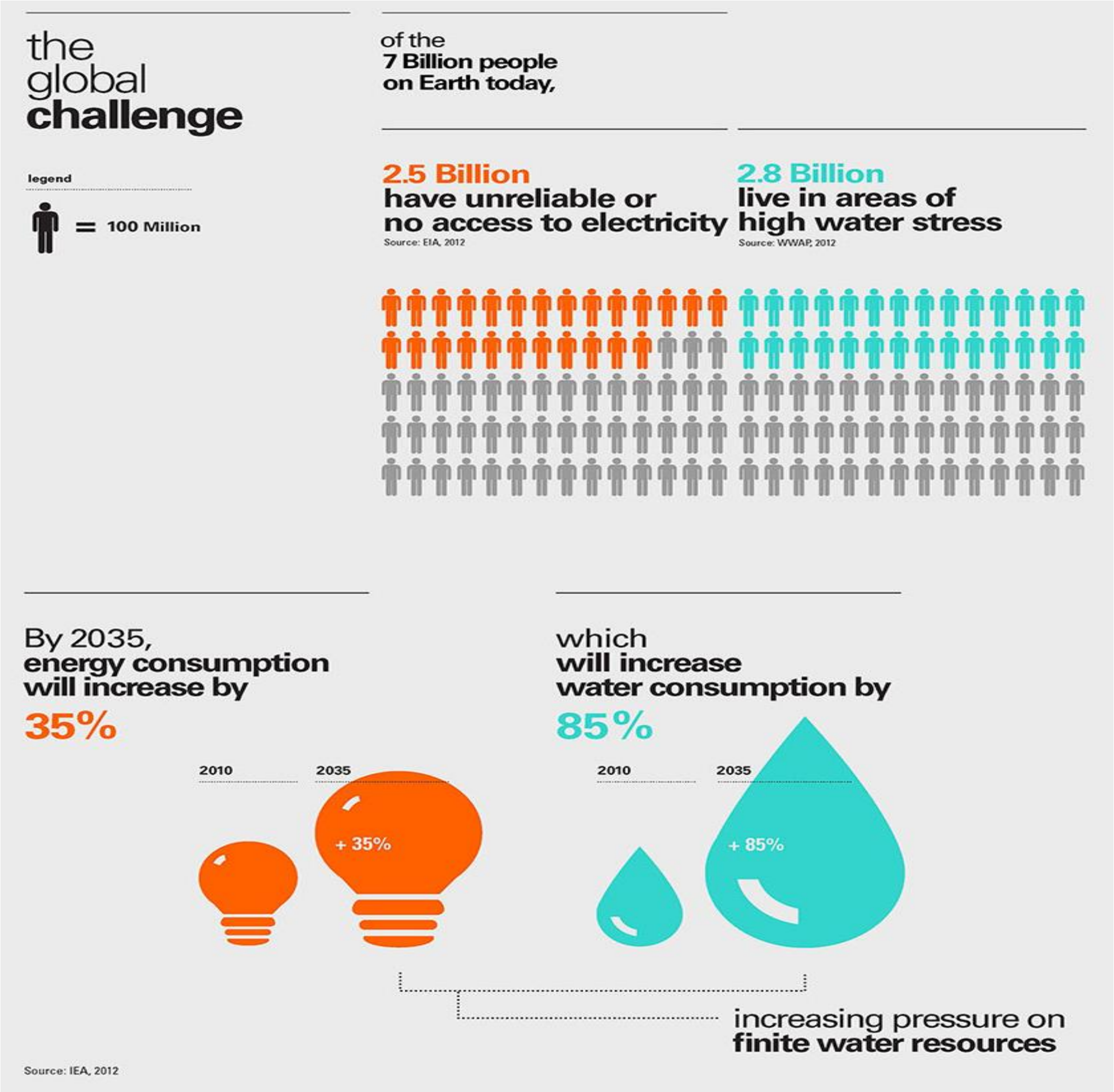
Stress Idrico = Rapporto fra prelievo idrico e disponibilità

ENERGIA


Energy Consumption Per Person, by country, 2010.
SOURCES: U.S.Energy Information Administration, International Energy Agency, CIA World Factbook, U.N. Dep't of Economics and Social Affairs
ANNUAL CONSUMPTION PER PERSON
Millions of British thermal units (Btu)
More than 400
250 to 400
150 to 249
75 to 149
25 to 74
10 to 24
5 to 9
< 5
1 million Btu = roughly 8 gallons of gasoline
GREENLAND
ICELAND
CANADA
UNITED STATES
MEXICO
CUBA
BELIZE
GUATEMALA
HONDURAS
NICARAGUA
PANAMA
COSTA RICA
VENEZUELA
COLOMBIA
ECUADOR
PERU
BRAZIL
BOLIVIA
PARAGUAY
CHILE
URUGUAY
ARGENTINA
NORWAY
UNITED KINGDOM
IRELAND
FRANCE
SPAIN
PORTUGAL
ITALY
POLAND
UKRAINE
TURKEY
RUSSIA
KAZAKHSTAN
MONGOLIA
CHINA
IRAN
IRAQ
AFGHANISTAN
PAKISTAN
INDIA
MOROCCO
ALGERIA
LIBYA
EGYPT
WESTERN SAHARA
MAURITANIA
MALI
NIGER
CHAD
SUDAN
NIGERIA
ETHIOPIA
SOMALIA
KENYA
SAUDI ARABIA
YEMEN
ANGOLA
ZAMBIA
ZIMBABWE
NAMIBIA
BOTSWANA
SOUTH AFRICA
MADAGASCAR
TAIWAN
VIETNAM
PHILIPPINES
MALAYSIA
INDONESIA
PAPUA NEW GUINEA
AUSTRALIA
NEW ZEALAND
BURN
an energy journal
A public radio project from SoundVision Productions
Anrica Deb, contributing digital producer
NSF

MALNUTRIZIONE

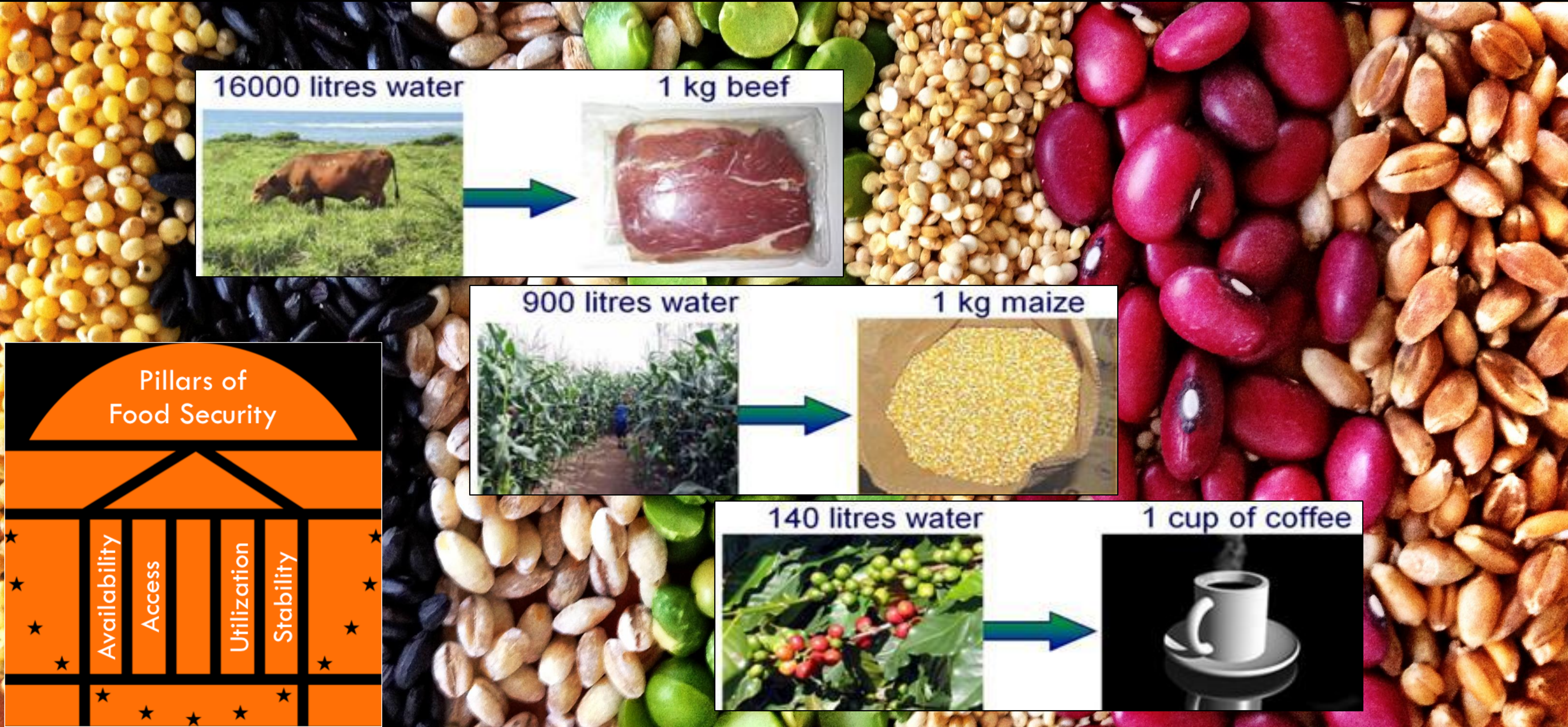




the global challenge
legend
= 100 Million
of the 7 Billion people on Earth today,
2.5 Billion have unreliable or no access to electricity
Source: EIA, 2012
2.8 Billion live in areas of high water stress
Source: WWAP, 2012
By 2035, energy consumption will increase by 35%
2010
2035
+ 35%
which will increase water consumption by 85%
2010
2035
+ 85%
increasing pressure on finite water resources
Source: IEA, 2012

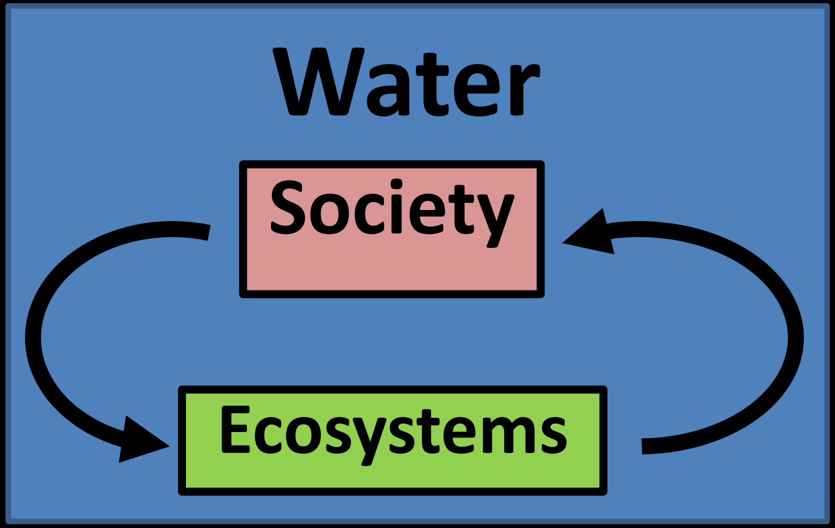
Water
Food
Climate
Energy
Nexus 2014
Sustainability
Security
Development

Food security exists when "all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" - WHO



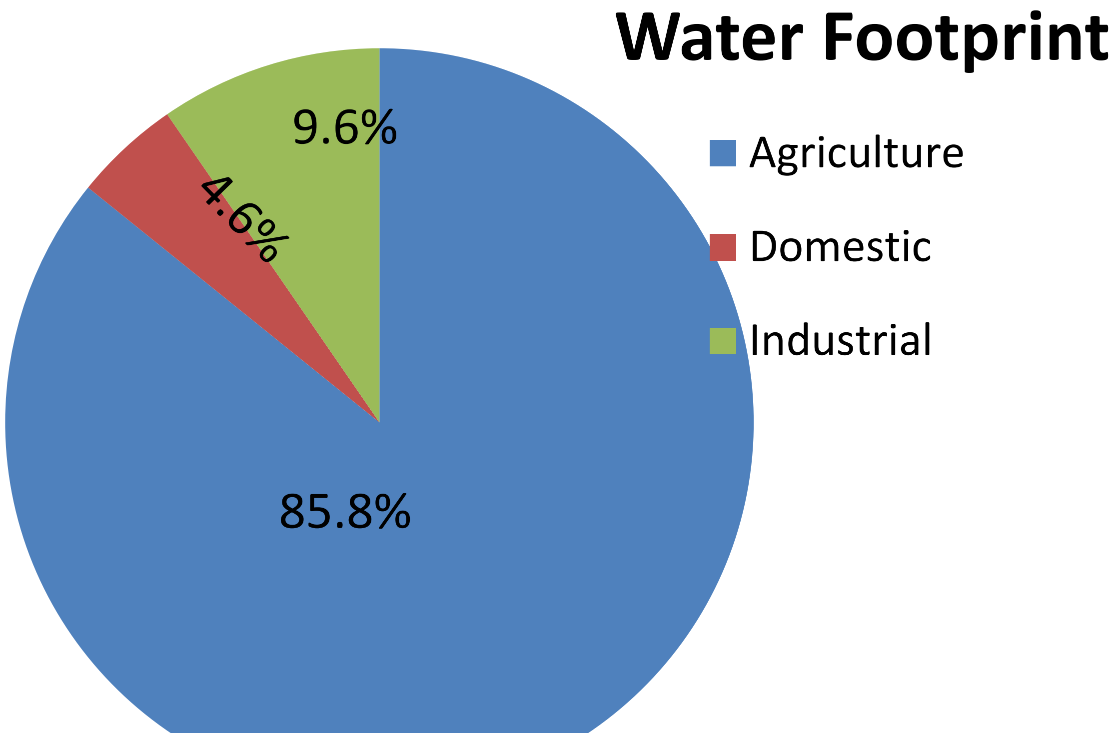
Water, Food, Energy and the FEW nexus

Increasing Demand for Food and Energy
Constraints Imposed by the Water Cycle
Redistribution & Globalization of Resources
Strategies for increasing food production

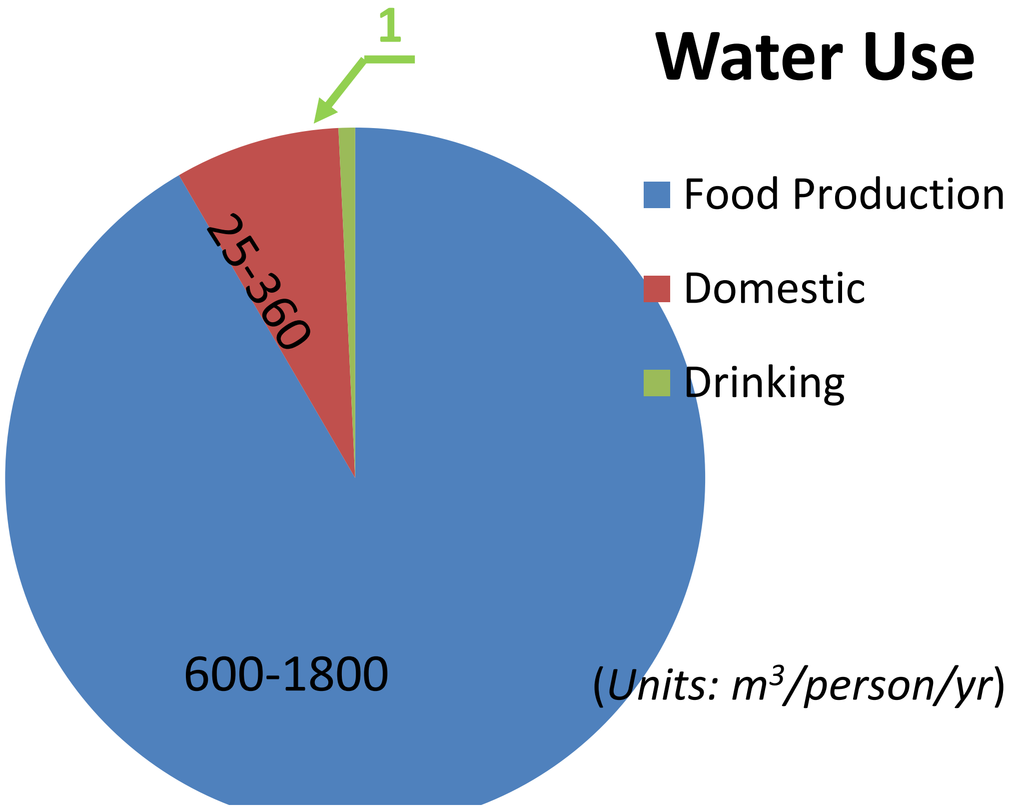


Most of our water footprint is due to agriculture

…mainly for food production



(data from Chapagain and Hoekstra, 2004)



(data from Falkenmark & Rockstrom, 2005)

Water Use in Agriculture

19% of agricultural land is irrigated and produces 40% of the food

Rainfed

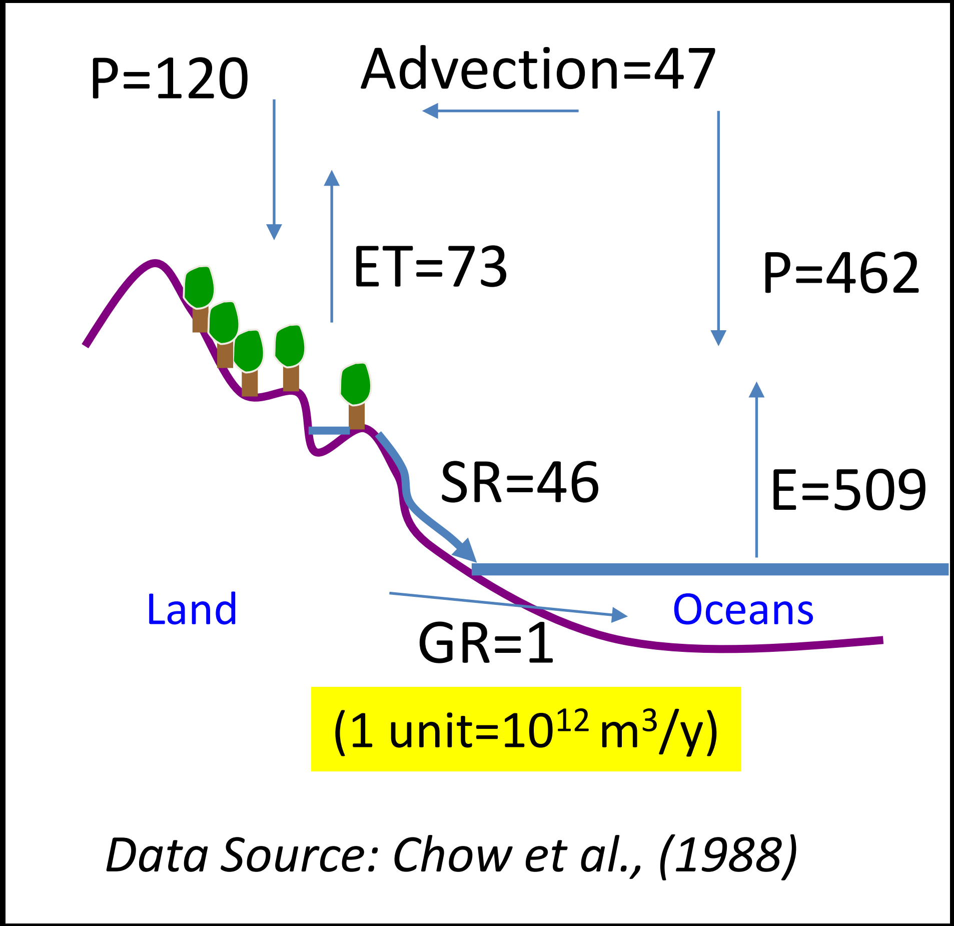
Uses "green" water

Irrigated

Both "blue & green" water

Water Footprint: amount of water consumed to produce a commodity or to sustain the consumption of commodities by an individual or a group of people ***(Hoekstra & Chapagain, 2004)***

Global Water Cycle



Water Used for Agriculture

in 2010: ≈12×10^{12} m^3/y (Carr, D'Odorico et al., PLoS1, 2013)

in 1996-2005: 6.75 $\times10^{12}$ m^3/y (Mekonnen & Hoekstra, 2011)

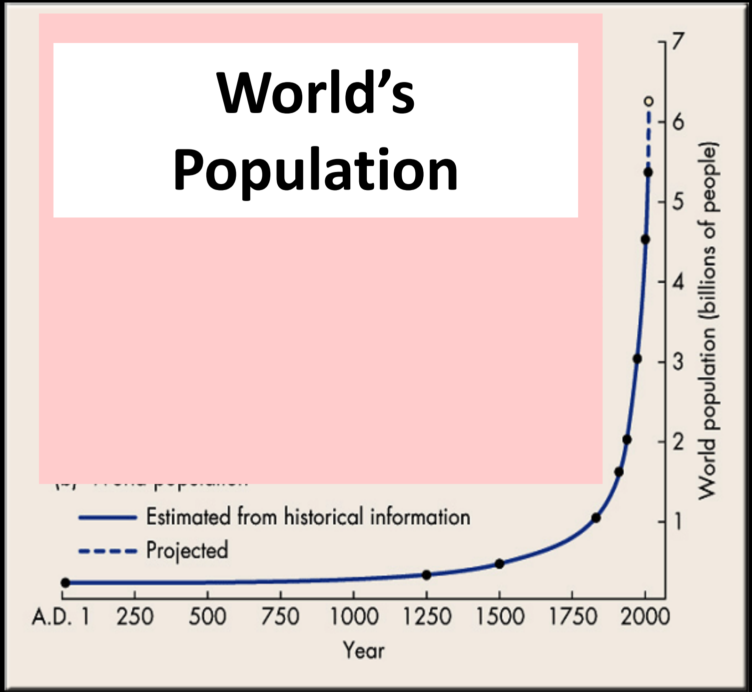
10% of precip over land is used for agriculture

16% of terrestrial ET is from agroecosystems

How can we meet the increasing food demand?

How did we increase water use in the last decade?

Increase in demand



How did we become 7 billion?

1 billion in	1804	
2 billion in	1927	(123 years later)
3 billion in	1960	(33 years later)
4 billion in	1974	(14 years later)
5 billion in	1987	(13 years later)
6 billion in	1999	(12 years later)
7 billion in	2011	(12 years later)
8 billion in	2025	(14 years later)

- Haber- Bosch Process (1909)
- Other Technology

1 billion people increase every 12-14 years!

Food Crises: "are we running out of water?"

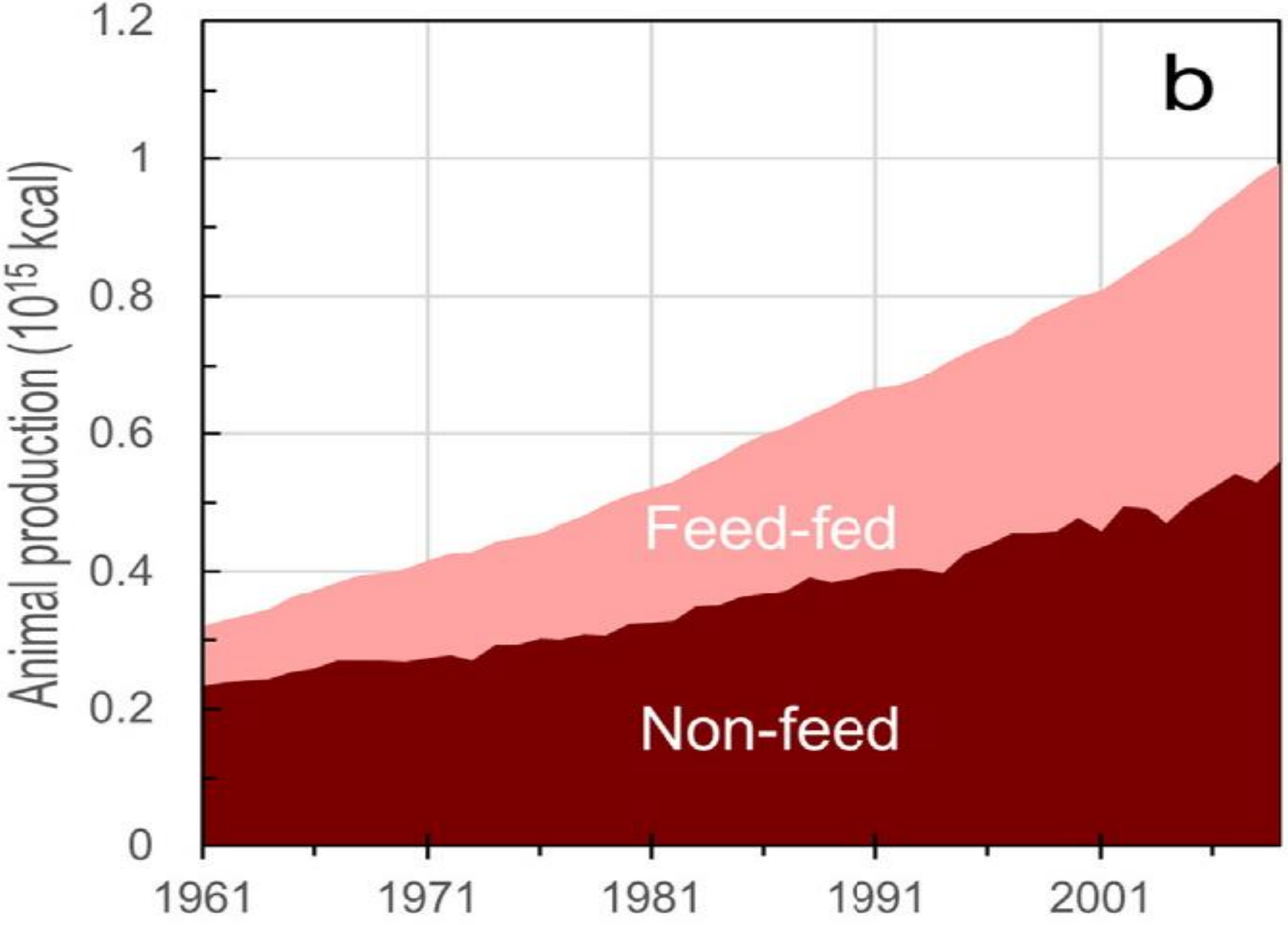
Erisman et al., Nature Geoscience, 2012.

FEATURE

How a century of ammonia synthesis changed the world

On 13 October 1908, Fritz Haber filed his patent on the "synthesis of ammonia from its elements" for which he was later awarded the 1918 Nobel Prize in Chemistry. A hundred years on we live in a world transformed by and highly dependent upon Haber–Bosch nitrogen.

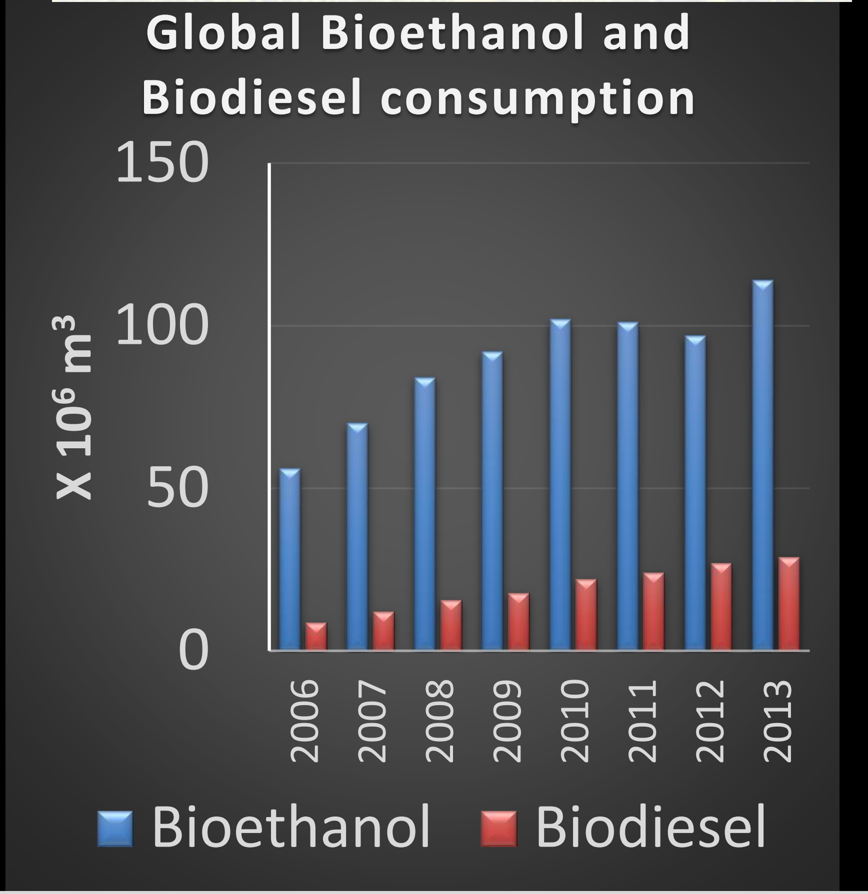
Increase in meat consumption



What about Water for Energy?

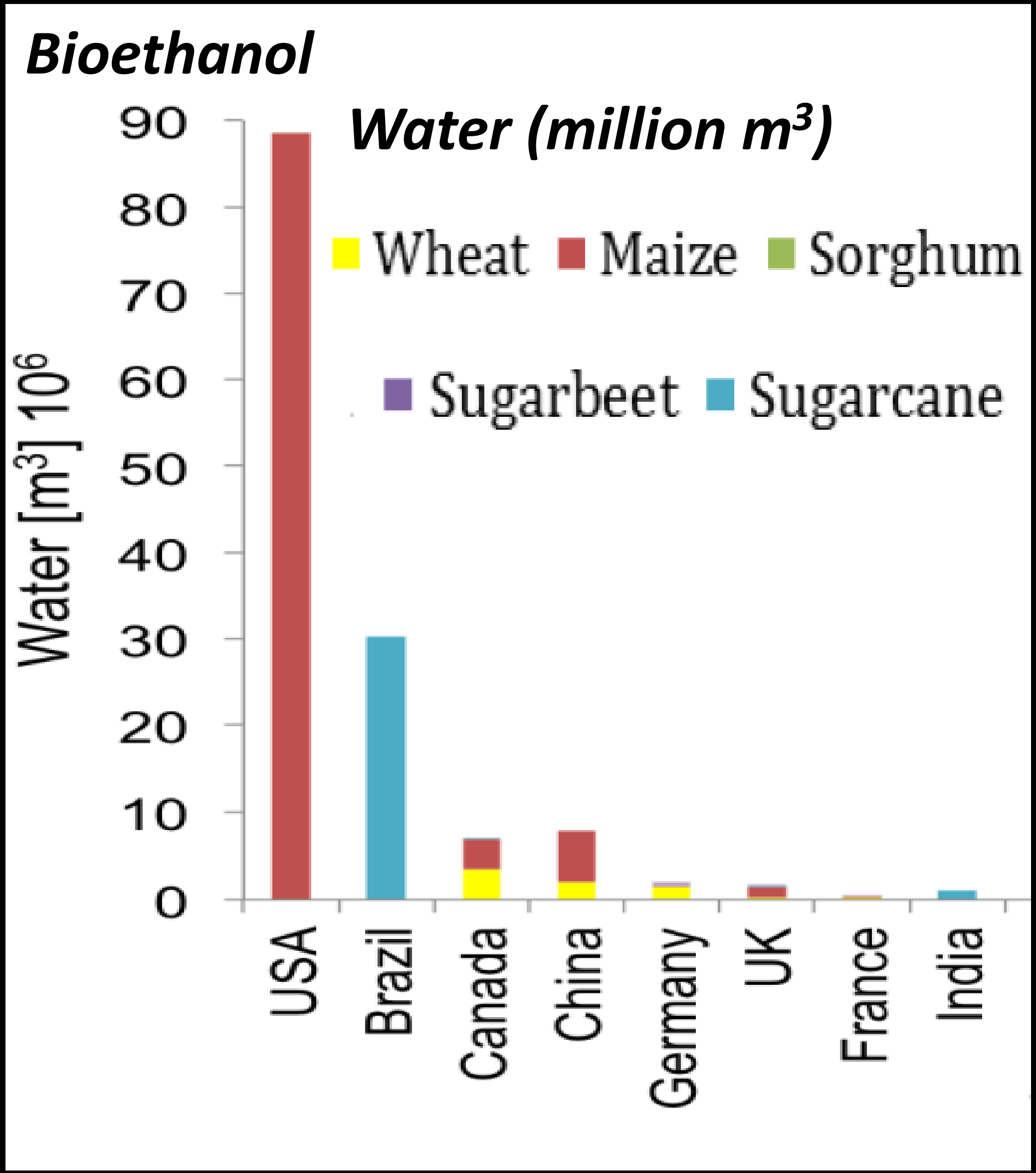
- Biofuel Production
- Extraction of fossil fuels
- Non-fuel based renewable energy

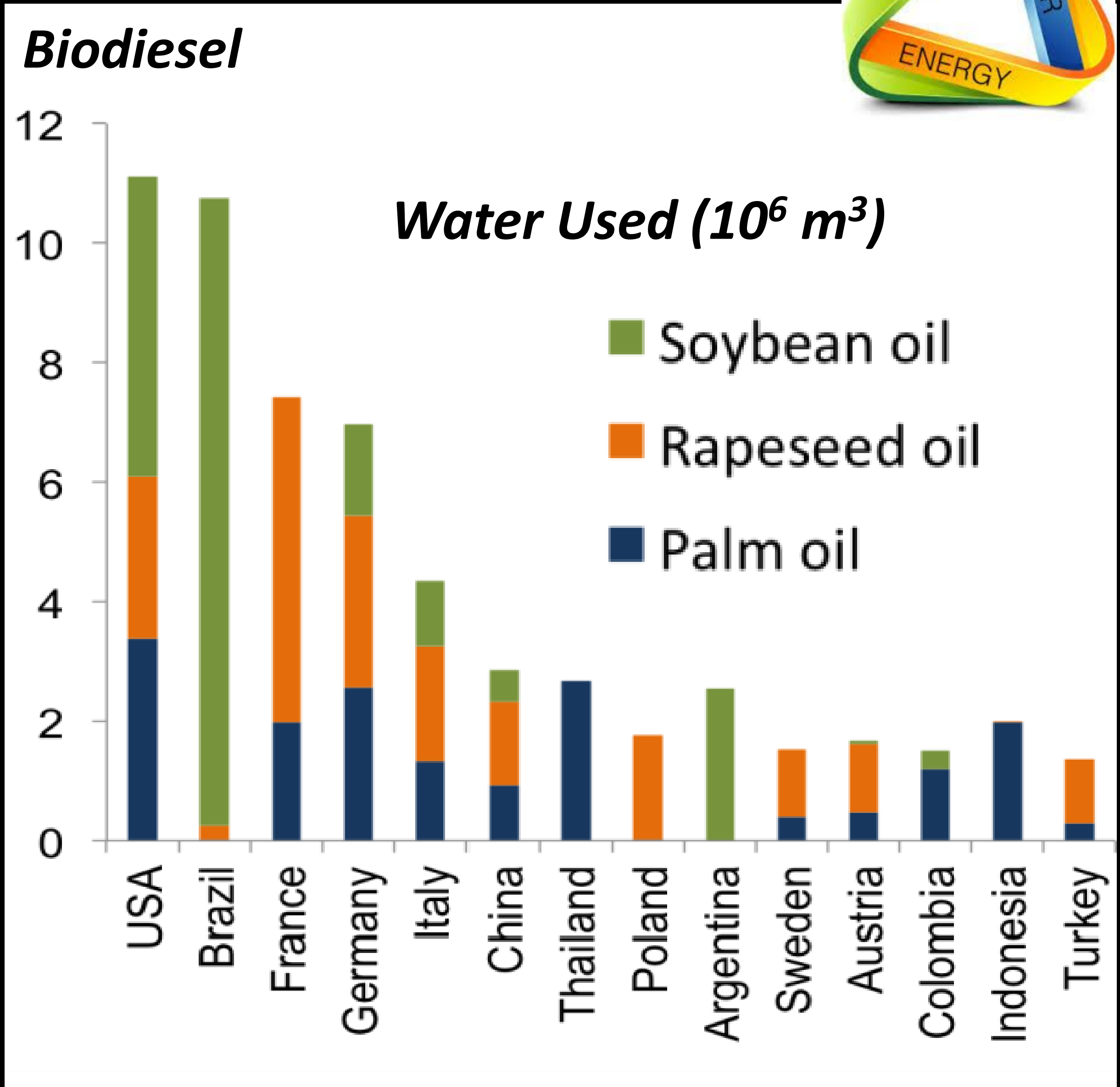
(data source: FAO-OECD, 2013)



Only 4 percent of global energy consumption by the transport sector and 0.2% of global energy use in all sectors

Global Bioethanol and Biodiesel Consumption





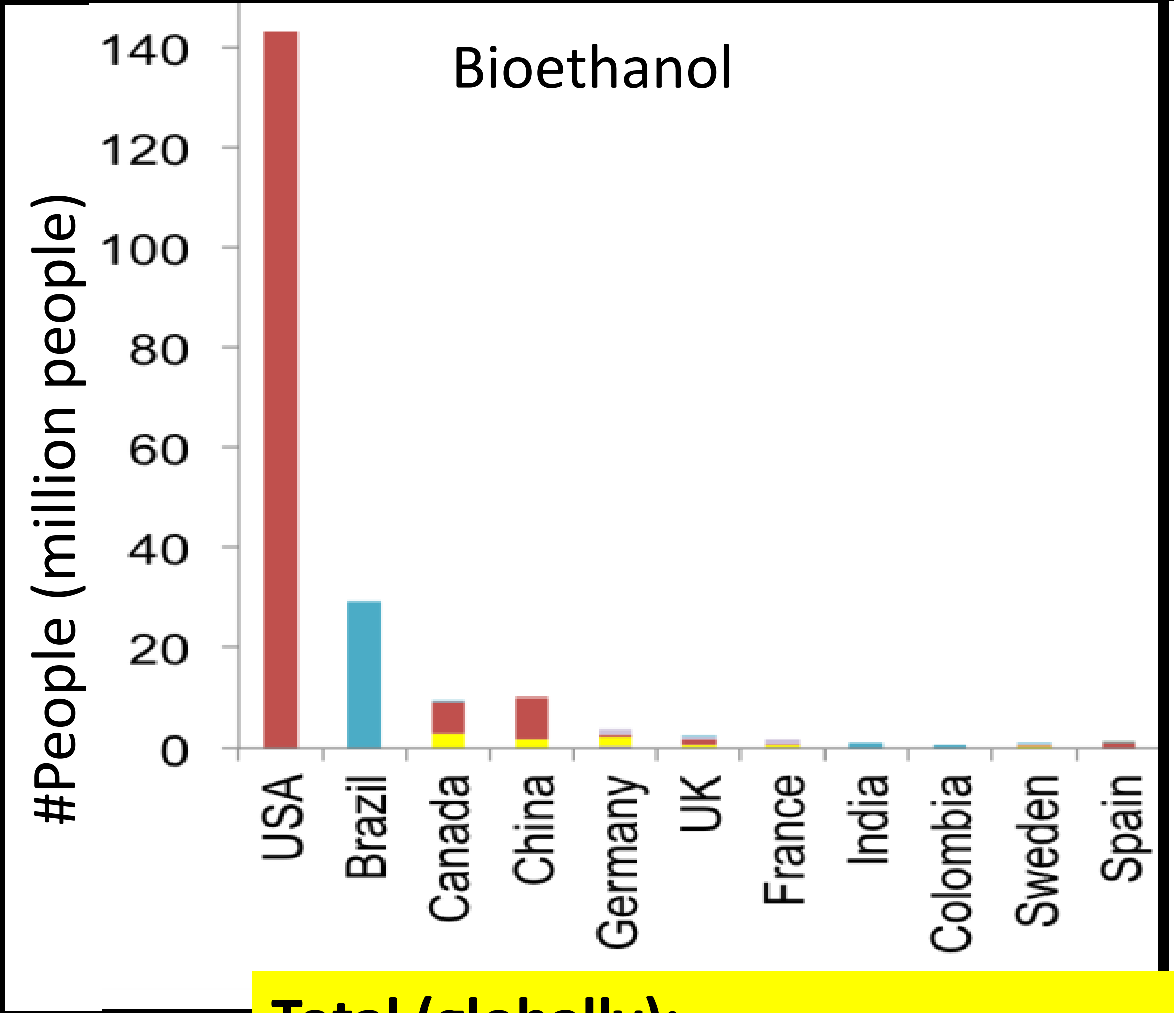
2-3% water use in agriculture for 0.2% of global energy use in all sectors (Rulli et al., Sci. Rep. 2016)

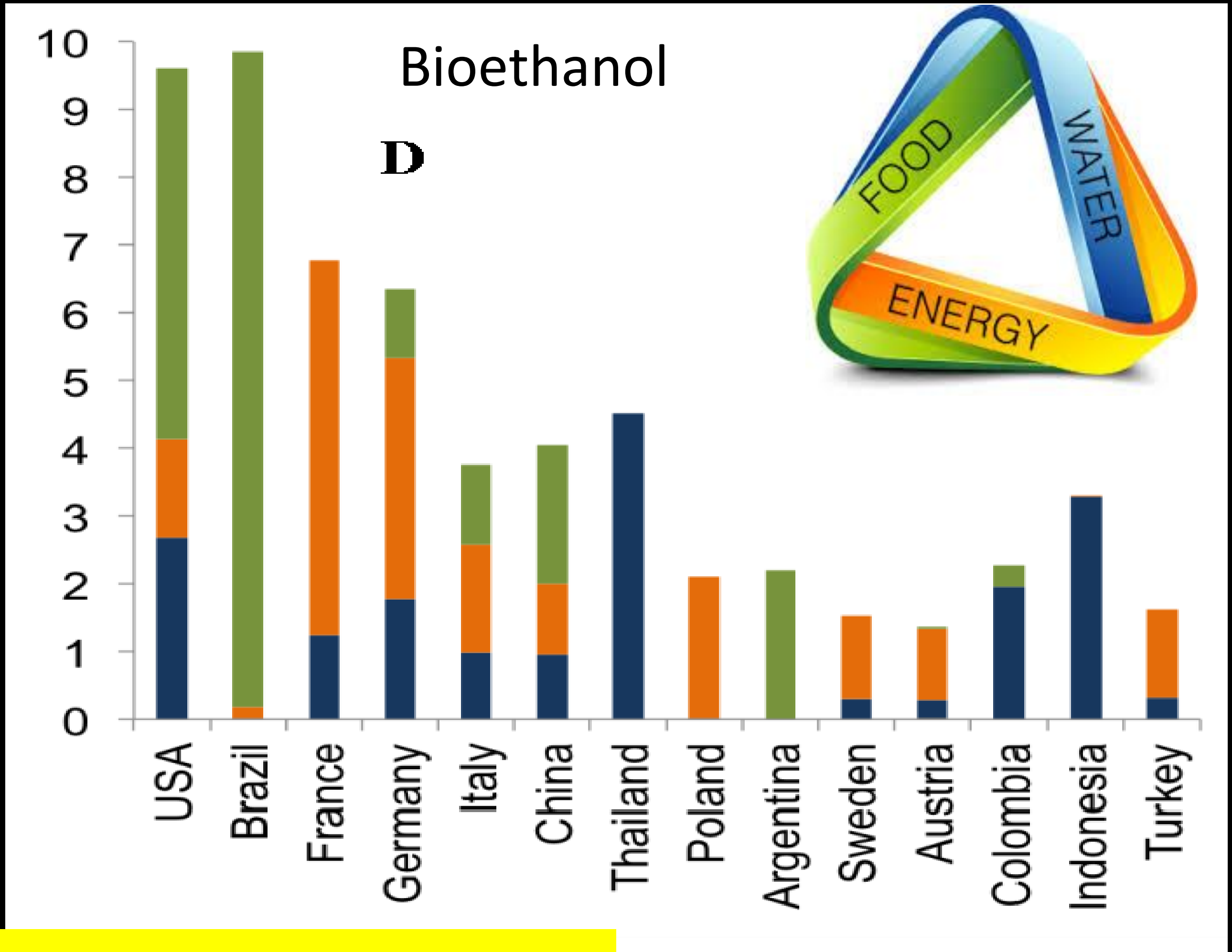
Comparison with other major water flows

	Annual flow ($m^3\ y^{-1}$)	Source
Water Used for Biofuels	$\approx 0.25 \times 10^{12}$	Rulli et al., 2016
Groundwater Depletion	0.14×10^{12}	Konikow, 2011
Freshwater Used for Food	7×10^{12}-12×10^{12}	Mekonnen & Hoekstra 2011 Carr, D'Odorico et al., 2013

Biofuels: 2-3 % of land and water use for agriculture

How many people could be fed?





Total (globally):
277 Million People (consumers' diet)
288 Million People (producers' diet)

Food-Energy Tradeoff

With **current agricultural area (A), diet (D), and EU per capita energy consumption (E_n)** → max global population (P)

area for food *area for biofuels*

E_n=0.0146-0.0267 TJ/cap/yr

y_e=0.1 TJ/ha

y_f=7.37 x 10^6 kcal/ha/y

Degree of reliance on Biofuels (m)	Population (billion people)
10%	4.8-6.7
20%	4.4-6.2
100%	2.5-3.9

(Rulli, et al., *Sci. Rep.*, 2016)

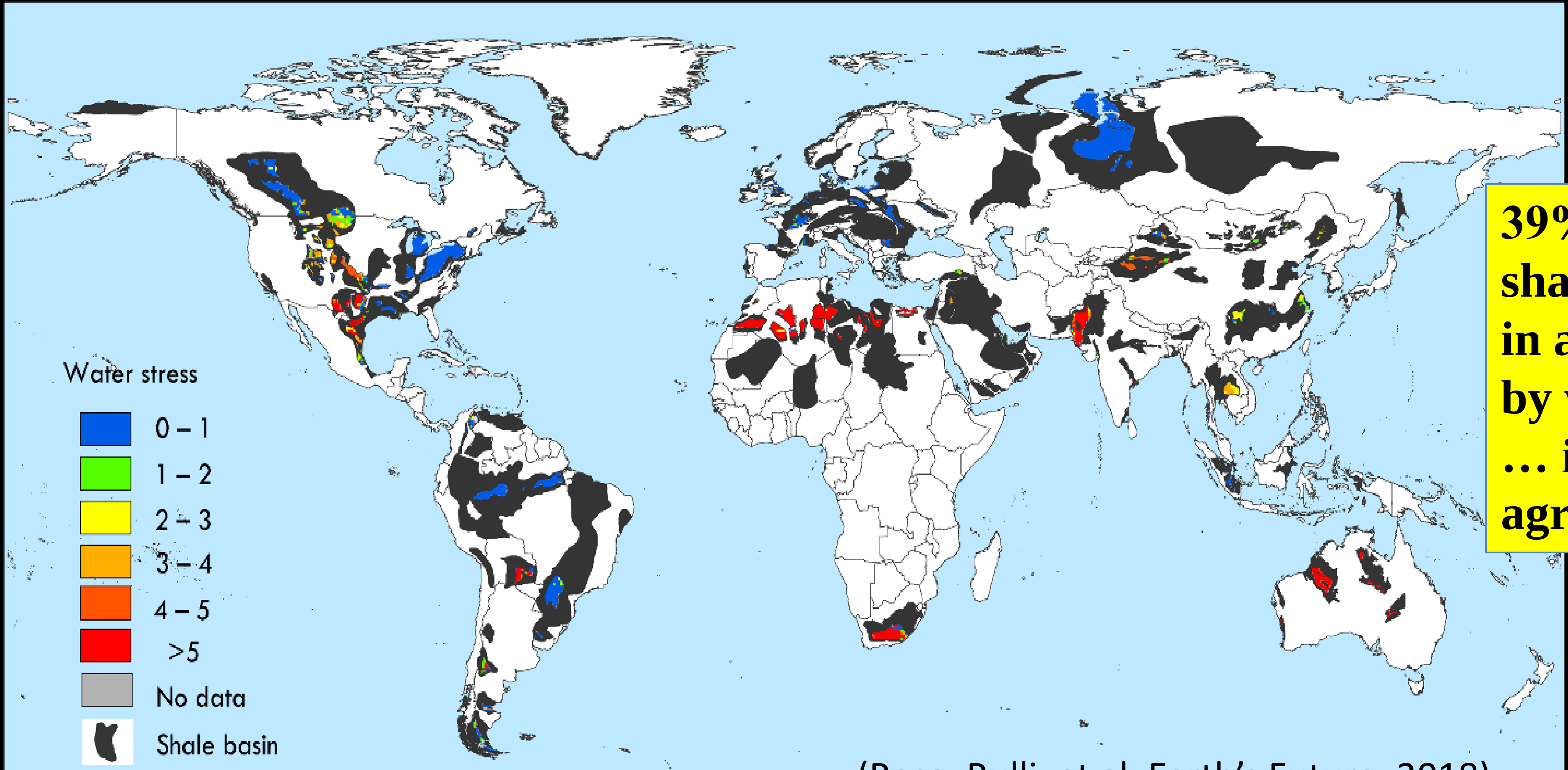
Not enough water to rely only on fuels from terrestrial biomass

Reliance on:

- Fossil fuels: 20% increase by 2040 (US EIA, 2016; Exxon Mob Corp. 2016)
  - Unconventional fossil fuels : 25-40% increase by 2040
    1) Oil sands/Tar Sands/Heavy Oil
    2) Shale Oil
    3) Shale Gas
- Non-fuel based energy (solar, w

Oil sands mining trucks and shovels. Photo courtesy: Caterpillar

Water Stress that could result from Shale Oil and Gas Extraction



(Rosa, Rulli, et al, Earth's Future, 2018)

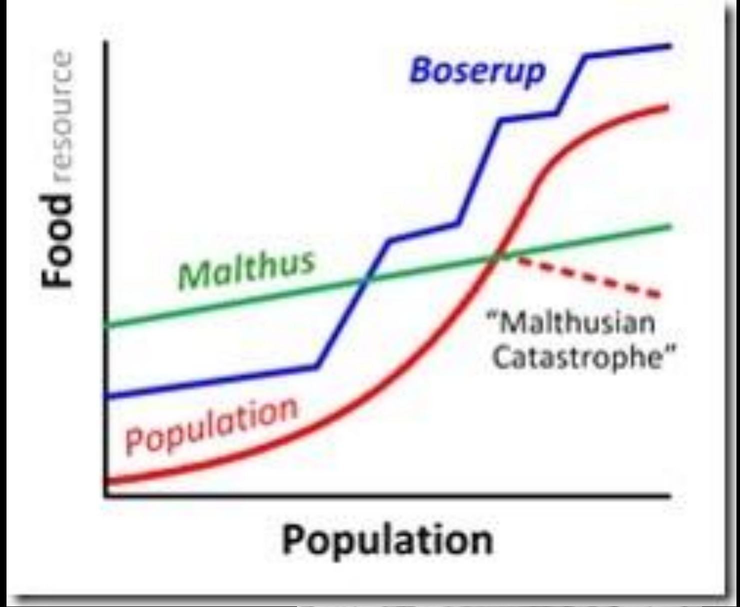
39% of world's shale deposits are in areas affected by water stress … including major agricultural areas!

Are we running out of Freshwater Resources for Food (and Energy)?

Are we running out of Freshwater Resources for Food and Energy?

Thomas Malthus

Malthus Demographic growth is faster than the increase in resources. In the long run not enough resources to feed everybody.



Technological innovations → increase food production *(Boserup, 1981)*

Amartya Sen

Amartya Sen *Poverty and Famines* (1981) Famines caused by lack of access → not a problem of availability

Esther Boserup

But the question: "*How many people can the planet feed?*" is still relevant. Soon, it will be difficult to meet the food & water needs of humanity (*Rosegrant, 2003; Godfray, 2010; Davis et al*., 2014)

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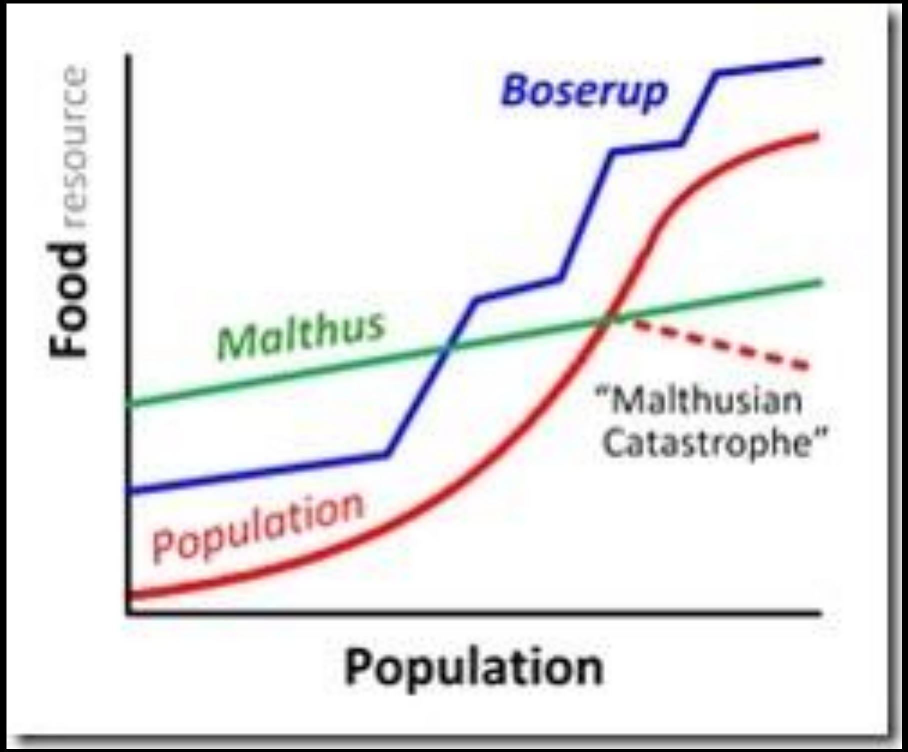
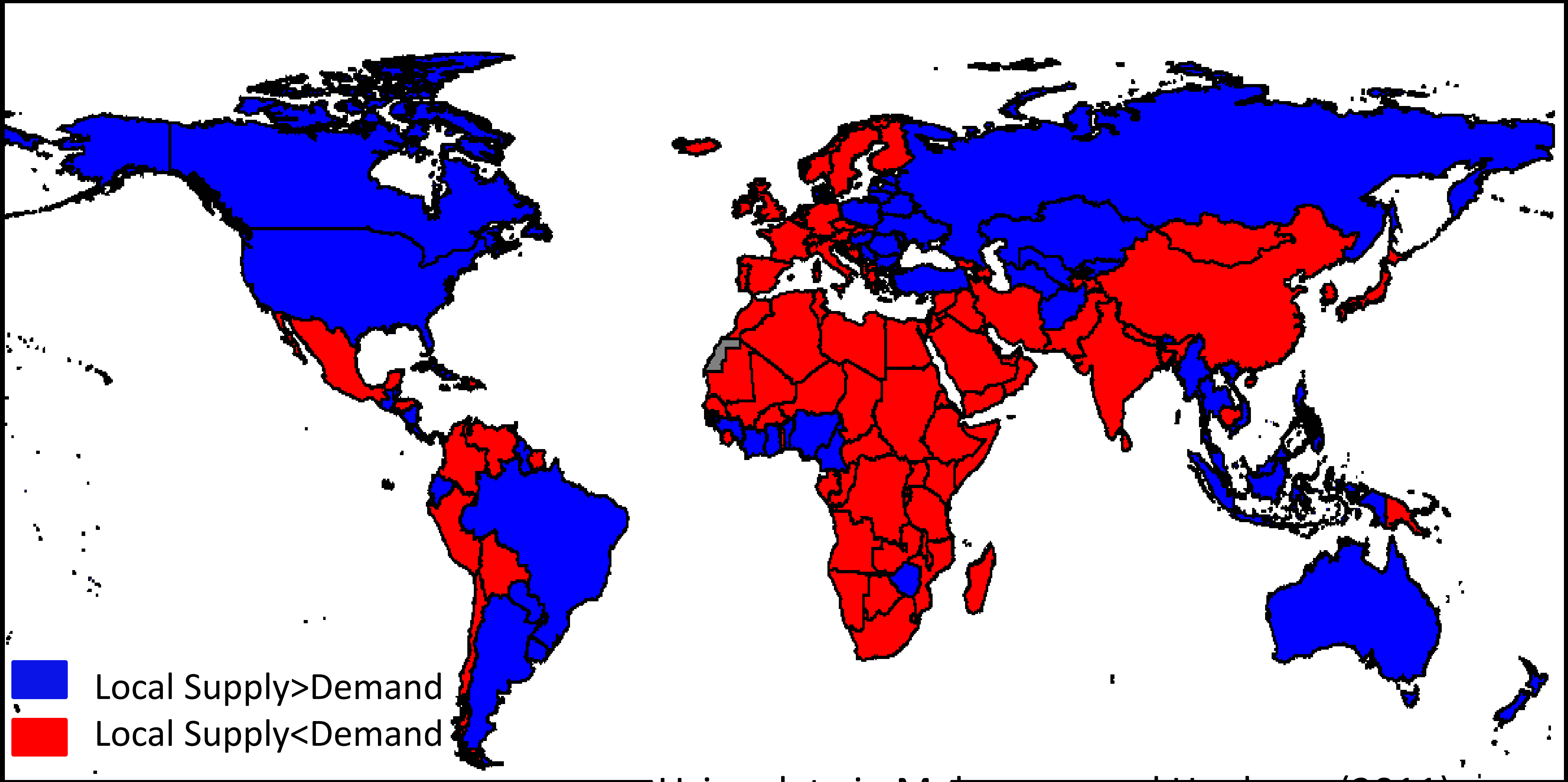


How can we meet the increasing demand of water for food?

Comparing Demand & Water Supply:
Areas of Abundance and Areas of Scarcity



Moving water is not easy!

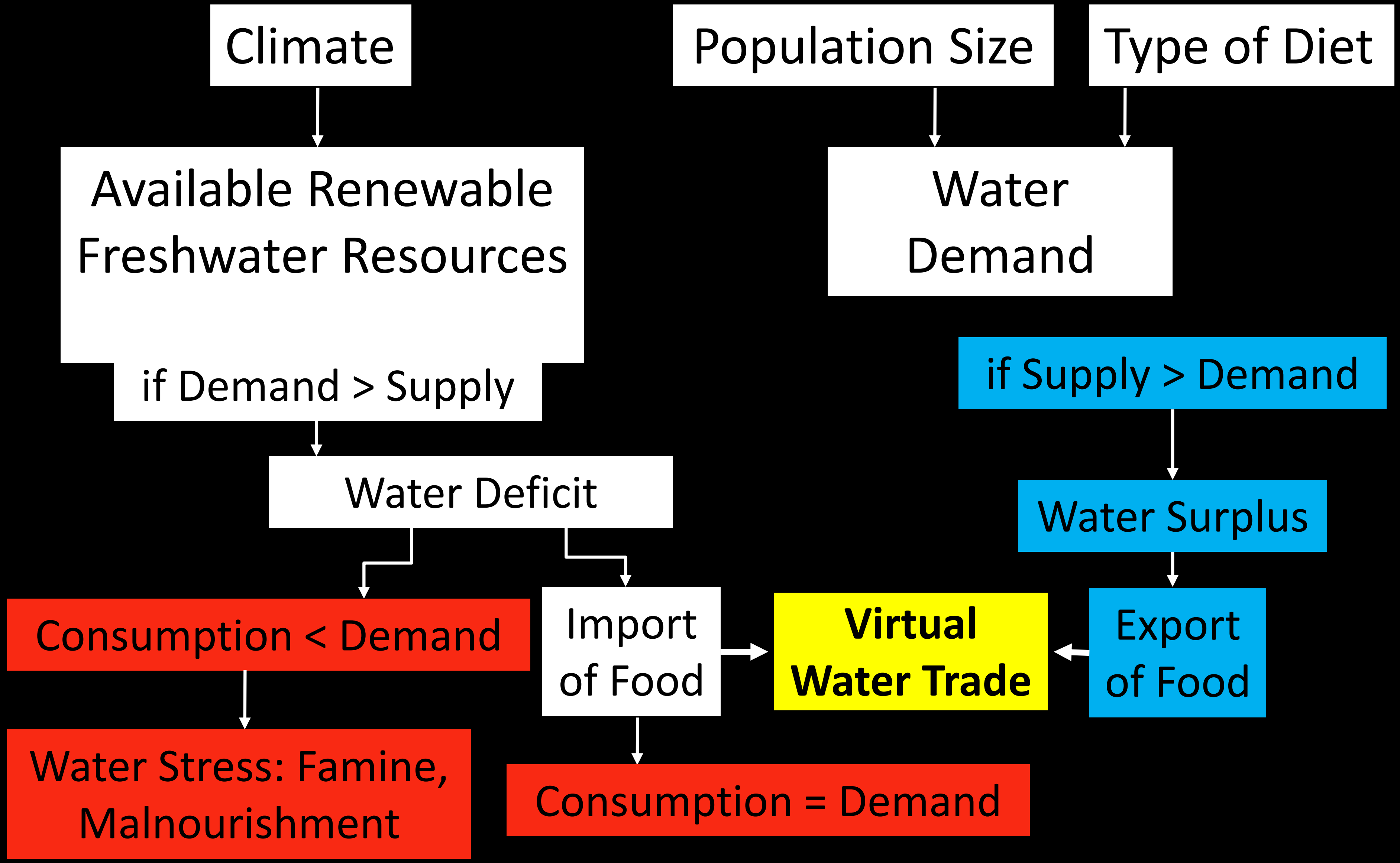
We use the concept of Virtual Water :

Water cost of the goods we use

It is virtually “embodied” in those goods *(Allan, 1998)*

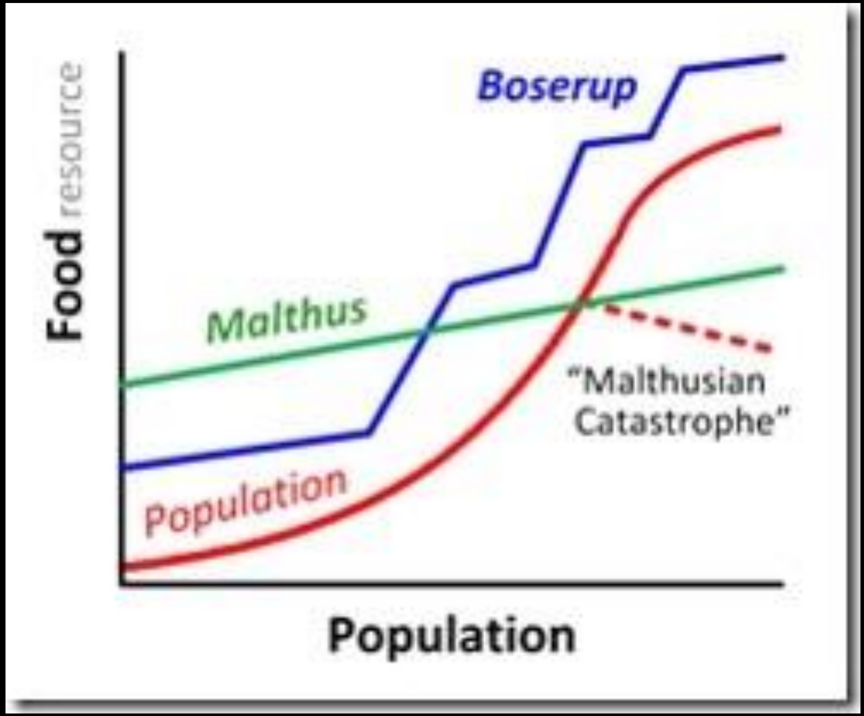
Photo Source: www.waterfootprint.org

(VIRTUAL) WATER BALANCE

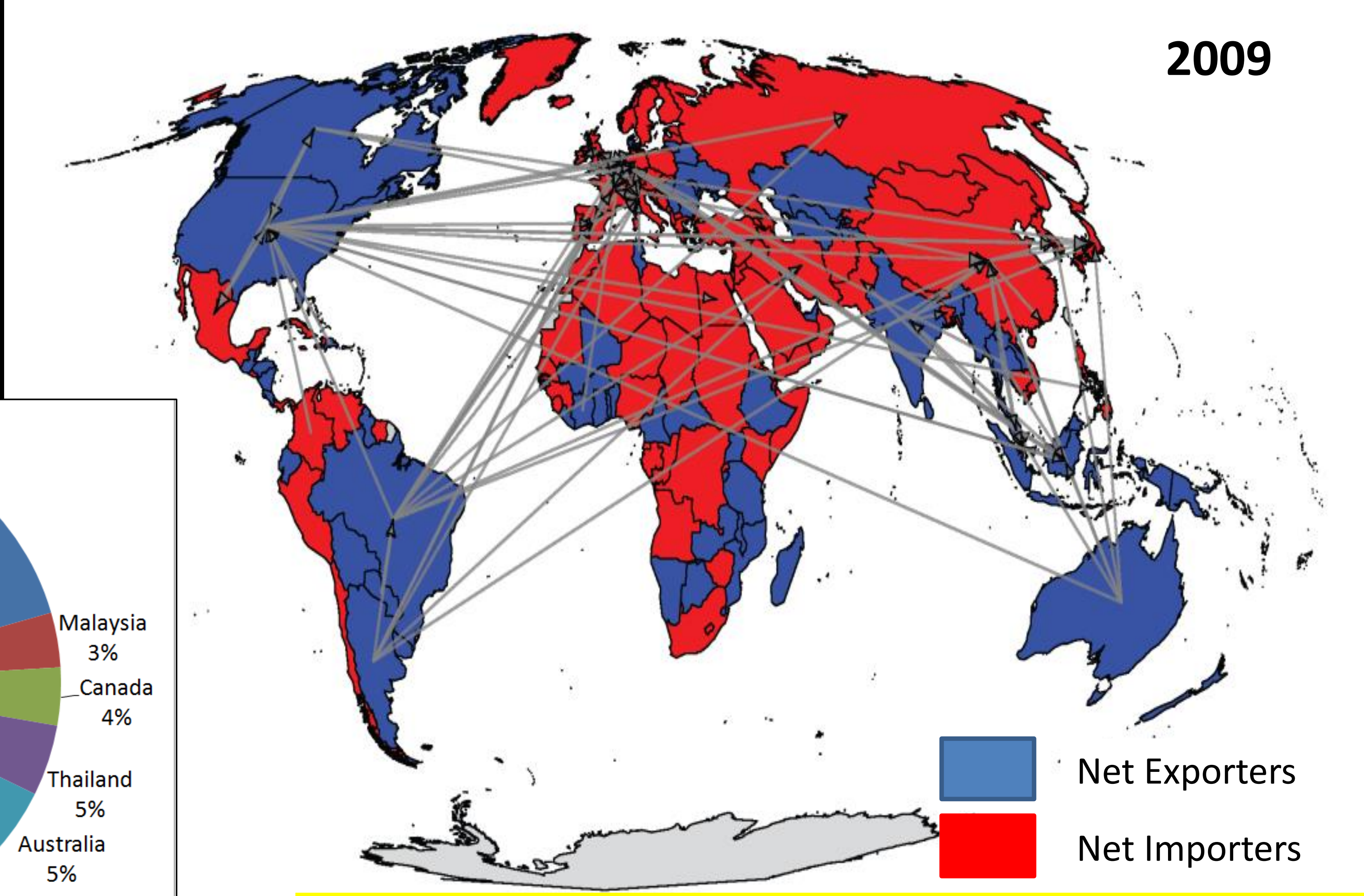


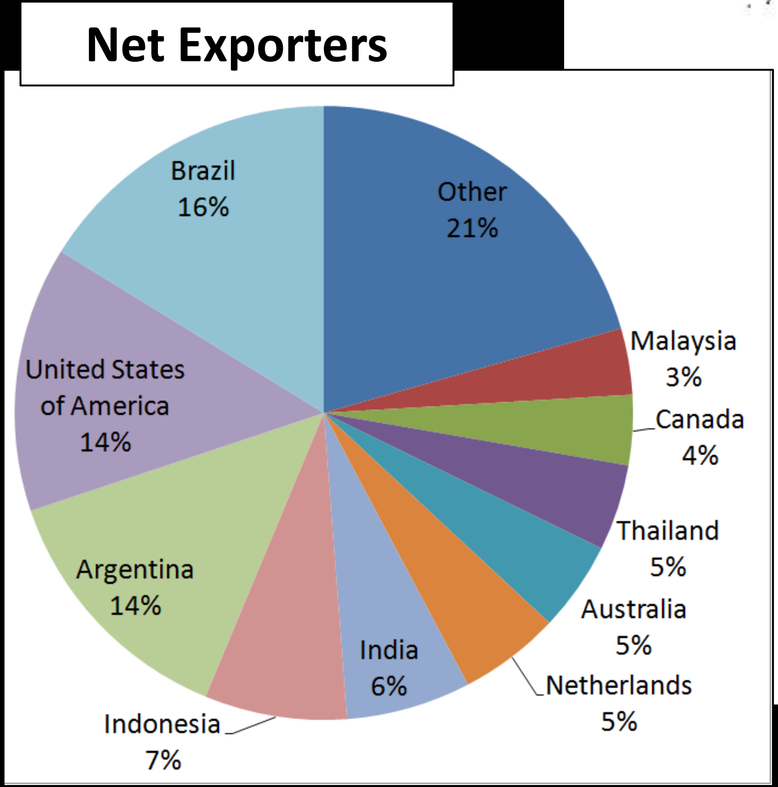
Major innovations have increased access to water and food

- Industrial Revolution
- Green revolution
- Global Trade of Food
- Close the Yield Gap (often through, land acquisitions in developing countries.)
- "Sustainable Intensification"



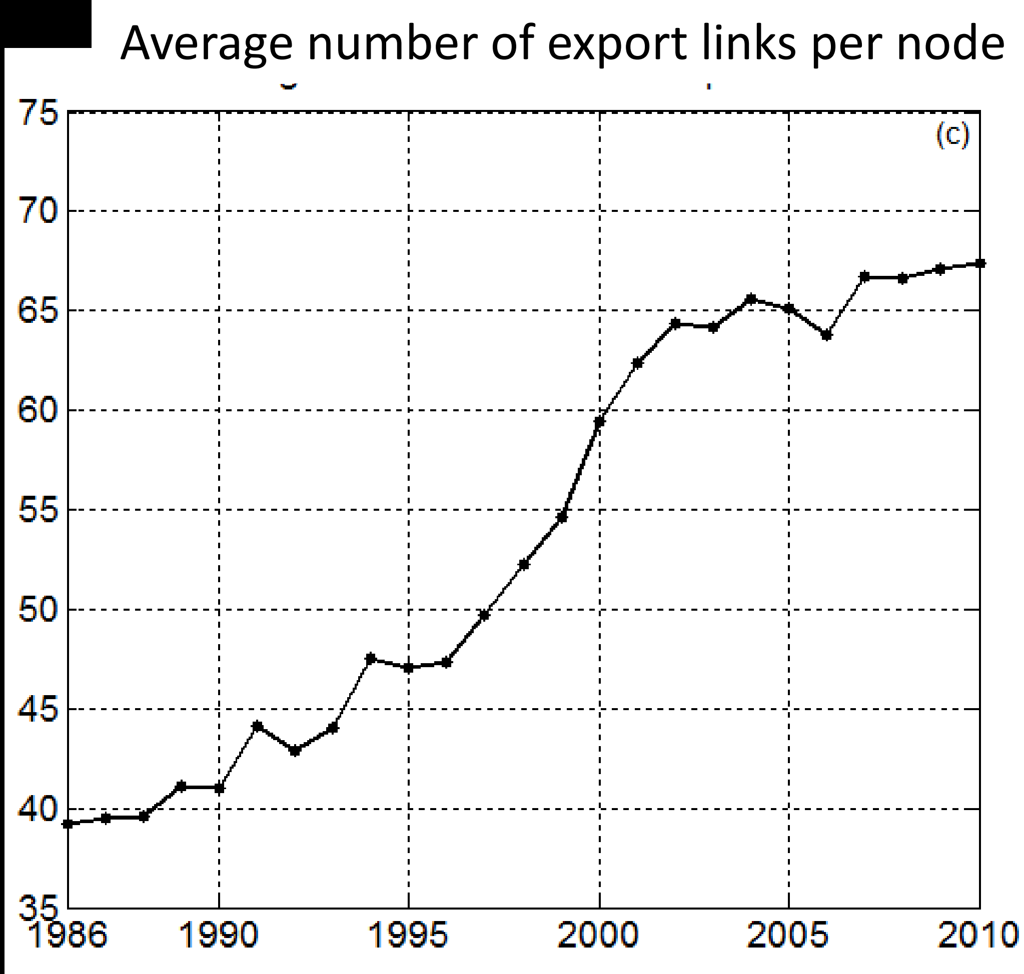
GLOBALIZATION OF WATER: “flows” of virtual water associated with the trade of agricultural products

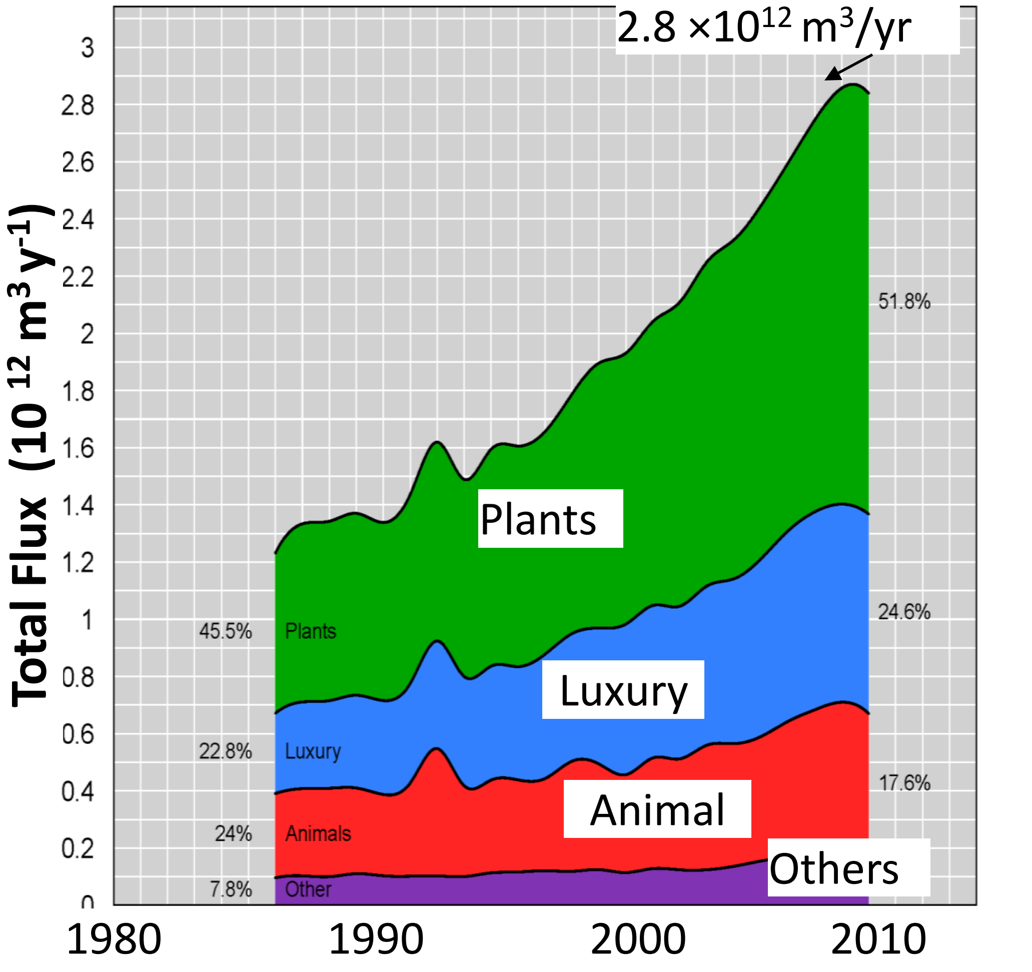




About 20-24% of the water used for food is traded internationally (Carr et al., PLoS One 2013)

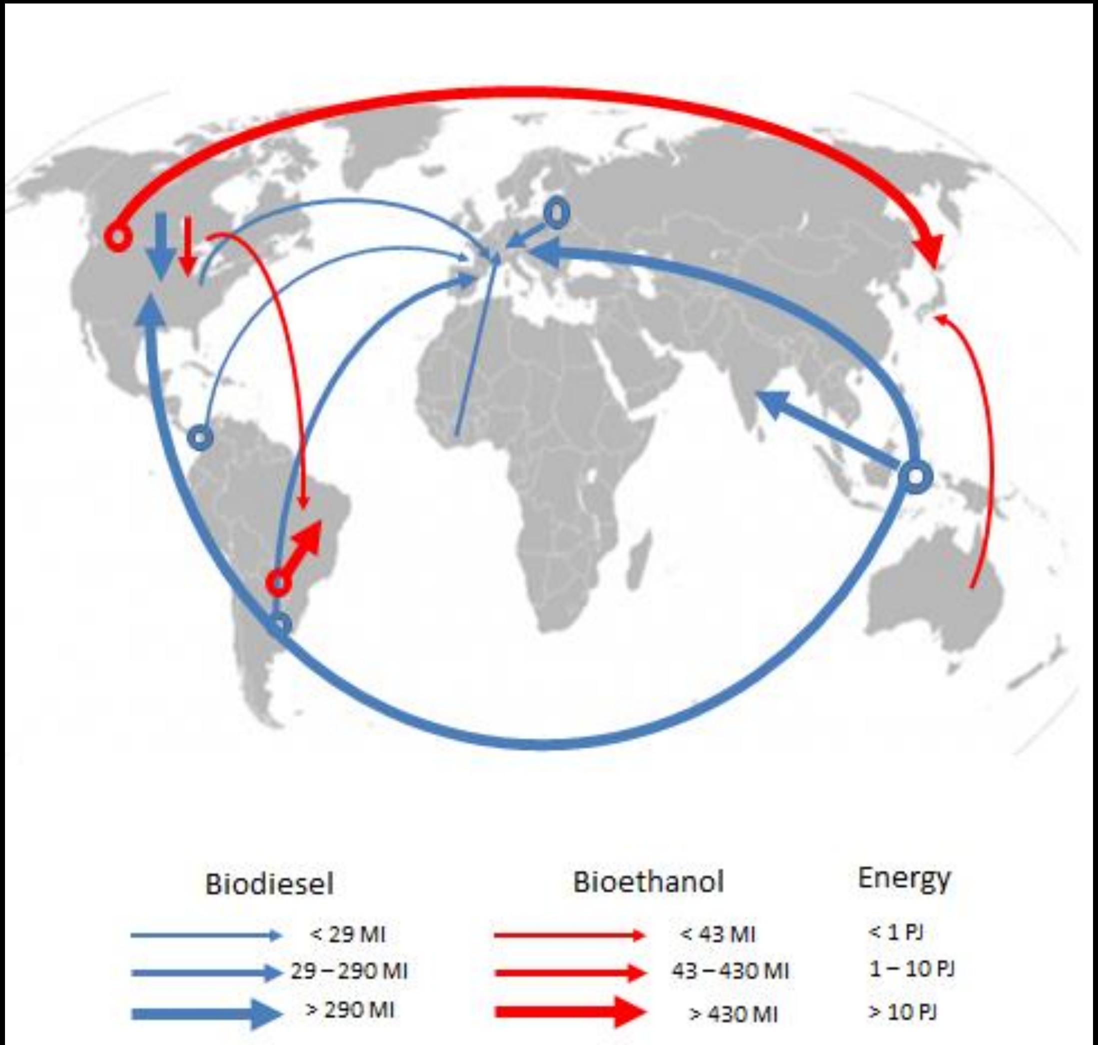
Temporal Changes in Virtual Water Trade

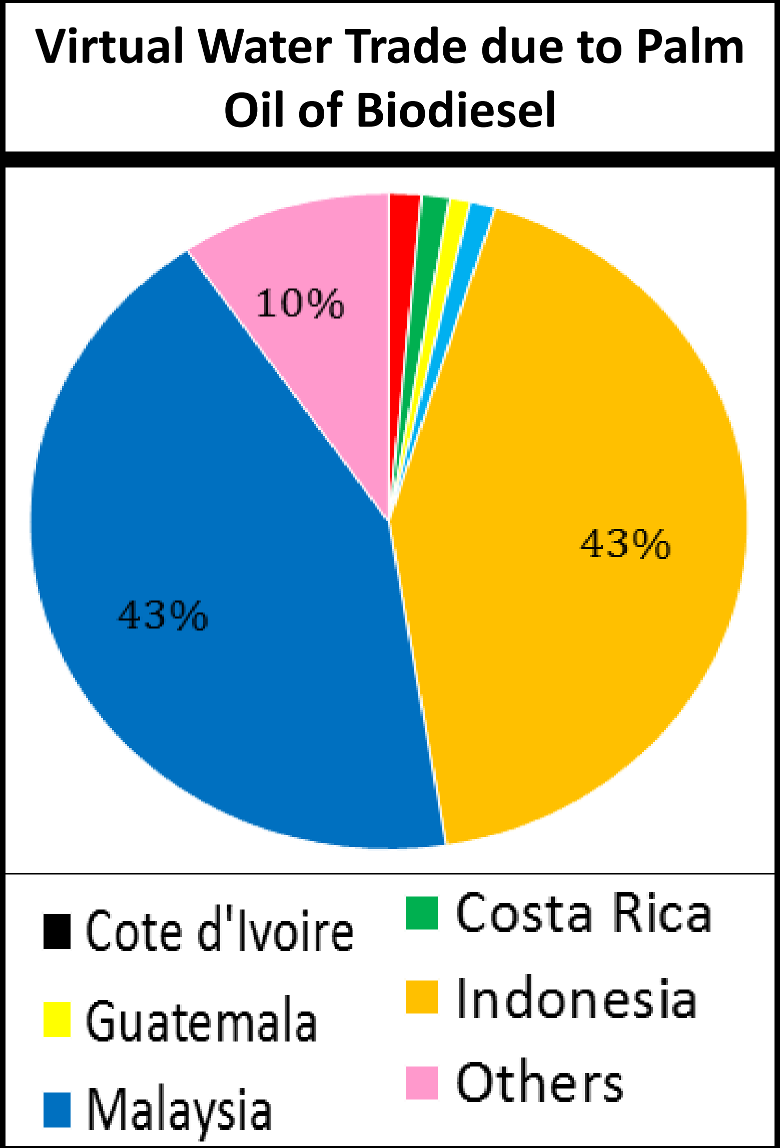




Based on FAOSTAT data: for 309 crop & animal products
(Carr et al., *GRL*, 2012; *PLOS1*,2013)

Water for Biofuels≈2-3% water for food





(Rulli, et al., The water-land-food nexus biofuels, *Sci. Rep.*, 2016)

The Virtue of Virtual Water

Virtual Water Trade: prevents famine and water conflicts

Vol. 36, No. 4 – GROUNDWATER- July-August 1998

GROUND WATER

Editorial

Virtual Water: A Strategic Resource

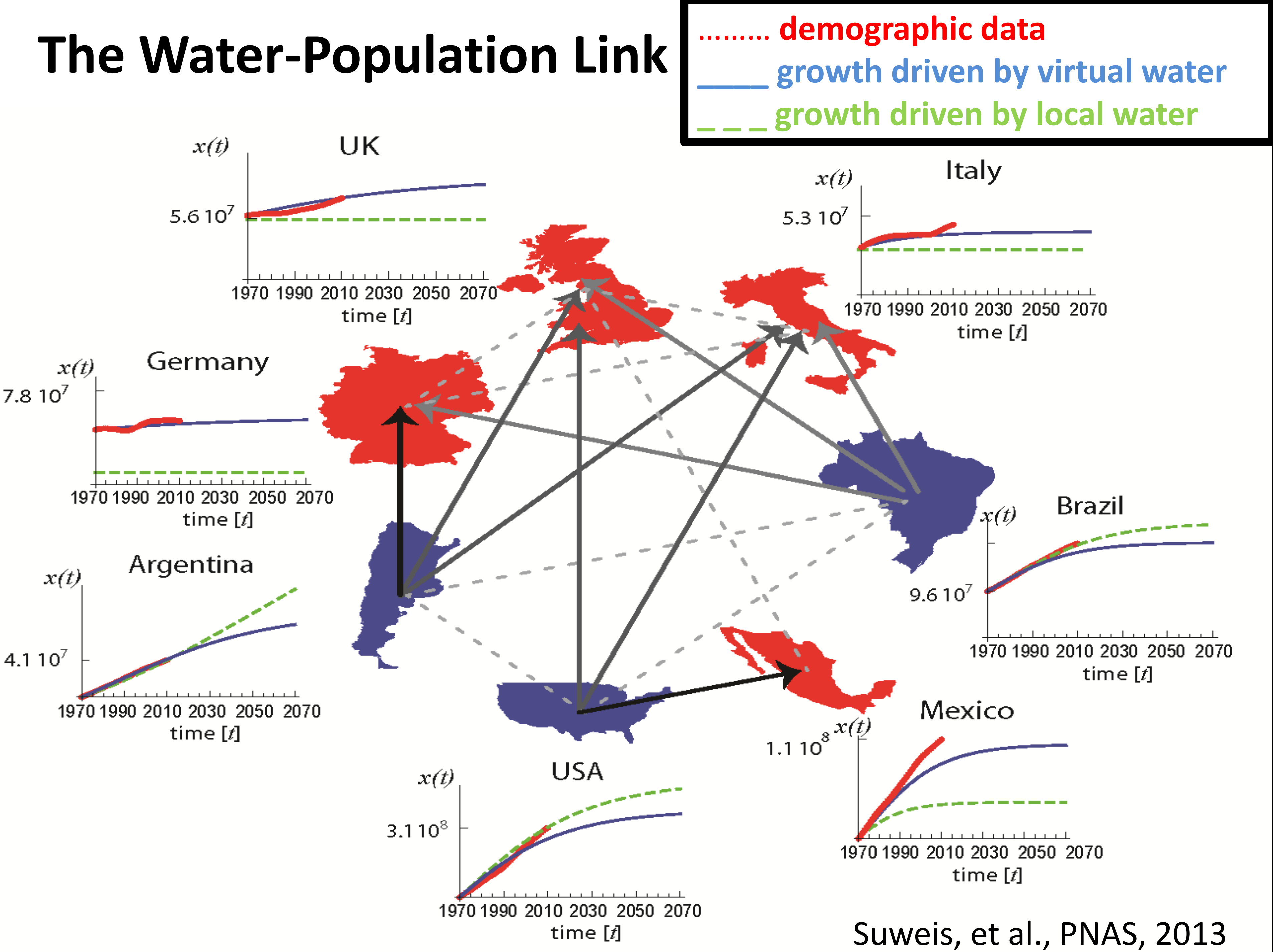
Global Solutions to Regional Deficits

by J.A. Allan[a]

Virtual water trade permits to support larger global populations without engendering massive emigrations of people



The Water-Population Link



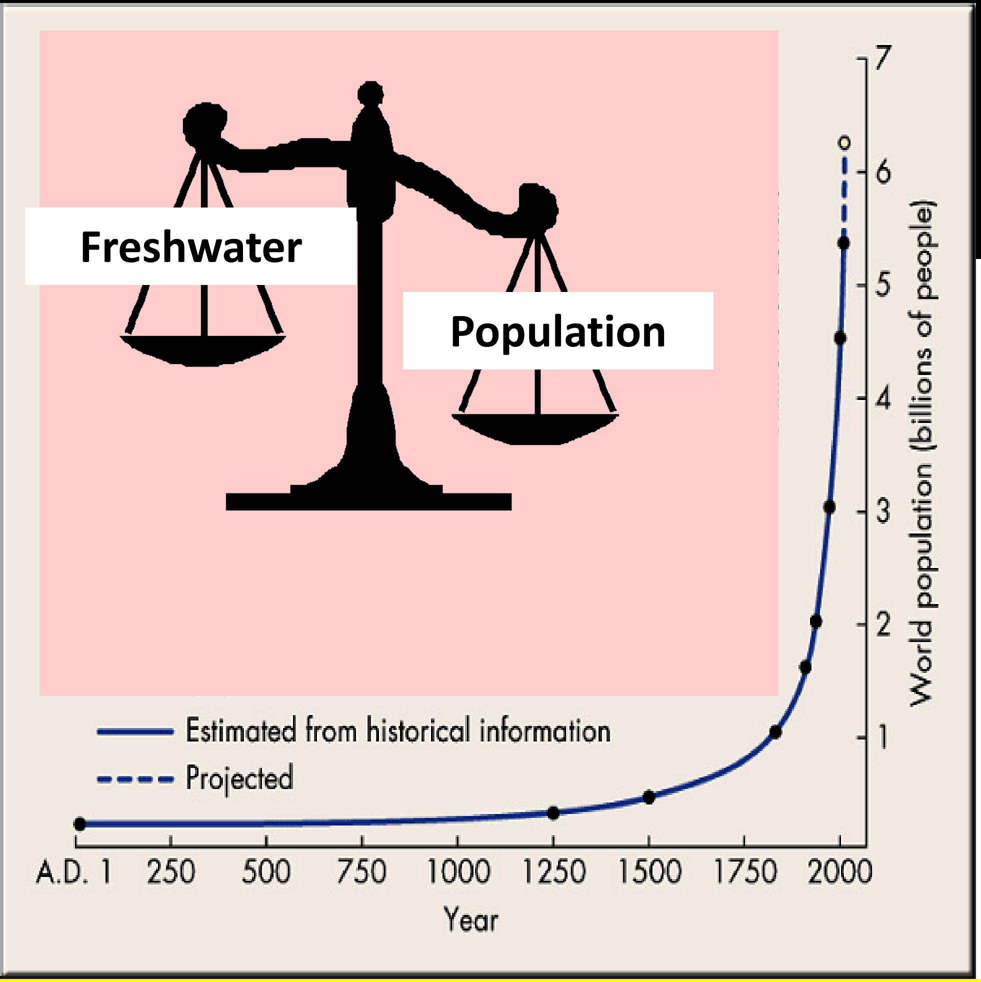
Suweis, et al., PNAS, 2013

Is Virtual Water a Virtue?

Some Negative Aspects of Virtual Water Trade

- Loss of societal resilience (D'Odorico et al., *GRL*, 2010)
- Loss of ecosystem stewardship (O'Bannon et al., *HESS*, 2014)
- Increase inequality (Seekell et al., *ERL*, 2011)
- **Not a long-term solution of the water crisis**. (Suweis et al., *PNAS*, 2013; 2015).
- Trade dependency (Suweis et al., *PNAS*, 2013).

Virtual water trade cannot be a long-term solution of the water crisis



Water-Population Out of Balance

Demographic growth of exporters does not account for VW exports.

But importers rely on imports.

Unbalanced situation

(Suweis et al. PNAS, 2013)

Exporting regions will have to reduce their exports

… as during the 2008 food crisis → Export bans

A look at the 2008 food crisis…

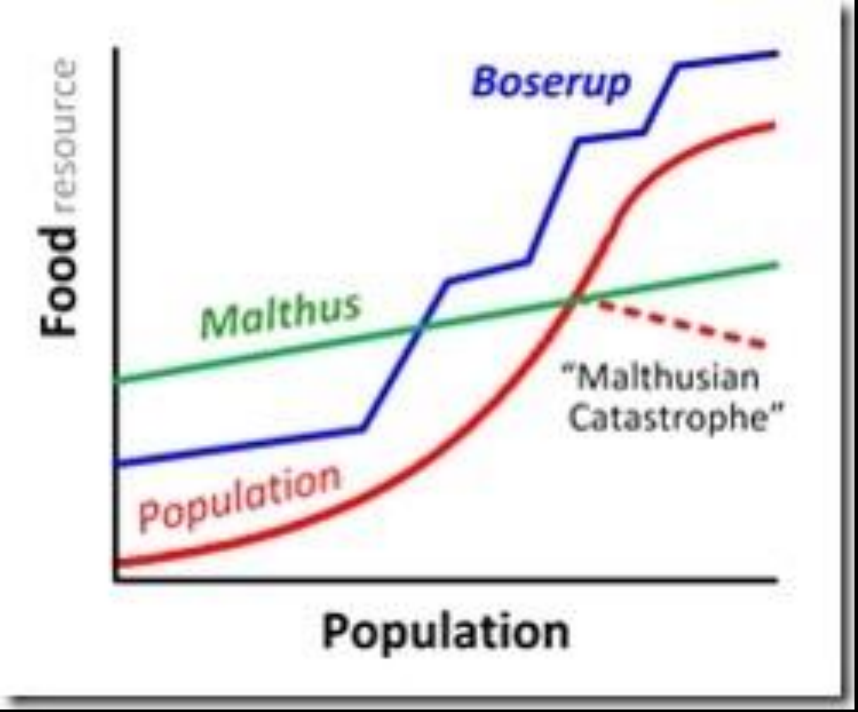
- Droughts in Russia, USA, Ukraine
- New policies on biofuels
- Increase in food prices, social unrest, riots…
- Export bans (e.g., Russia, Indonesia, and Argentina)
- Food insecurity

- Uncertain markets: Need for **secure access** to food → More **Direct** Control of natural resources

Need for more food→Yield gap closure in underperforming lands → Need for investments in Technology

Major innovations have increased access to water and food

- Industrial Revolution
- Green revolution
- Global Trade of Food
- Close the Yield Gap (often through, land acquisitions in developing countries.)
- "Sustainable Intensification"



NATURE GEOSCIENCE | VOL 6 | JUNE 2013 | www.nature.com/naturegeoscience

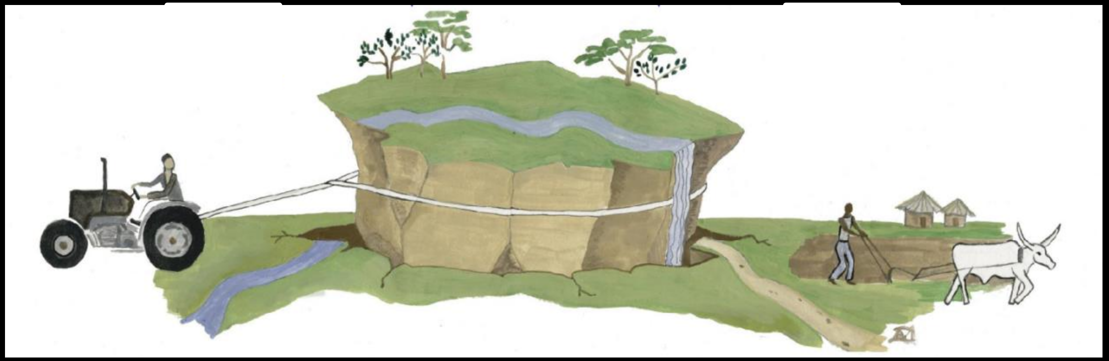
The fourth food revolution

Paolo D'Odorico and Maria Cristina Rulli

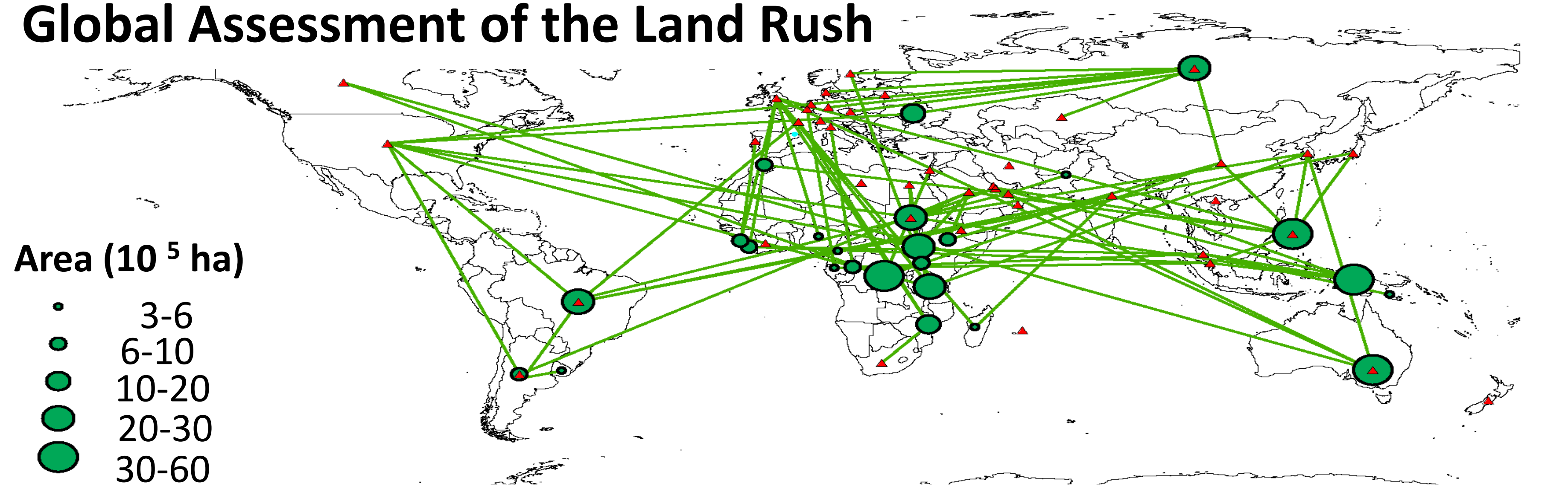
In areas of the developing world that have benefited only marginally from the intensification of agriculture, foreign investments can enhance productivity. This could represent a step towards greater food security, but only if we ensure that malnourished people in the host countries benefit.

Land (and Water) Rush

Governments and corporations securing property rights on agricultural land in developing countries.

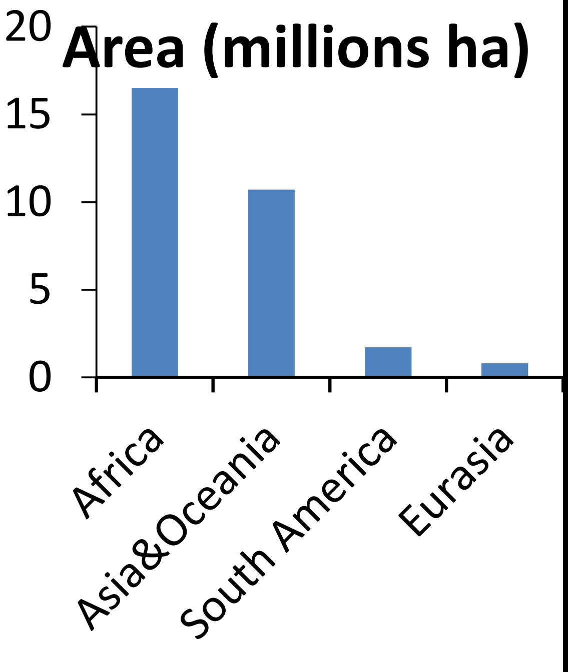


- >48 million ha
- Total area > Italy
- 4 x Portugal



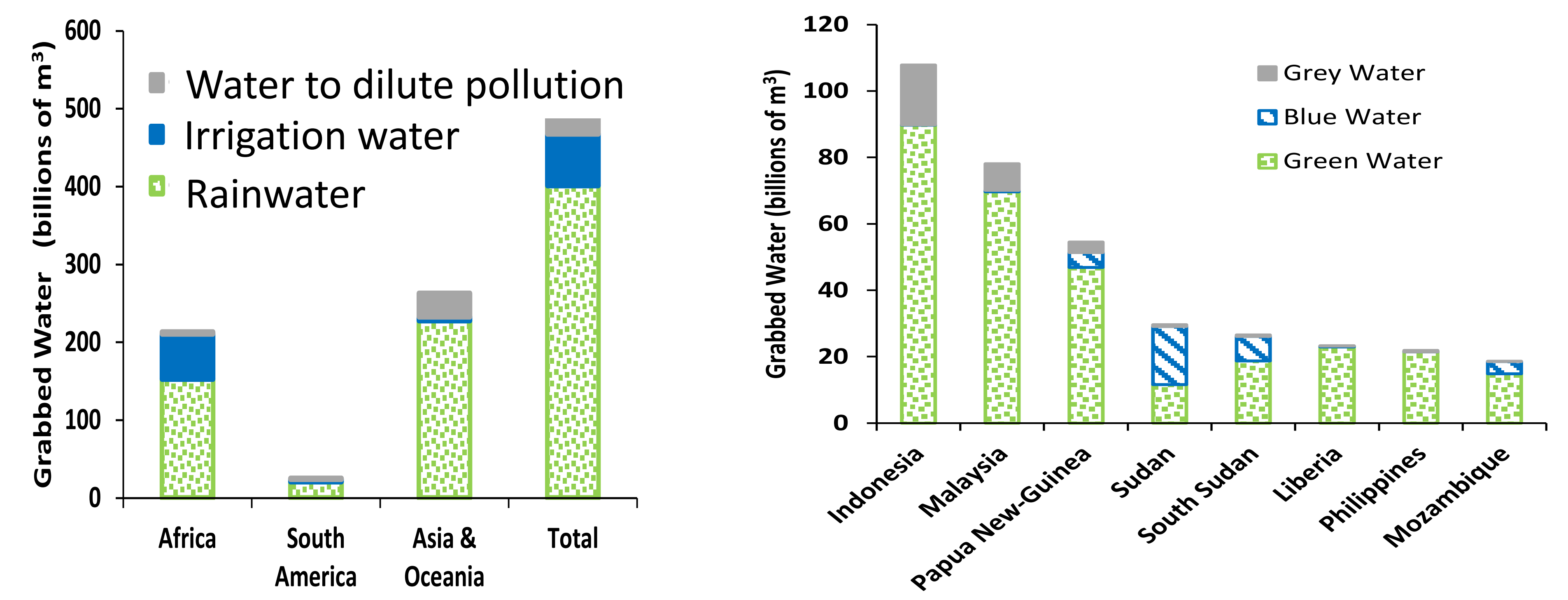
Data from The Land Matrix and GRAIN, 2012

(Rulli et al., PNAS, 2013)



(Source: Monte Wolverton, Cagle Cartoons)

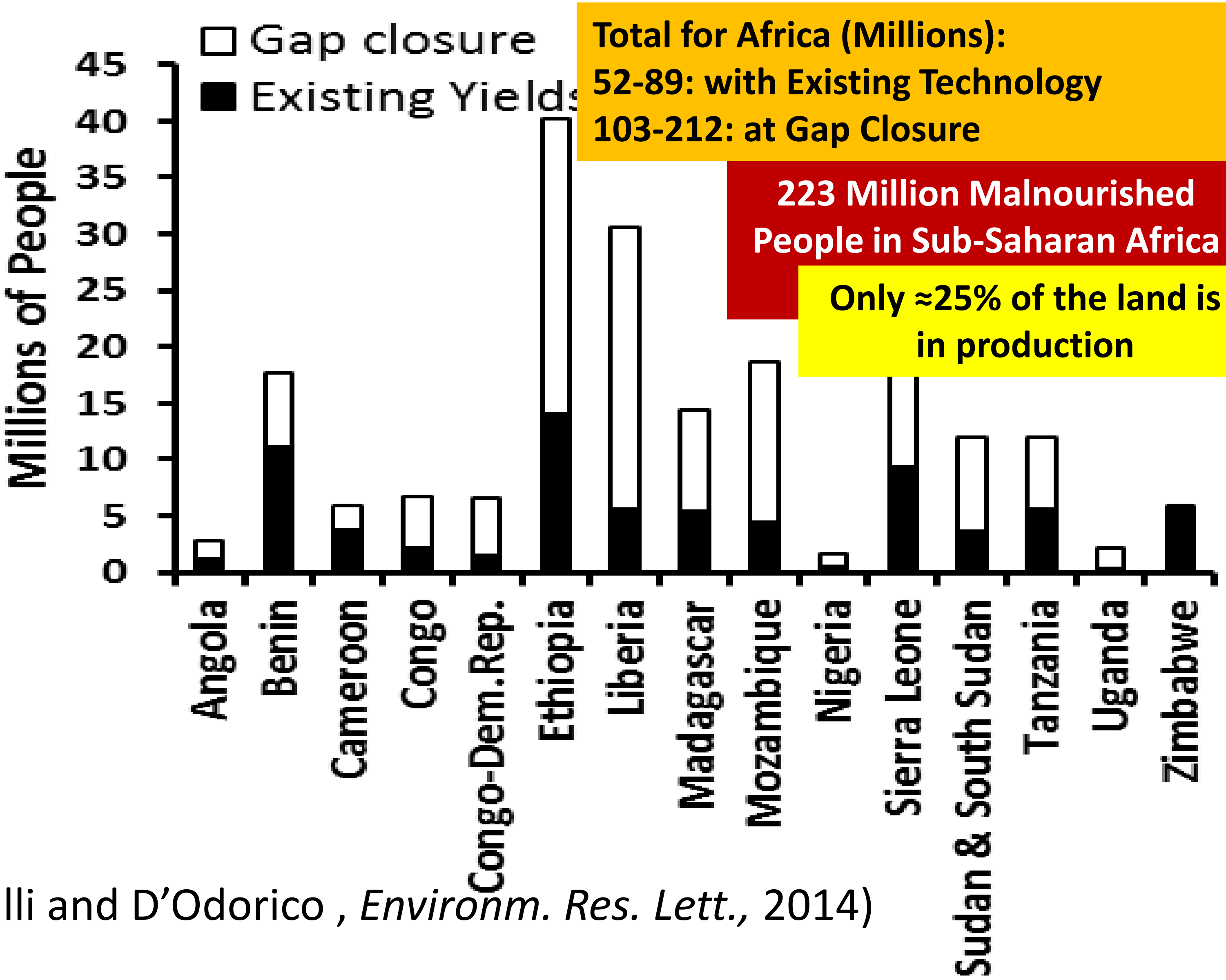
Water needed for LSLAs cultivation



[*Rulli et al. PNAS* (2013); *Rulli and D'Odorico, GRL, 2013*]

	Annual flow	Year	Source
Water "Grabbing"	0.4×10^{12} (m^3 y^{-1})	2012	Rulli and D'Odorico,2013.
Groundwater Depletion	0.14×10^{12} (m^3 y^{-1})	2001	Konikow, 2011
Water Used for Biofuels	≈ 0.25×10^{12} (m^3 y^{-1})	2010	Rulli et al., 2016
Virtual Water Trade (food only)	2.81×10^{12} (m^3 y^{-1})	2010	Carr et al., 2013
Freshwater Used for Food	11.8×10^{12}	2010	Carr et al., 2013

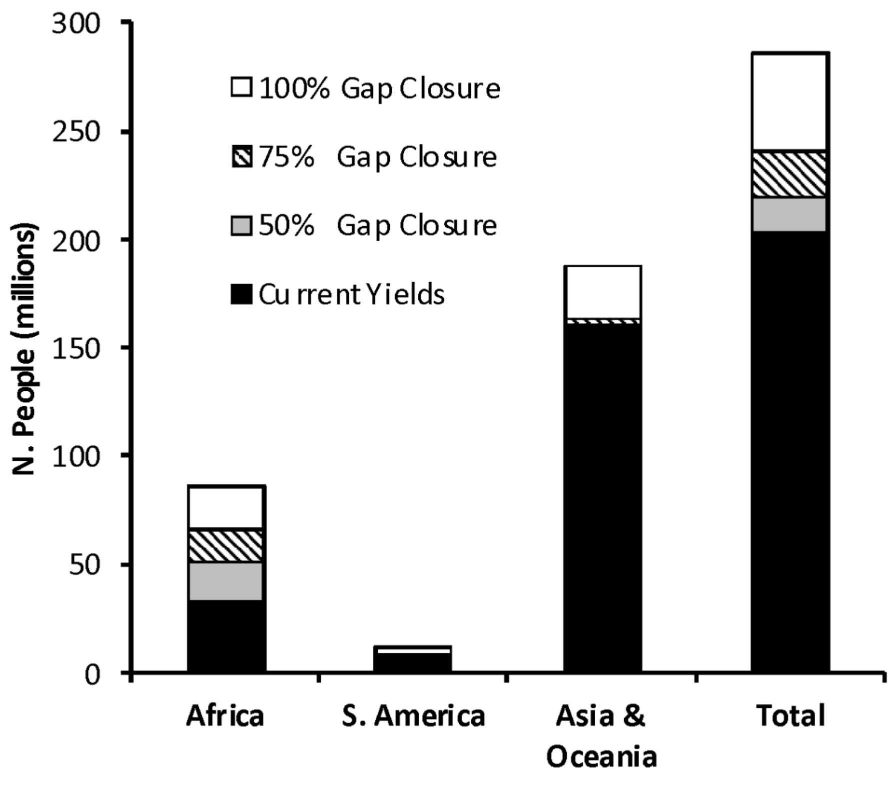
How many People Could be Fed?



Total for Africa (Millions):
52-89: with Existing Technology
103-212: at Gap Closure

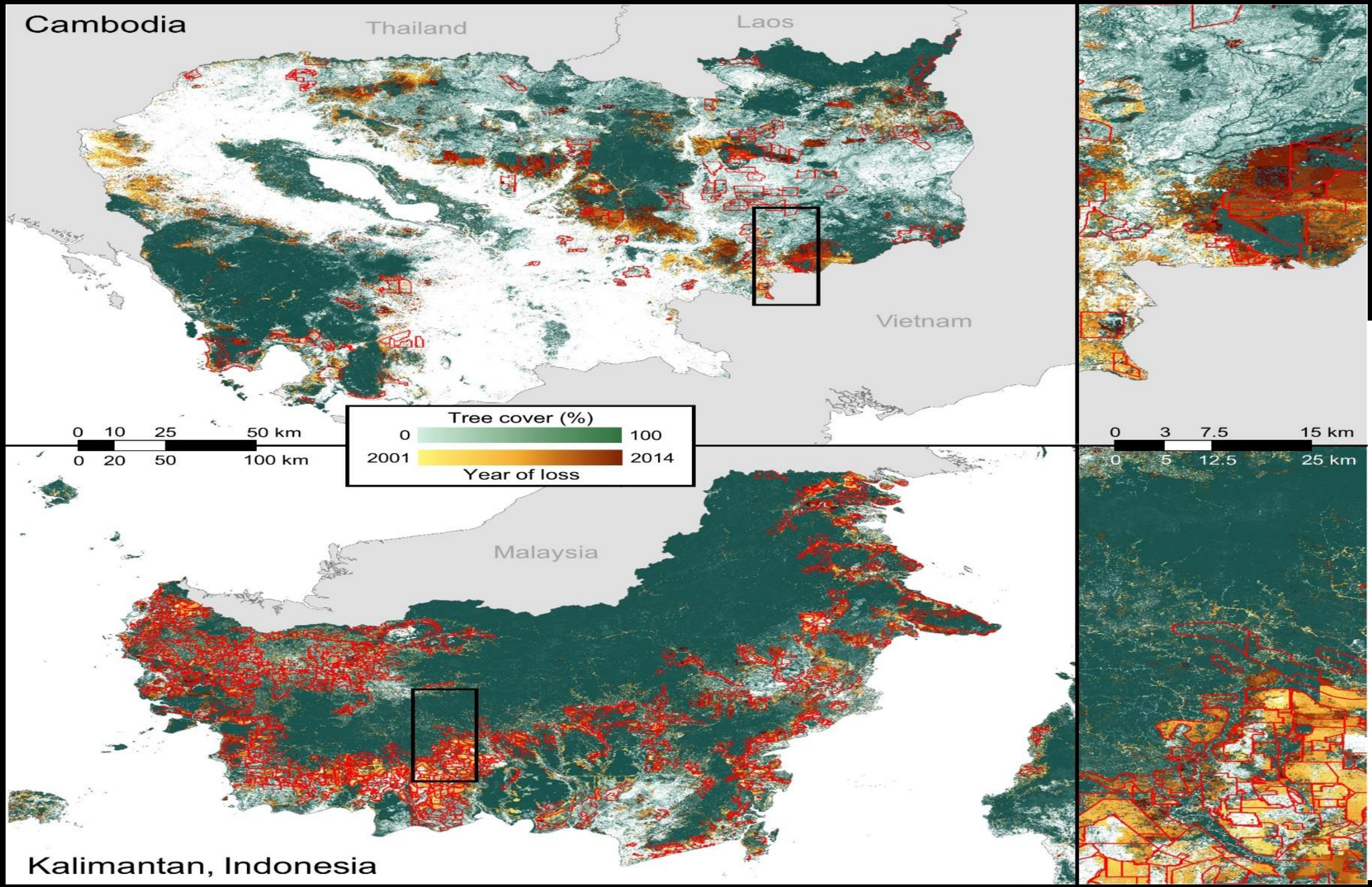
223 Million Malnourished People in Sub-Saharan Africa

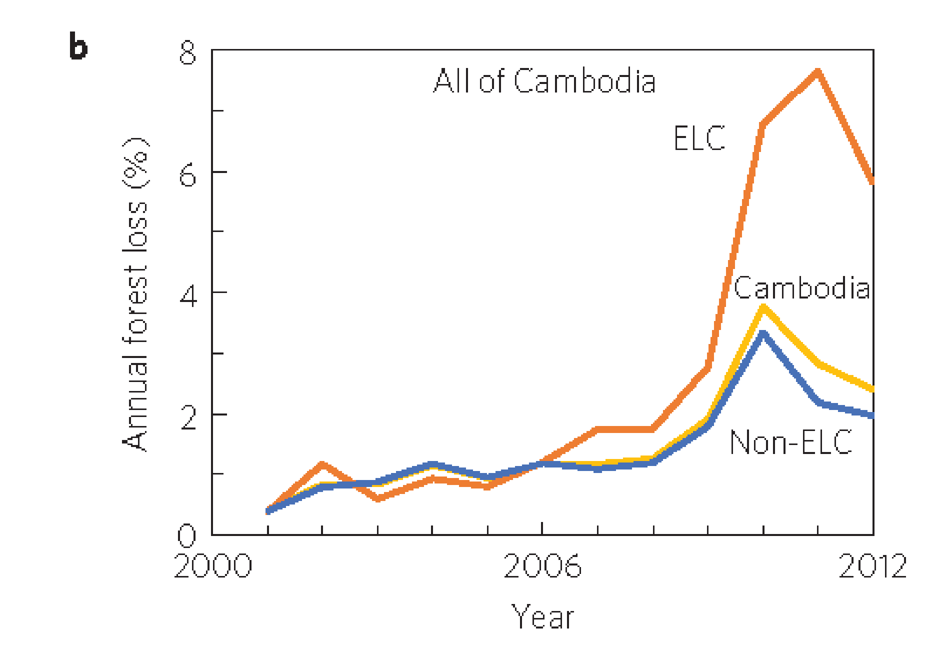
Only ≈25% of the land is in production



(Rulli and D'Odorico , *Environm. Res. Lett.*, 2014)

Deforestation for LSLAs cultivation

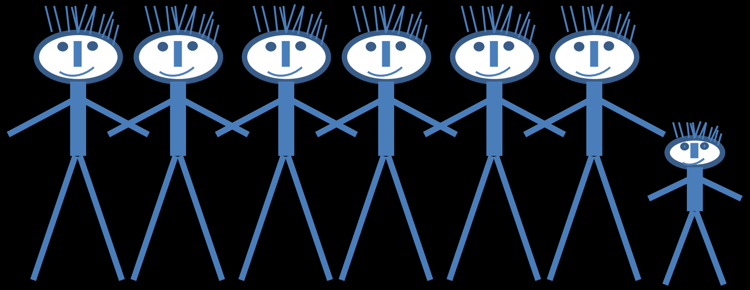


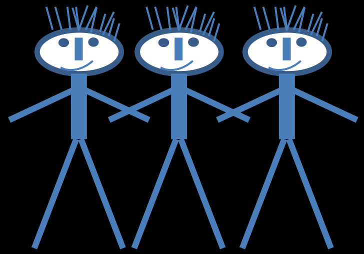


(Davis, Rulli, D'Odorico, Nature Geosci., 2015.)

Are we running out of Freshwater Resources for Food and Energy?

Water for Food: (Falkenmark & Rockstrom, J. Wat Res Plann, 2006)





In 2006
6.5 Billion People
800 million Malnourished
Water use for food production **4500 km^3 y^{-1}**

by 2050
Additional 3 Billion People
Eradication of Malnourished
Almost Double Water use for food production
Additional Water use for food production **4200 km^3 y^{-1}**

Increase in Irrigation

Soil Water Management
Reduce Evaporation Losses

More Crop per Drop
(increase water use efficiency)

How can we meet the increasing global demand for water for food?

Agricultural Intensification
(Godfray, *Science*, 2010; Foley et al., *Nature*, 2011)

↓

Close the Yield Gap
(irrigation, fertilizers,…)

↓

Transition to Commercial Agriculture
- Loss of livelihoods?

Agricultural Extensification

↓

Expand the cultivated area

↓

Land Use Change
Deforestation
Biodiversity losses

Sustainable Intensification

↓

Improve Efficiency
Adopt More Suitable Crops

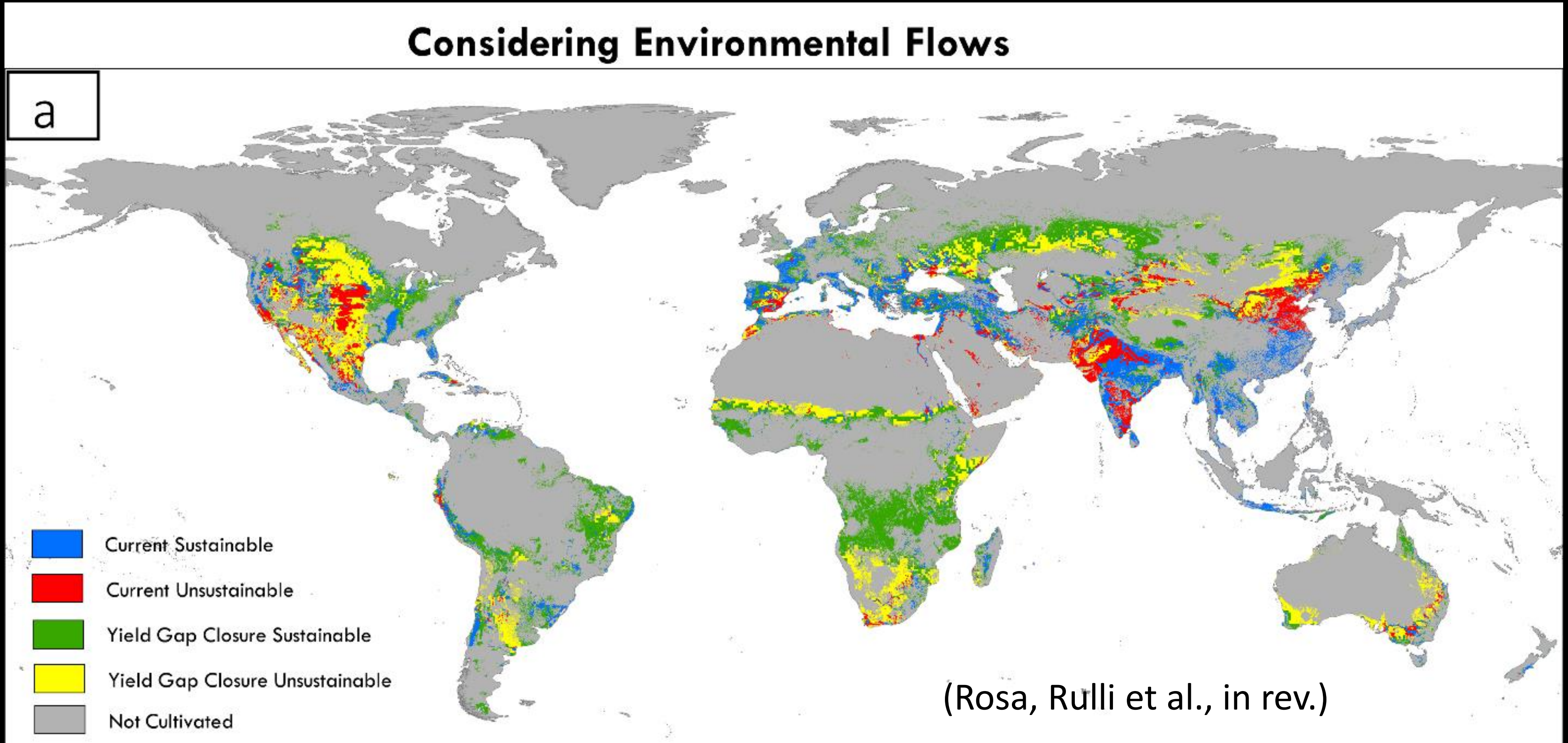
↓

Increase production without requiring more land, water

Agricultural Intensification: how many people can we feed?

We can feed 4Billion people if we close the yield gap (Davis, Rulli, D'Odorico, Earth's Future, 2014)

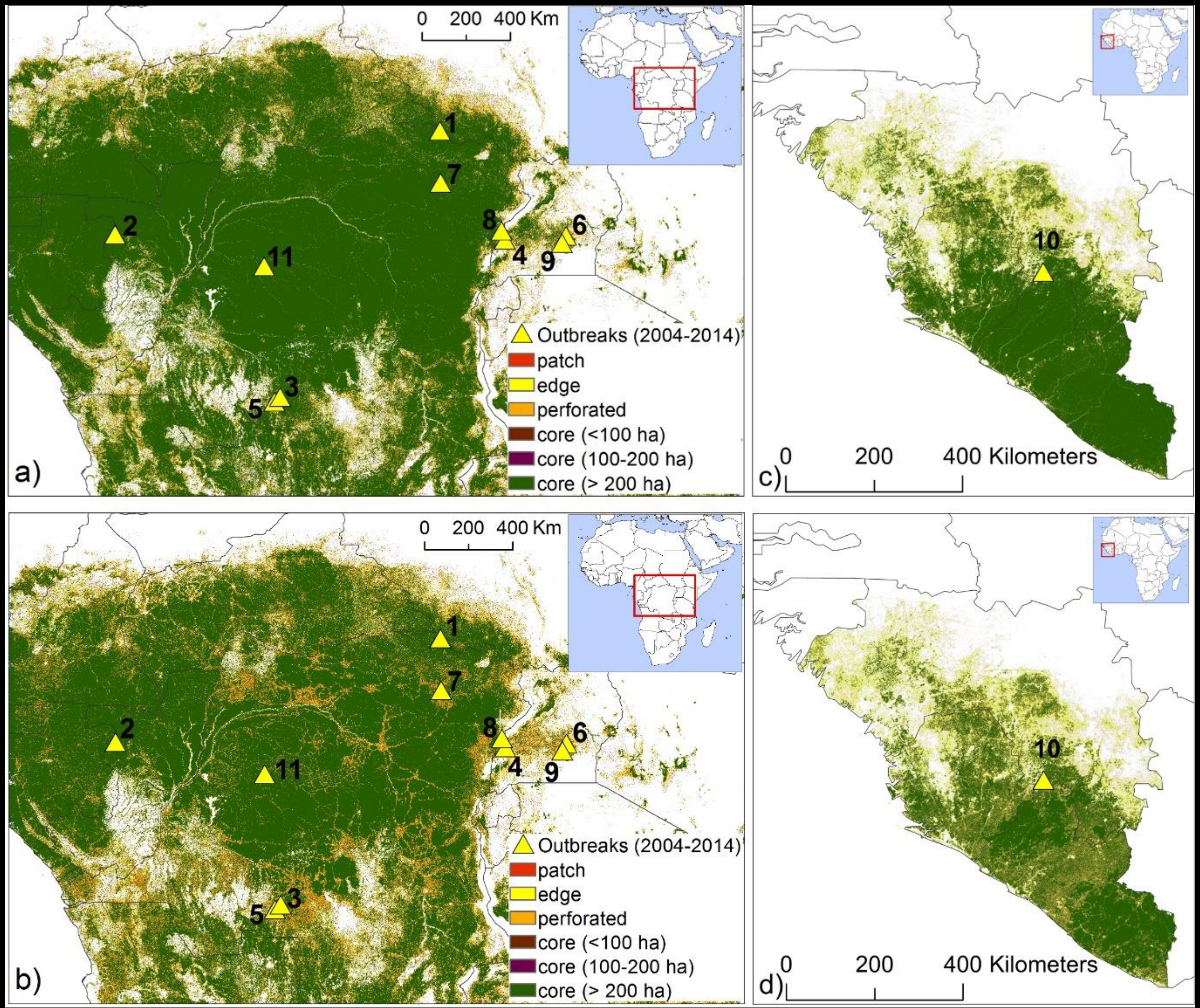
But, is there enough water to close the yield gap?



(Rosa, Rulli et al., in rev.)

Agricultural extensification:

What about the direct and indirect consequences ?



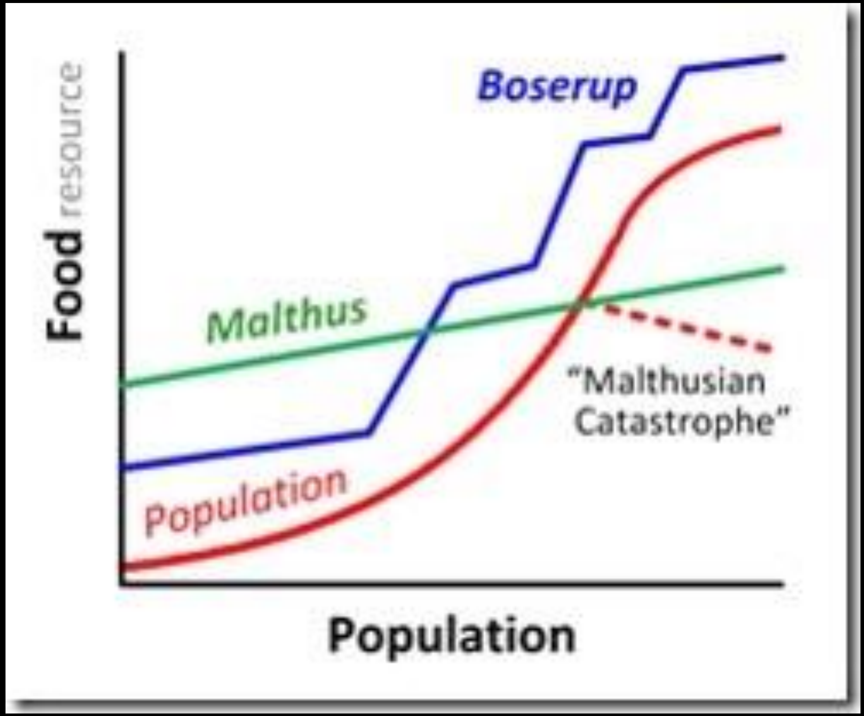
Forest fragmentation in Central and West Africa. Forest fragmentation in Central (panels a, and b) and West Africa (Panels c and d) in 2000 (top panels) and 2014 (bottom panels).

The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks

(Rulli , Santini,Hyman, D'Odorico Scientific Reports 2017)

Major innovations have increased access to water and food

- Industrial Revolution
- Green revolution
- Global Trade of Food
- Close the Yield Gap (often through, land acquisitions in developing countries.)
- "Sustainable Intensification"



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Sustainable Intensification

↓

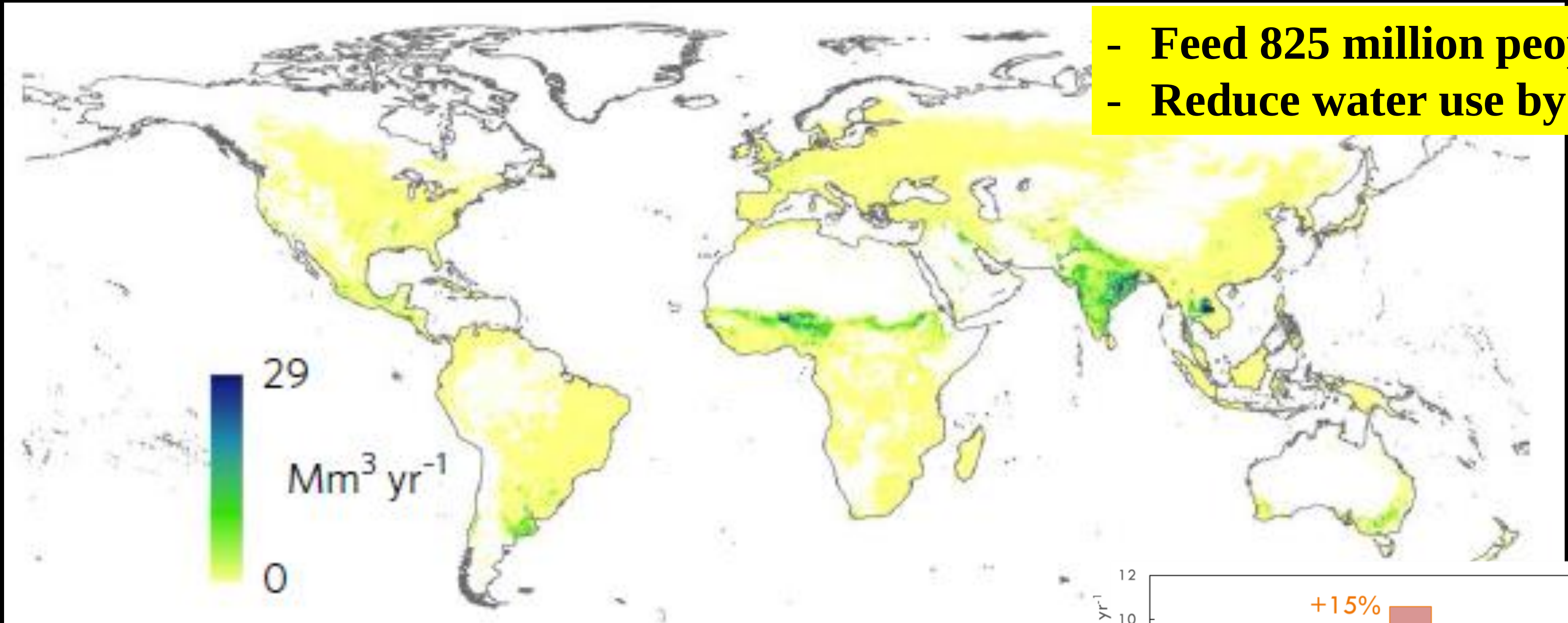
Improve Efficiency
Adopt More Suitable Crops

↓

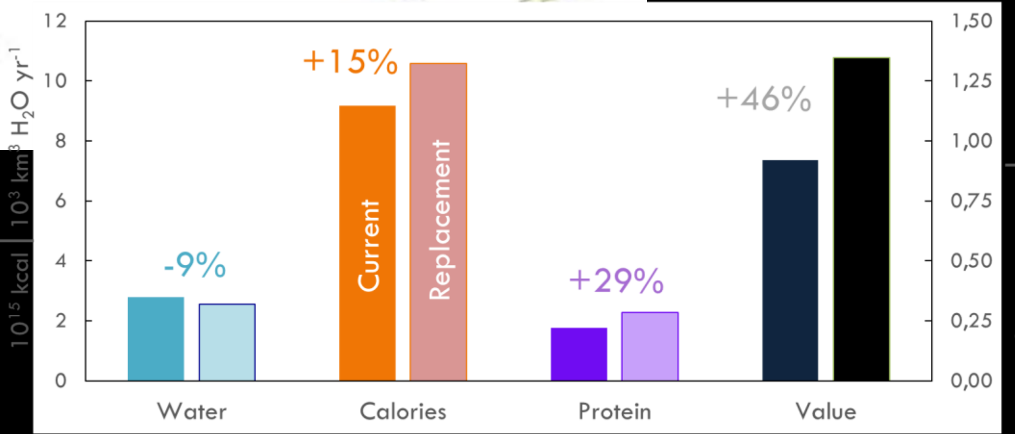
Potentially increase production without requiring more land, more water

More efficient distribution of crops

- **Feed 825 million people more**
- **Reduce water use by 10%**

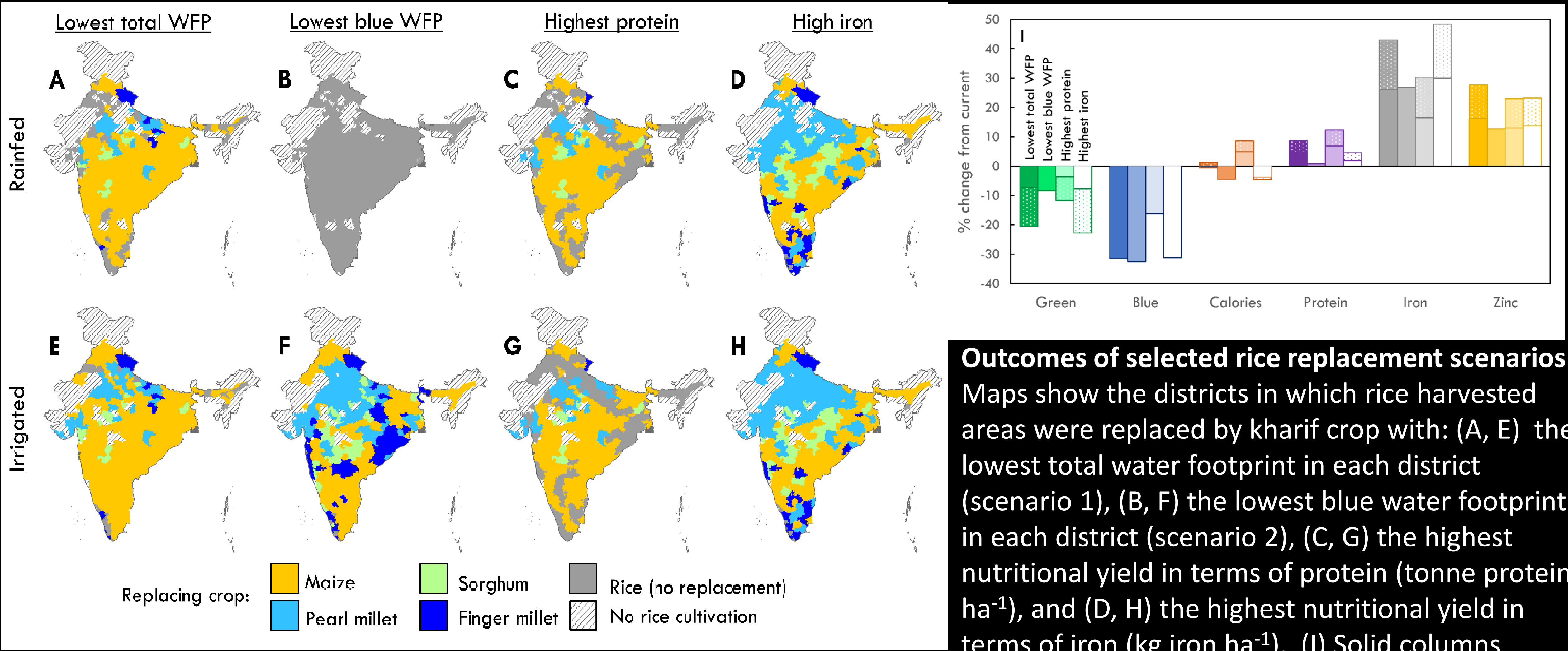


(Davis, Rulli, D'Odorico Nature Geoscience, 2017)



- *Increasing the production of groundnuts, roots, soybeans, sorghum and tubers,*
- *Reducing millets, rice, sugar crops, and wheat*

The potential nutritional and water use benefits of alternative cereals (i.e., maize, millets, and sorghum)



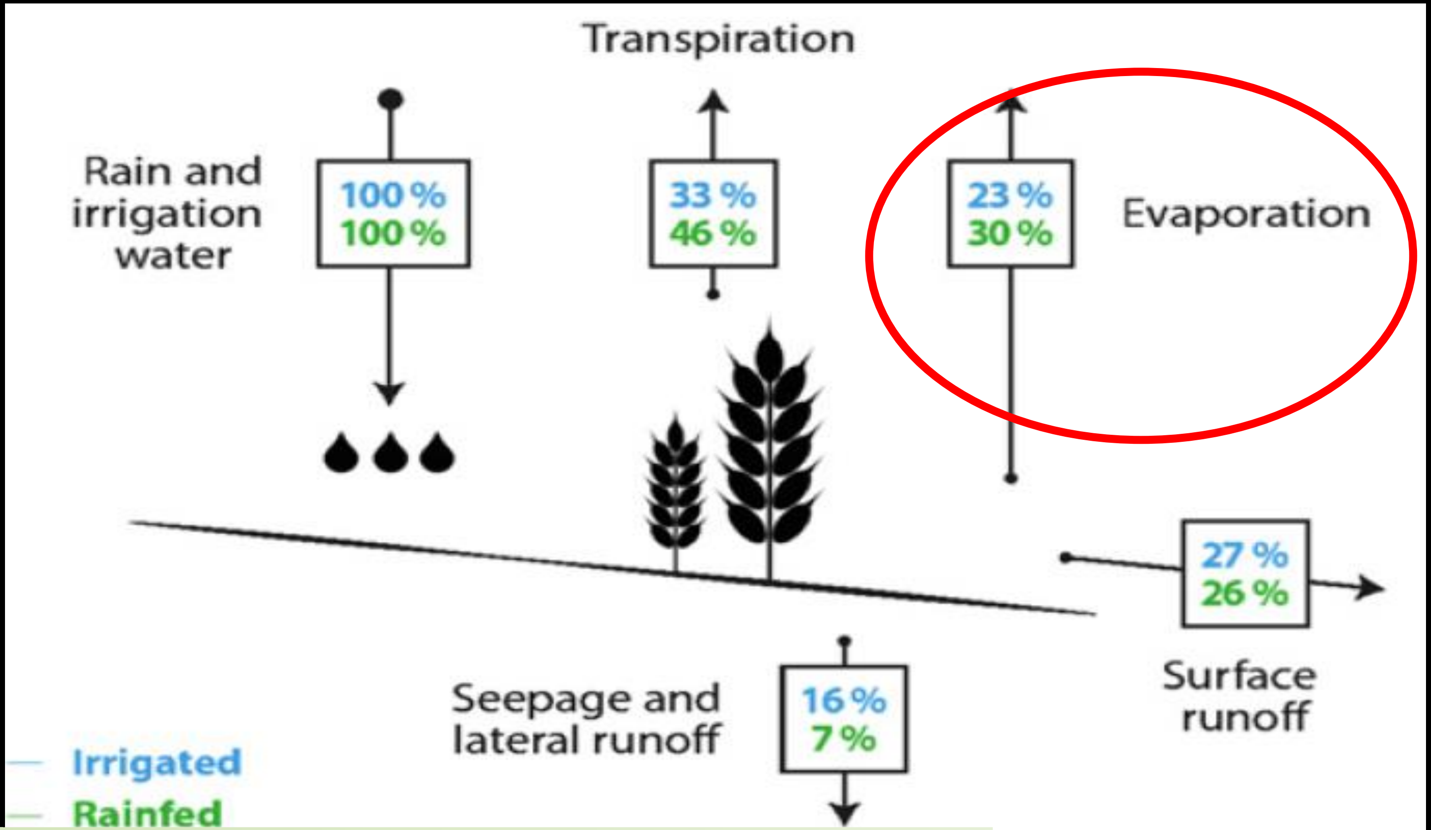
Outcomes of selected rice replacement scenarios. Maps show the districts in which rice harvested areas were replaced by kharif crop with: (A, E) the lowest total water footprint in each district (scenario 1), (B, F) the lowest blue water footprint in each district (scenario 2), (C, G) the highest nutritional yield in terms of protein (tonne protein ha^{-1}), and (D, H) the highest nutritional yield in terms of iron (kg iron ha^{-1}). (I) Solid columns correspond to irrigated (*I*) areas, and patterned columns correspond to rainfed (*R*) areas

Davis, Rulli et al., Science adv, 2018 In press

Soil Water Management

- Reduce Evaporation by 48%
- Use the water saved to intensify or extensify irrigation
- Increase Global Production by 41%

(*Jagermeyr et al., ERL, 2016*)



RESEARCH ARTICLE

No-tillage and high-residue practices reduce soil water evaporation

by Jeffrey P. Mitchell, Purnendu N. Singh, Wesley W. Wallender, Daniel S. Munk, Jon F. Wroble, William R. Horwath, Philip Hogan, Robert Roy *and* Blaine R. Hanson

Integrated crop water management might sustainably halve the global food gap

J Jägermeyr[1,2], D Gerten[1,2], S Schaphoff[1], J Heinke[1,3,4], W Lucht[1,2] and J Rockström[5]

Sustainable Intensification and Other Solutions

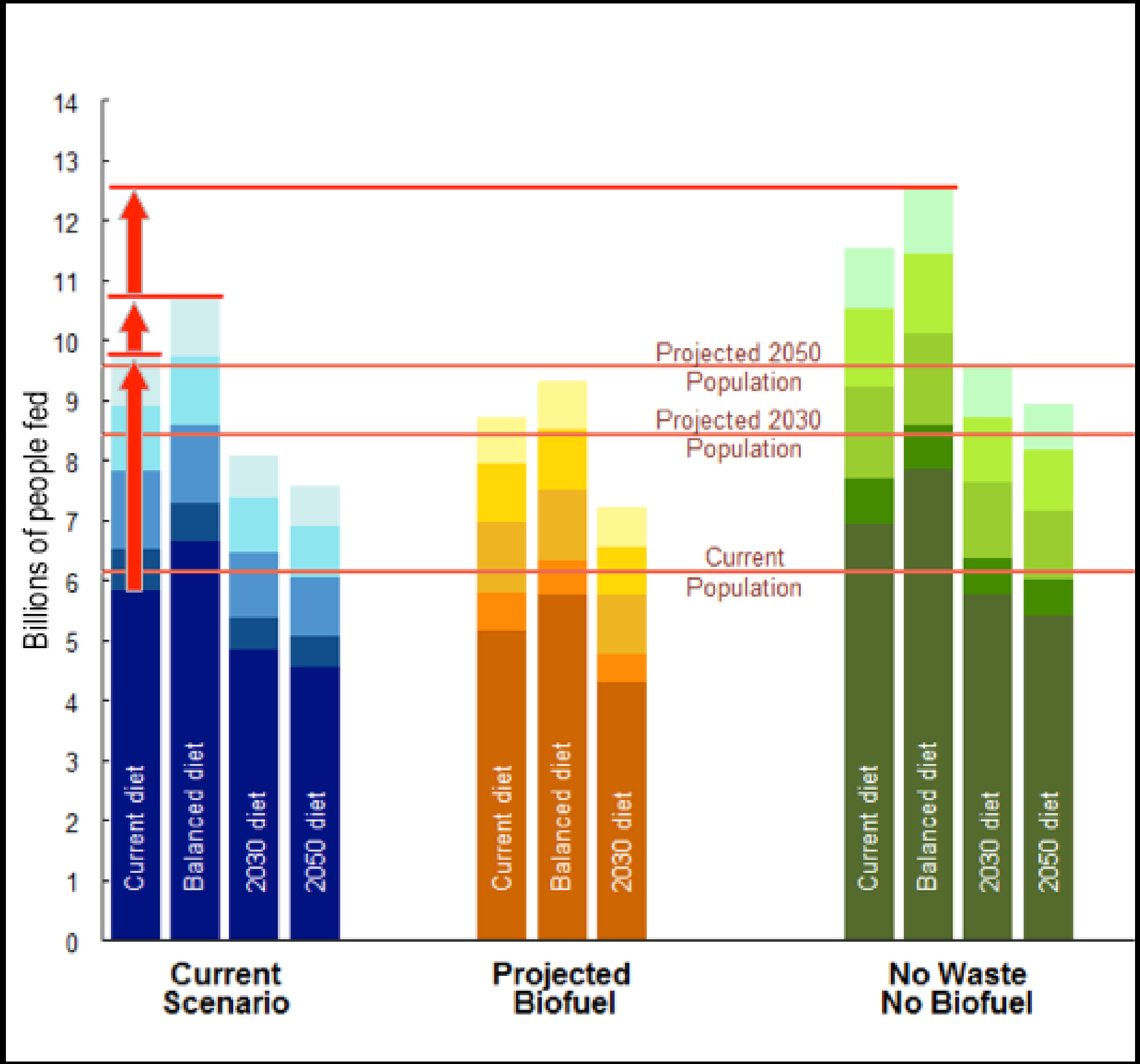
- Soil water management
- Change crop distribution
- Changes in diets
- Reduce food waste

Table 1 | Comparison of savings from water conservation solutions in agriculture (After Davis et al., Nat Geoscience, 2017)

Solution	Potential water savings ($km^3 yr^{-1}$)	Production increase (10^{15} kcal)	Reference
Crop redistribution	416 (green) 56 (blue)	1.4	Davis et al., 2017
Improvements in crop water productivity	77	0.1	Braumann et al., 2013
Promote irrigation efficiency	292	2.5	Jägermeyr et al., 2016
Minimization of food waste	78 **(blue water)** **≈ 300-600 (green + blue)**	0.7	Kummu et al., 2012
Reduced dietary protein from animal products (25% of total)	683	–	Jalava et al., 2014

Towards a sustainable food system

- Reduce food waste
- Change dietary patterns
- Closing yield gaps and increasing efficiencies
- Optimizing crops distribution



Davis, Rulli, Seveso, D’Odorico, 2017 Nature Geoscience

Conclusions

- ***Water remains a major constraint on food production***
- ***Some countries are in conditions of chronic water deficit***
- ***Trade and international investments → Globalization of Water, Land, and Food***
- ***Sustainable intensification:*** *more suitable crop distribution, water savings through waste reduction, changes in diets, soil water management*