Water limits to global sustainable food security:

the sustainable global water and food security challenges

2019 Edition Doctoral Winter School

DATA RICH HYDROLOGY

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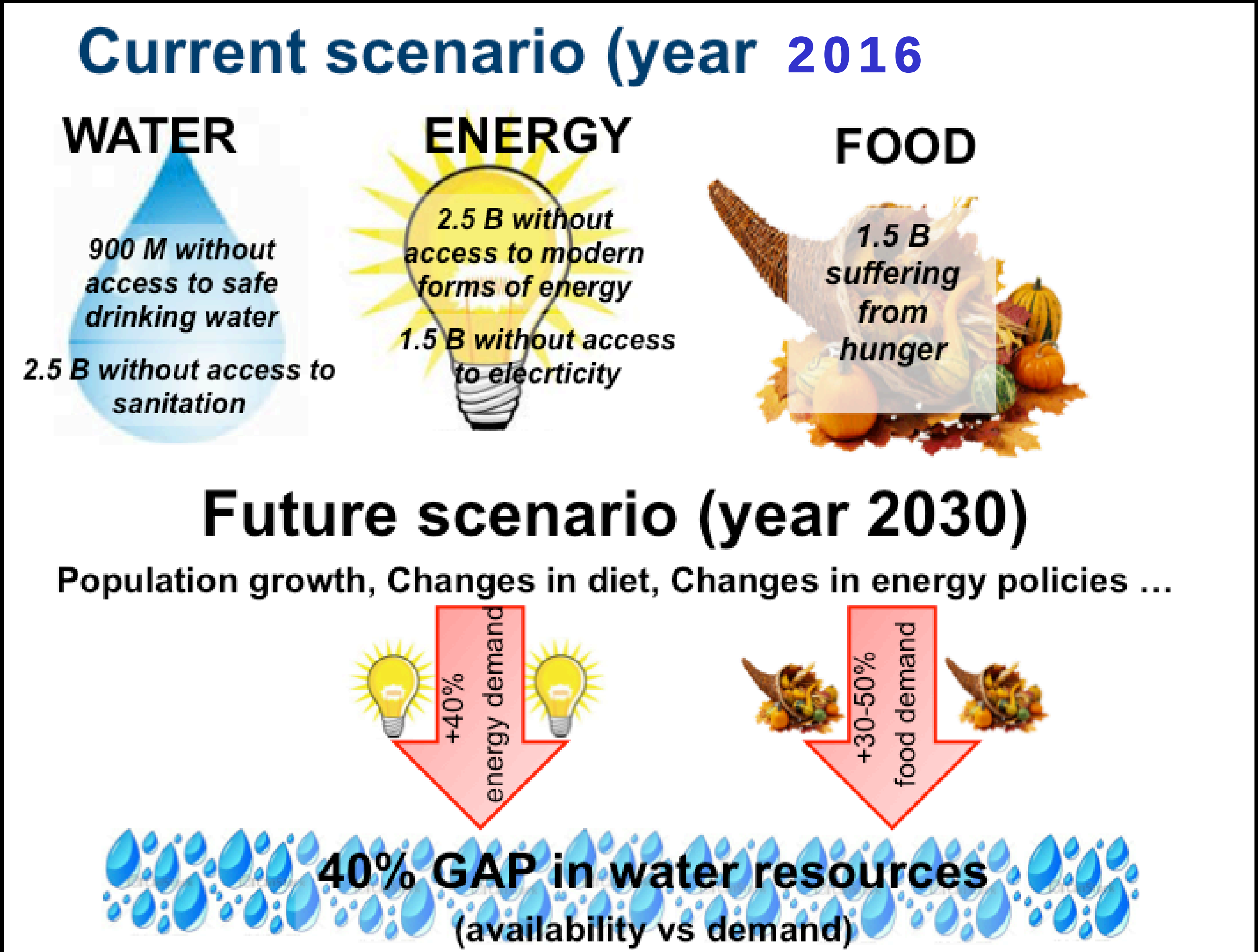
Università per Stranieri di Perugia


Current scenario (year 2016
WATER
900 M without access to safe drinking water
2.5 B without access to sanitation
ENERGY
2.5 B without access to modern forms of energy
1.5 B without access to elecrticity
FOOD
1.5 B suffering from hunger
Future scenario (year 2030)
Population growth, Changes in diet, Changes in energy policies …
+40% energy demand
+30-50% food demand
40% GAP in water resources
(availability vs demand)

Food for thought

Global population growth and water use is increasinsing significally in the last decades

Our global volume of water is the same as it was 2000 years ago!!!

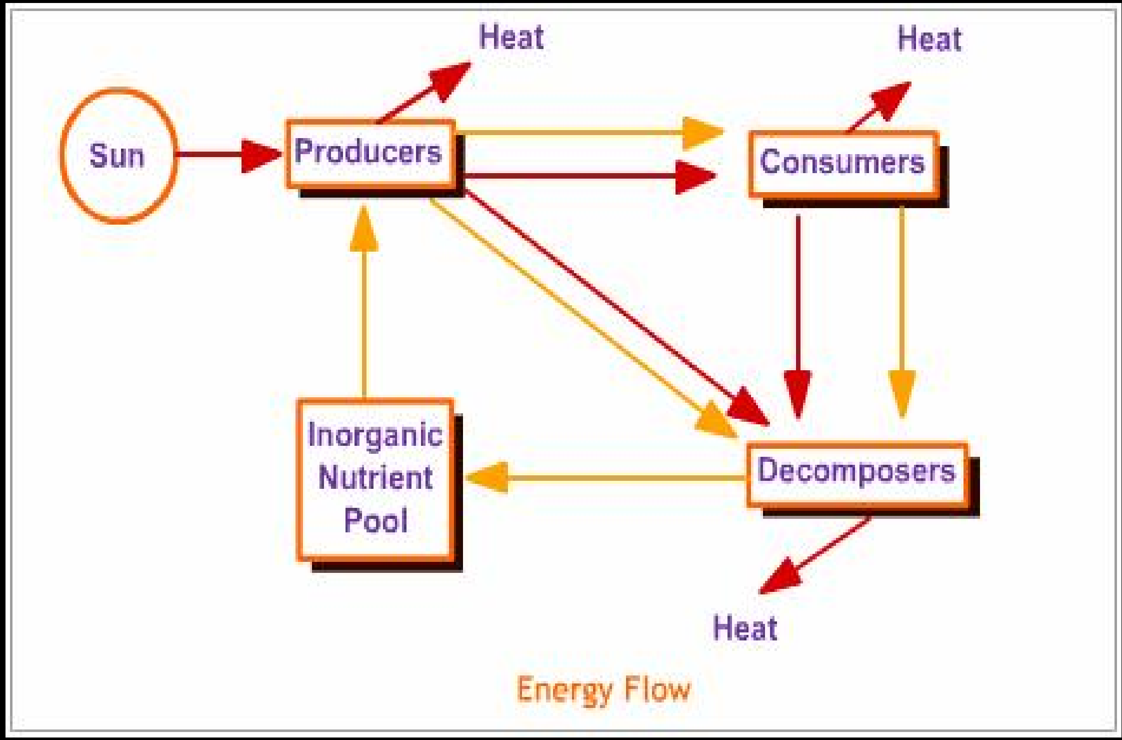
Plants (eatable too!) need water to grow up

Energy production needs of water

How do we produce food?

Organisms that produce their own food are called **autotrophs, producers or primary producers (plants** and bacteria). These organisms create their own food through **photosynthesis**. They are the basis for most ecological systems..

Without producers, consumers like humans, would not have the food or energy they need to survive



How do plants make food?

What does a plant NEED to make its own food?

What about the role of water in producing food?

What role does water play in plant growth?

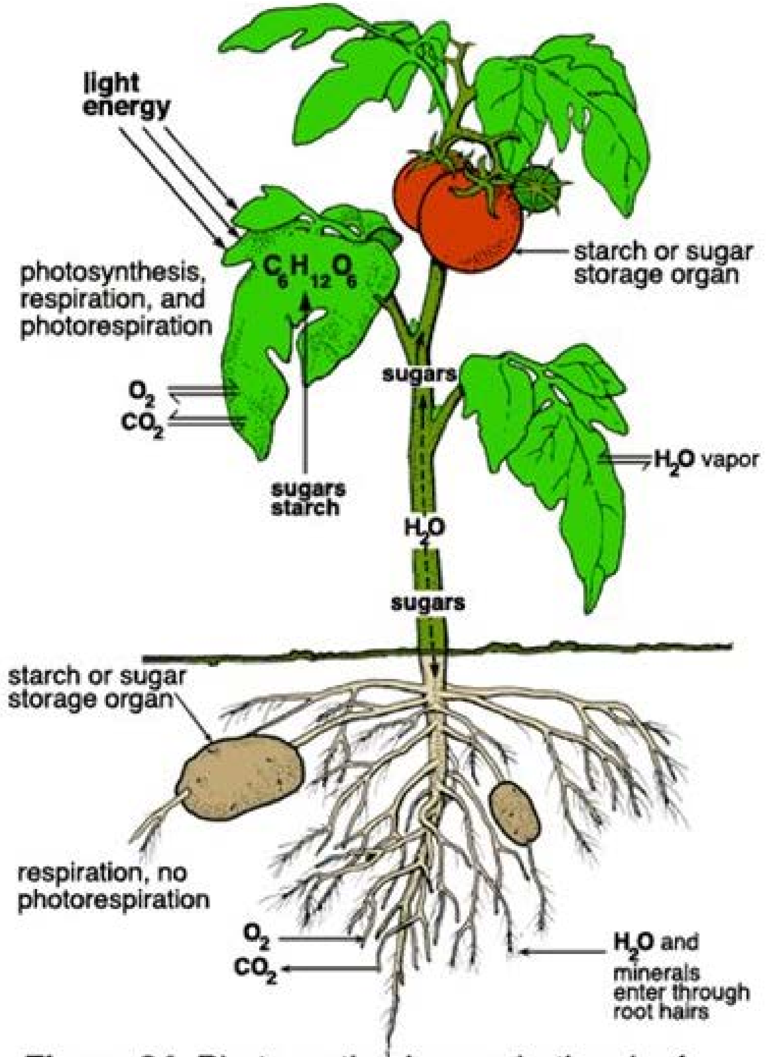
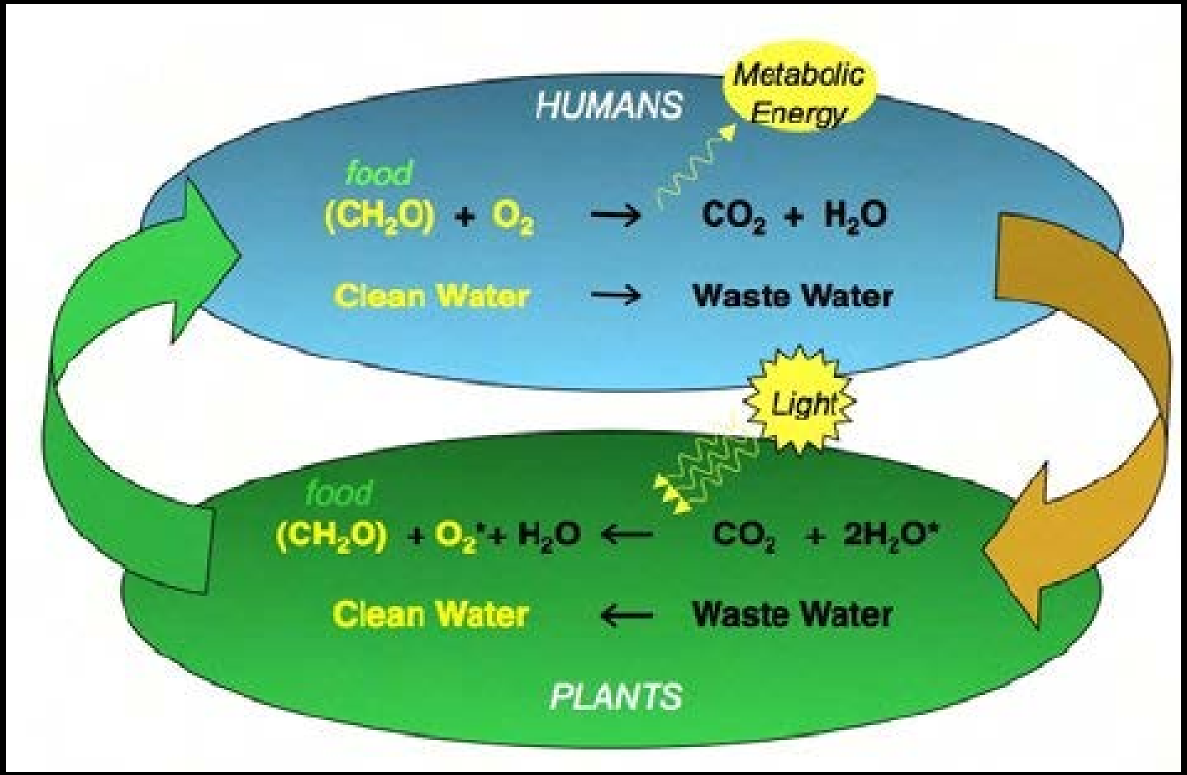
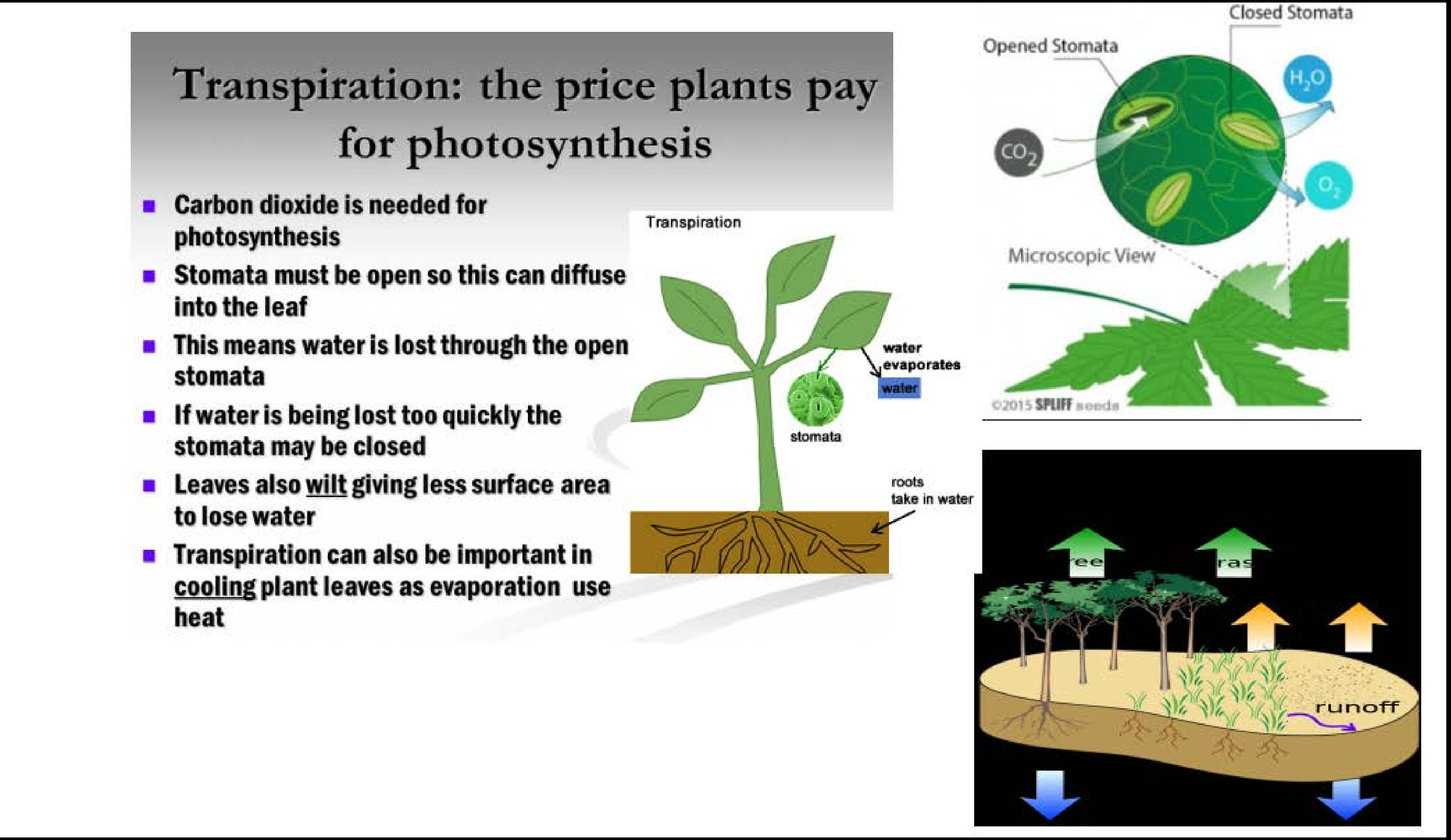


Figure 24. Photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant.

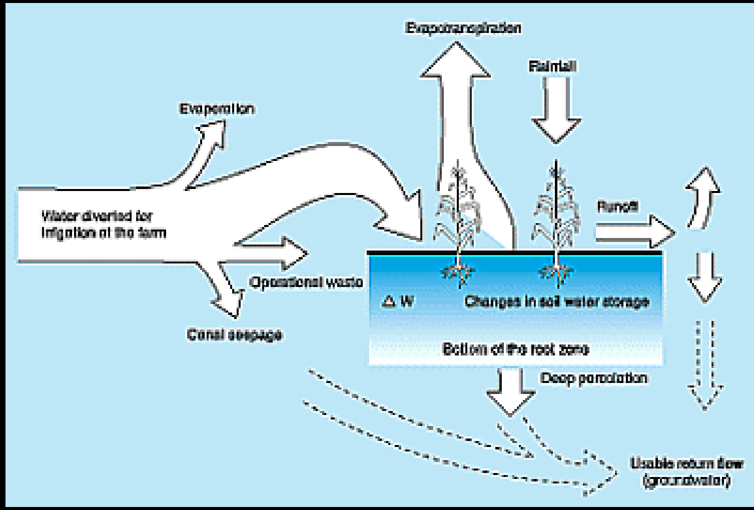


Simplified equations showing photosynthesis (bottom) and human respiration (top). The products of photosynthesis are oxygen (O 2) and carbohydrate (CH 2 O), which can be used as food. Through the process of transpiration, plant systems

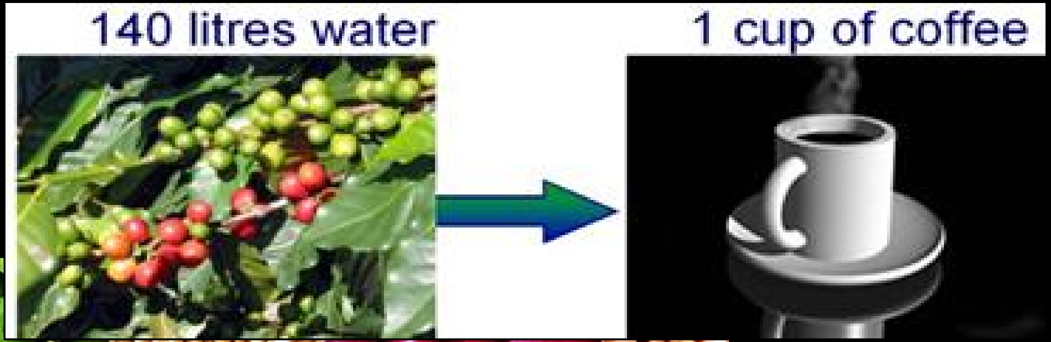
What about the water price plants pay for making photosynthesis?



More than 95% of the water used for making the entire process of photosynthesis is **TRANSPIRED**!



How much water do we need for producing food?



A balanced diet requires on average 1500-1600 m^3 of water for food production per person per year

How much water do we need for producing energy?

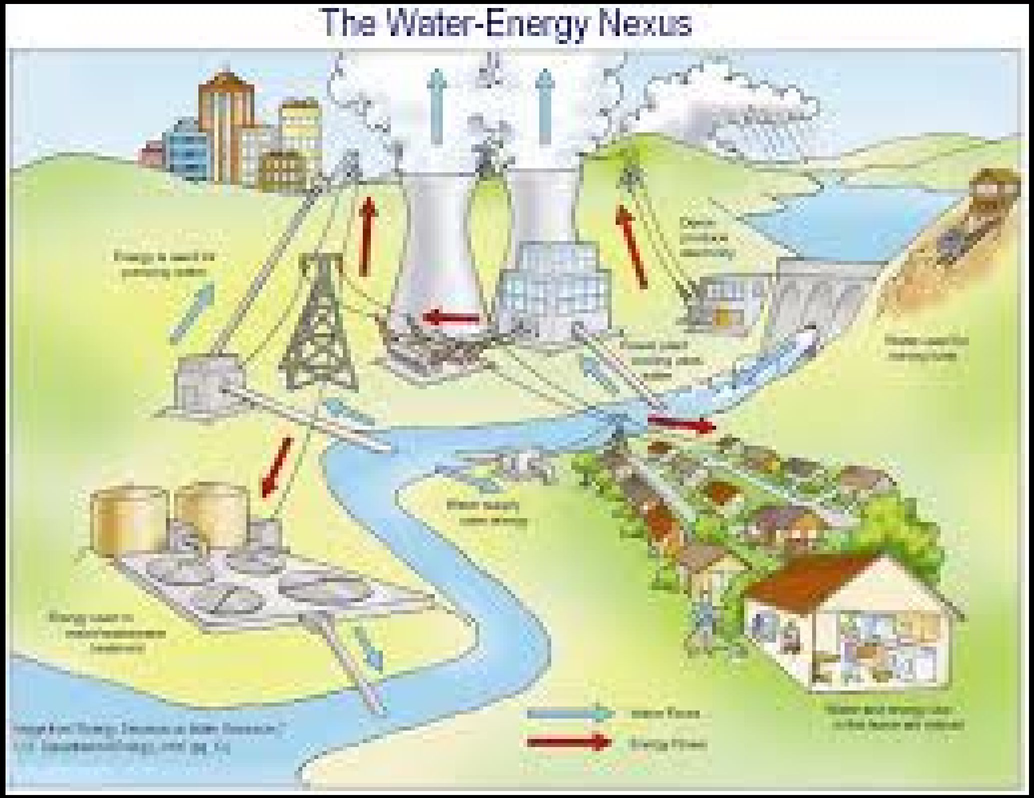
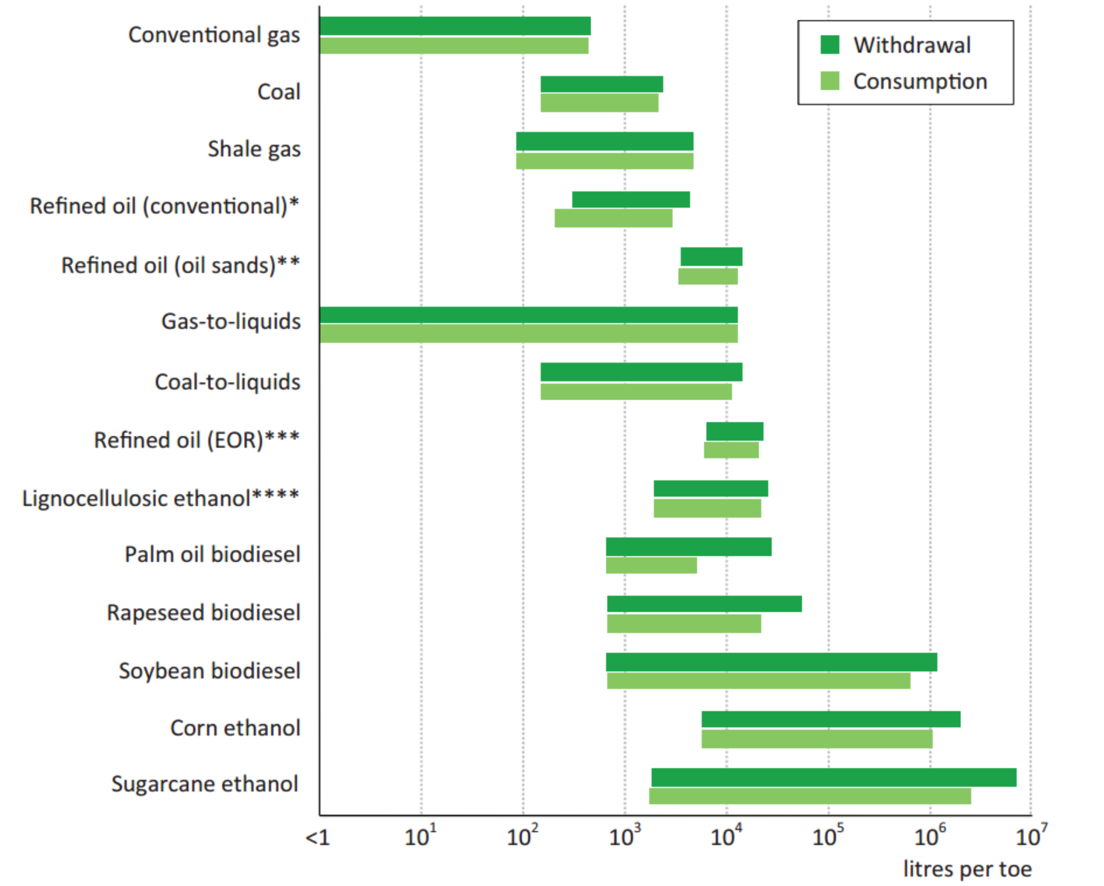
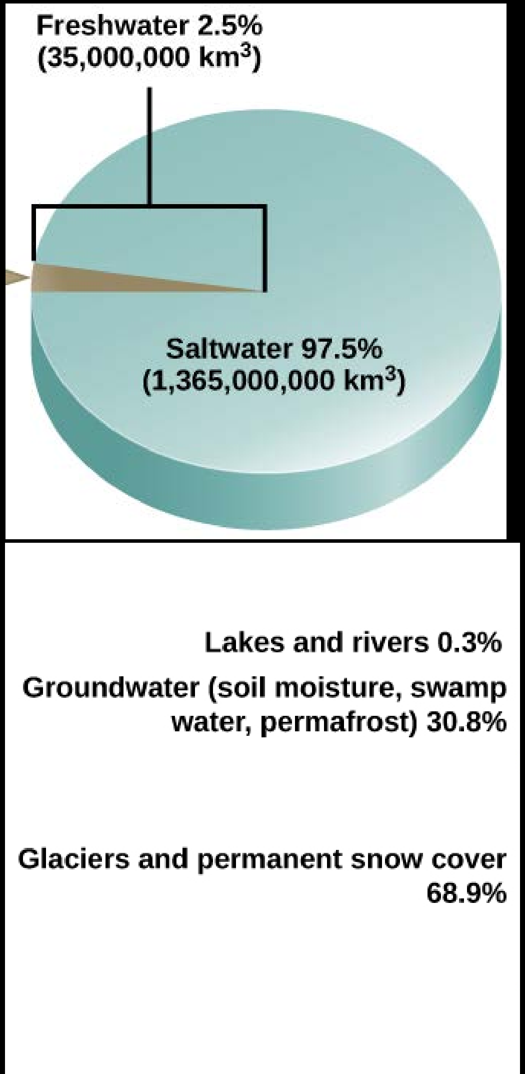
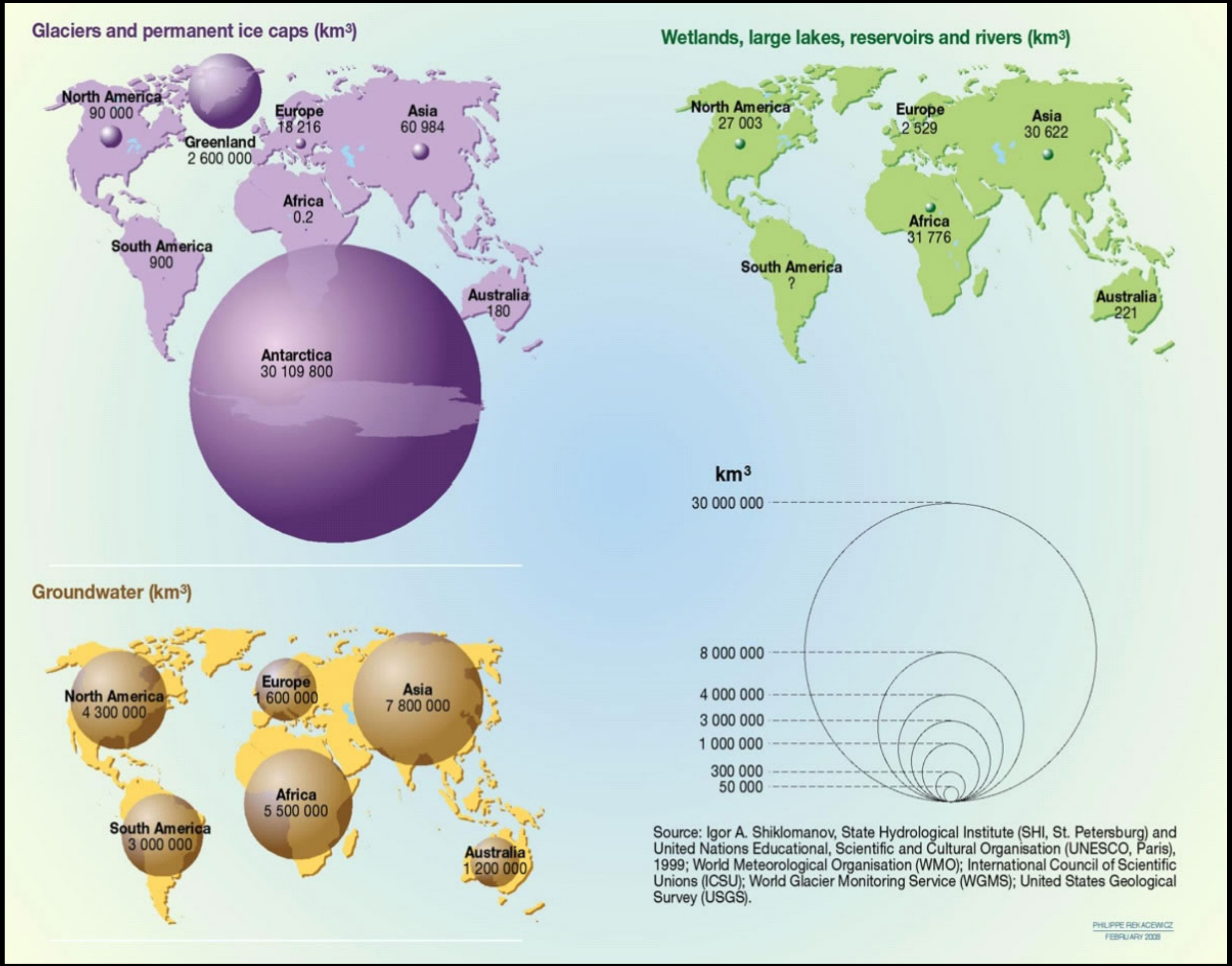


Figure 17.3 ▹ Water use for primary energy production

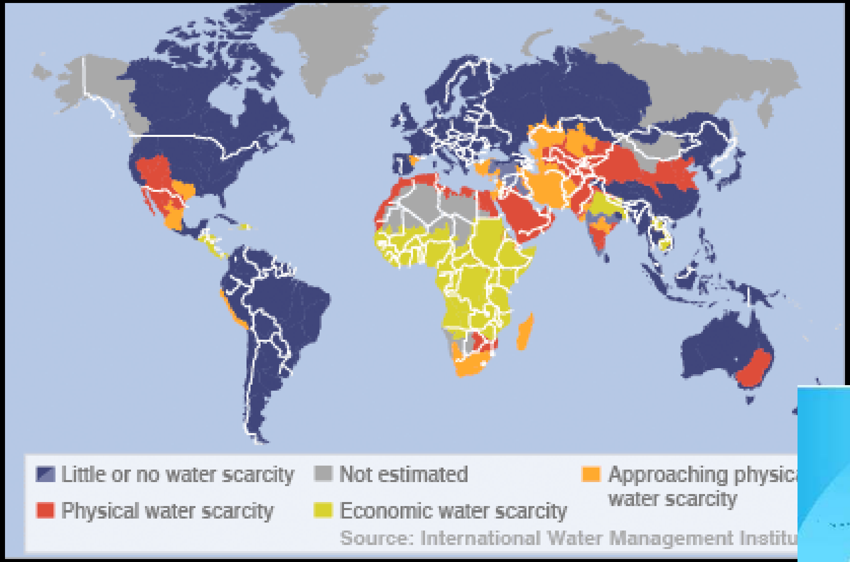


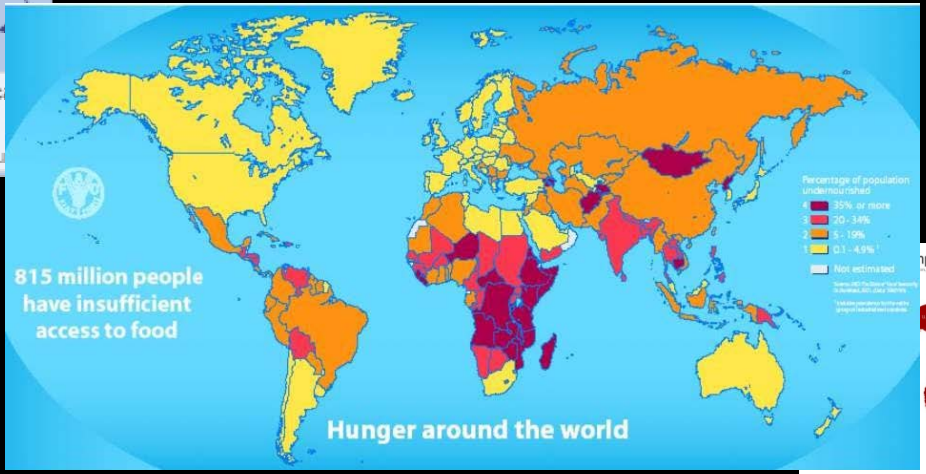
Water as a limiting factor … availability and distribution

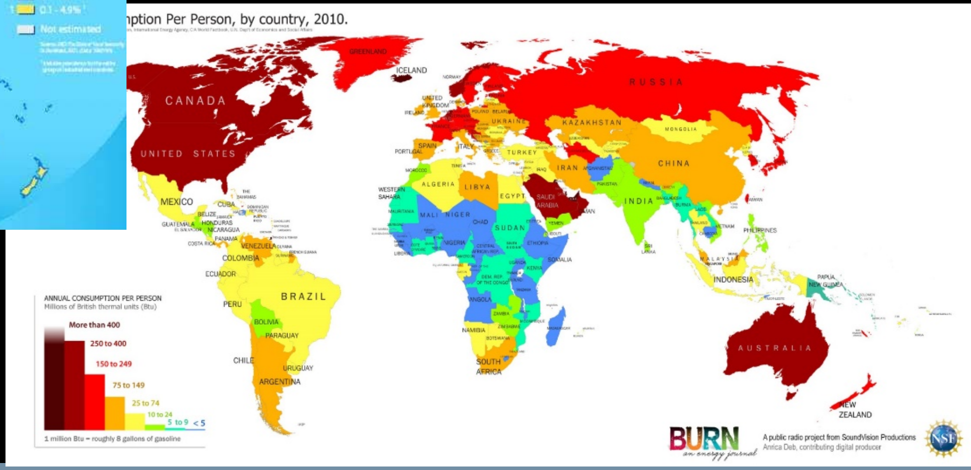




Water as a limiting factor …







Water security is the ability to access sufficient quantities of clean **water** to maintain adequate standards of food and goods production, proper sanitation, and sustainable health care (UN-Water).

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

Energy security is the the uninterrupted availability of **energy** sources at an affordable price (IEA).

Facts about FOOD, WATER, ENERGY SECURITY…

780 million people live without clean drinking water.

Compared to today, five times as much land is likely to be under "extreme drought" by 2050.

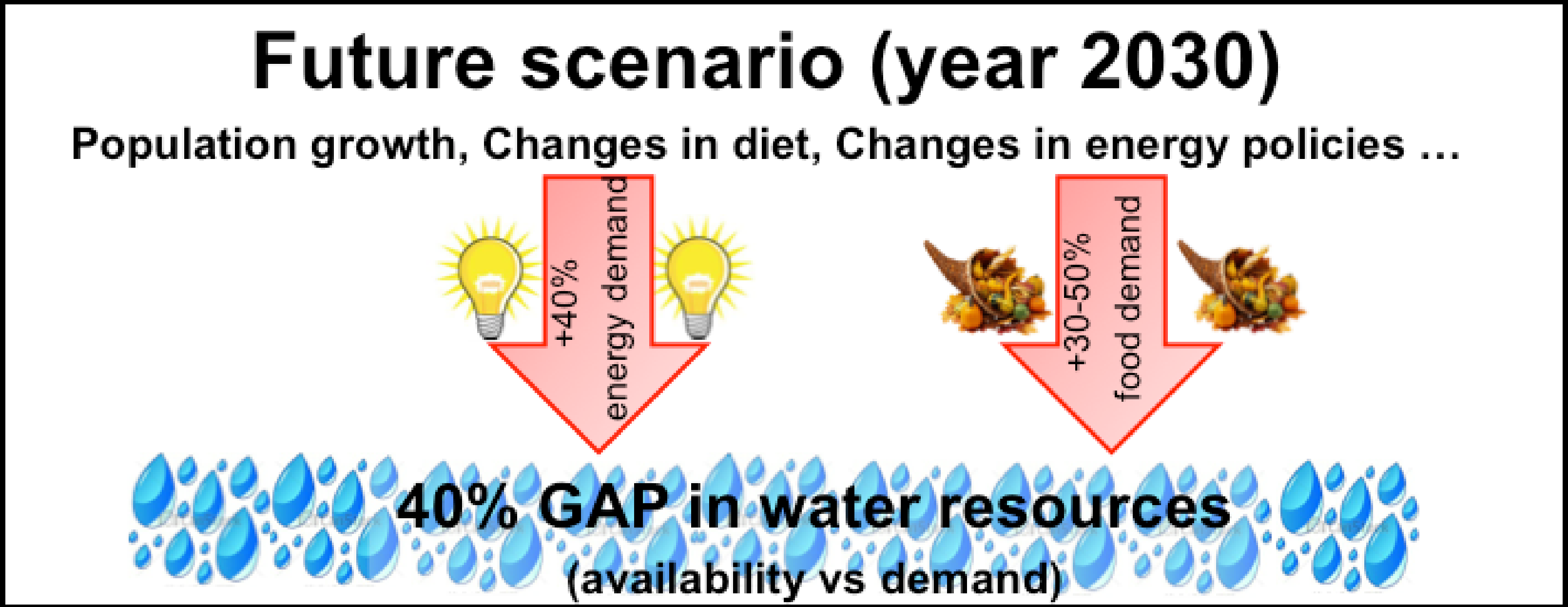
Some 795 million people in the world do not have enough food to lead a healthy active life. That's about one in nine people on earth.

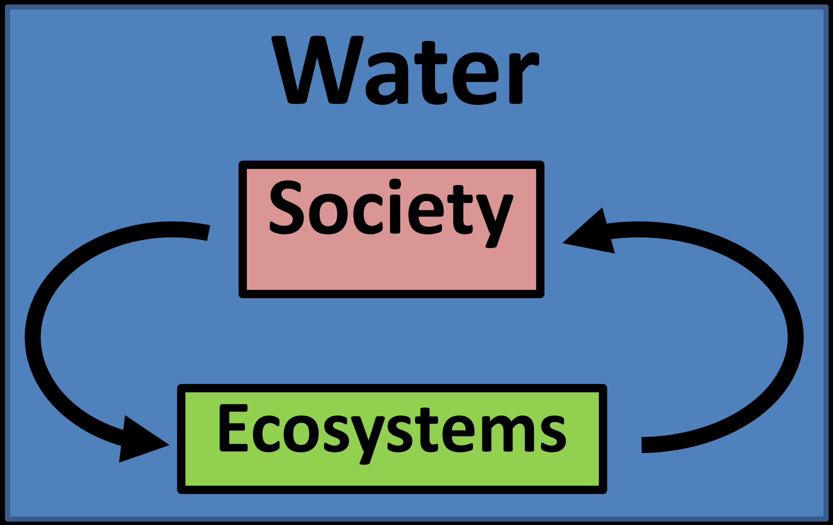
The vast majority of the world's hungry people live in developing countries, where 12.9 percent of the population is undernourished.

About 1.3 billion people do not have access to electricity.

2.6 billion people do not have access to clean and energy efficient cooking technologies.

How can we face the future water demand ?



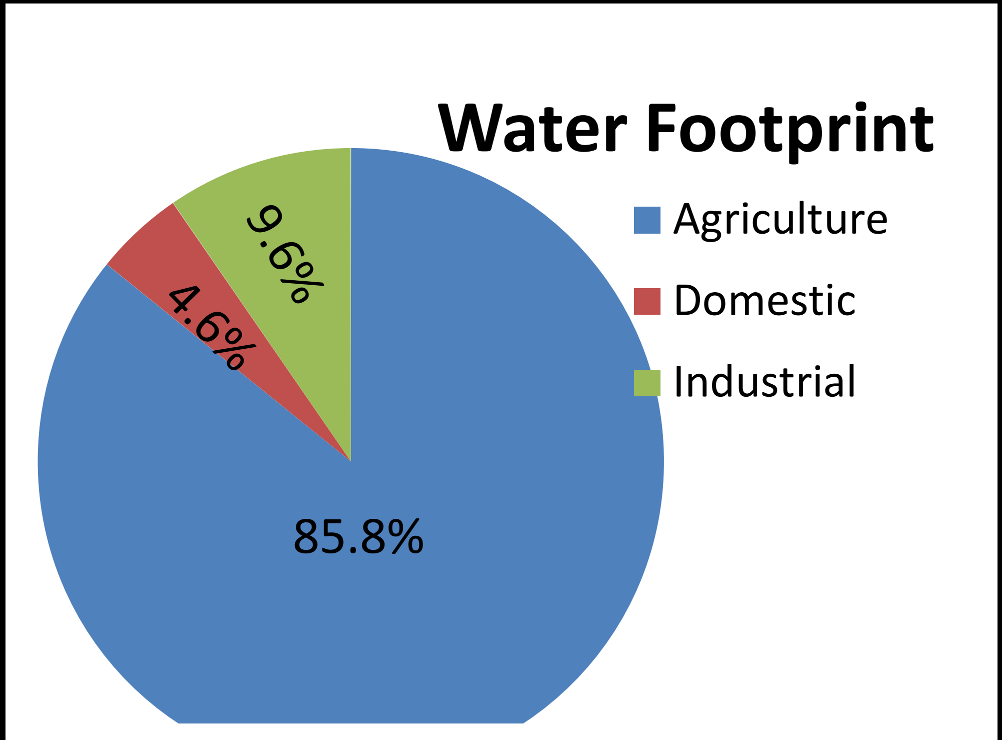


- Increasing Demand for Food and Energy
- Constraints Imposed by the Water Cycle
- Redistribution & Globalization of Resources
- Strategies for increasing food production

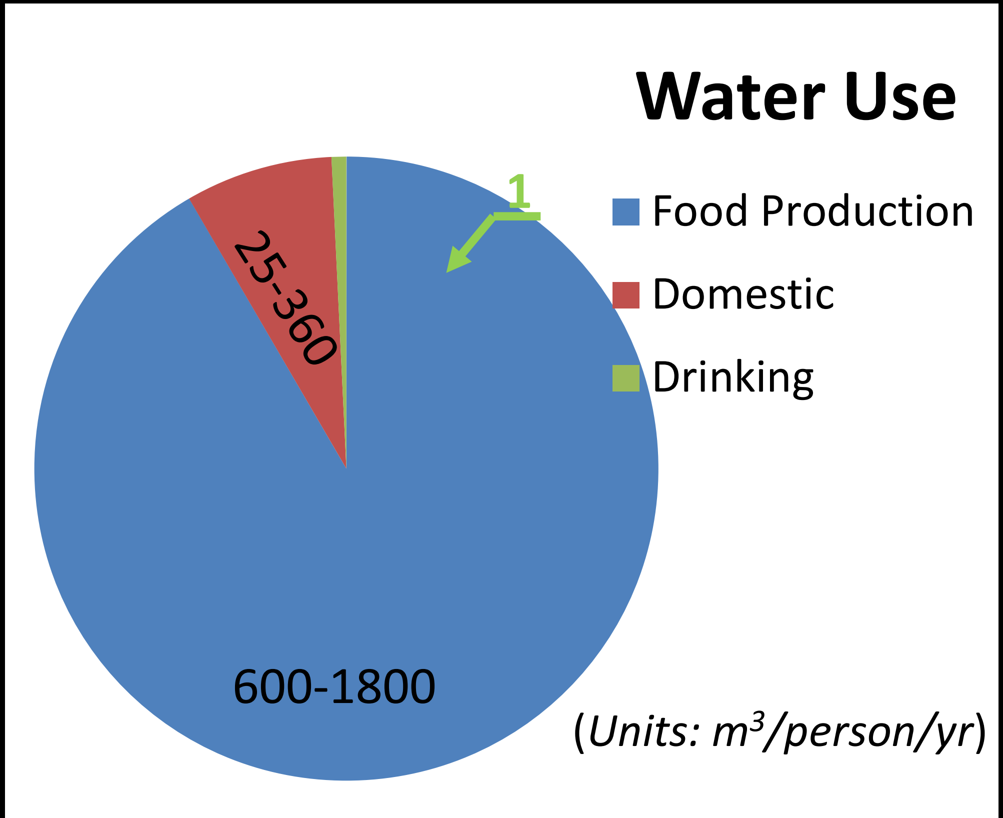
Water, Food, Energy and the FEW nexus

Most of our water footprint is due to agriculture

…mainly for food production



(data from Chapagain and Hoekstra,



(Falkenmark & Rockstrom, 2005)

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)**

Water Use in Agriculture

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

Rainfed

Uses “green” water

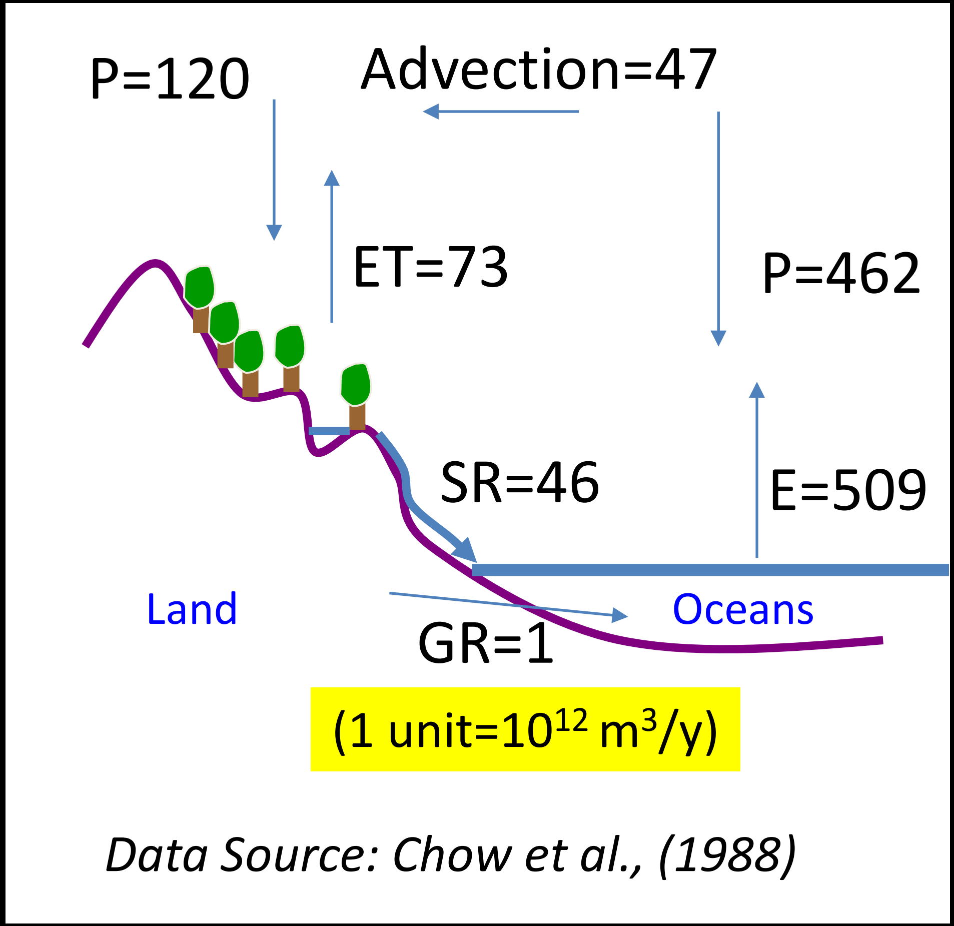
Irrigated

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



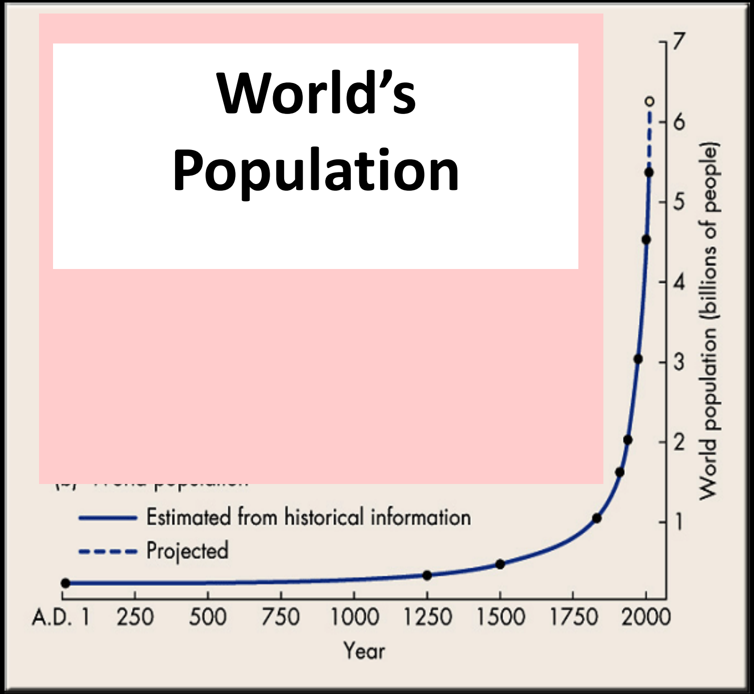
in 2010: ≈12×10^{12} m^3/y (Carr, D'Odorico et al., PLoS1, 2013)

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

Increase in demand…population growth



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	(14 years later)
8 billion in	2025	(15 years later)

- Haber- Bosch Process (1909)
- Other Technology

1 billion people increase every 12-14 years!

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

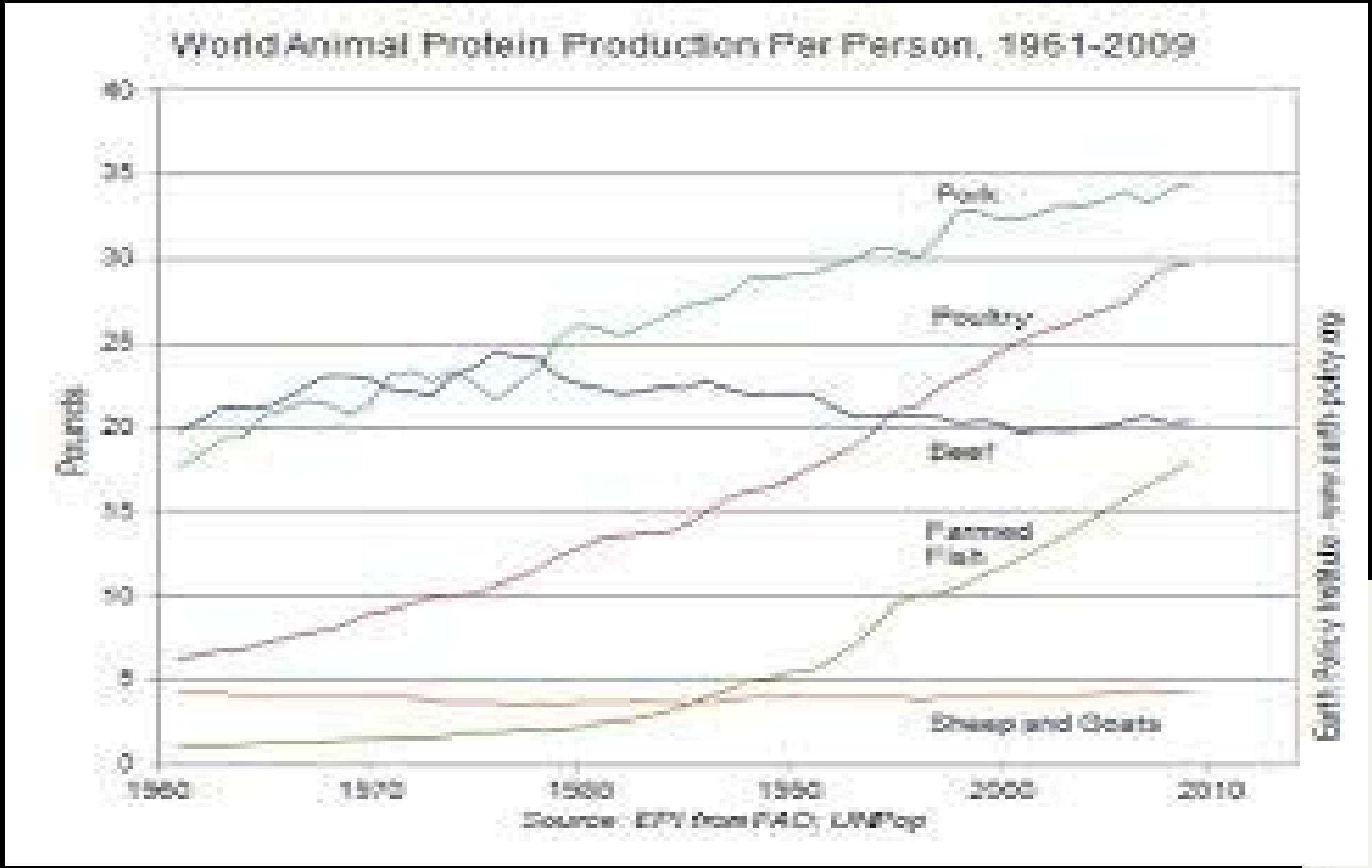
Erisman et al., Nature Geoscience, 2012.

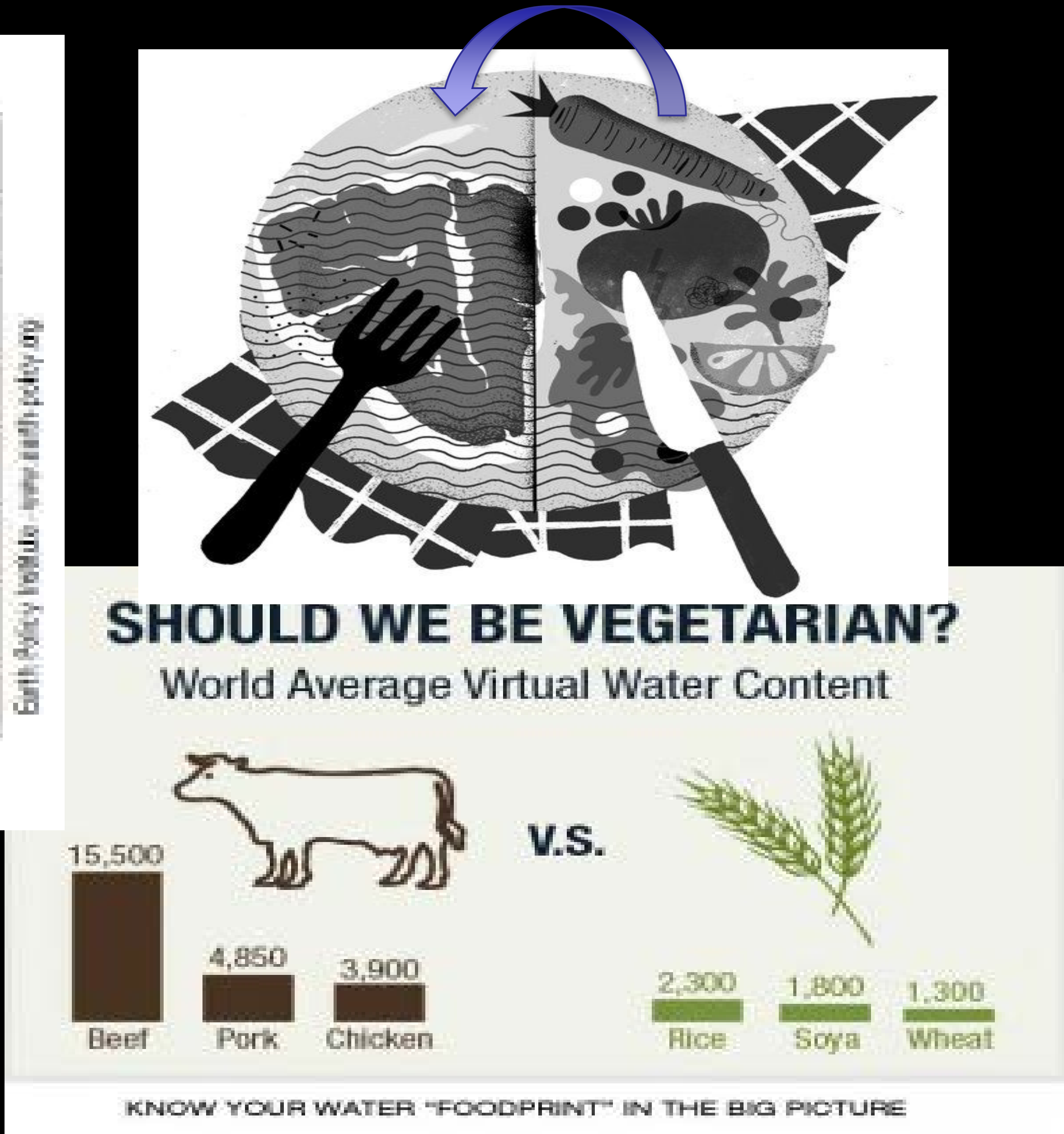
FEATURE

How a century of ammonia synthesis changed the world

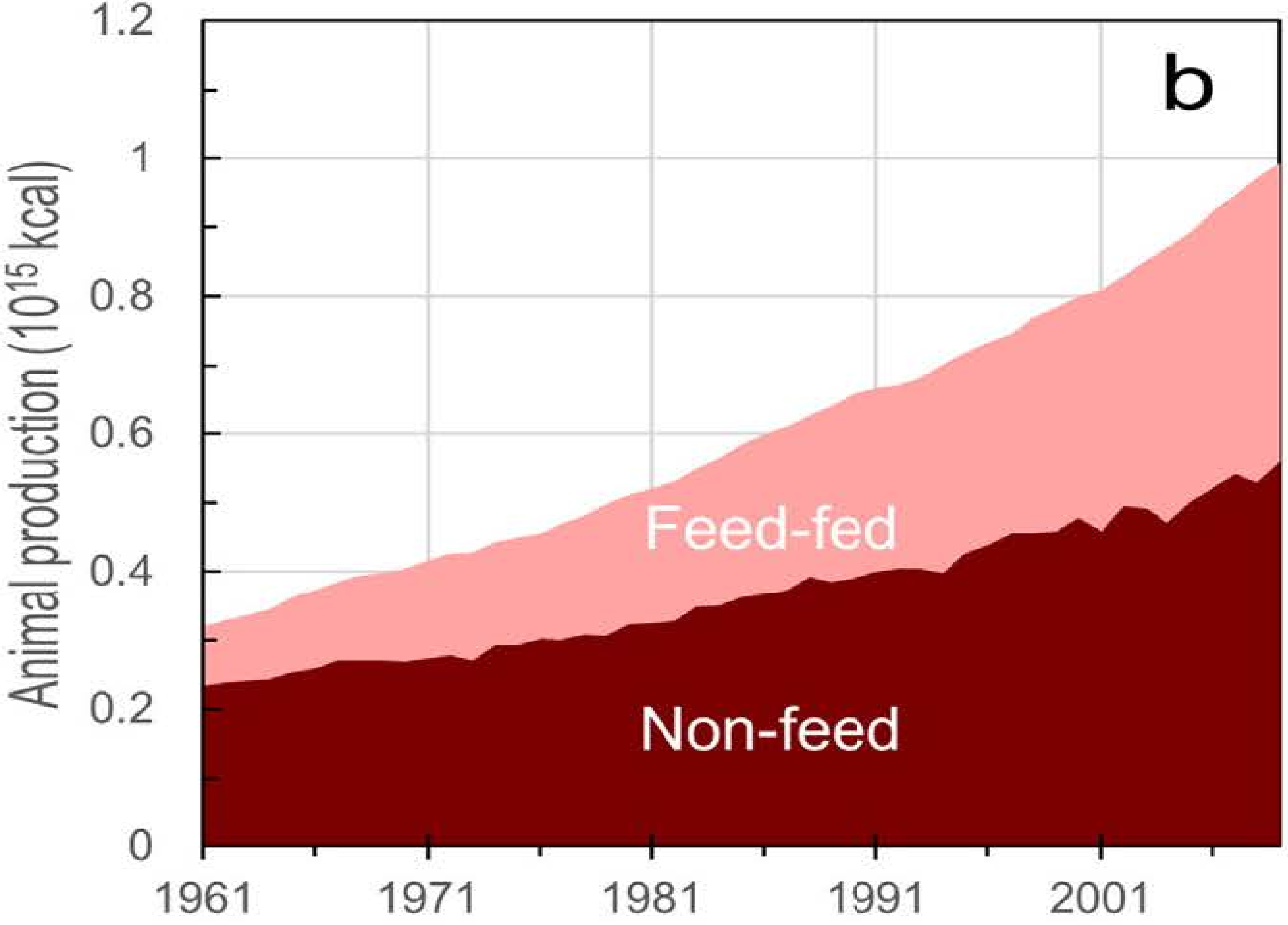
On 13 October 1908, Fritz Haber filed his patent on the "synthesis of ammonia from its elements" for which he was later awarded the 1918 Nobel Prize in Chemistry. A hundred years on we live in a world transformed by and highly dependent upon Haber–Bosch nitrogen.

Increase in demand…Changing in Diet

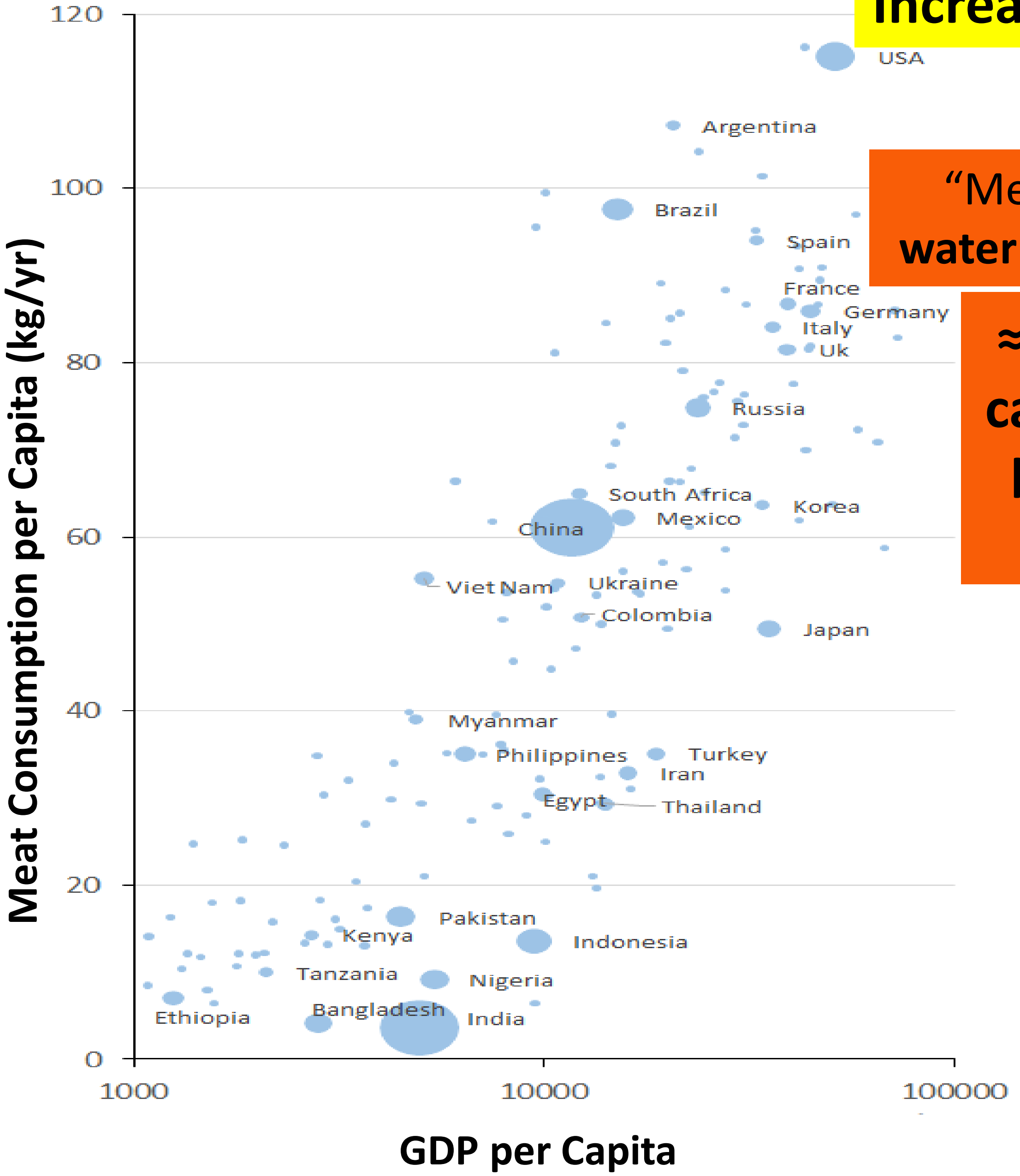




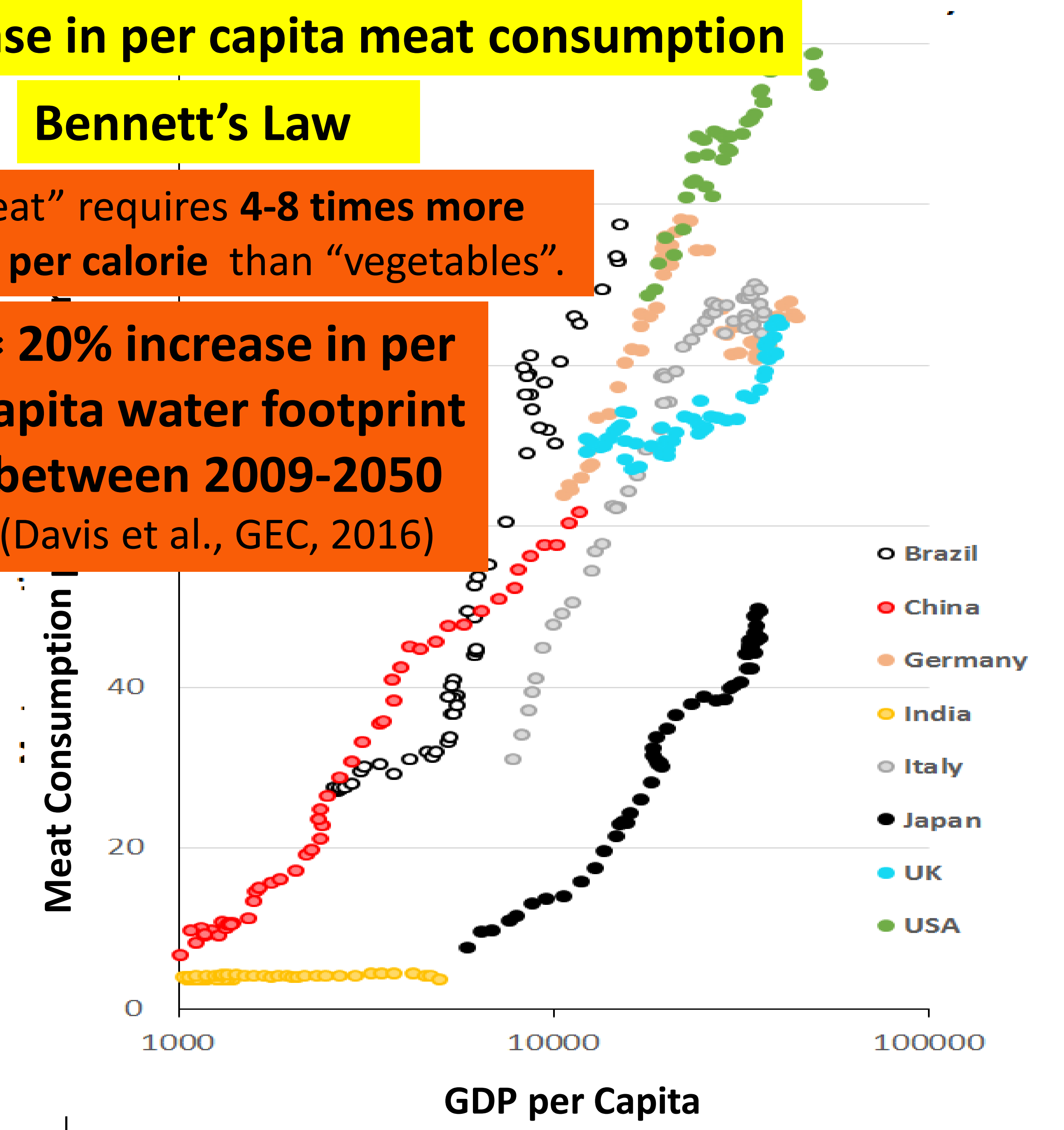
Increase in meat consumption



Meat Consumption vs. GDP per Capita (2013)



Meat Consumption vs. GDP per Capita (1961-2013)



Increase in per capita meat consumption

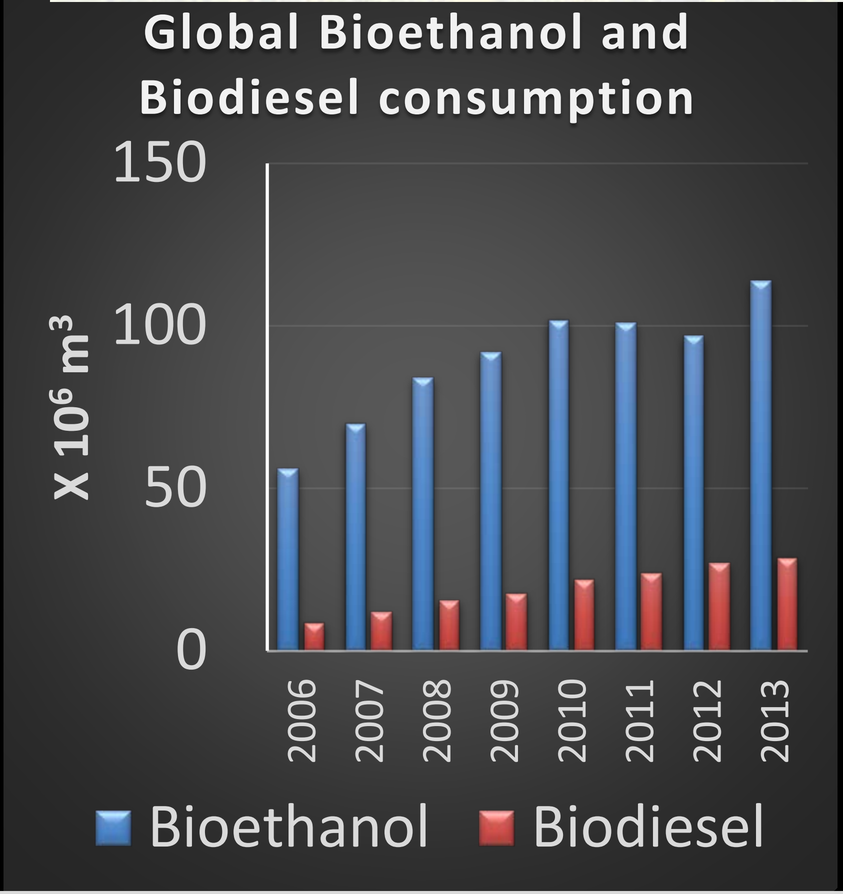
Bennett's Law

"Meat" requires **4-8 times more water per calorie** than "vegetables".

≈ 20% increase in per capita water footprint between 2009-2050
(Davis et al., GEC, 2016)

What about Water for Energy?

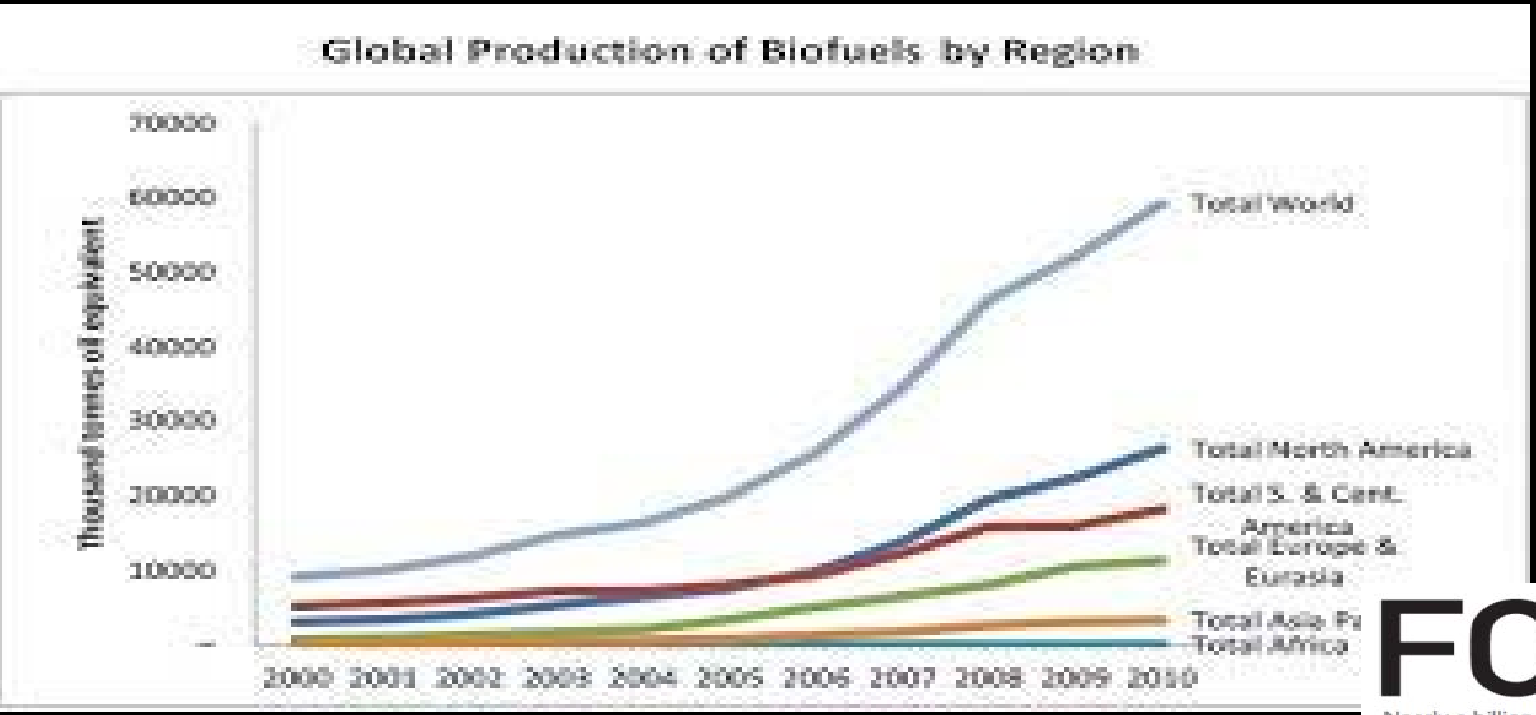
- **Biofuel Production**
- **Extraction of fossil fuels**
- **Non-fuel based renewable energy**

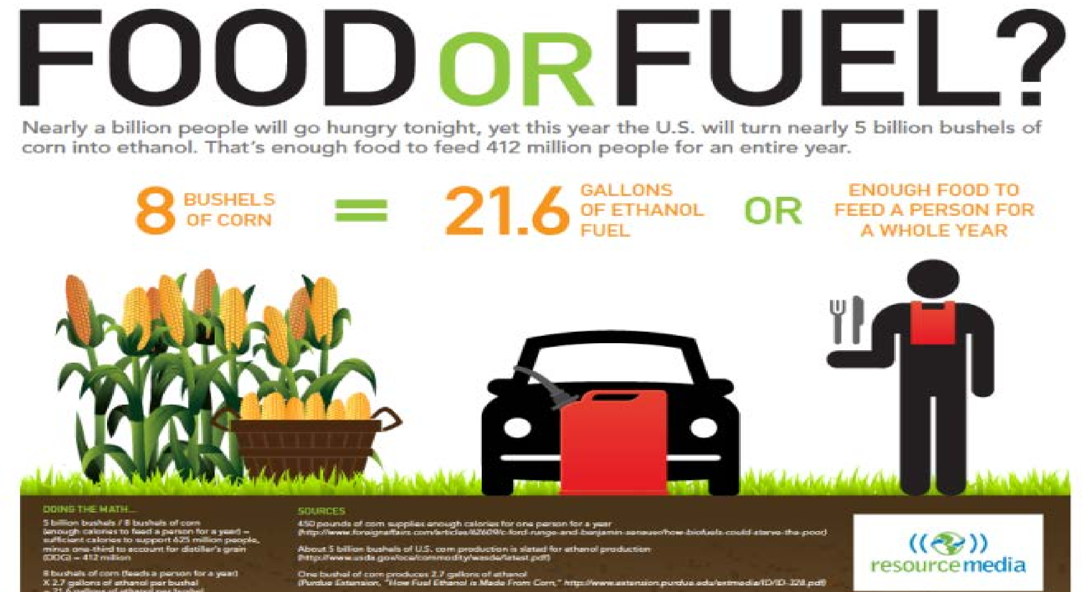


(data source: FAO-OECD, 2013)

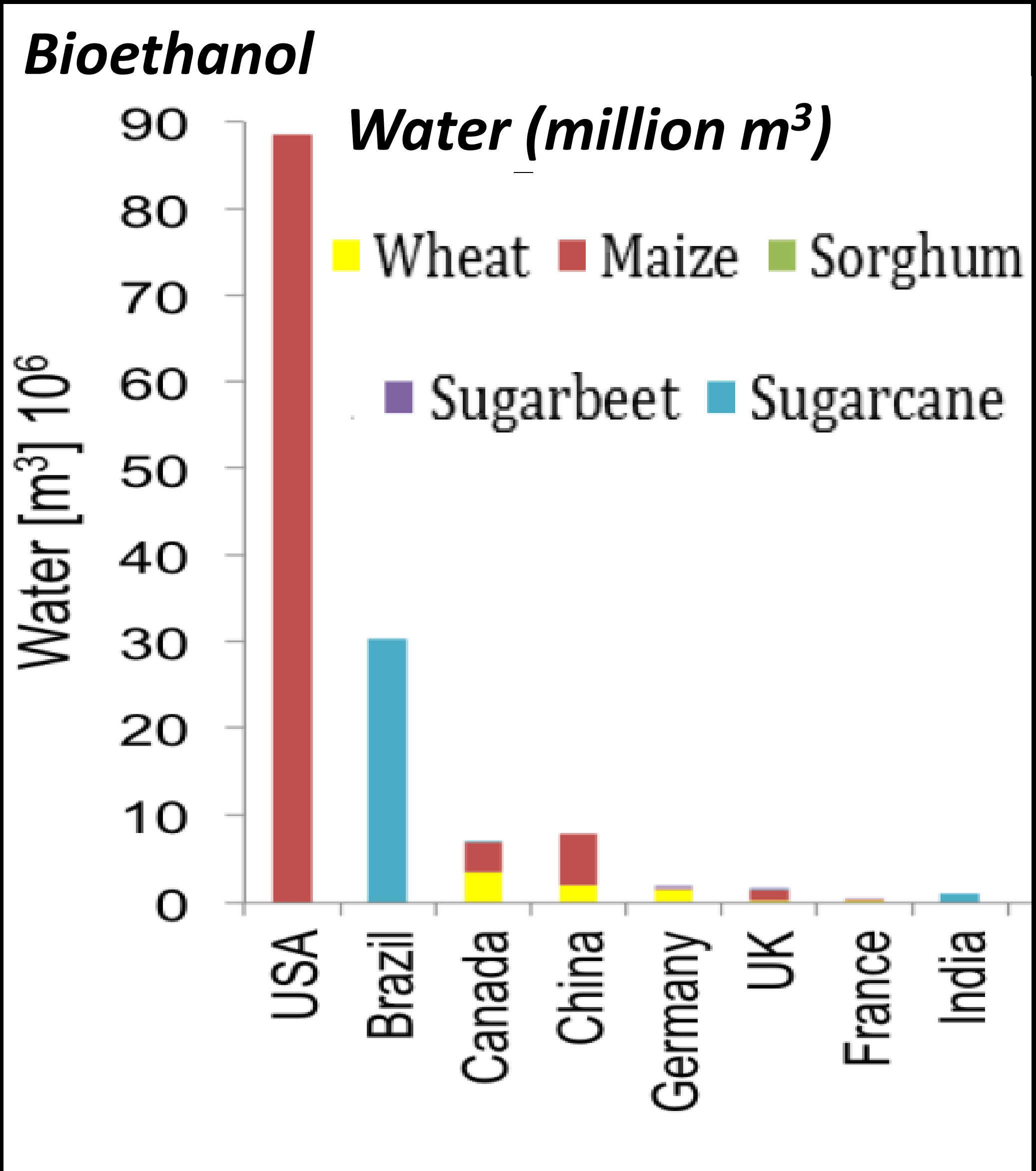
Only 4 percent of global energy consumption by the transport sector and 0.2% of global energy use in all sectors

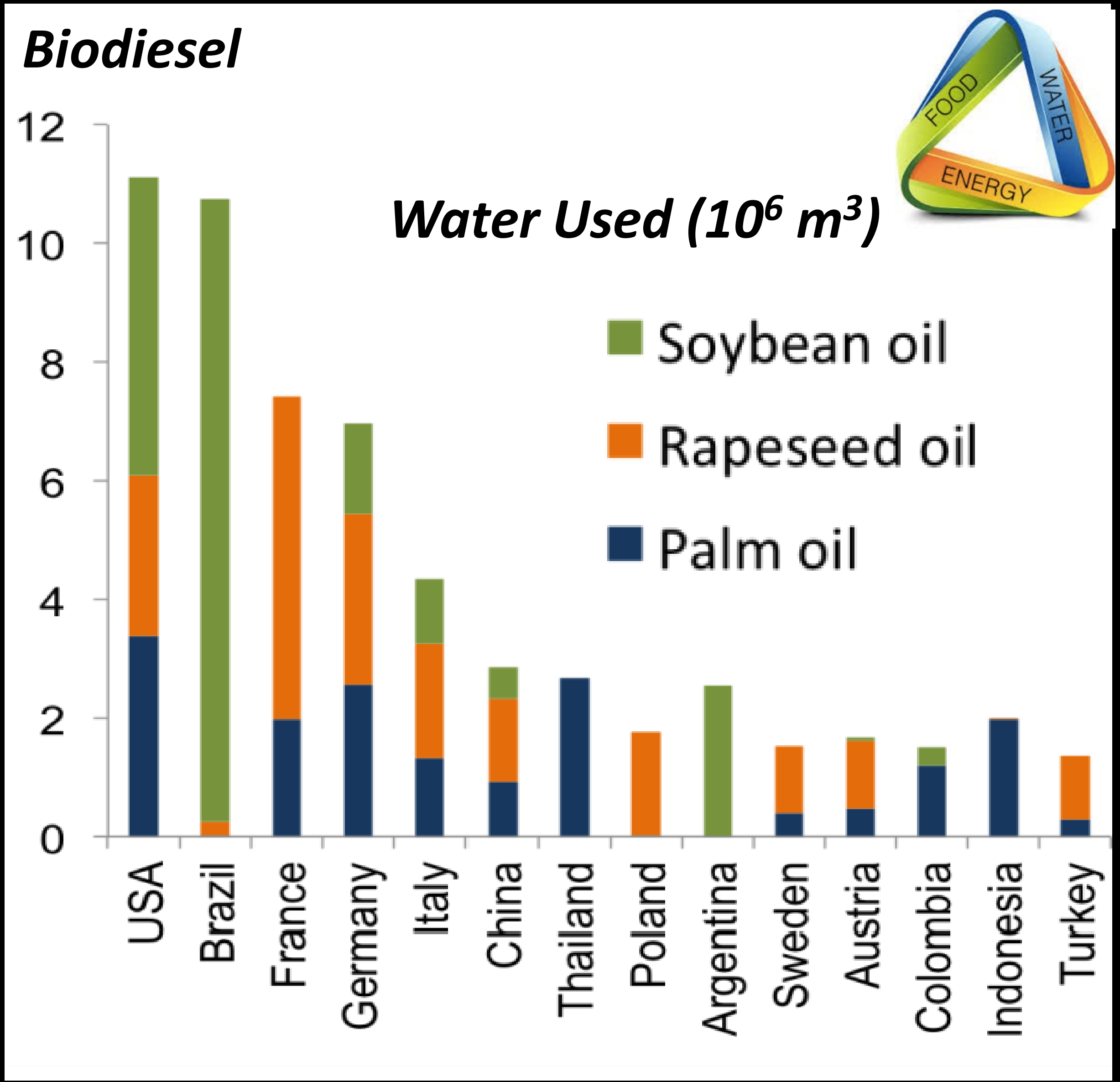
Increase in demand…Changing in Energy Policies





Global Bioethanol and Biodiesel Consumption (2015)





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

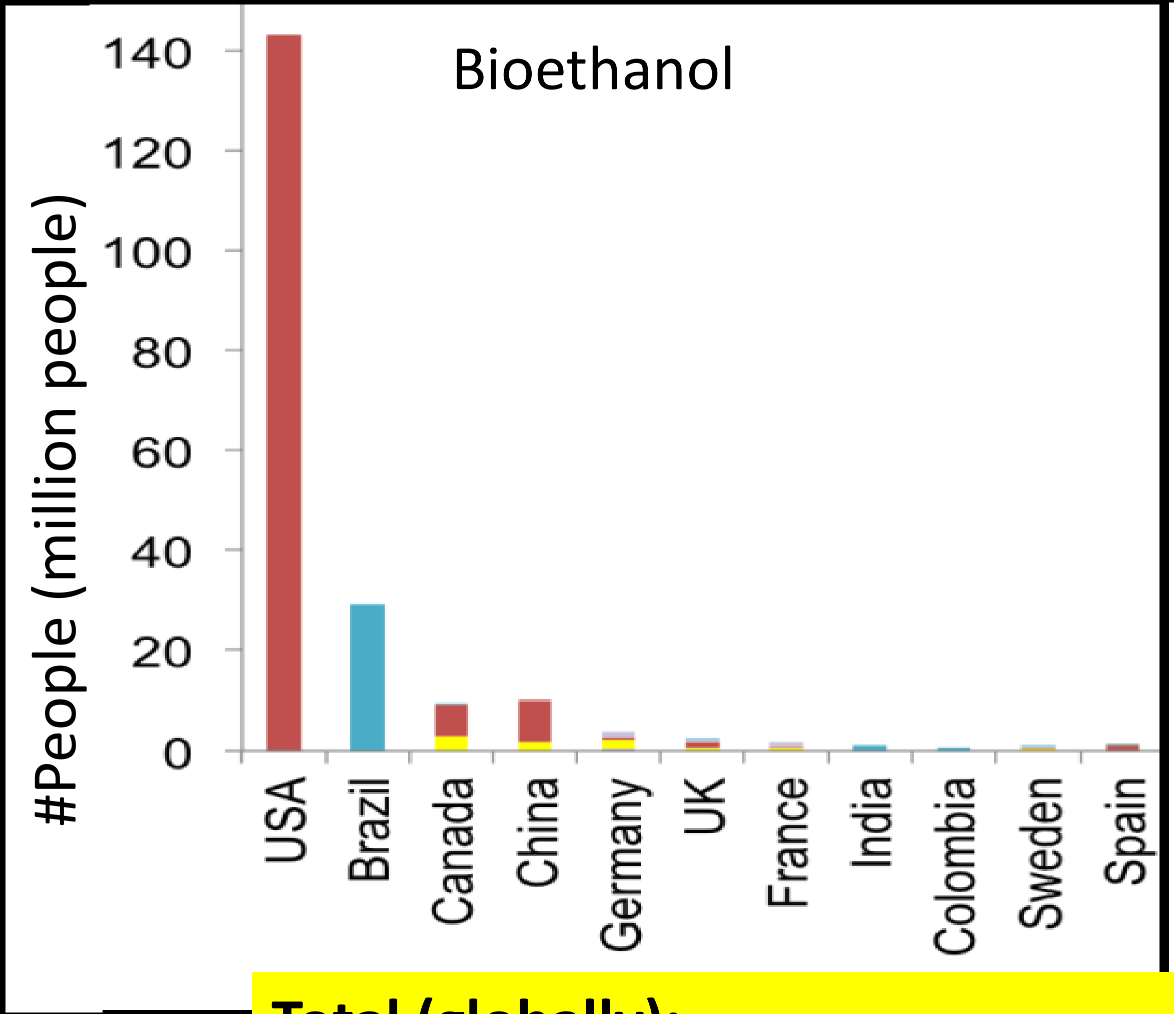
Comparison with other major water flows

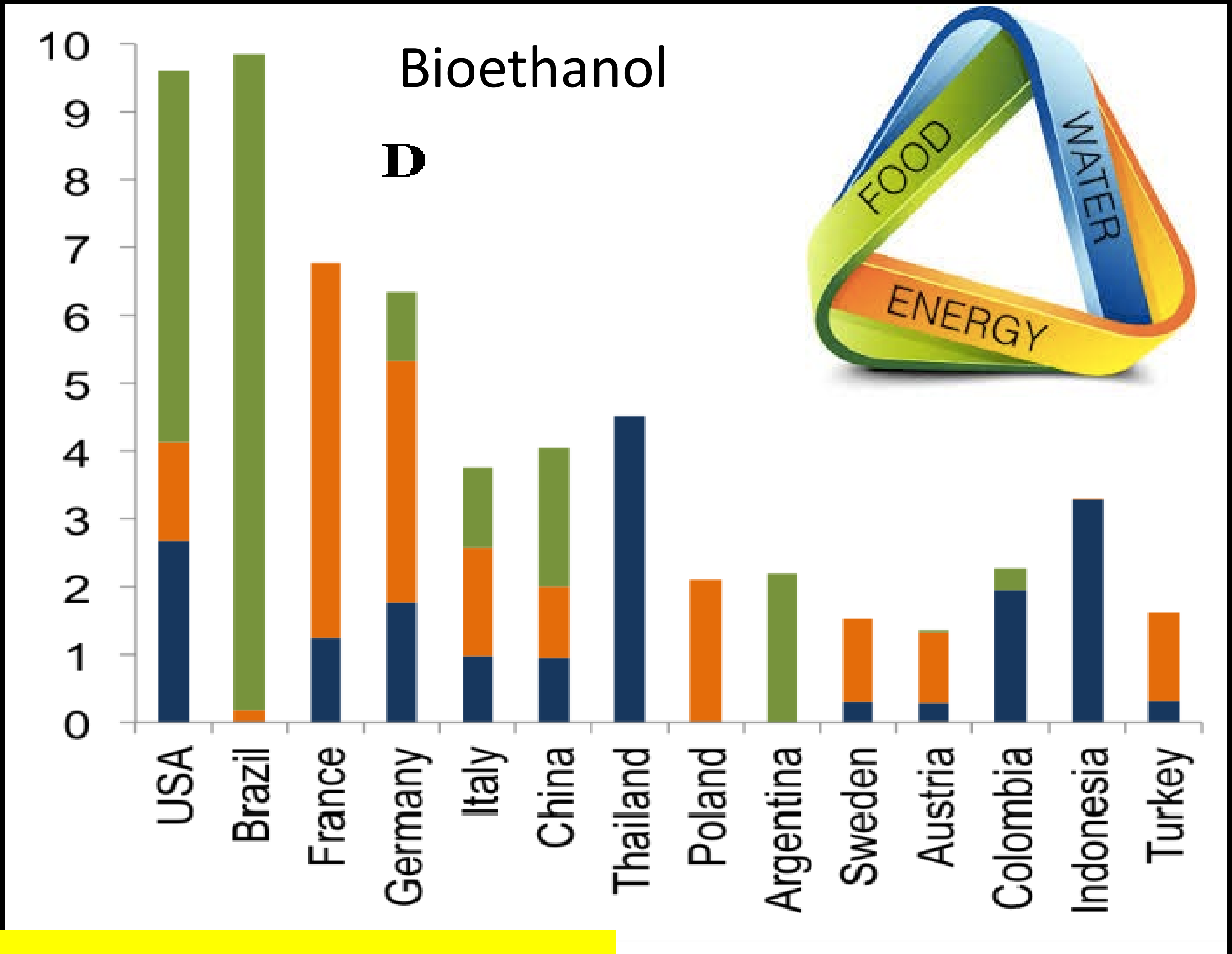
	Annual flow ($m^3\ y^{-1}$)	Source
Water Used for Biofuels	**$\approx 0.25 \times 10^{12}$**	**Rulli et al., 2016**
Groundwater Depletion	0.14×10^{12}	Konikow, 2011
Freshwater Used for Food	7×10^{12}-12×10^{12}	Mekonnen & Hoekstra 2011 Carr, D'Odorico et al., 2013

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

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

How many people could be fed?





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

Is there enough water to rely only on fuels from terrestrial biomass?

Reliance on:

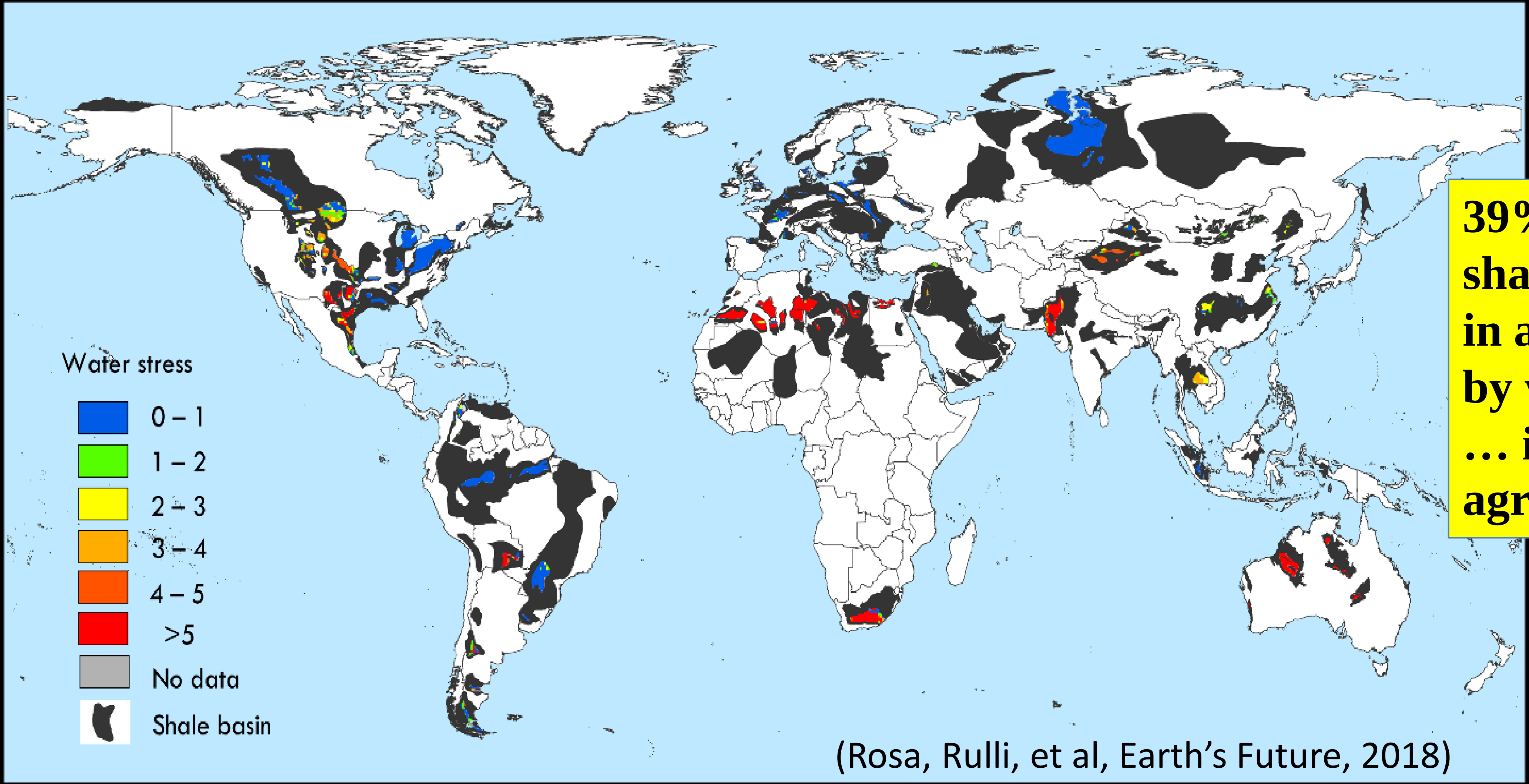
- Fossil fuels: 20% increase by 2040 (US EIA, 2016; Exxon Mob Corp. 2016)

- Unconventional fossil fuels : 25-40% increase by 2040 (US EIA, 2016; Exxon Mob Corp. 2016)

1) Oil sands/Tar Sands/Heavy Oil
2) Shale Oil
3) Shale Gas

Oil sands mining trucks and shovels. Photo courtesy: Caterpillar

Water Stress that could result from Shale Oil and Gas Extraction

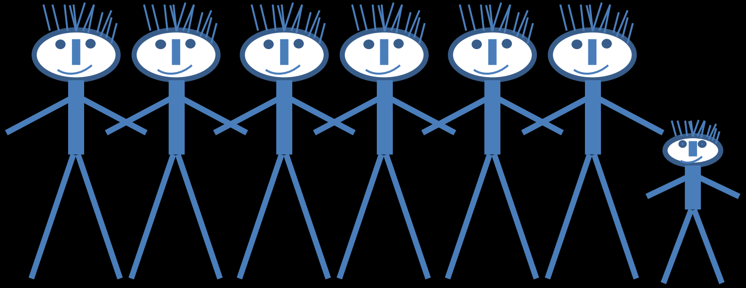


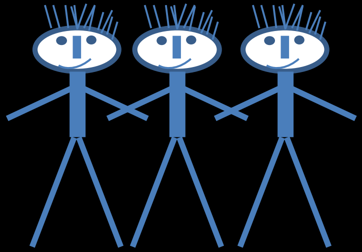
39% of world's shale deposits are in areas affected by water stress … including major agricultural areas!

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

How much water do we need for producing food?

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 much water do we need for producing food?

(From Falkenmark and Rockstrom, 2006)

- Water use for food production **4500 km^3 y^{-1}**
- To give a balanced diet to everybody & feed the additional 3 billion by 2050: **4200 km^3 y^{-1}**

… without even accounting for diet shifts & biofuels

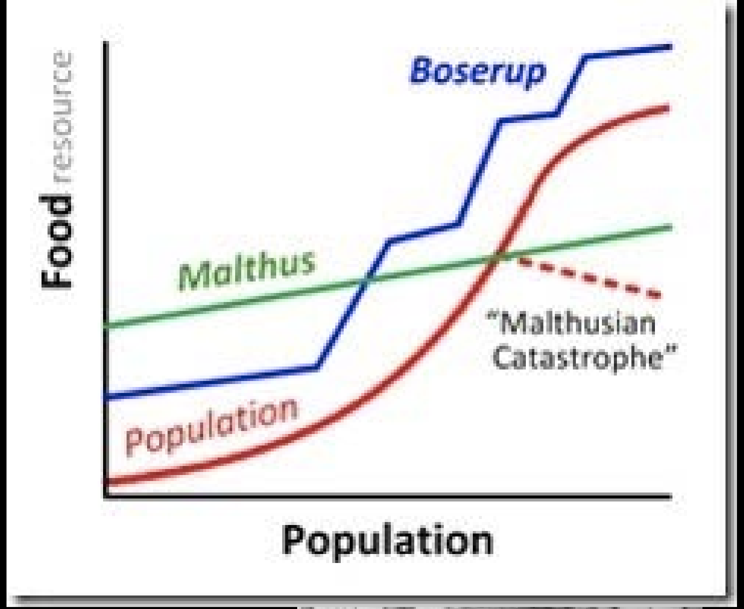
Where do we find this water?

Is the humanity about to run out of water for FOOd and ENERGY?

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

Thomas Malthus

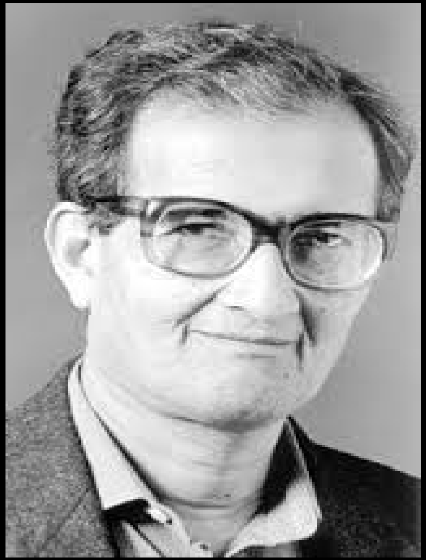
Malthus Demographic growth is faster than the increase in resources. In the long run not enough resources to feed everybody.



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

Esther Boserup

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



Amartya Sen

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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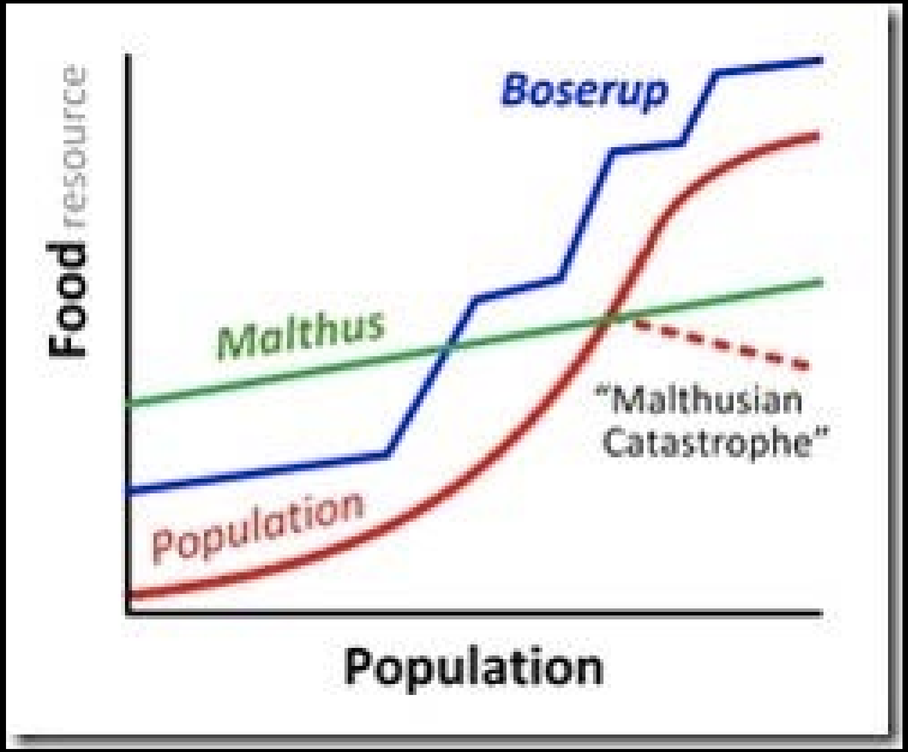
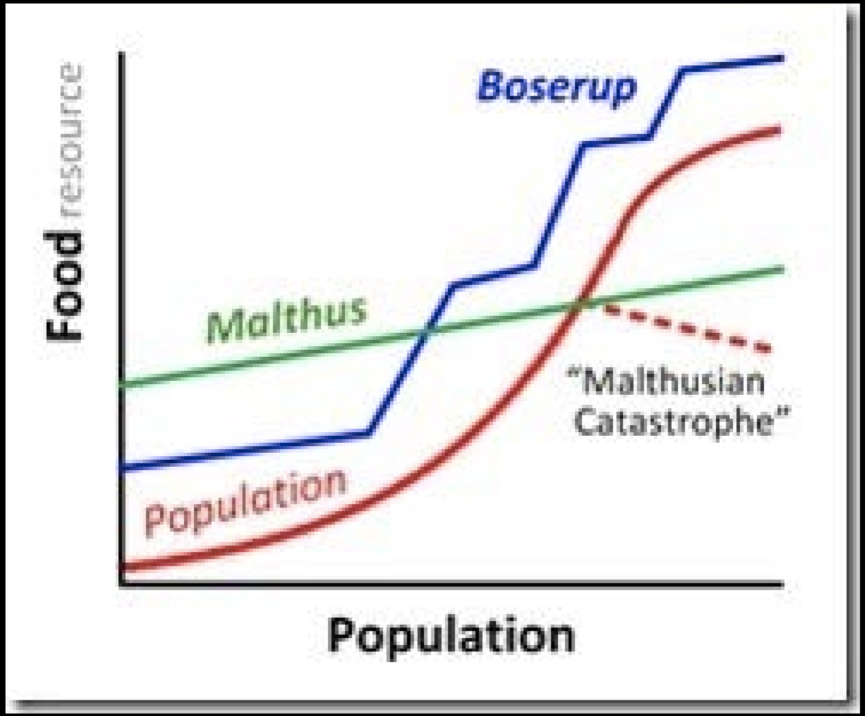
Soon, it will be difficult to meet the food & water needs of humanity (*Rosegrant, 2003; Godfray, 2010; Davis et al*., 2014)



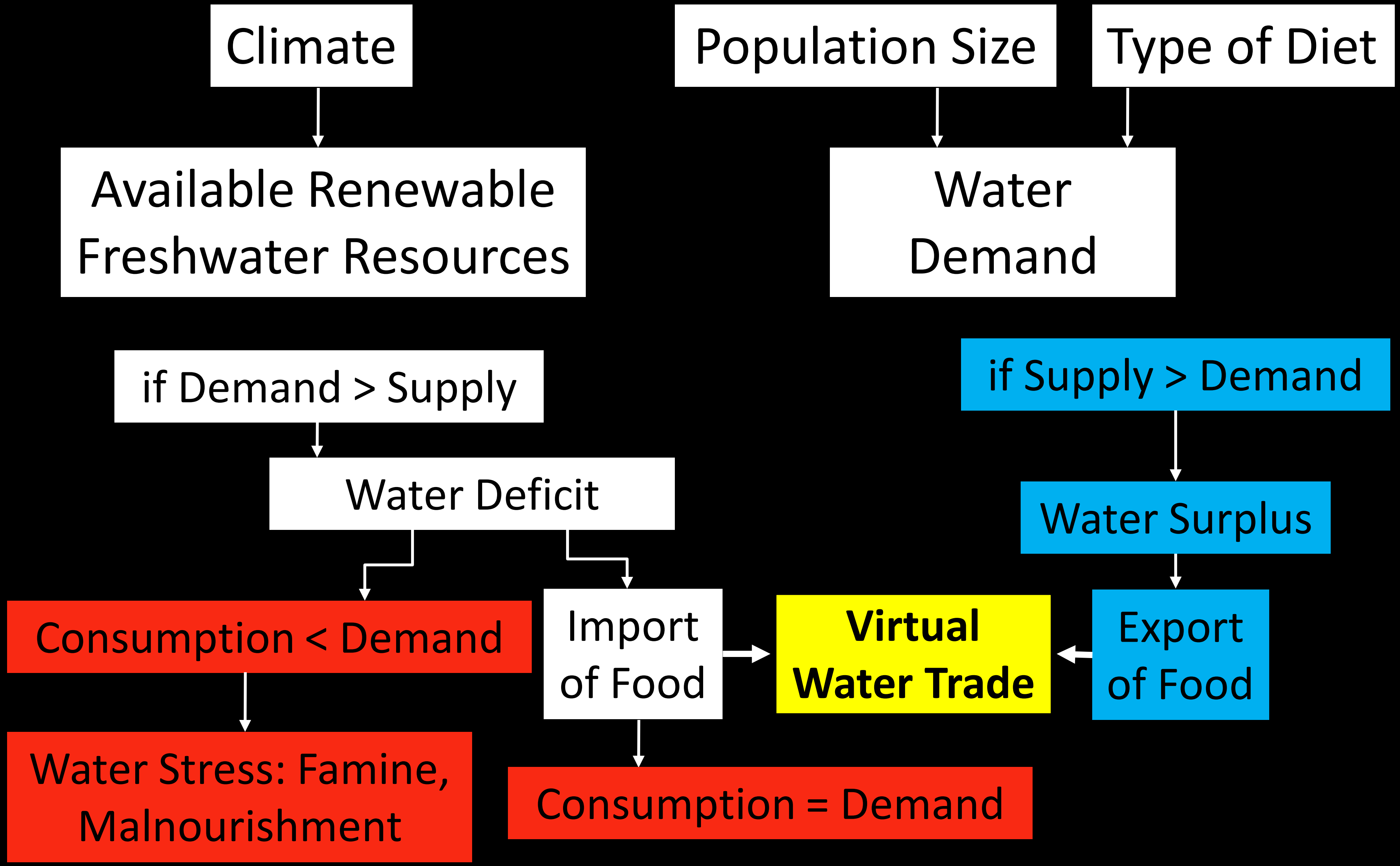
How can we meet the increasing demand of water for food?

Major innovations have increased access to water and food

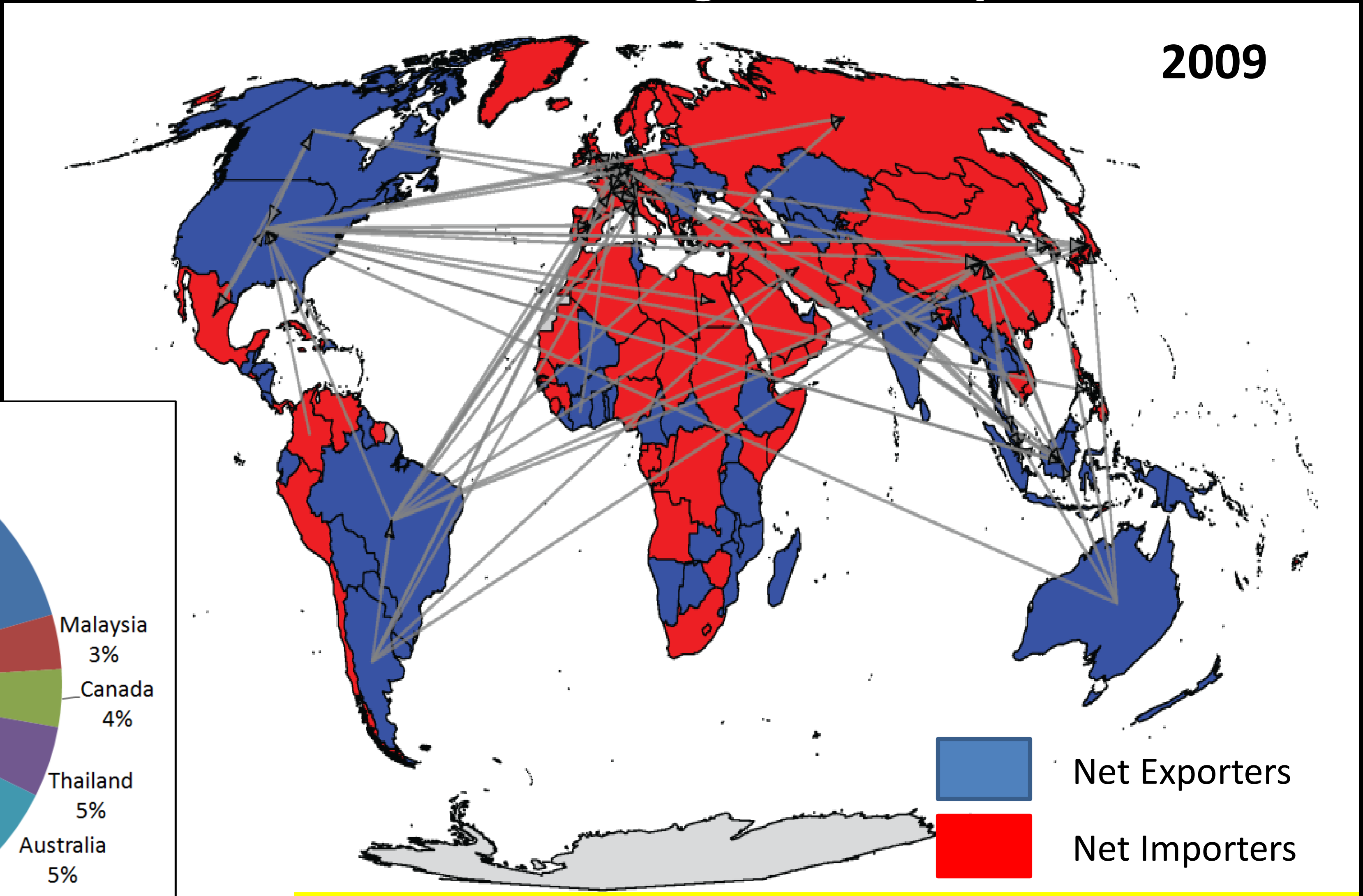
- Industrial Revolution
- Green revolution
- Global Trade of Food
- Close the Yield Gap (often through, land acquisitions in developing countries.)
- “Sustainable Intensification”

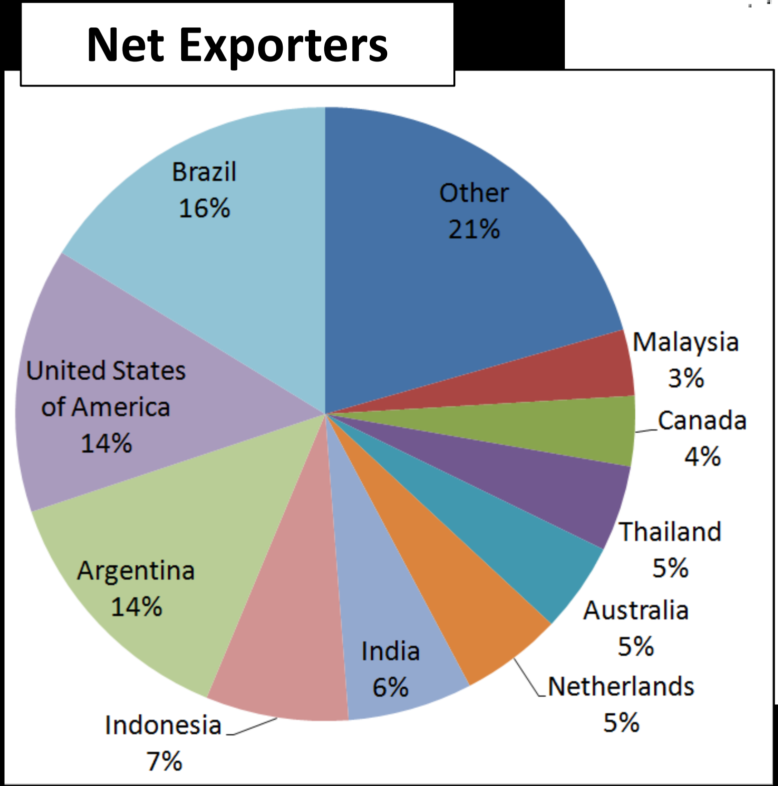


(VIRTUAL) WATER BALANCE



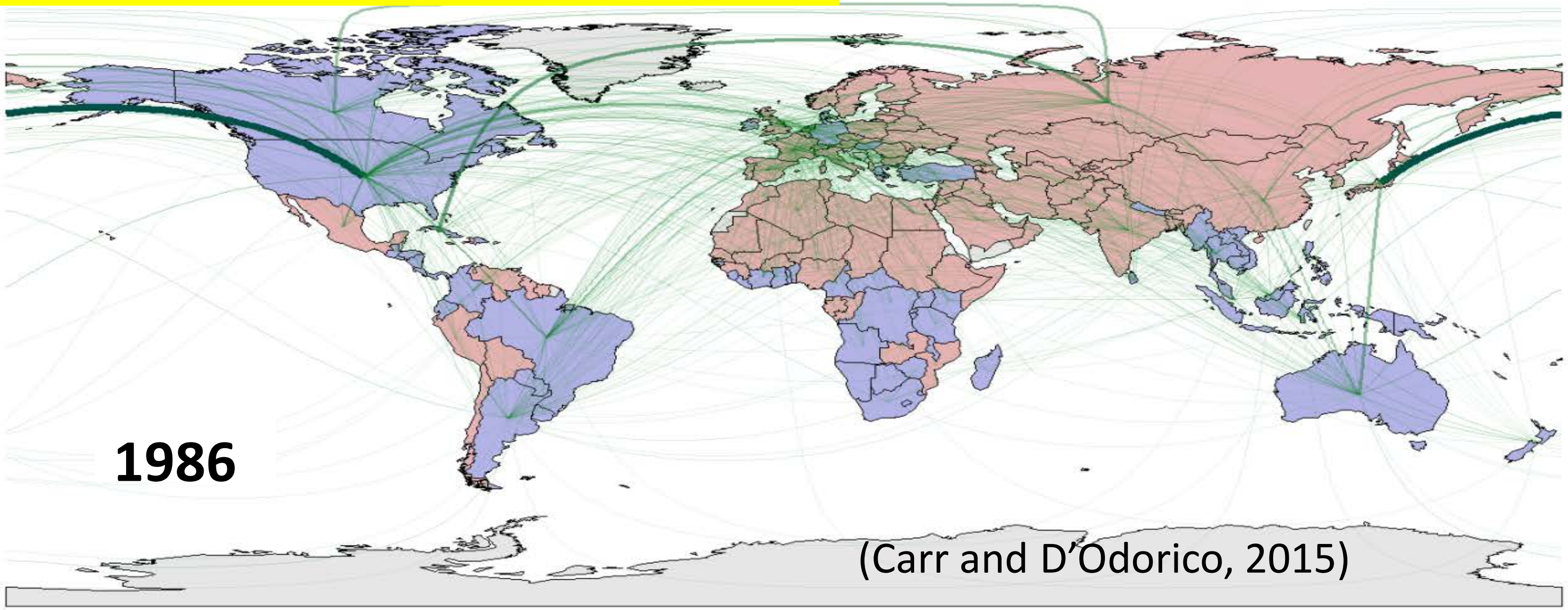
GLOBALIZATION OF WATER: “flows” of virtual water associated with the trade of agricultural products

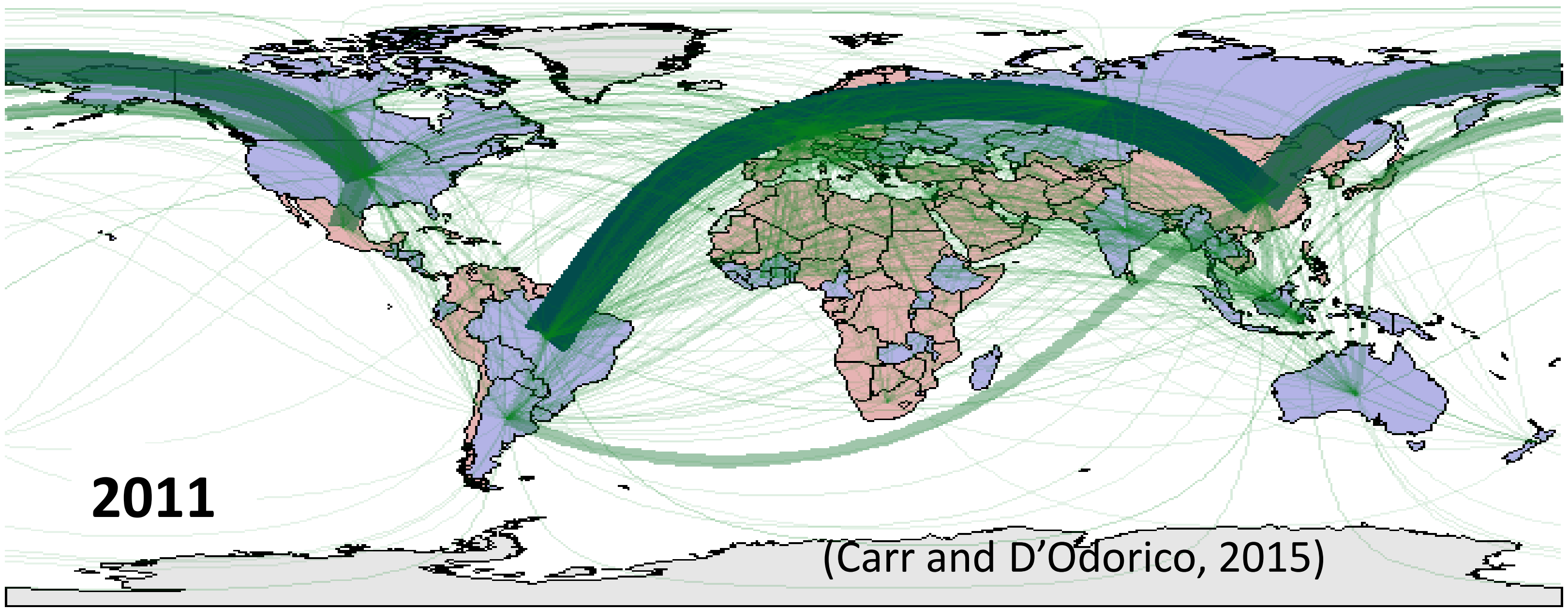




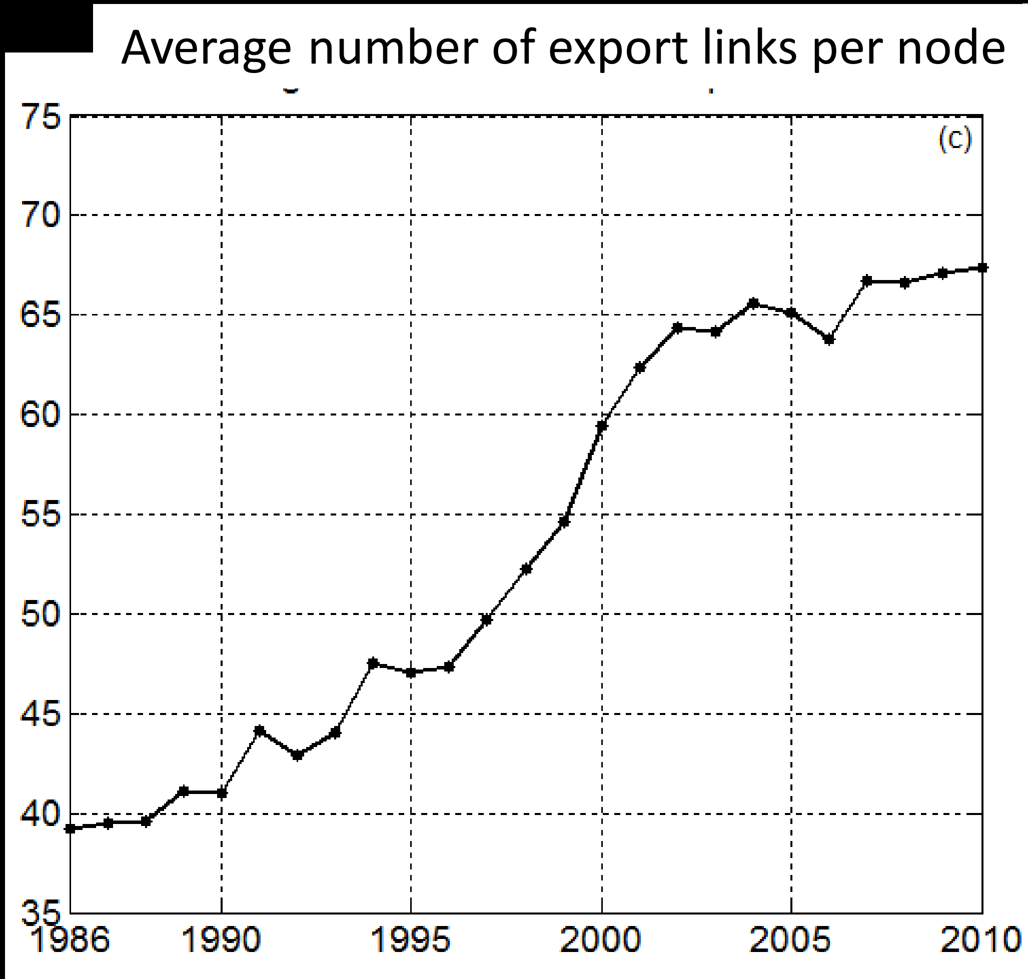
About 20-24% of the water used for food is traded internationally (Carr et al., PLoS One 2013)

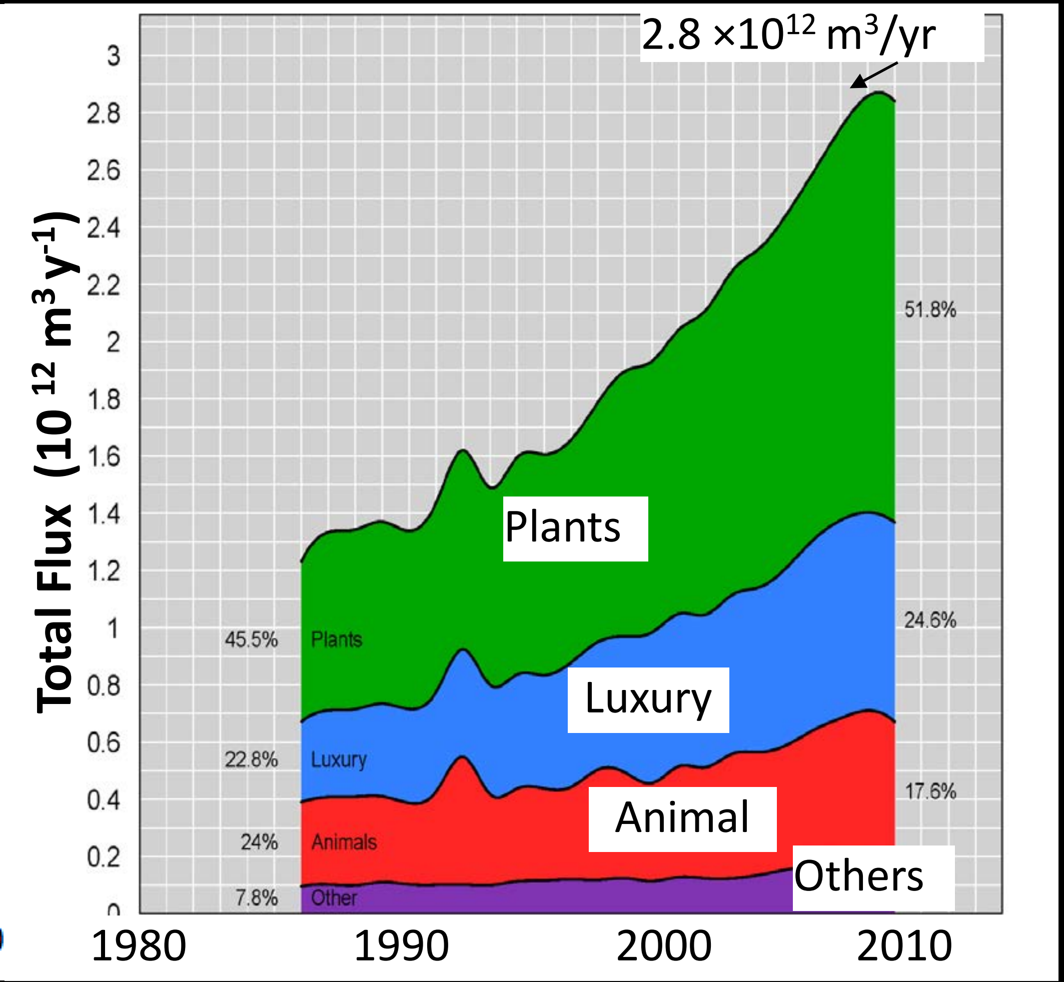
GLOBALIZATION OF WATER through trade





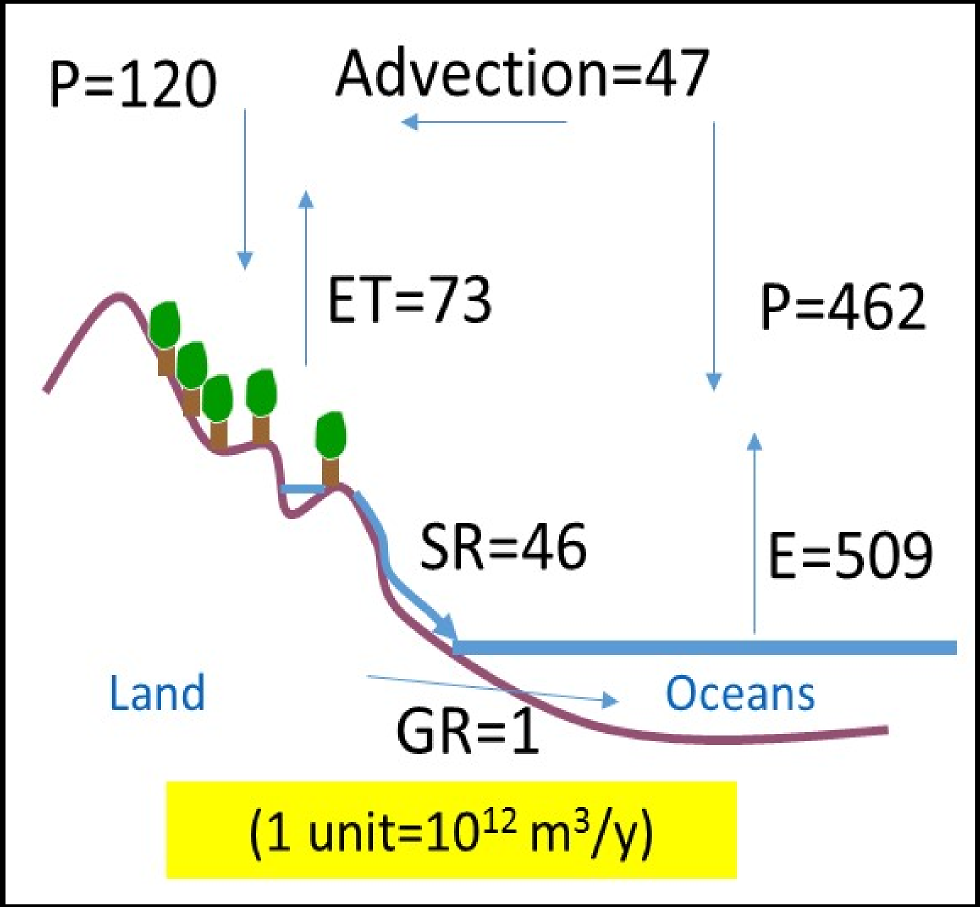
Temporal Changes in Virtual Water Trade



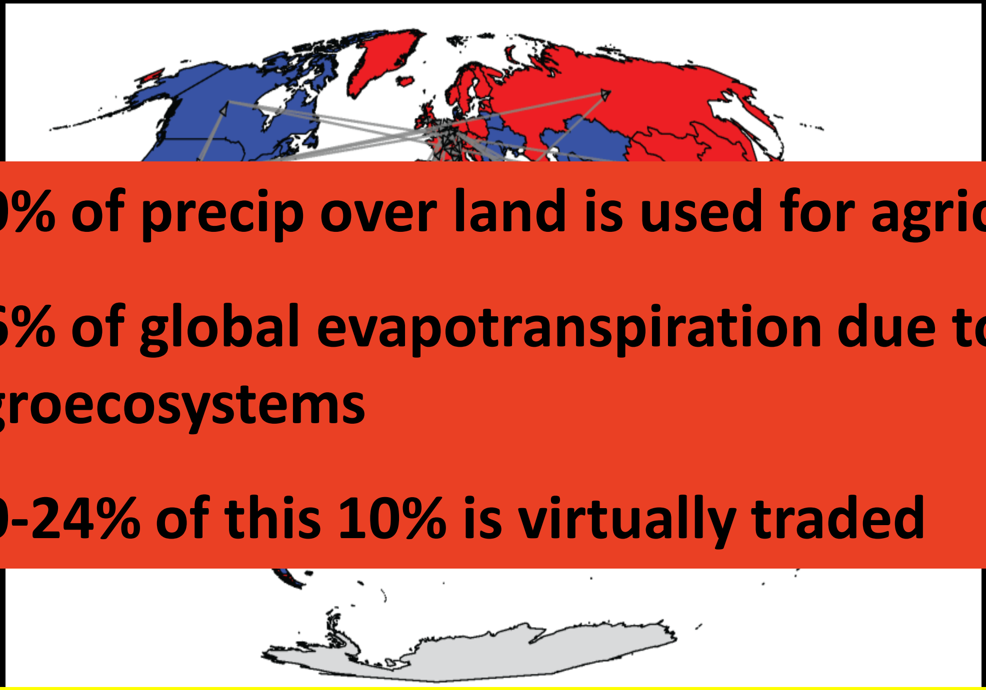


Based on FAOSTAT data: for 309 crop & animal products
(Carr et al., *GRL*, 2012; *PLOS1*,2013)

Global Water Cycle



Virtual Water Trade



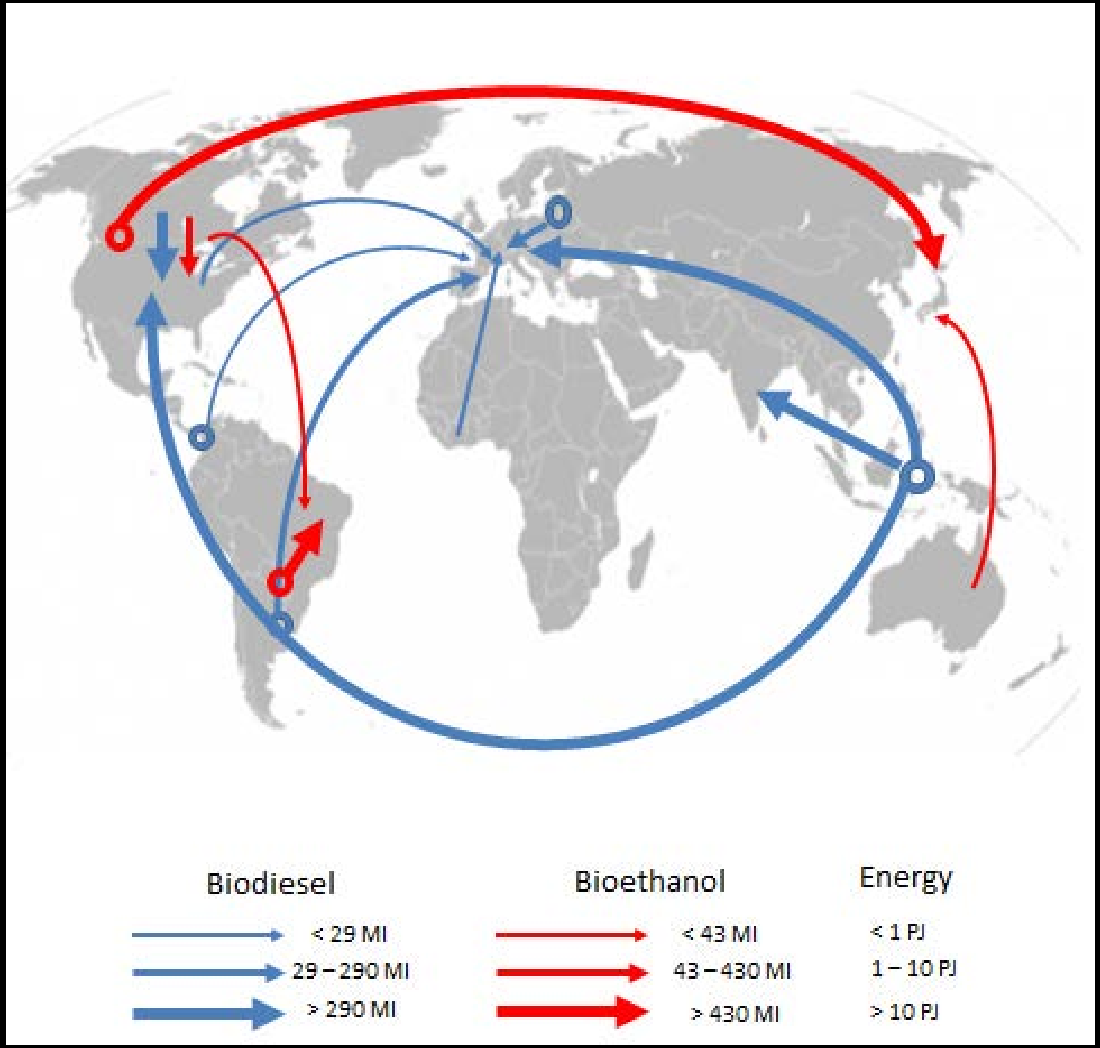
10% of precip over land is used for agriculture

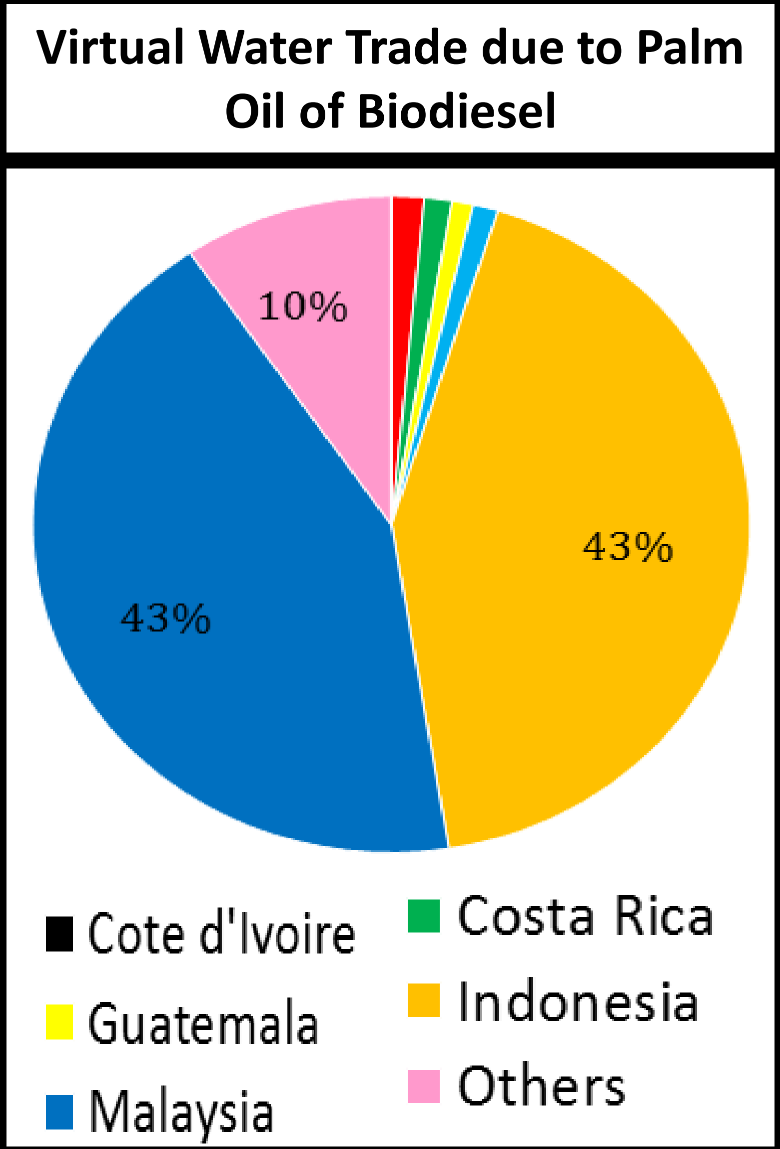
16% of global evapotranspiration due to agroecosystems

20-24% of this 10% is virtually traded

Carr et al., (GRL, 2012) : 2.8×10^{12} m^3/y

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

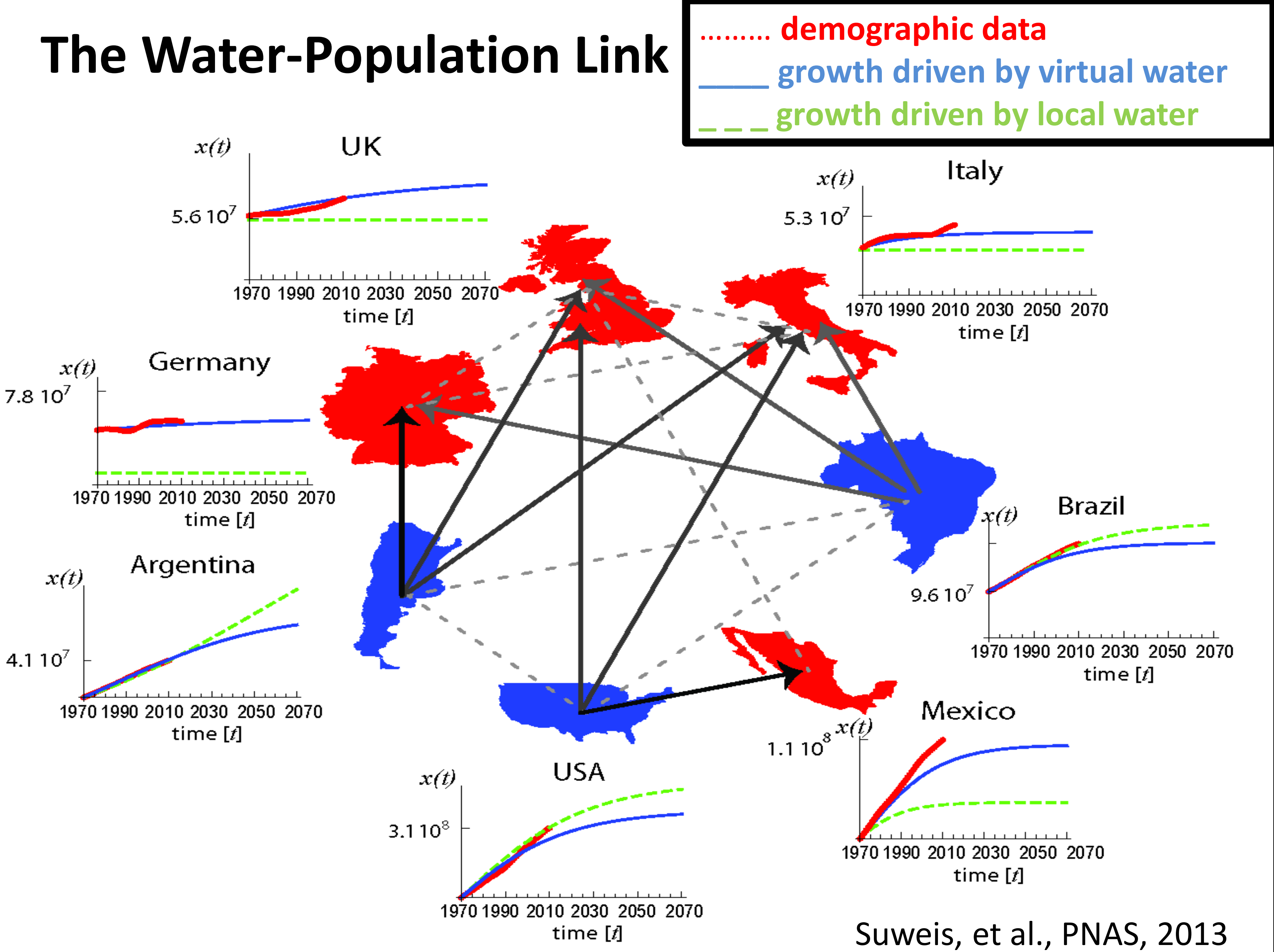
Virtual Water: A Strategic Resource

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



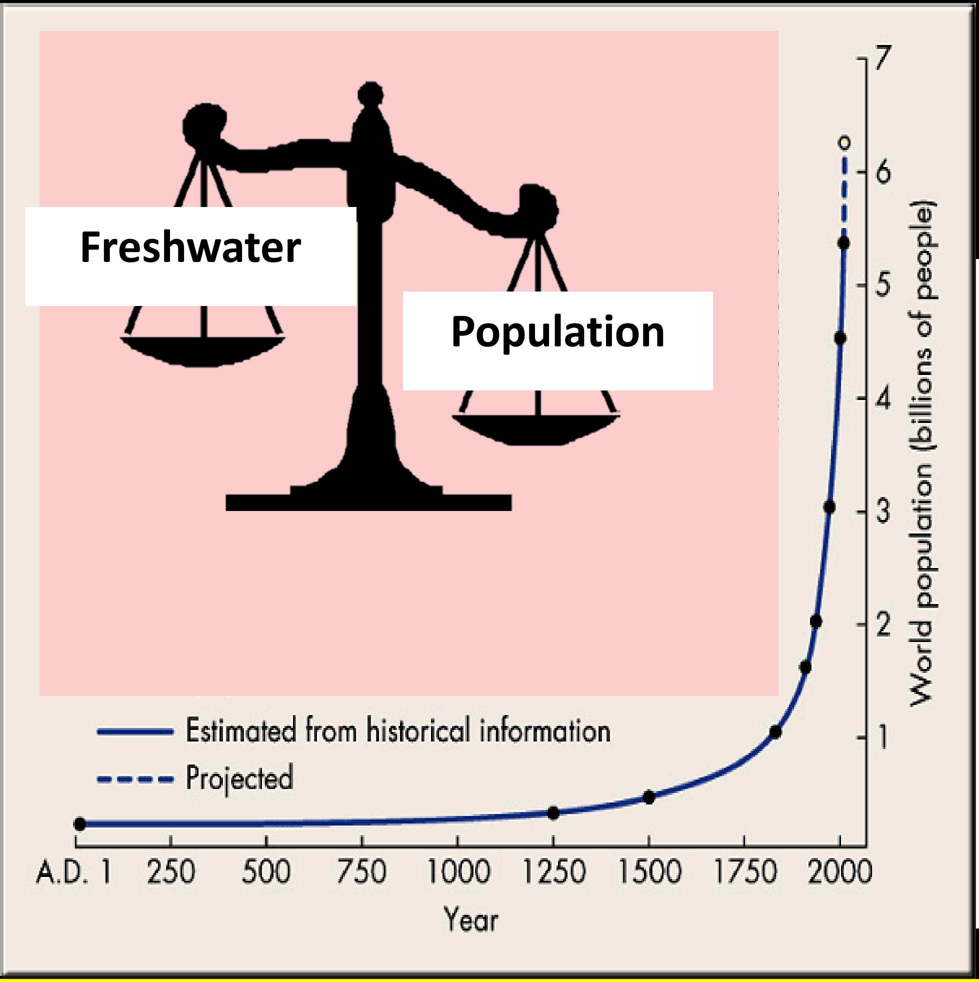
Suweis, et al., PNAS, 2013

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)

What will happen if exporting regions will have to reduce their exports … as during the 2008 food crisis → Export bans

A look at the 2008 food crisis for learning from the recent past what the reactions can be…

Driver of 2008 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

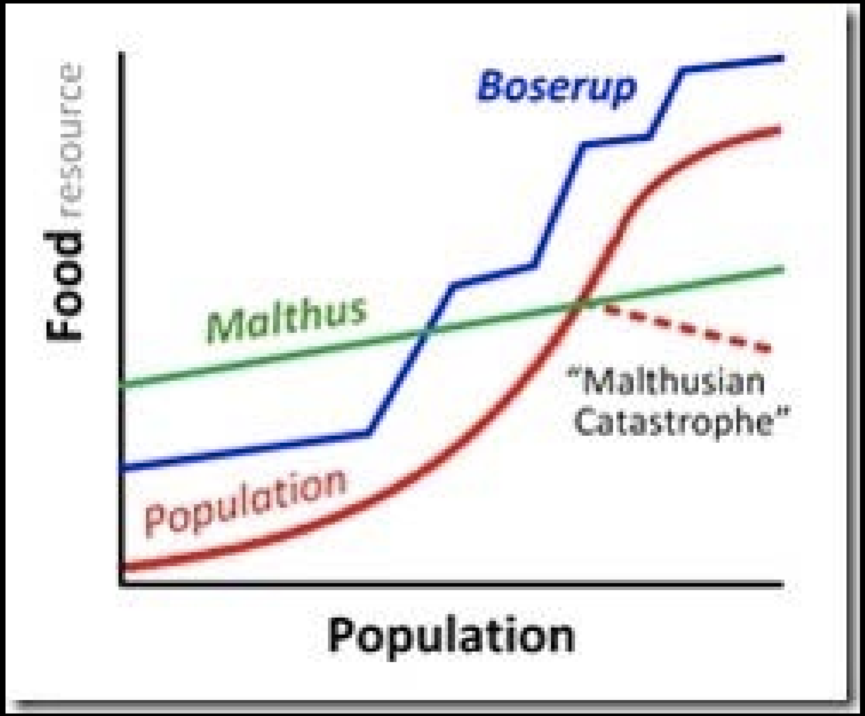
Effects:

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"



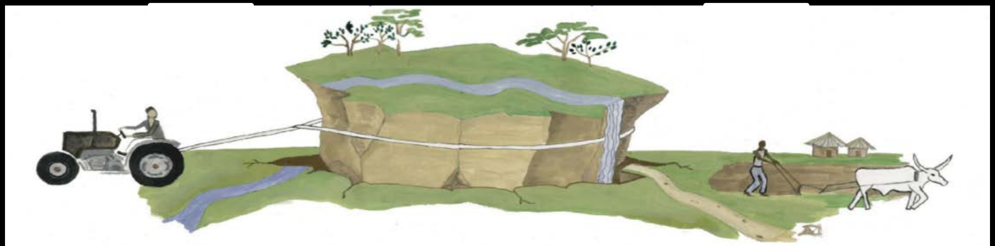
NATURE GEOSCIENCE | VOL 6 | JUNE 2013 | www.nature.com/naturegeoscience

The fourth food revolution

Paolo D'Odorico and Maria Cristina Rulli

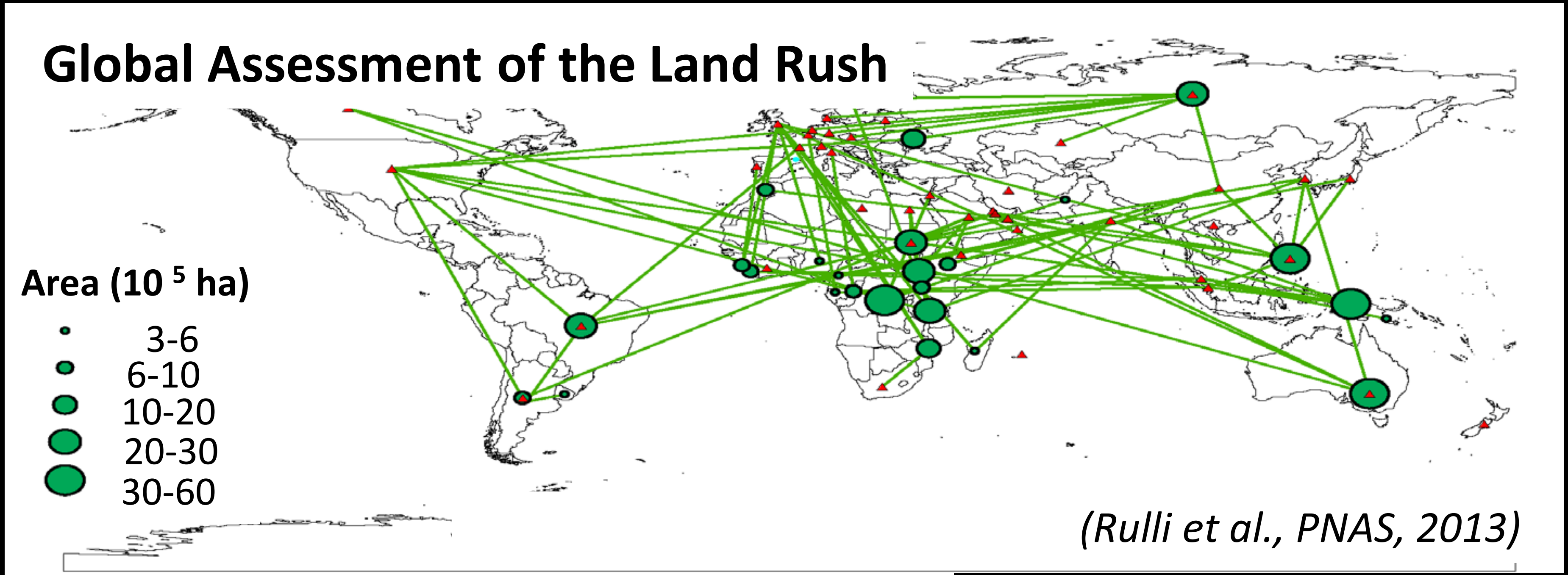
In areas of the developing world that have benefited only marginally from the intensification of agriculture, foreign investments can enhance productivity. This could represent a step towards greater food security, but only if we ensure that malnourished people in the host countries benefit.

Need for **secure access** to food → More **Direct** Control of natural resources



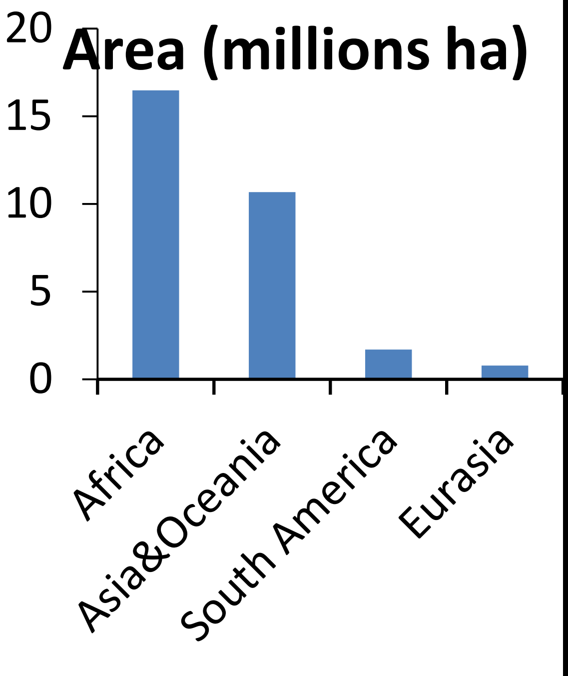
Land (and Water) Rush

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



Data from The Land Matrix and GRAIN, 2012

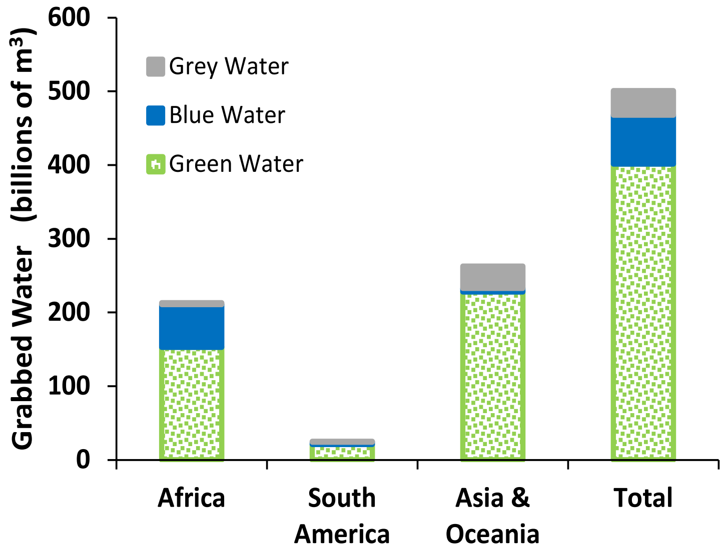
- >48 million ha
- Total area > Italy
- 4 x Portugal

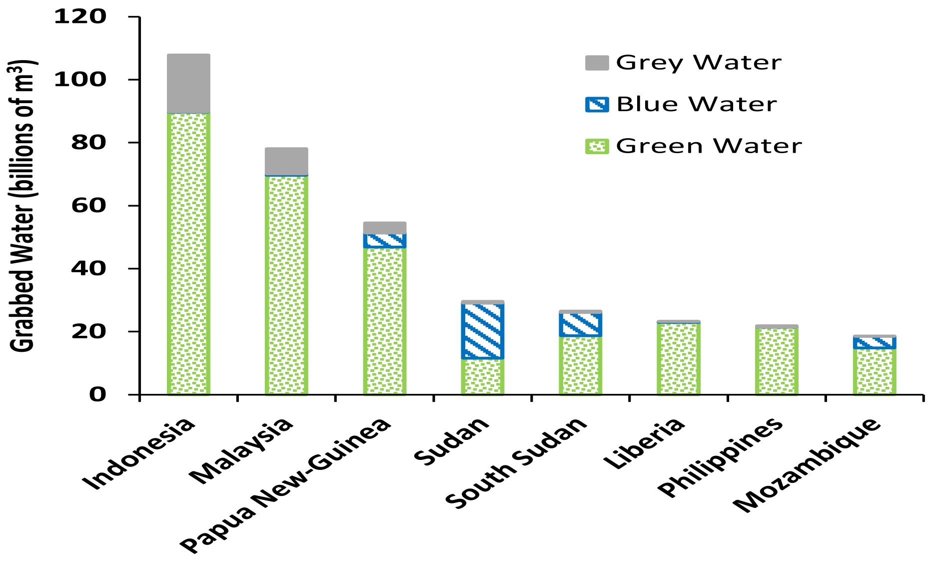


Need for **secure access** to food → More **Direct** Control of natural resources

Water needed for LSLAs cultivation

(Source: Monte Wolverton, Cagle Cartoons)



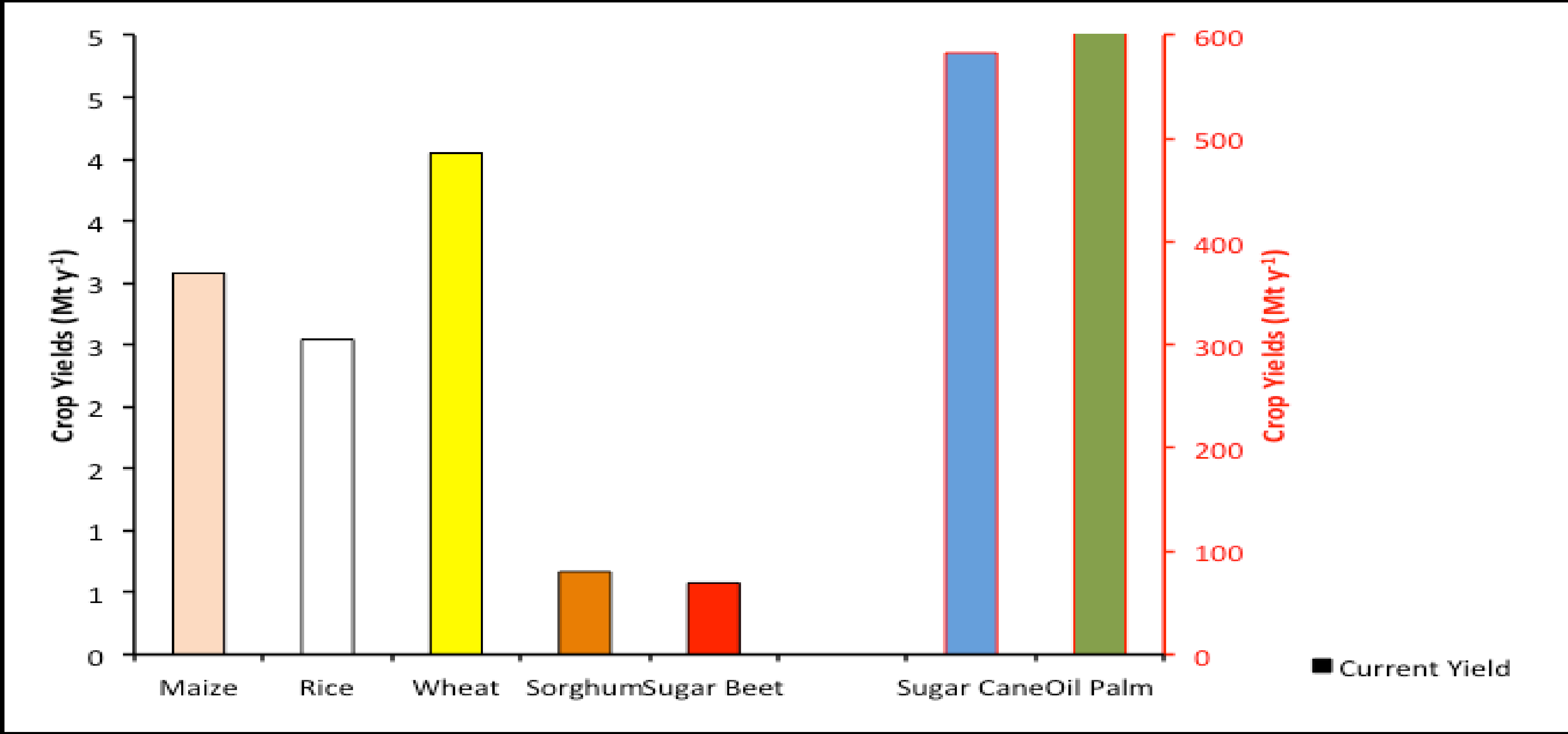


[*Rulli et al. PNAS* (2013); *Rulli and D'Odorico, GRL, 2013*]

	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	$\approx 0.25 \times 10^{12}$ (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

Need for **secure access** to food → More **Direct** Control of natural resources

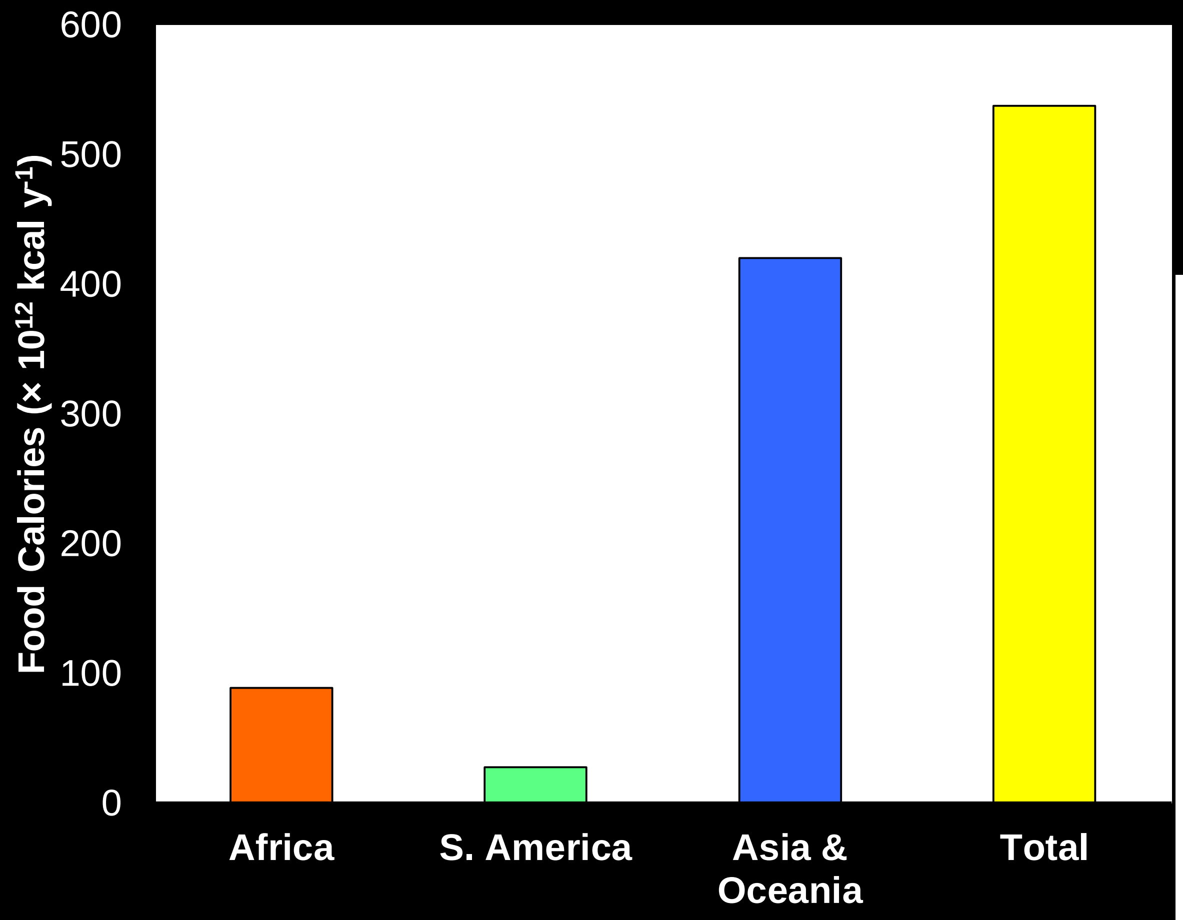
Direct food production



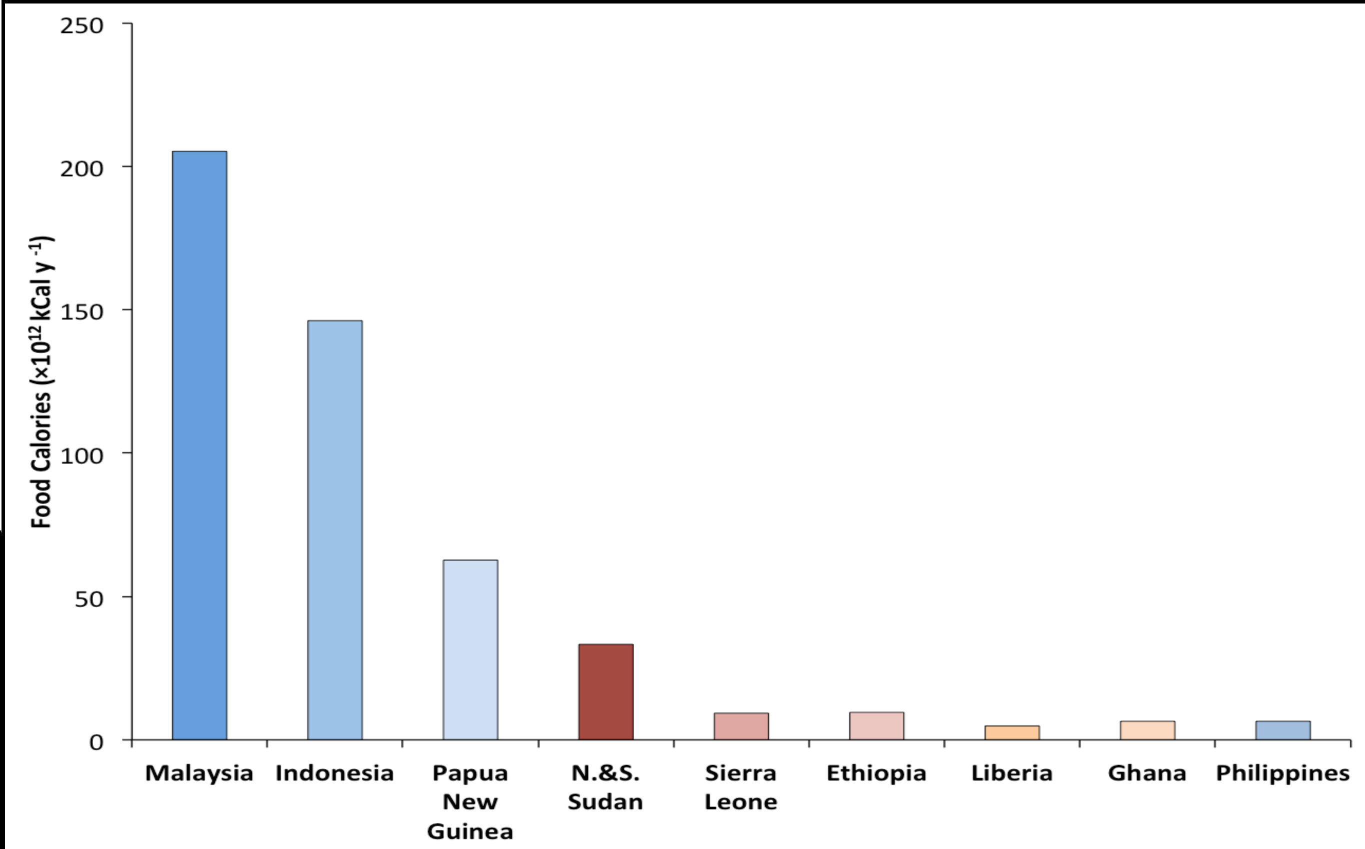
Expected rates of crop production for some of the major crops planted in grabbed farmland worldwide. (Calculations are based on land deals data as reported by Land Matrix 2013 dataset, accessed on 20 June 2013).

Need for **secure access** to food → More **Direct** Control of natural resources

Direct food production

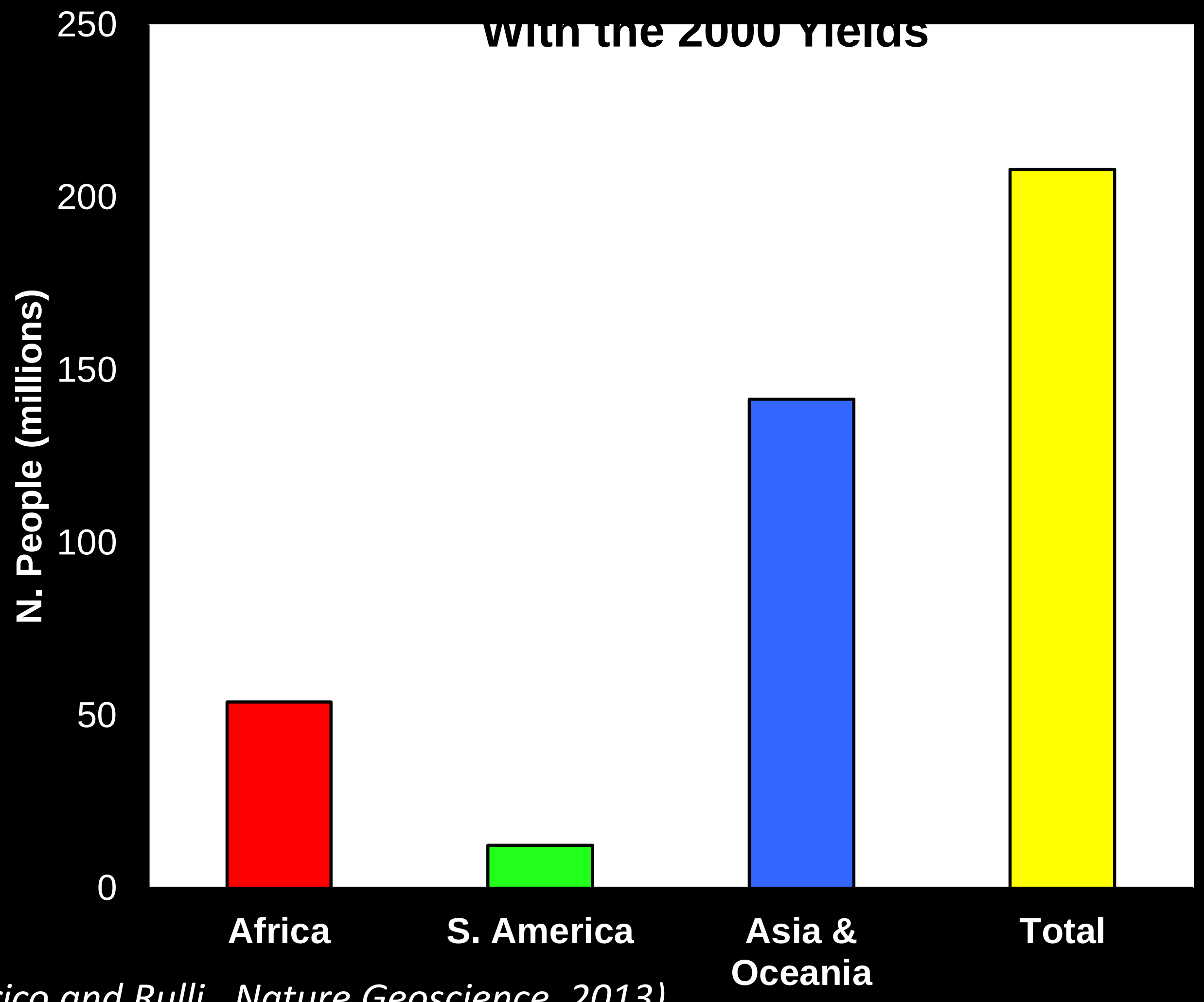


Amount of food calories that can be produced by the grabbed lands. by continent (A). (B) for a few selected countries. (Calculations are based on land deals data as reported by Land Matrix 2013 dataset, accessed on 20 June 2013).



Need for **secure access** to food → More **Direct** Control of natural resources

Direct food production



(D'Odorico and Rulli , Nature Geoscience, 2013)

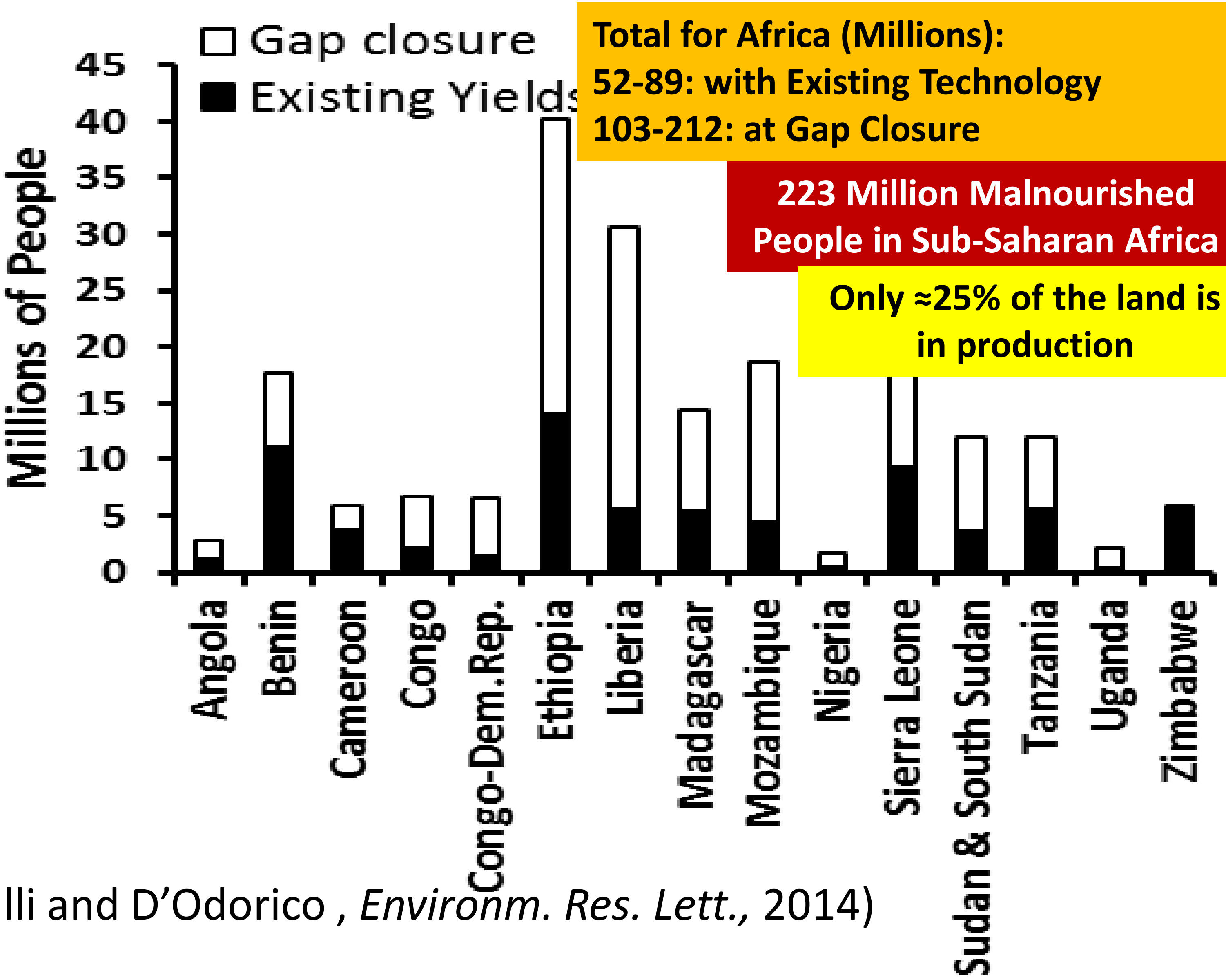
Number of people who could be fed by the grabbed land in the case of "balanced diet", assuming a 50% biofuel use for oil palm and sugarcane. (Calculations are based on land deals data as reported by Land Matrix 2013 dataset, accessed on 20 June 2013).

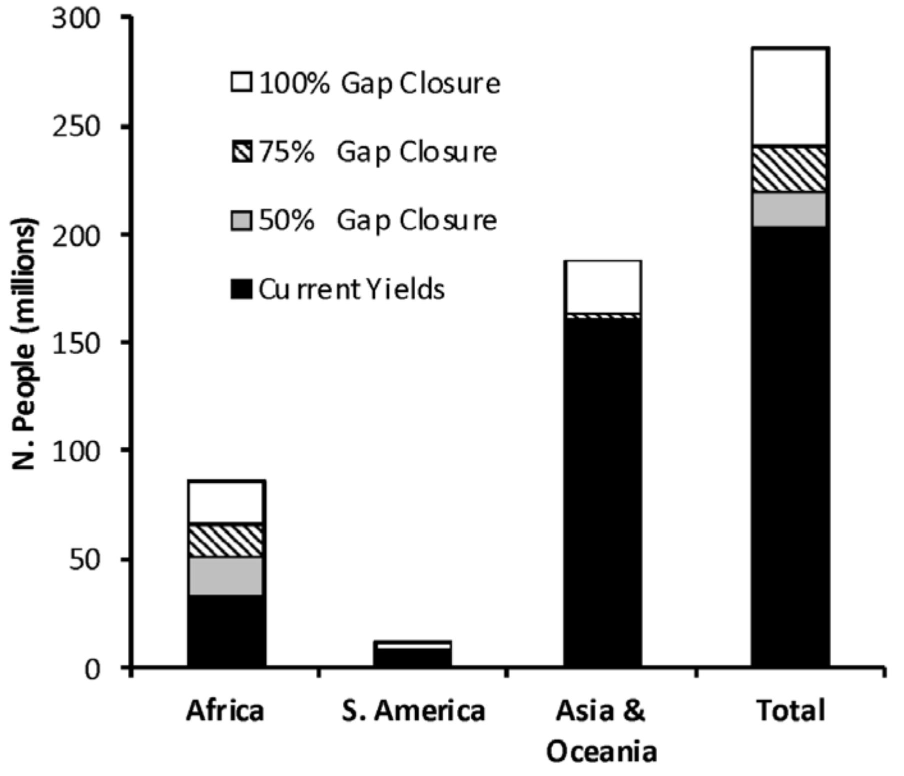
How many People Could be Fed?

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

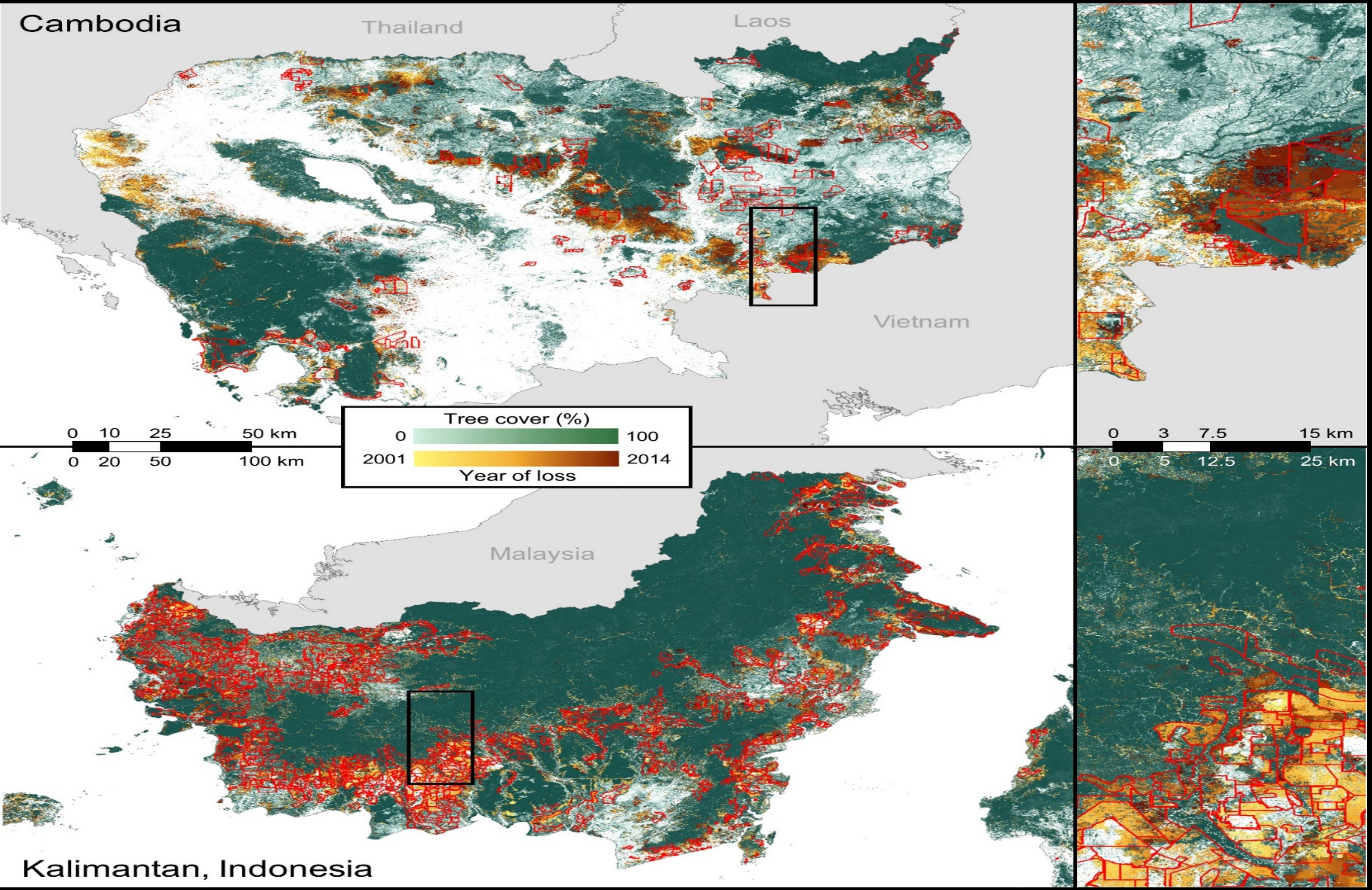


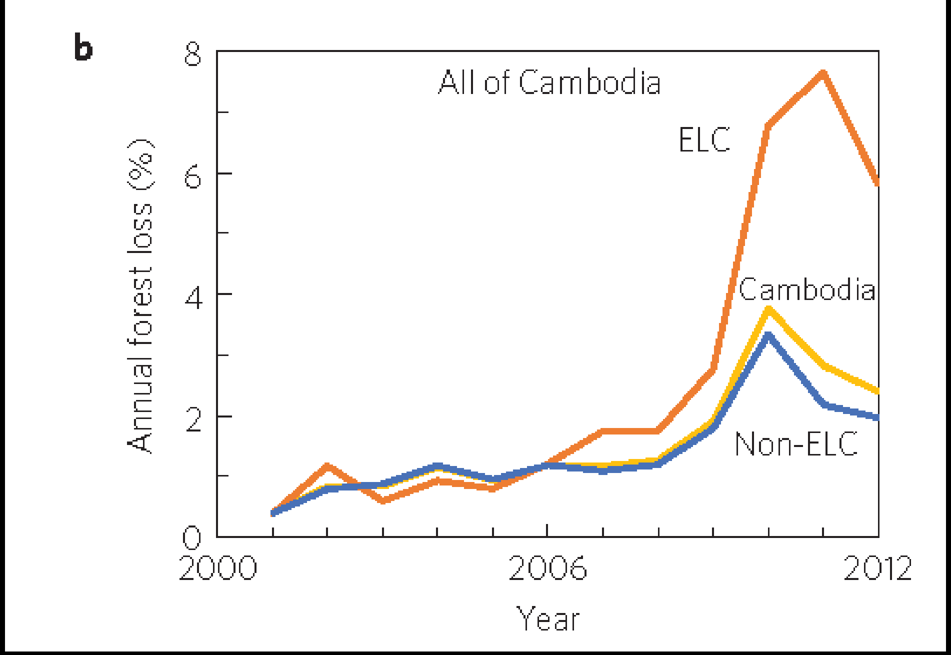


(Rulli and D'Odorico , *Environm. Res. Lett.*, 2014)

Need for **secure access** to food → More **Direct** Control of natural resources

Deforestation for LSLAs cultivation





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

Controversial issues:
Development opportunities or loss of rural livelihoods?

- Increase yields → Agricultural Intensification
- … but the land is often not used for production → no real development
- Dispossession of local communities → Loss of Rural Livelihoods
- Counterargument: the land was "unused"→ Agricultural Extensification

Questions:

- **How much more food can be produced at gap closure?**
- **Prior land use? Evidence of Deforestation?**
- **What's the role of water?**

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

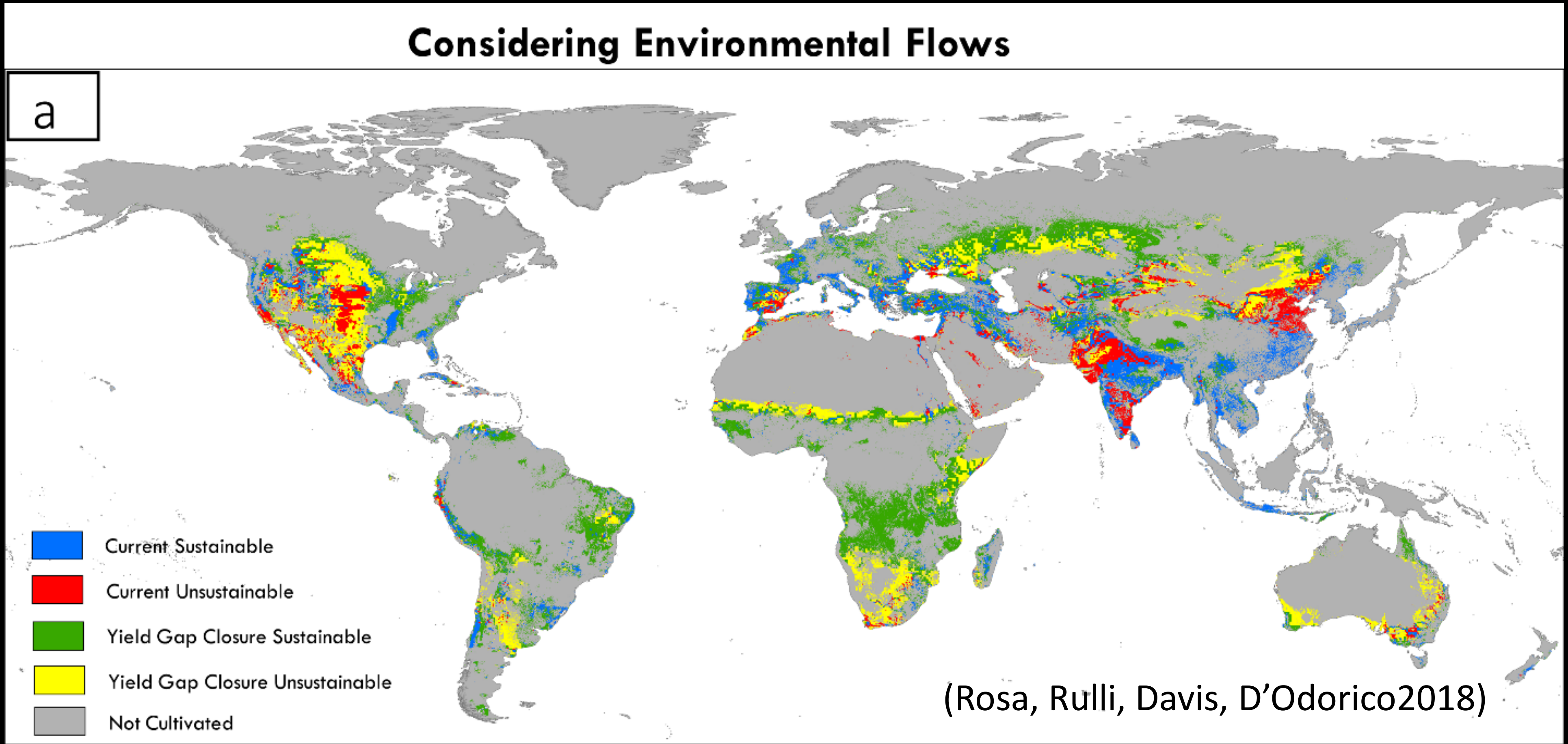
↓

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)

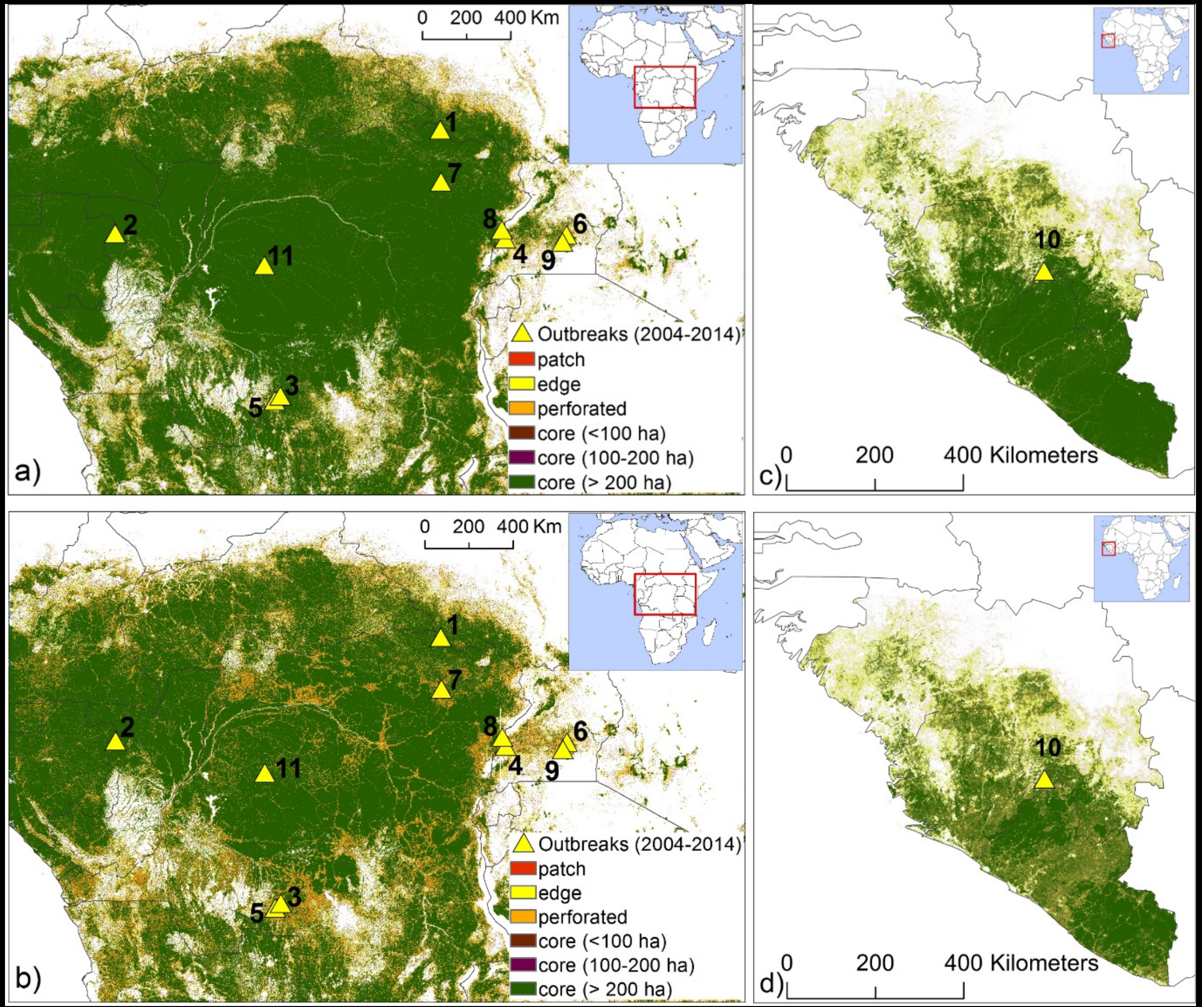
But, is there enough water to close the yield gap?



(Rosa, Rulli, Davis, D'Odorico2018)

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)

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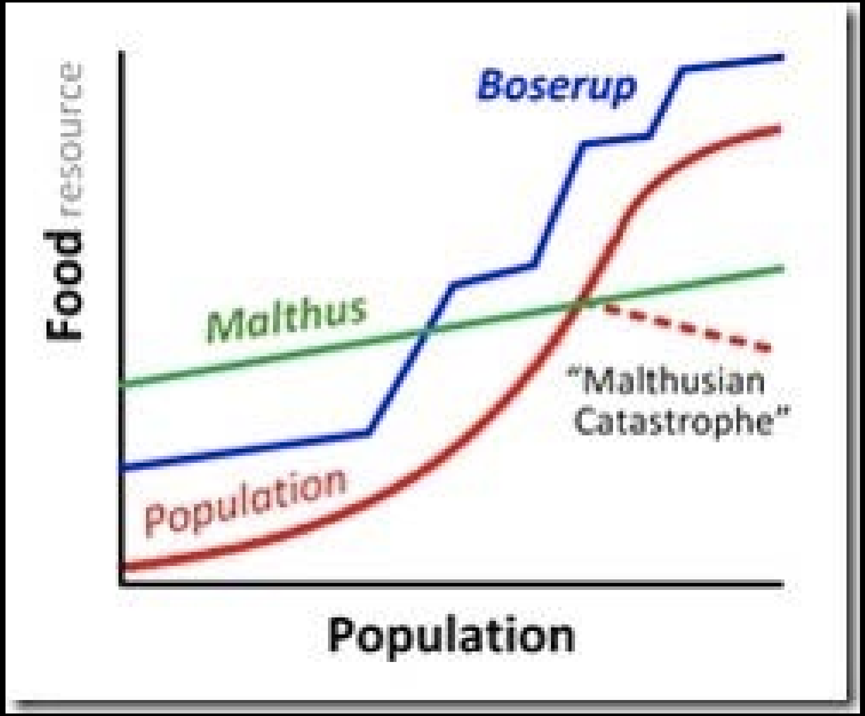

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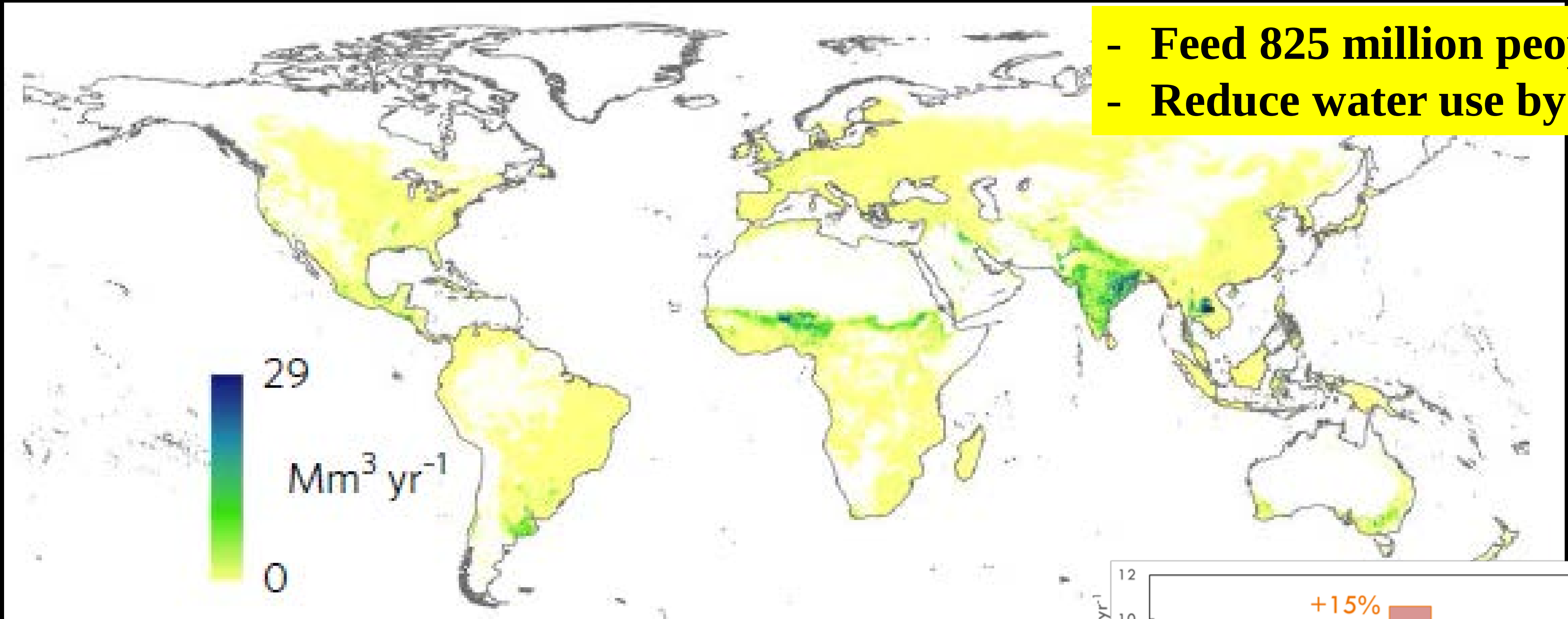
Improve Efficiency
Adopt More Suitable Crops

↓

Potentially increase production without requiring more land, more water

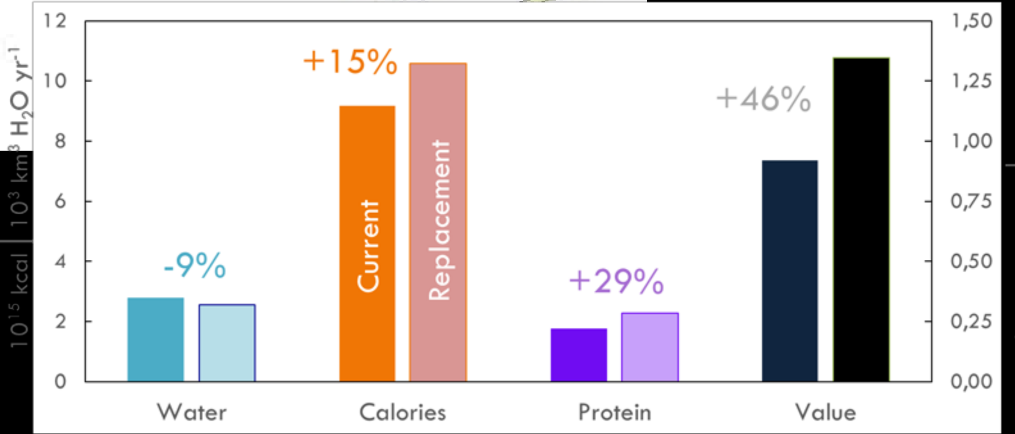
More efficient distribution of crops



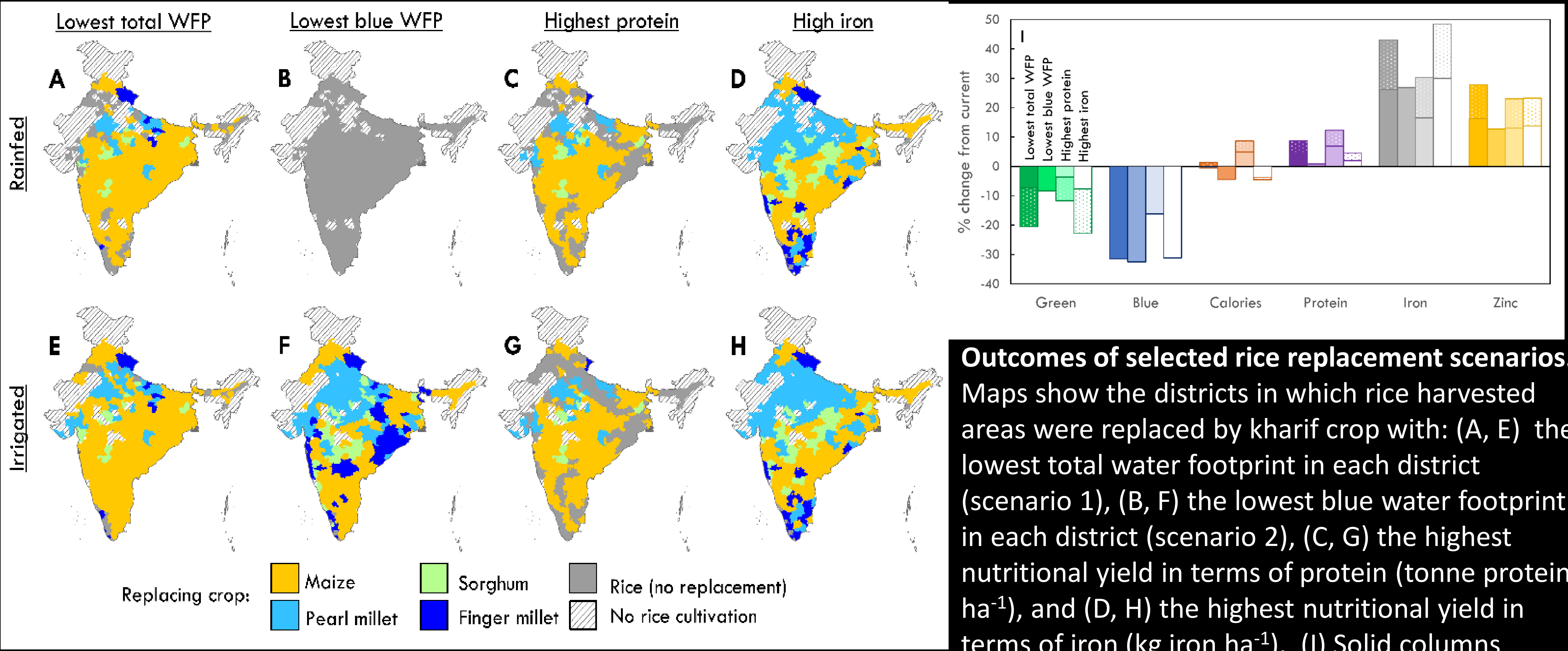
- Feed 825 million people more
- Reduce water use by 10%

(Davis, Rulli, Seveso, 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)



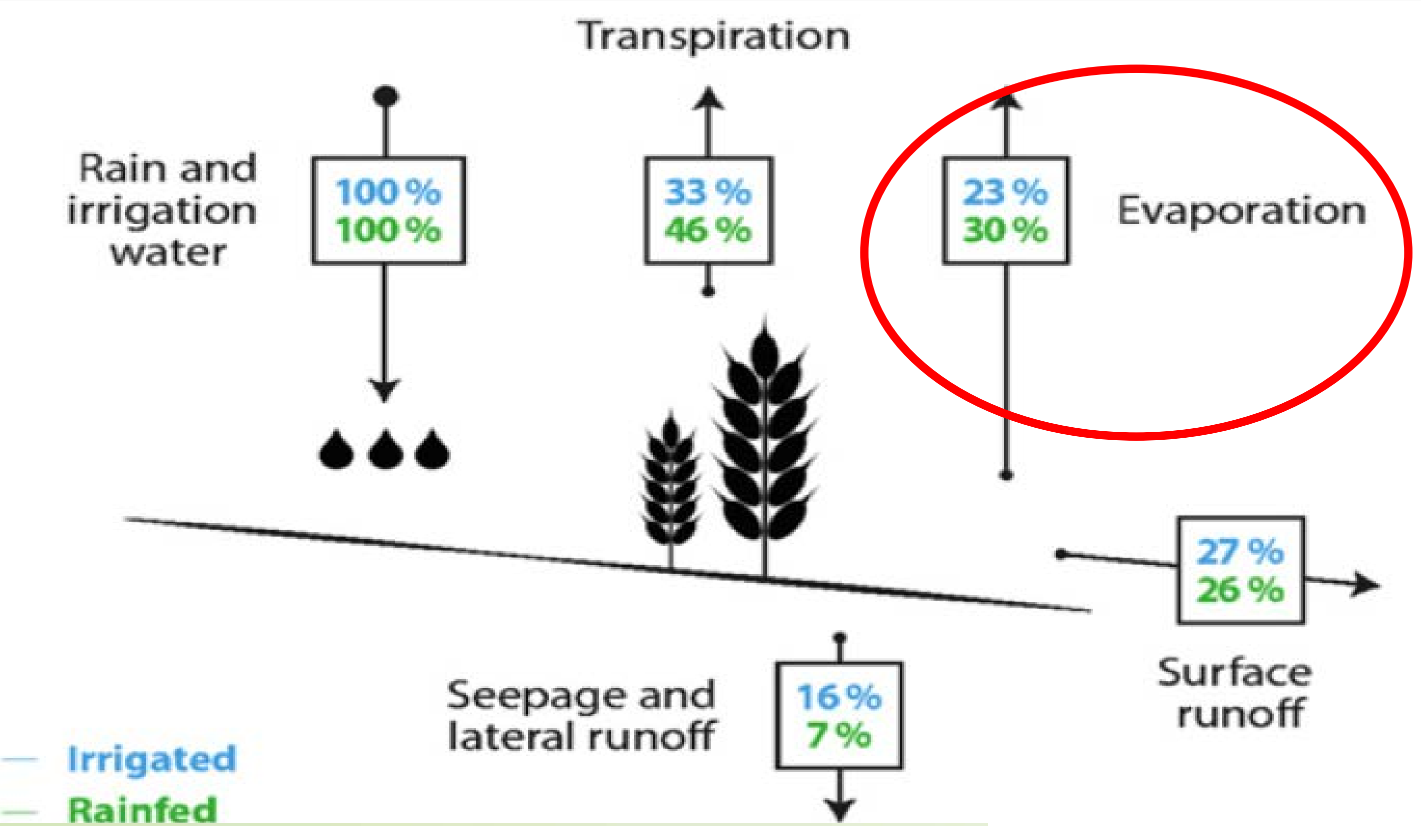
Davis, Rulli et al., Science adv, 2018

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

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

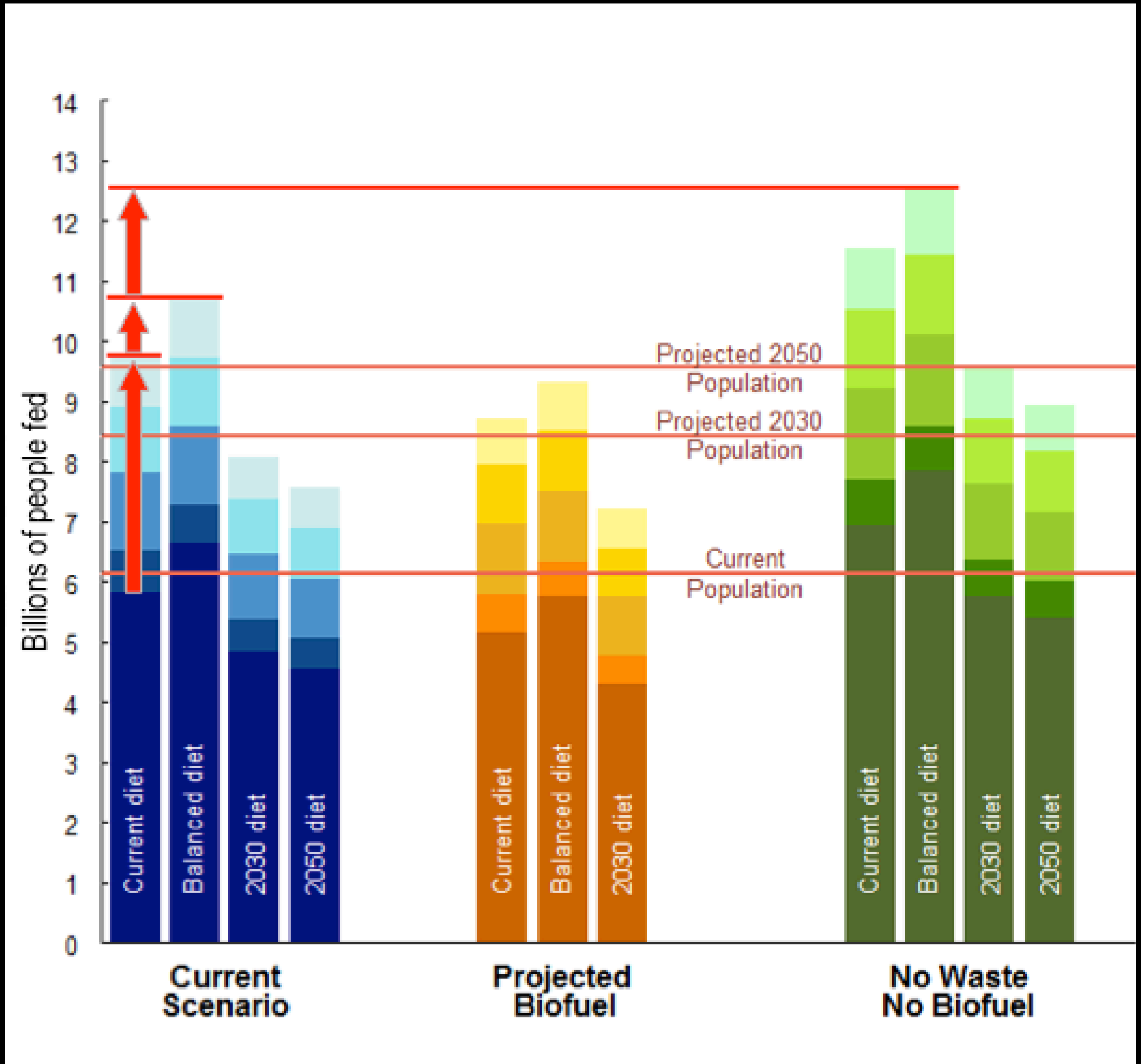
- Soil water management
- Change crop distribution
- Changes in diets
- Reduce food waste

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

Take back message

- ***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*

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Lorenzo Rosa


Kyle Davis


Jampel Dell’Angelo