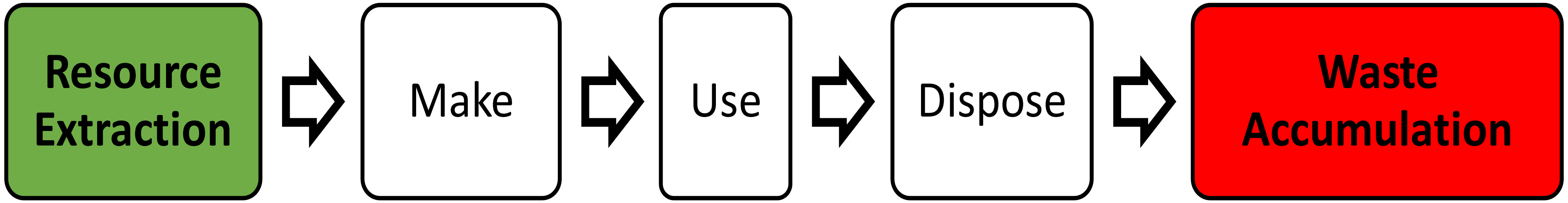
Ripensare Circolare - La gestione sostenibile delle risorse idriche

Paolo D'Odorico,
Department of Environmental Science, Policy, and Management
University of California, Berkeley

In collaborazione con:

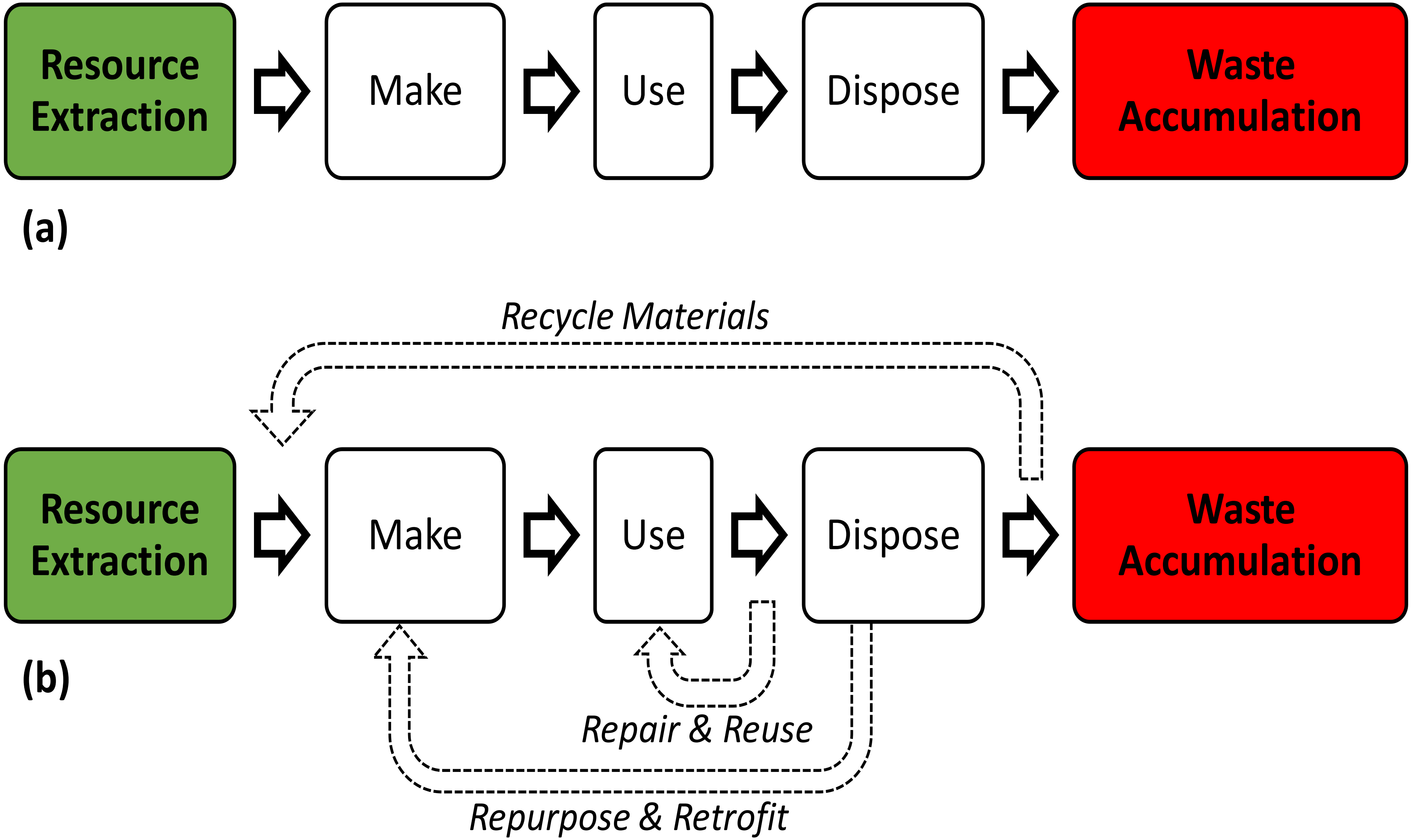
- Maria Cristina Rulli, Politecnico di Milano
- Davide Chiarelli, Politecnico di Milano
- Kyle Davis, University of Delaware
- Lorenzo Rosa, ETHZ
- Luca Ridolfi, Politecnico di Torino
- Francesco Laio. Politecnico di Torino

“Classic” *linear* consumption pattern

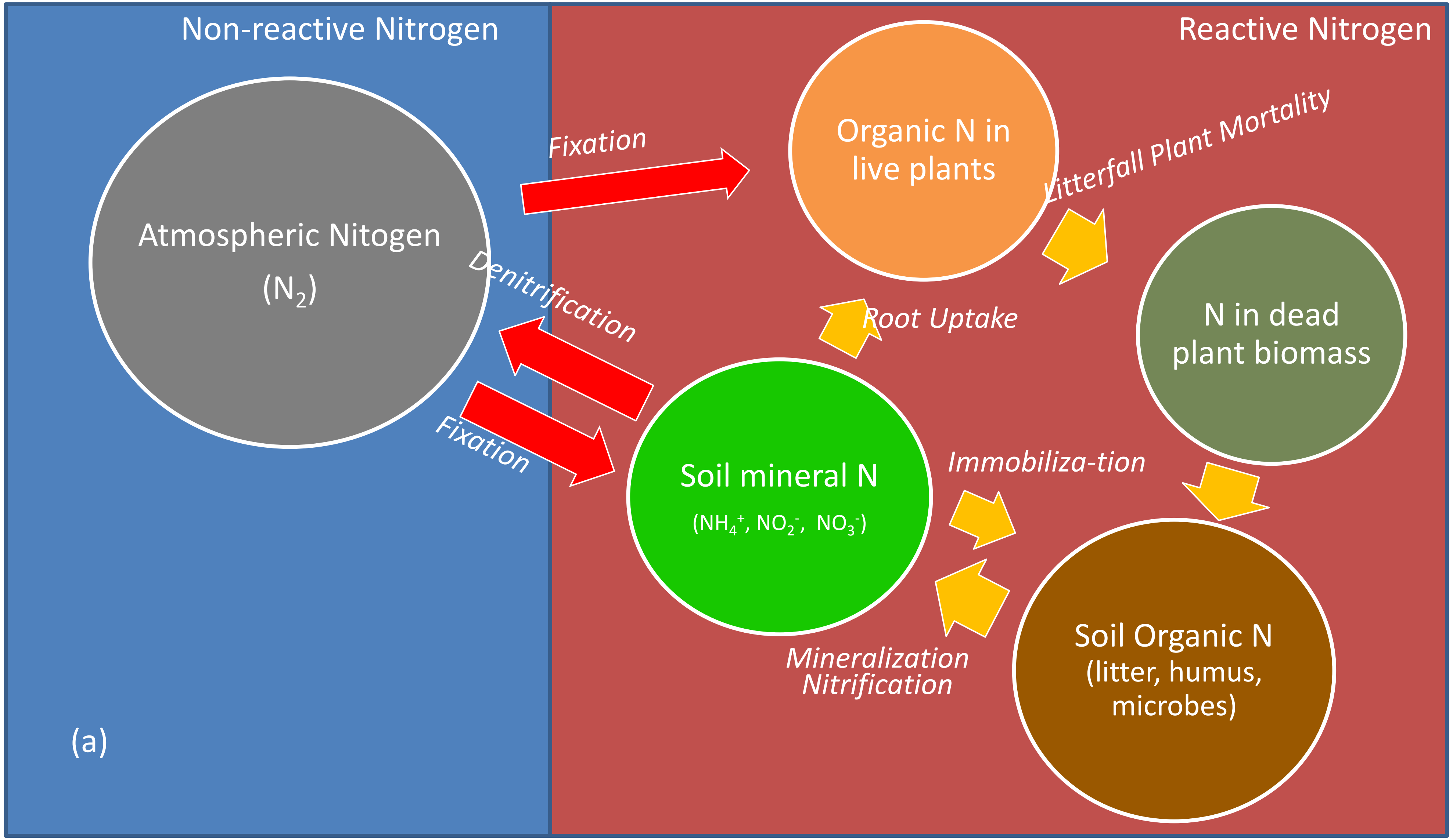


(a)

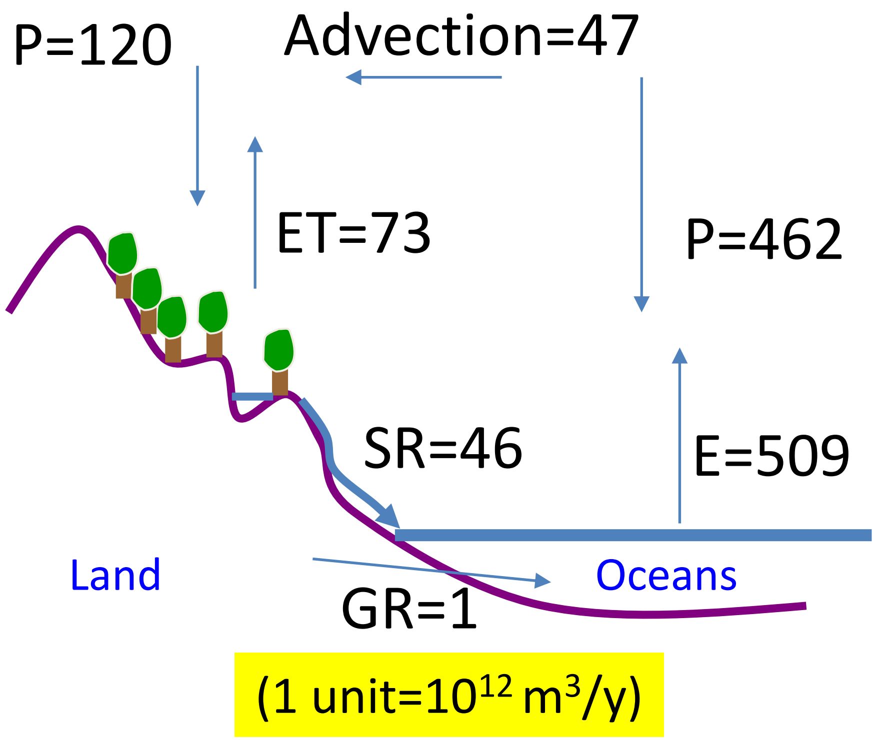
Circular Economy of Production Systems



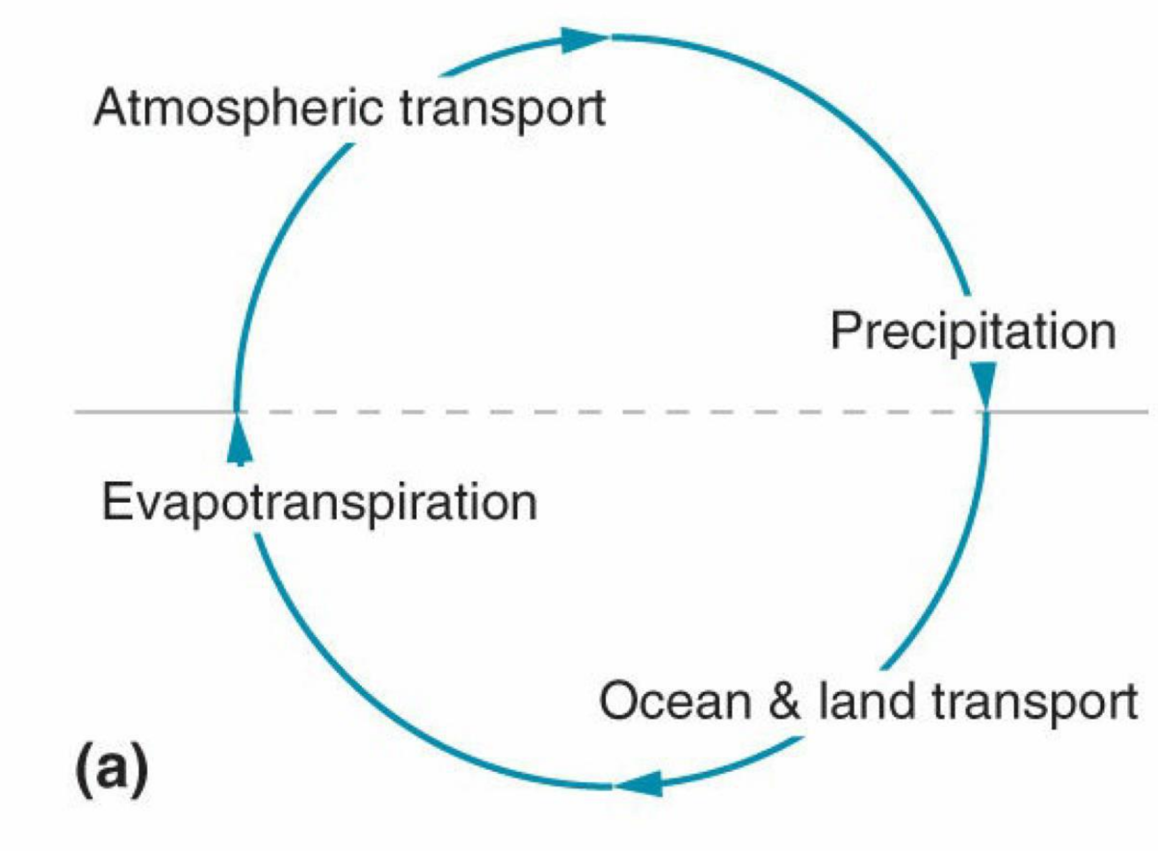
Nature Works in Cycles – e.g., The Nitrogen Cycle



The Global Water Cycle



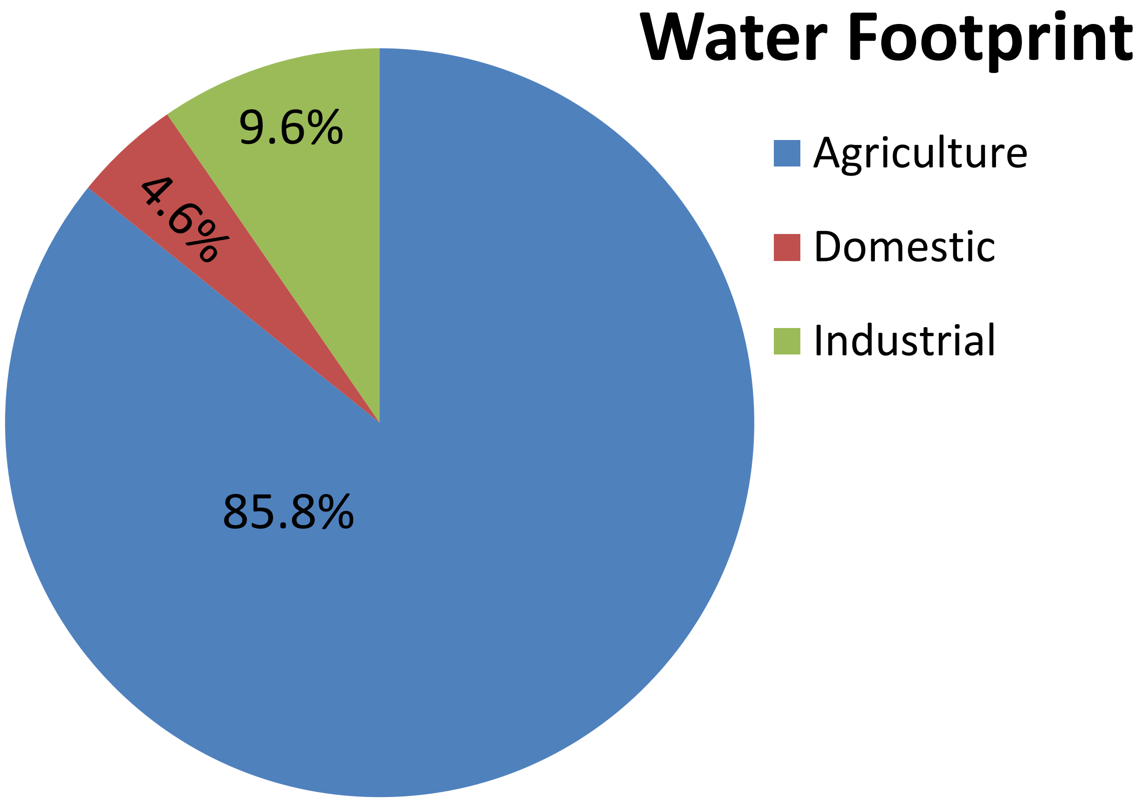
Data Source: Chow et al., (1988)



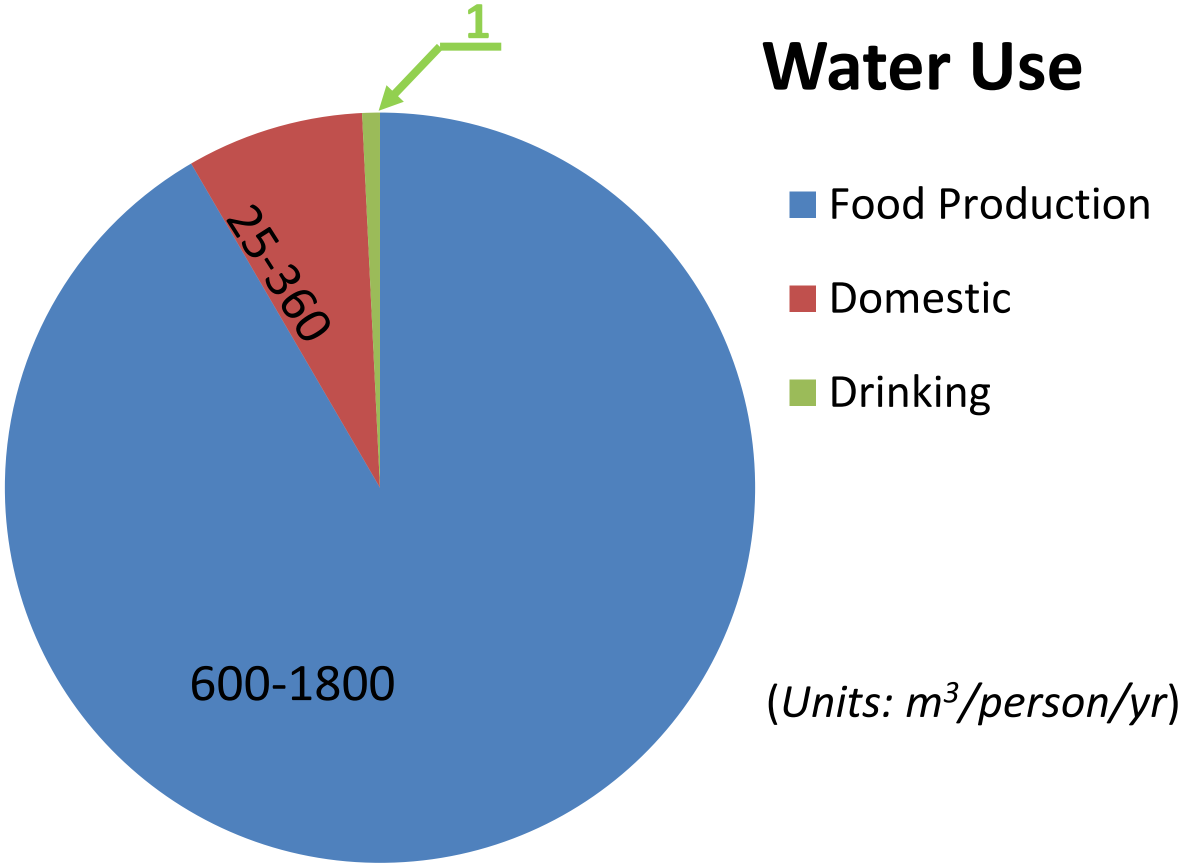
How Can we Promote a Circular Economy of Water?

Most human water we uses are for 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

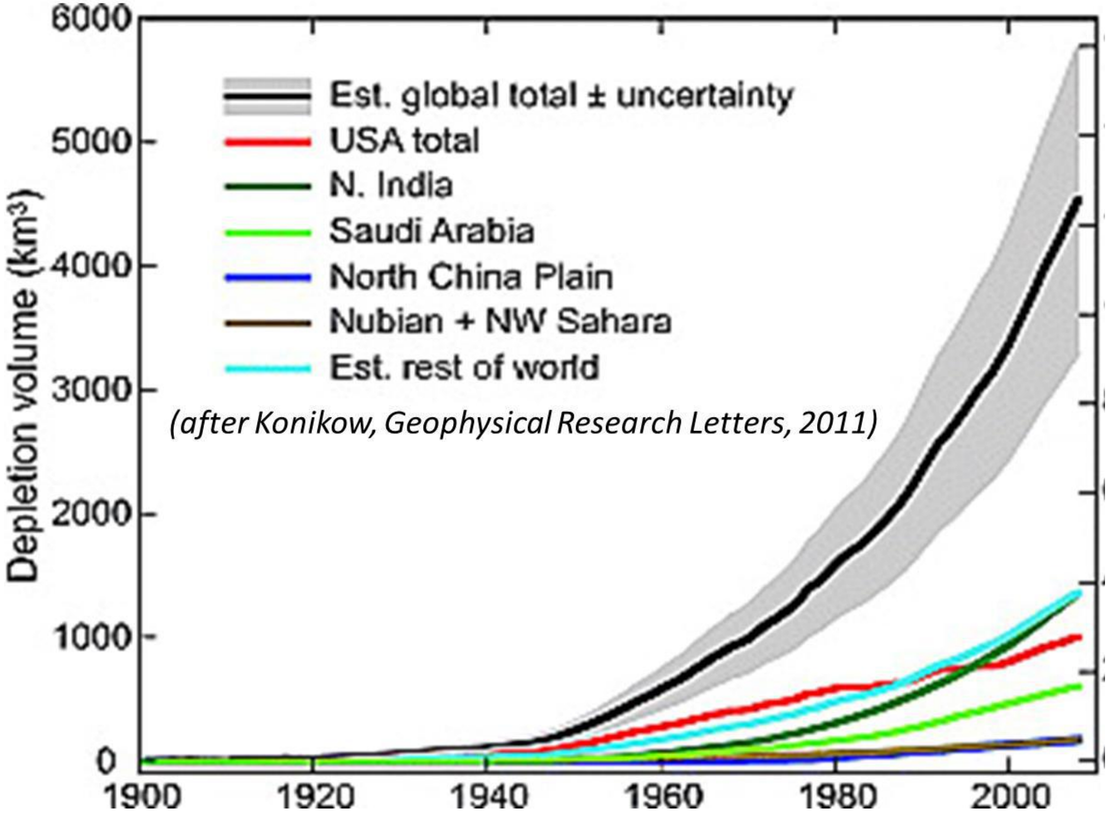
"Green Water": Root-zone soil moisture

"Blue Water": Water from Rivers, Lakes, Aquifers

Global Freshwater Resources are Limited

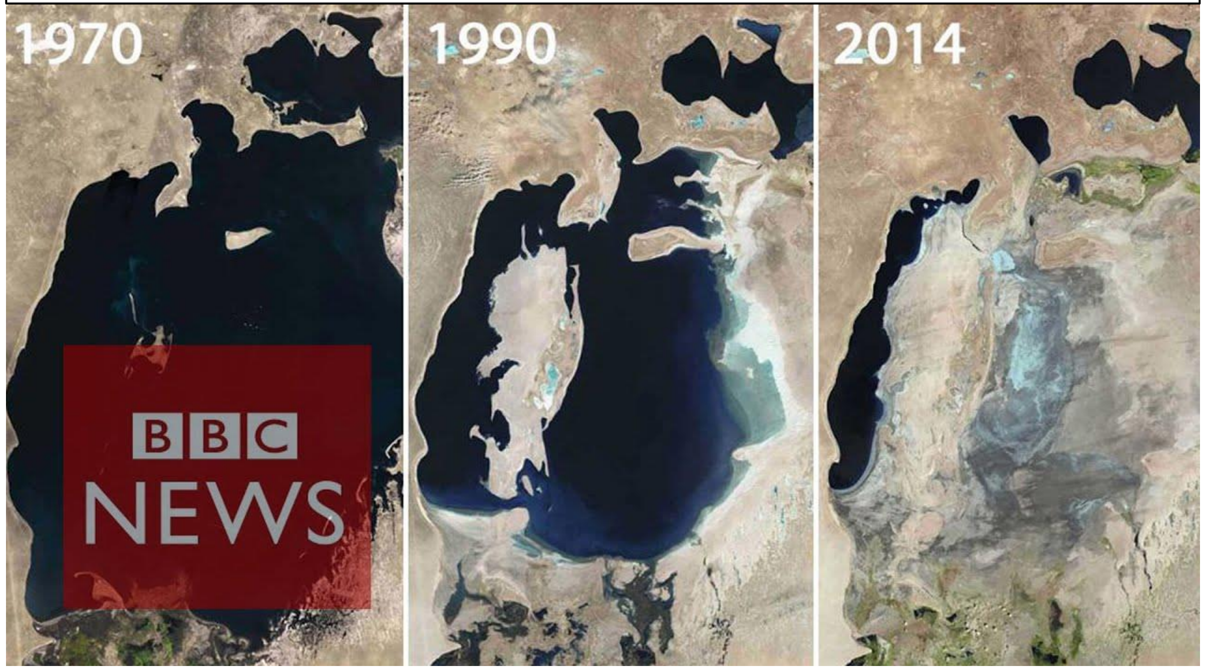
Human appropriation of water resources destroys habitat & depletes water stocks

Estimated global groundwater depletion, 1900–2008

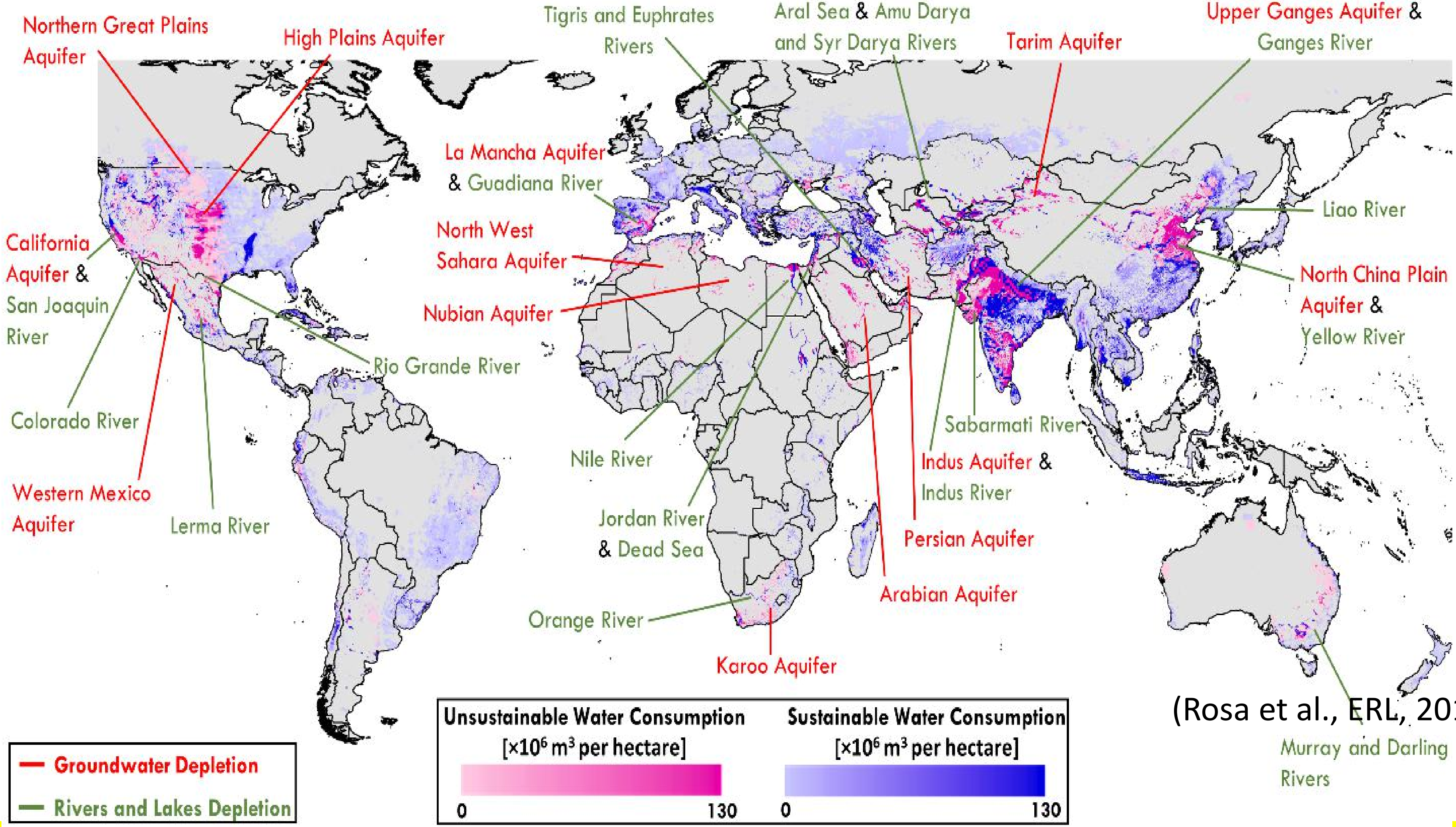


Mouth of the Colorado River

Shrinking of the Aral Sea



Sustainable and Unsustainable Irrigation

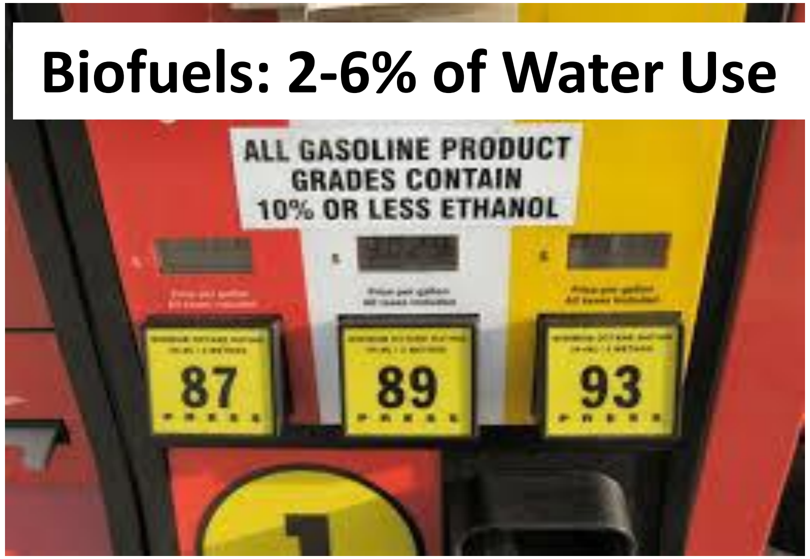


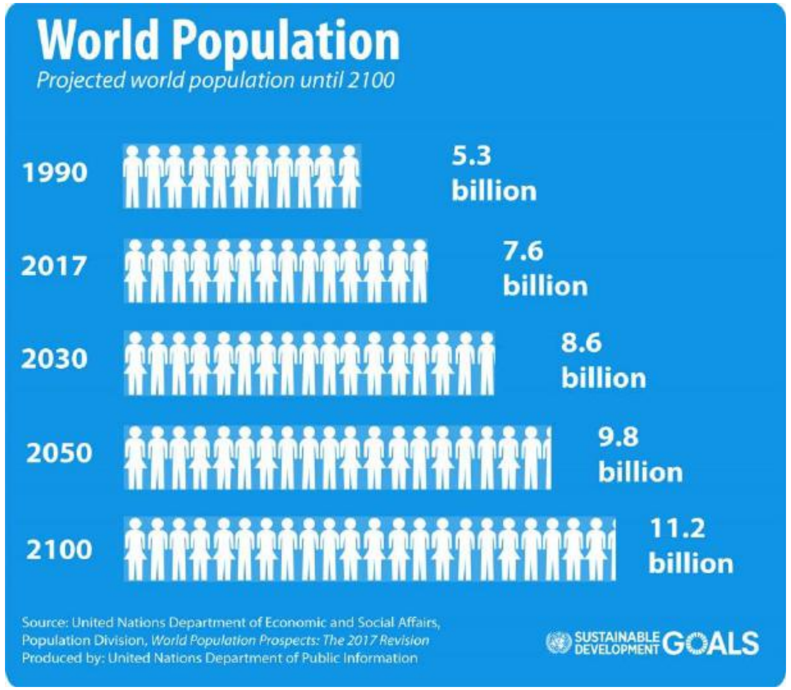
(Rosa et al., ERL, 2019)

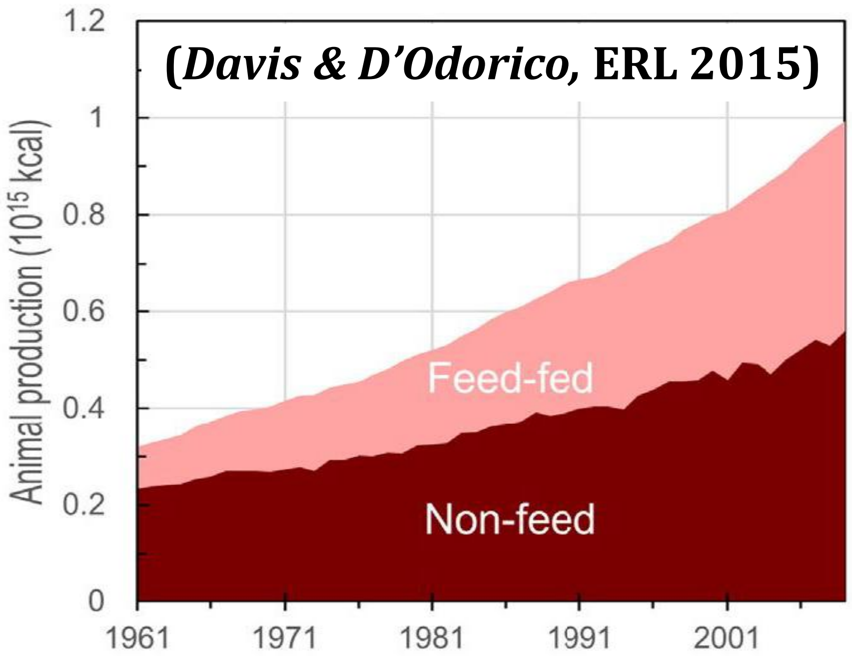
Unsustainable if: *Water Consumption > Runoff-Environmental Flows*

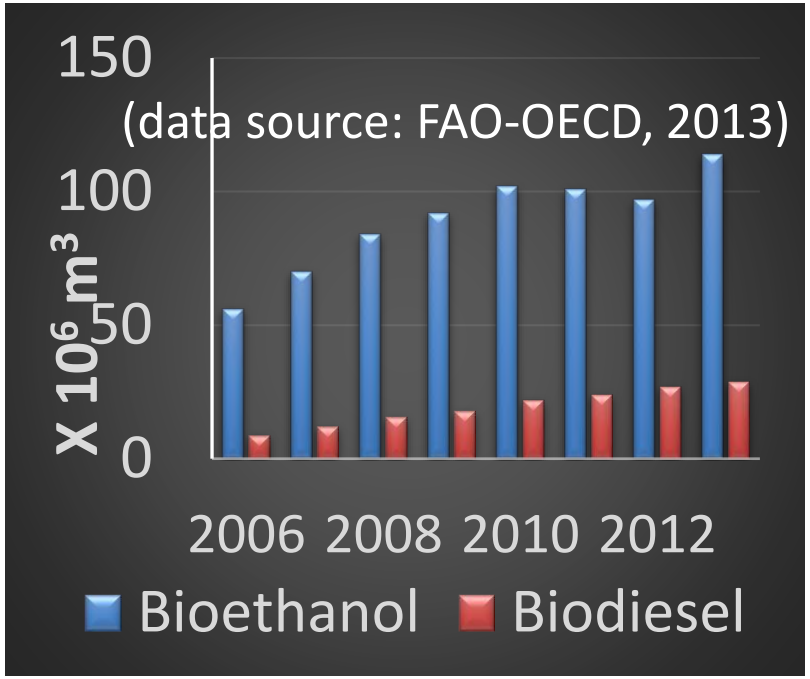
40% of irrigation is unsustainable

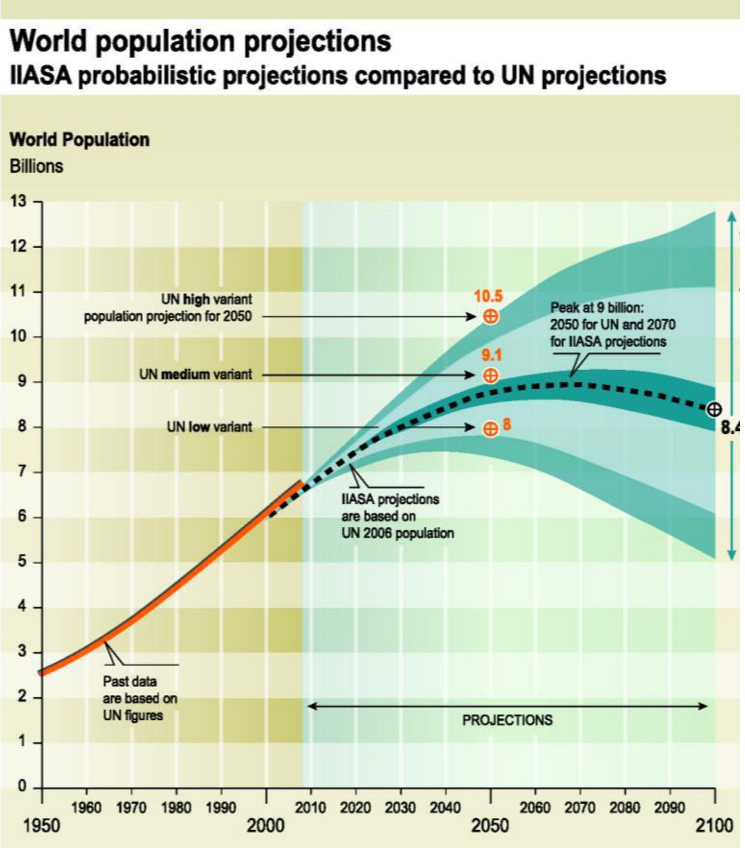
Increase in Demand











Population year	Year	Time to 1 billion+
1 billion	1804	—
2 billion	1927	(123 years later)
3 billion	1960	(33 years later)
4 billion	1974	(14 years later)
5 billion	1987	(13 years later)
6 billion	1999	(12 years later)
7 billion	2011	(13 years later)
8 billion	2025 (projection)	(14 years later)

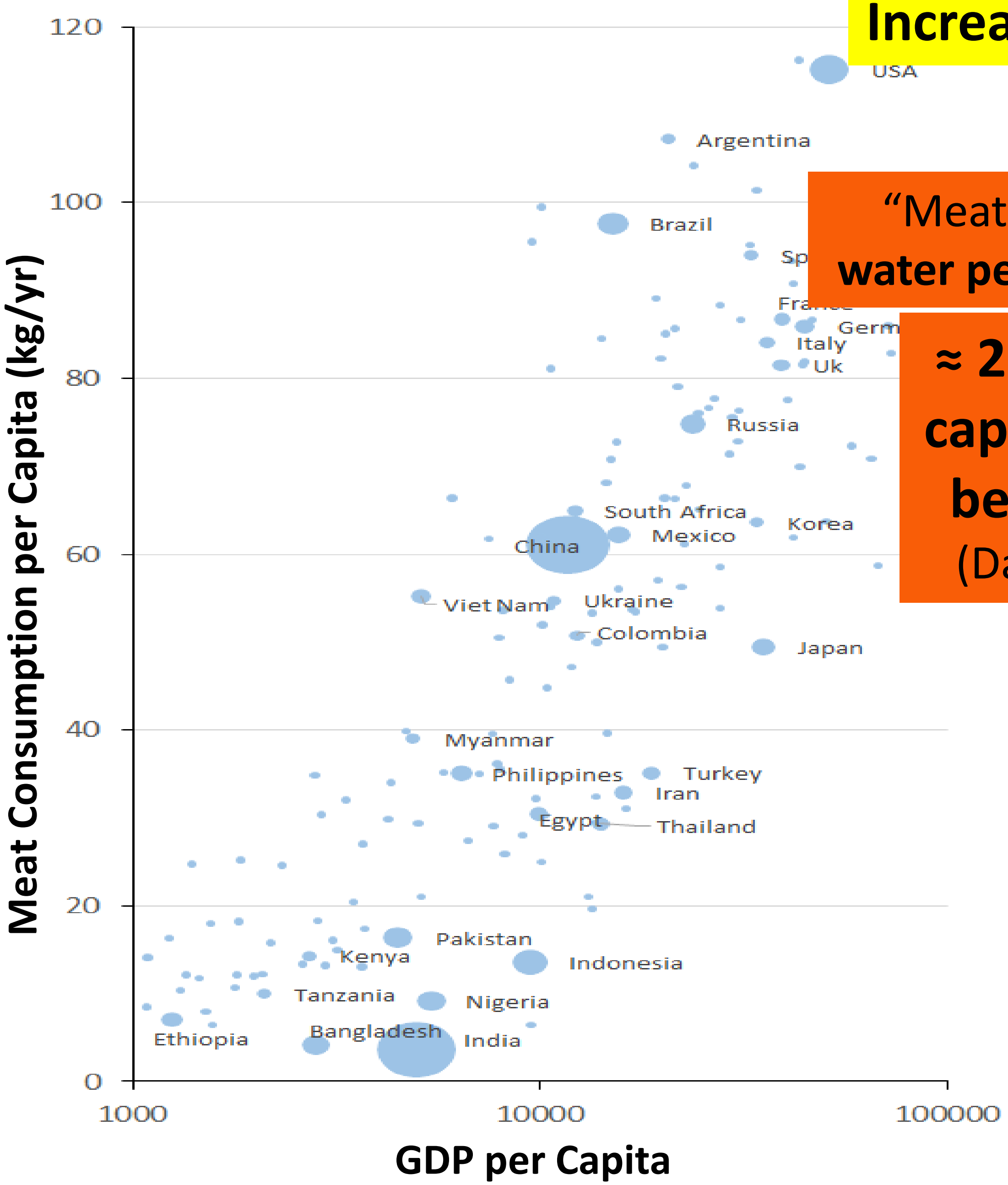
Industrial Revolution →
Green Revolution →
Green Revolution →
Trade
Intensification
Food Crises: "running out of water?" →

FEATURE

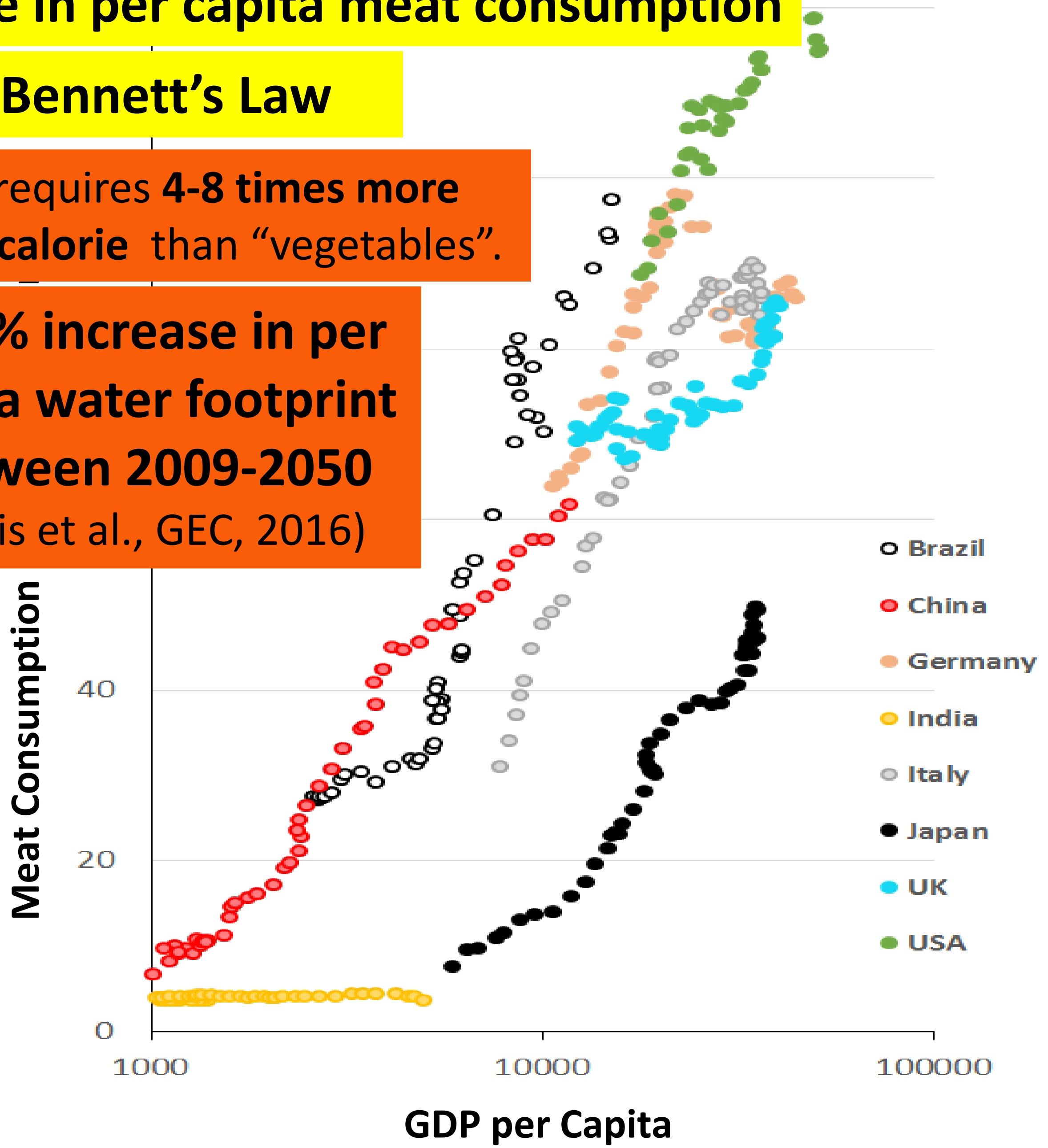
Erisman et al., Nature Geoscience, 2012.

How a century of ammonia synthesis changed the world

Meat Consumption vs. GDP per Capita (2013)



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



Increase in per capita meat consumption

Bennett's Law

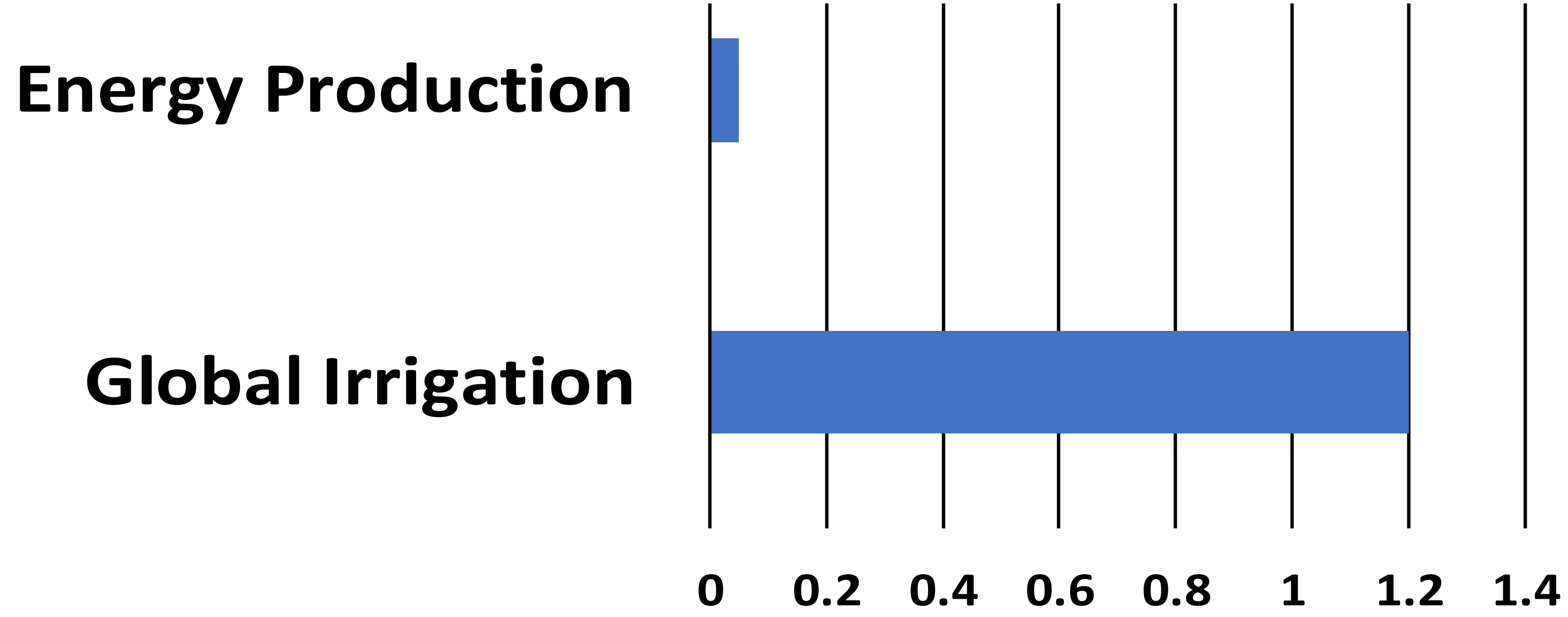
"Meat" requires **4-8 times more water per calorie** than "vegetables".

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

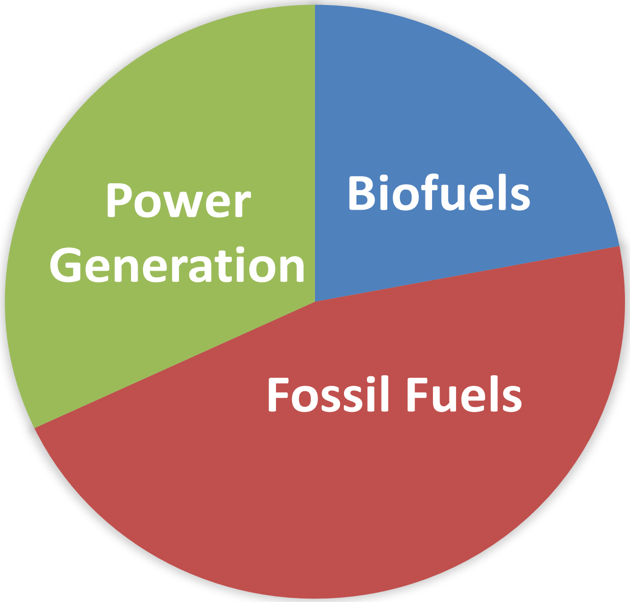
Water for Energy

Blue Water Consumption (x 10 ^{12} m^3 y^{-1})

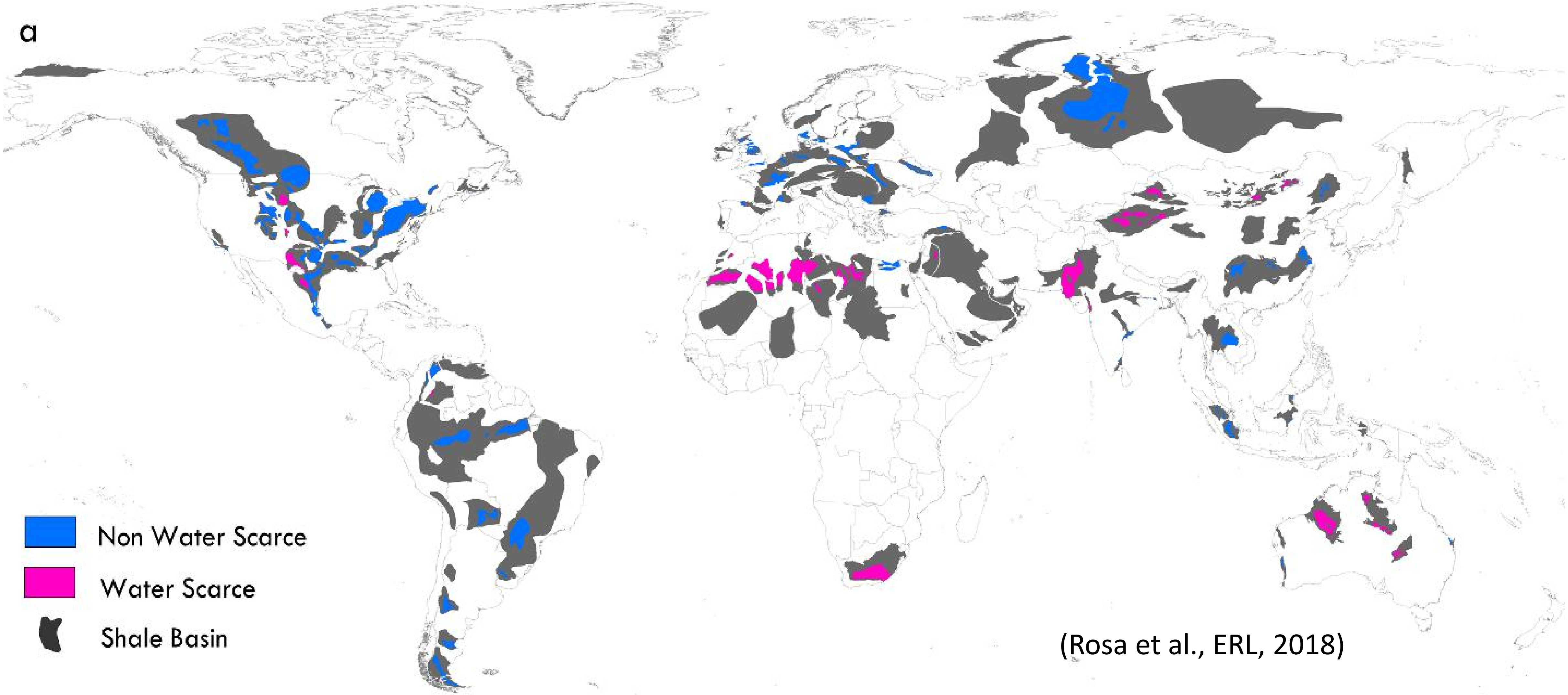
(IEA, 2016; D'Odorico et al., Rev. of Geophys., 2018)



BLUE WATER CONSUMPTION FOR ENERGY PRODUCTION



Areas where shale oil/gas extraction could compete for water with agriculture

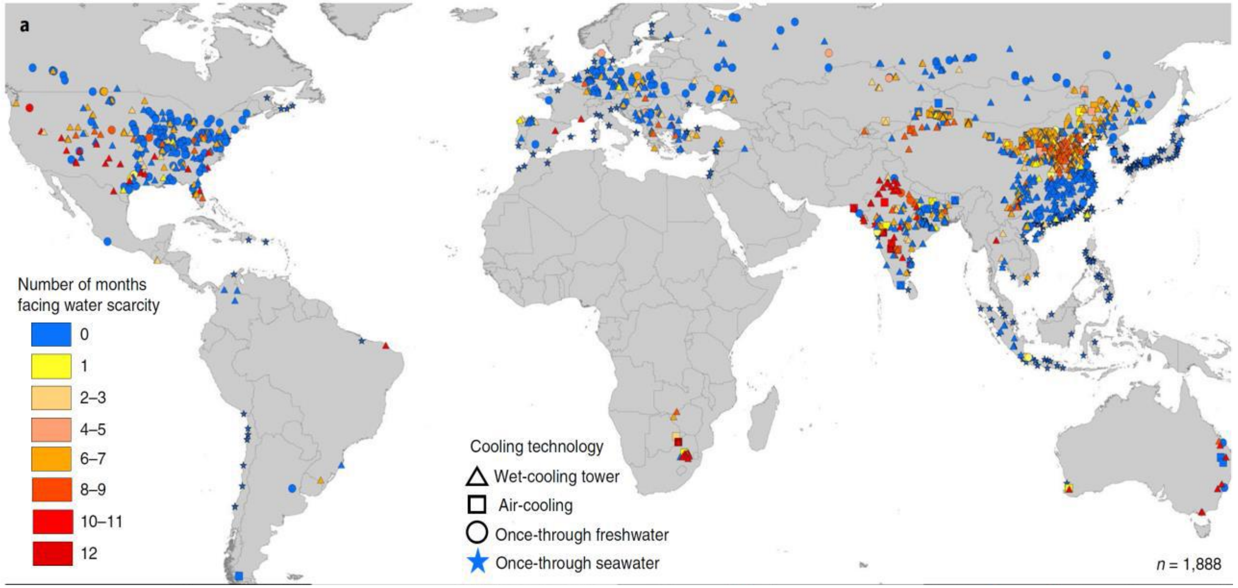


(Rosa et al., ERL, 2018)

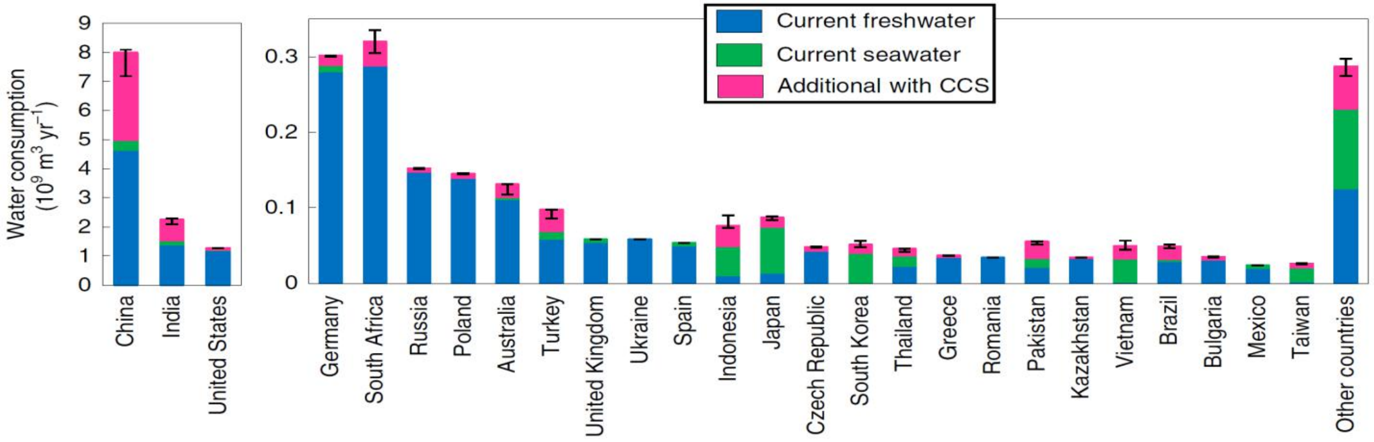
Are we running out of Freshwater Resources for Food and Energy?

Water Limitations in Coal Fired Power Plants

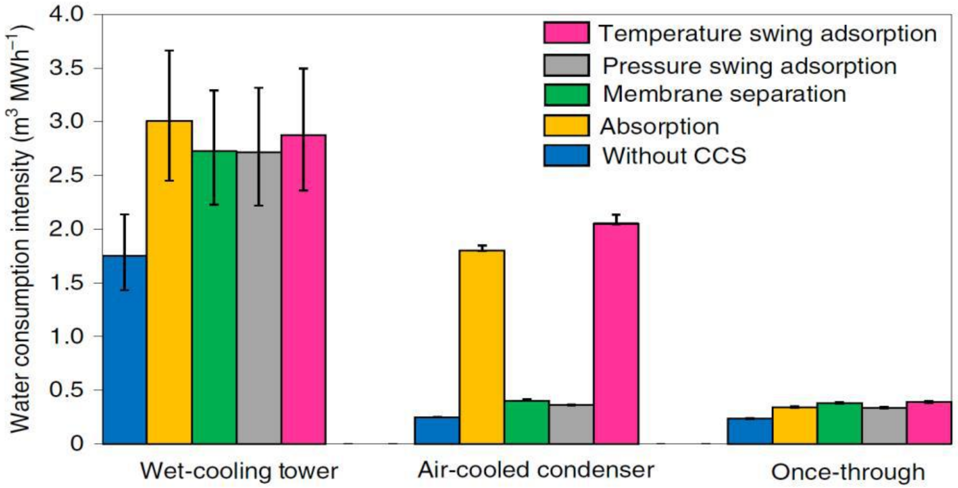
Duration of water scarcity in Coal Fired Power Plants



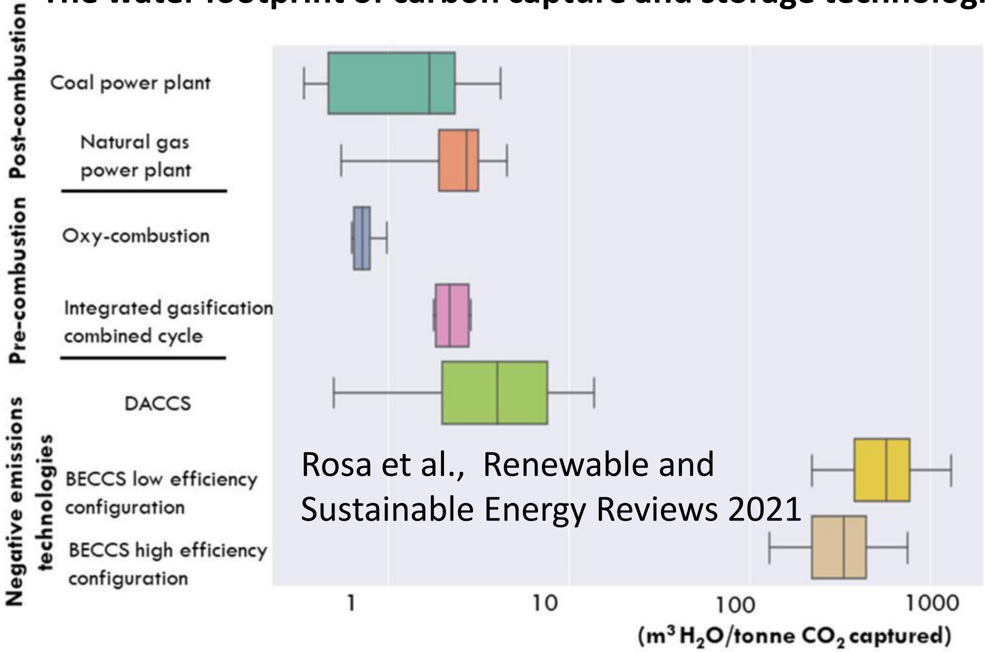
(Rosa et al., *Nature Sustainability*, 2020)



Increasing water needs from Carbon Capture and Storage



The water footprint of carbon capture and storage technologies



Rosa et al., Renewable and Sustainable Energy Reviews 2021

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

Agricultural Intensification

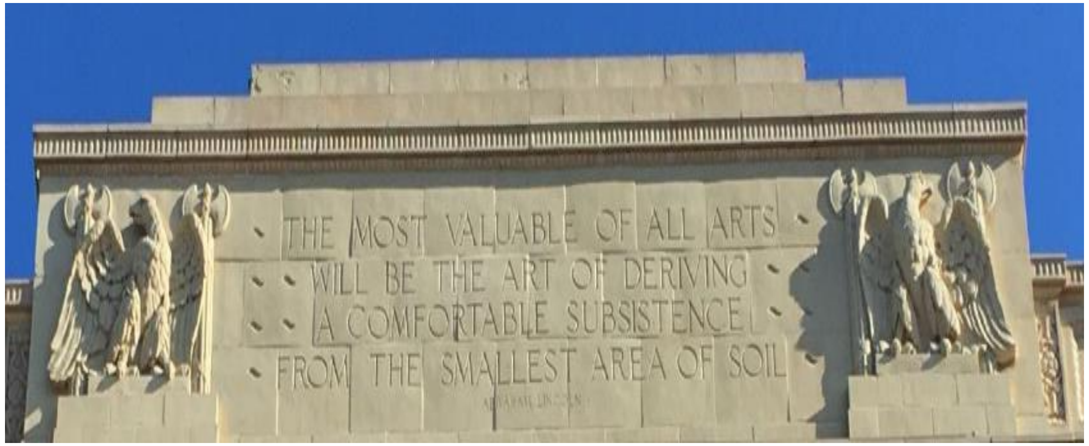
Close the Yield Gap (irrigation, fertilizers,…)

Agricultural Extensification

Expand the cultivated area

Land Use Change
Deforestation
Biodiversity losses

Scientists often advocate for intensification (e.g., Foley et al., 2011)



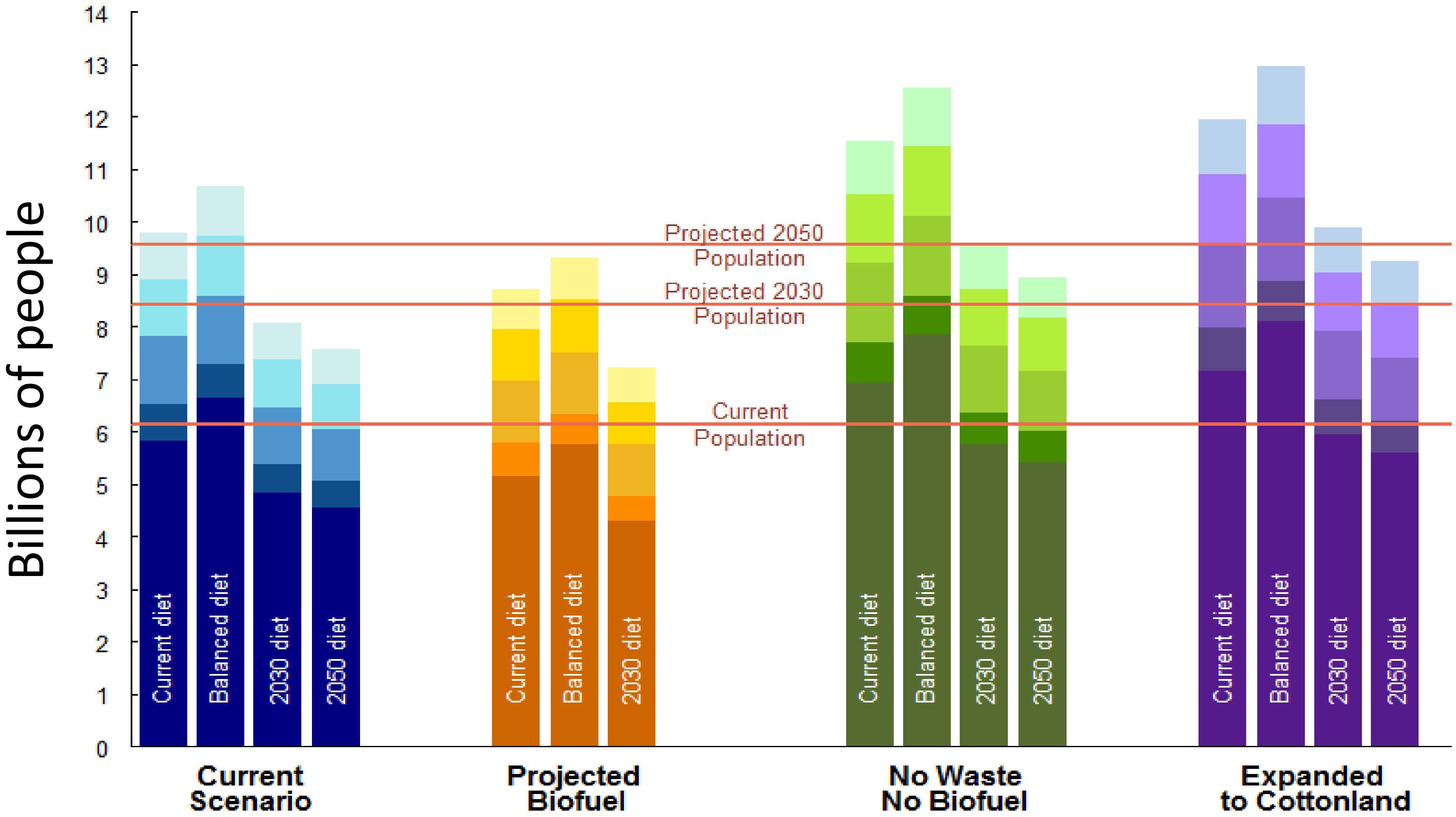
“Bisogna dare la massima fertilita’ ad ogni zolla di terra”
(Scritta che appare sul muro del consorzio di bonifica di Mogliano Veneto)

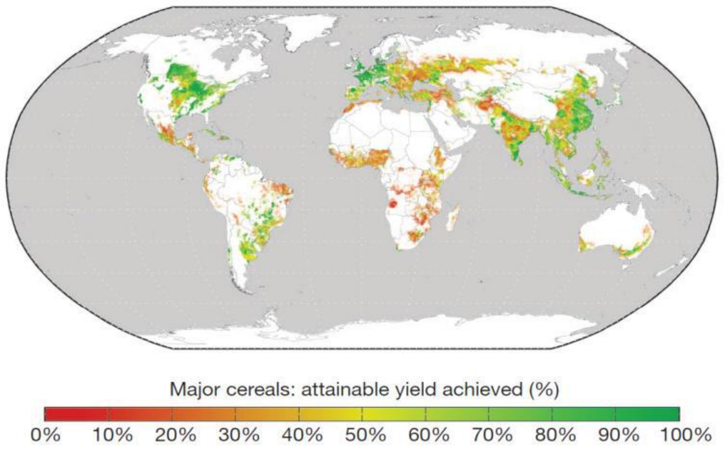
… is there enough water to do it sustainably?

by closing the yield gap we can feed 4 Billion people

Yield Gaps (Mueller et al., 2012)

(Davis et al., Earth's Future, 2014)



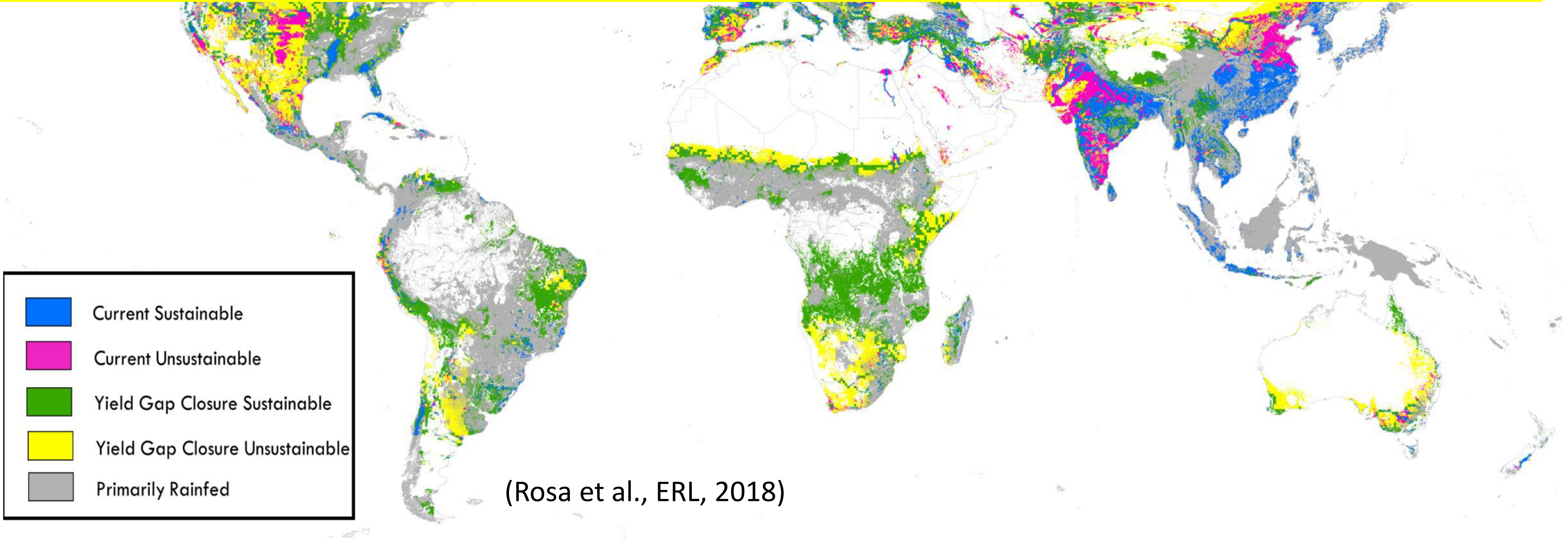


… but, is there enough water to do it sustainably?

If we account for water availability and environmental flows

It is possible to sustainably
- expand irrigation to 26% of currently rainfed areas
- feed an additional 2.8 billion people

Eliminating unsustainable irrigation:
- in this case the world could feed additional 1.8 billion people

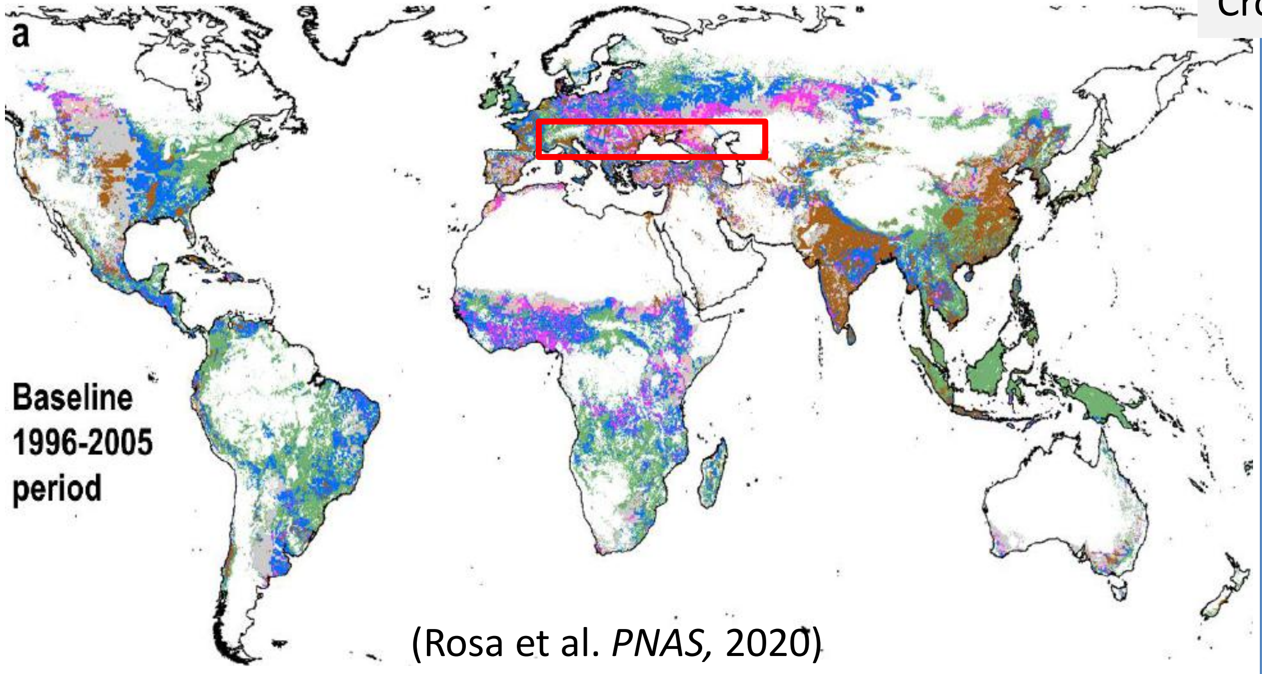


(Rosa et al., ERL, 2018)

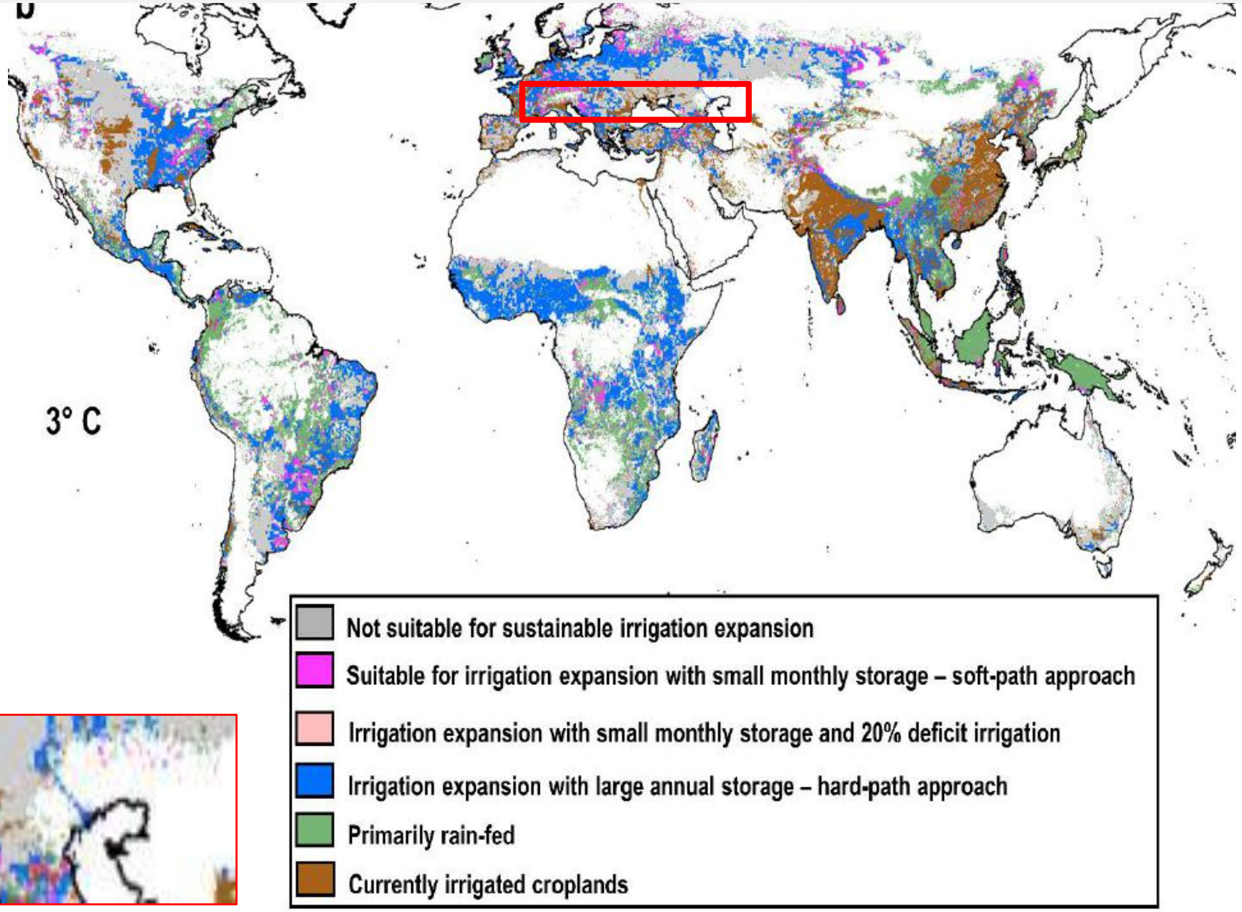
Effects of Climate Change on Irrigation Suitability

- Sustainable irrigation expansion potential under baseline and 3 °C warmer climate conditions with respect to preindustrial era.

RCP8.5: Climate models: GFDL-ESM2M, HadGEM2-ES, MIROC-ESM-CHEM
Hydrological Models: LPJmL, H8, WATERGAP2
Crop Water Model: WATNEEDS (Chiarelli et al., 2020)



(Rosa et al. *PNAS,* 2020)

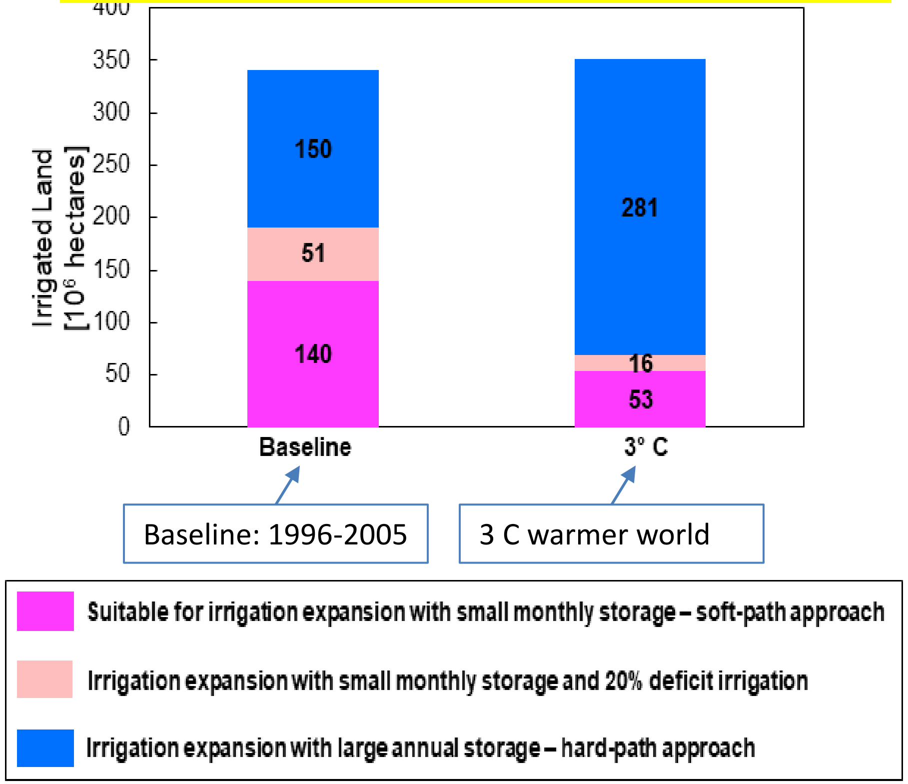


Baseline

3C Warmer

Global potential for “sustainable” irrigation expansion

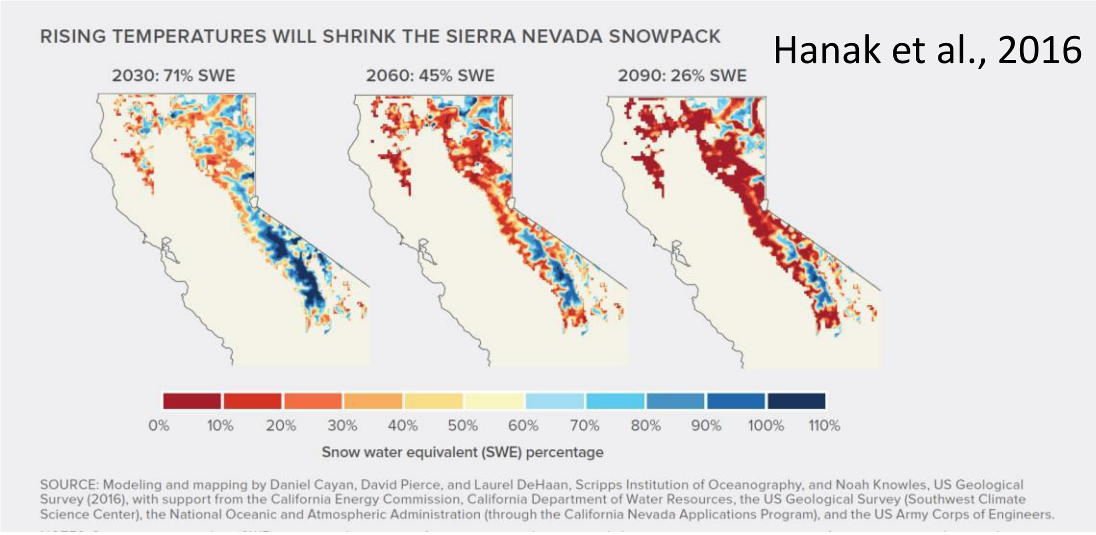
Expansion of Irrigation to Rainfed Areas



- Increasing needs for water storage

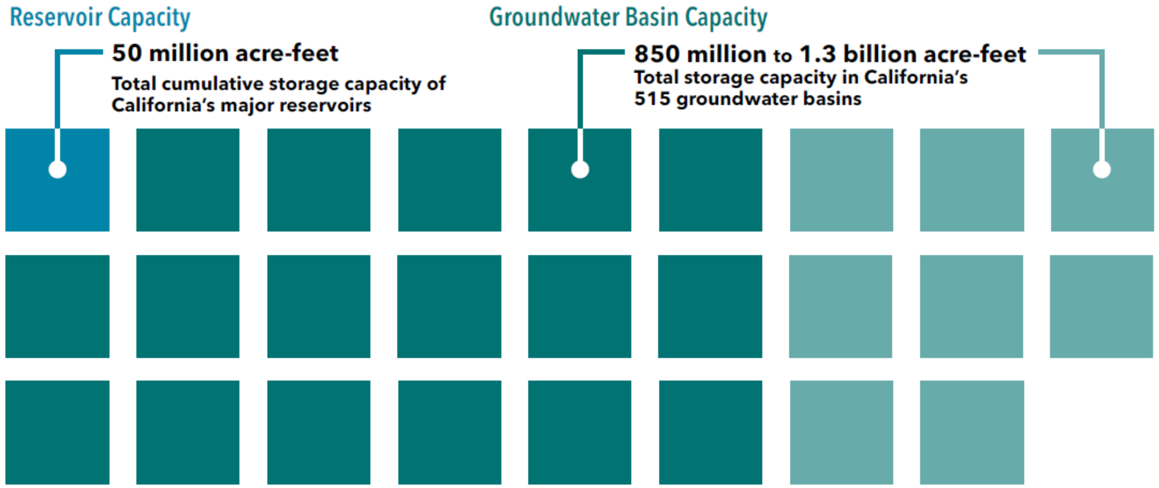
The Problem of Water Storages

- Surface water storage
  - → Environmental impacts
  - → Who benefits from large dams?
- Loss of snowpack → loss of seasonal storage
- Store water below ground → Managed Aquifer Recharge, ‘Water Banks’
- Small farm-scale detention ponds → ‘Green Infrastructure’



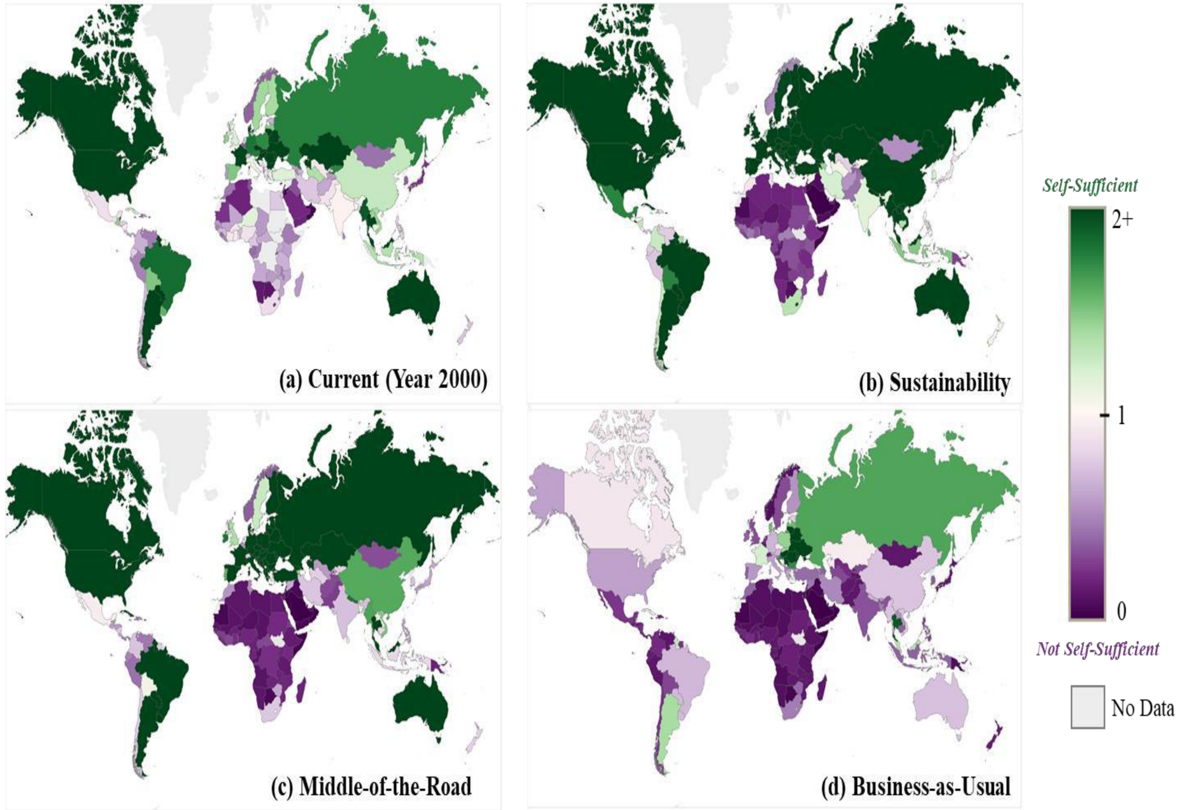
Hanak et al., 2016

Figure 5 Reservoir Capacity vs. Groundwater Basin Capacity



We live in an interconnected planet

Global self-sufficiency ratios.

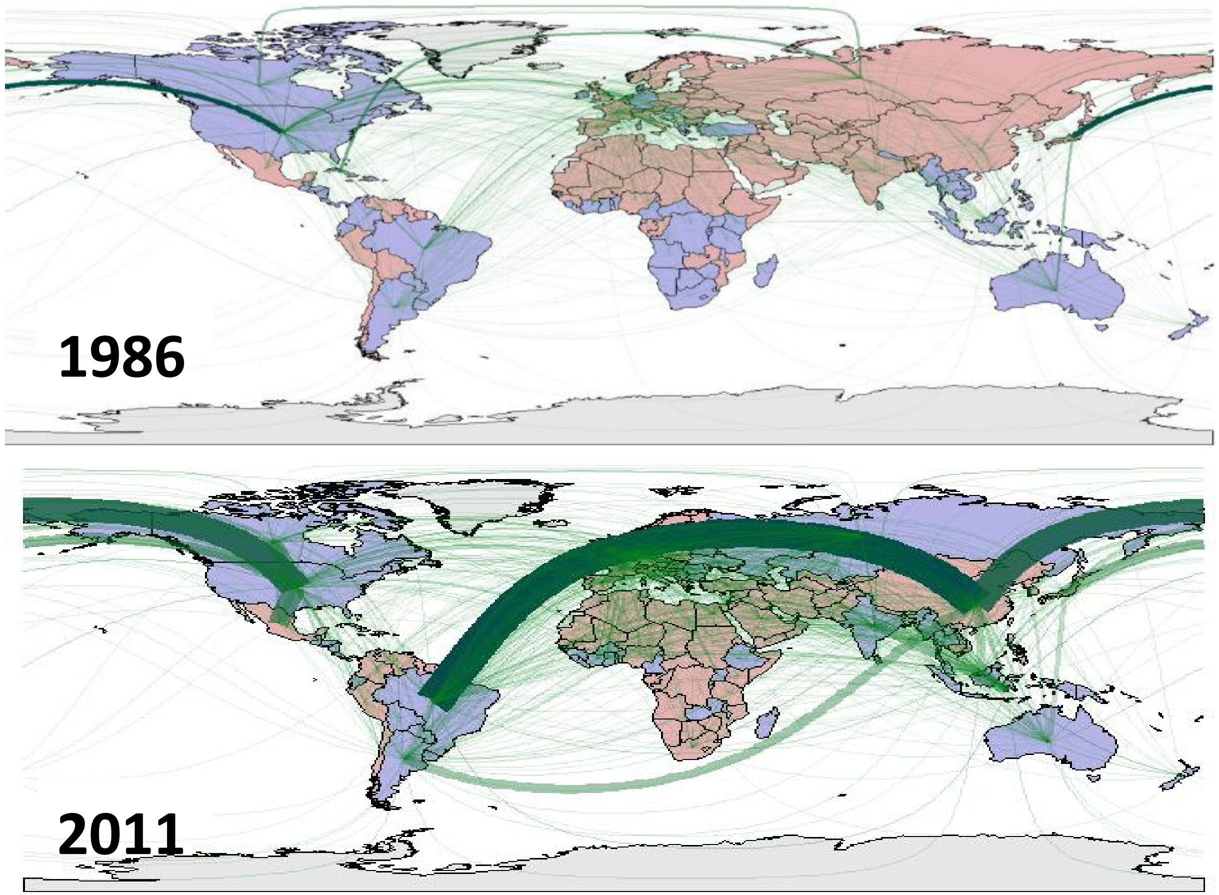


Self-sufficiency ratios in year 2000 (a) and projected for 2100 (*Beltran-Pena, et al., ERL, 2020*)

RCP: scenarios (RCP 2.6, RCP 6.0, and RCP 8.5) from five global gridded crop models

Shared socioeconomic pathways: SSP1, SSP2, SSP3 →Diets and Population

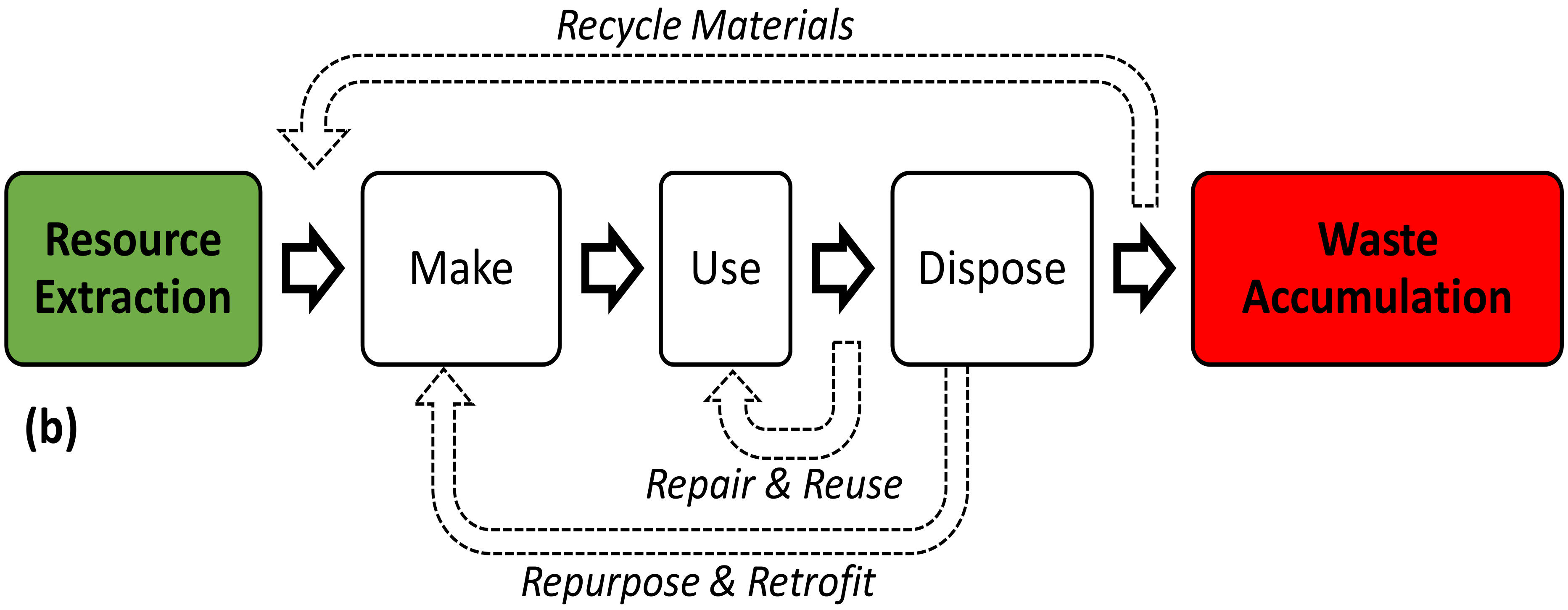
Virtual Water Trade



(Carr et al., 2017)

24% of the food (and water) we eat is internationally traded

Toward a Circular Economy of Water in Agriculture



"Reuse what you can, recycle what you cannot reuse, repair what is broken, remanufacture what cannot be repaired" (Stahel, *Nature*, 2016)

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

Sustainable Intensification

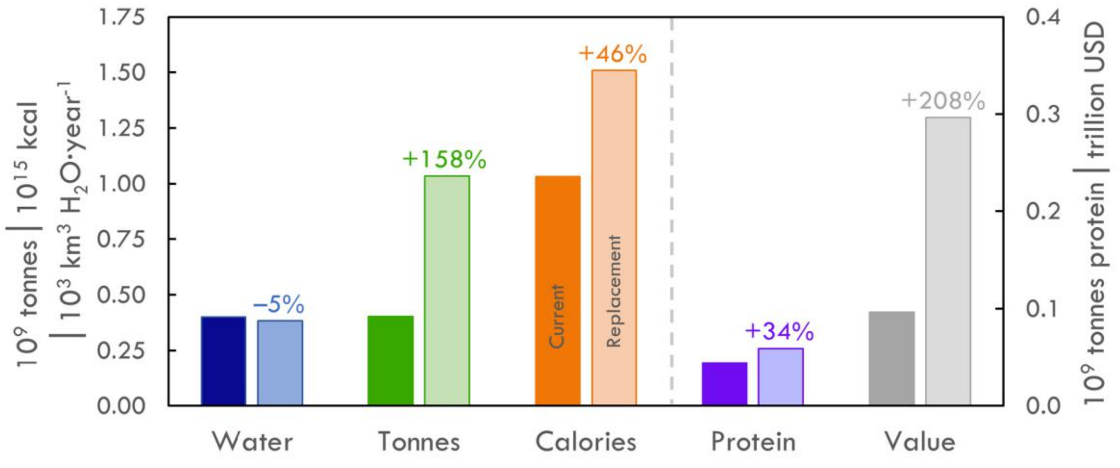
- Sustainable irrigation expansion on rainfed areas
- Use water more efficiently - “more crop per drop”
  - →Soil water conservation (reduce soil evaporation)
  - →Crops with better water-use efficiency. Not necessarily transgenic. Plant the right crop in the right place

Reduce the Demand

- Reduce waste of food, water, nutrients
- Change diets (less animal products)
- Circular economy of food

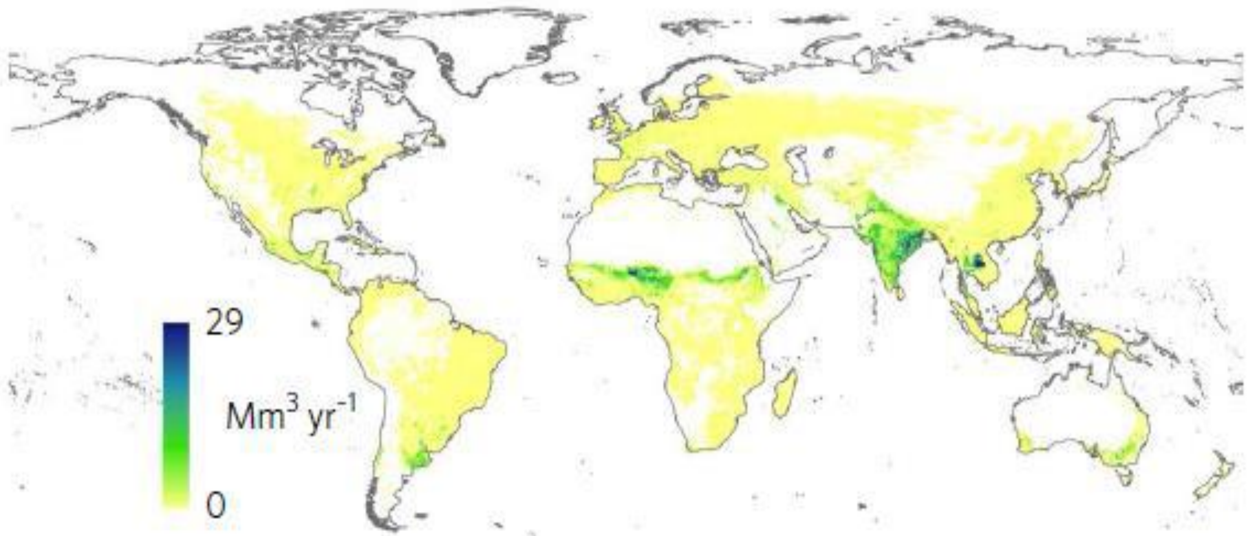
More optimal crop distributions

Use crops with better water-use efficiency. **Plant the right crop in the right place**



(Davis et al., *Water, 2017*)

"Don't Plant Thirsty Crops in Dry Places"



(Davis et al., Nature Geoscience, 2017)

Crop replacement criteria to "optimize" production

- Increase in calorie production (+46% increase)
- Increase in protein production(+34% increase)
- Decrease in water consumption (-5% decrease)

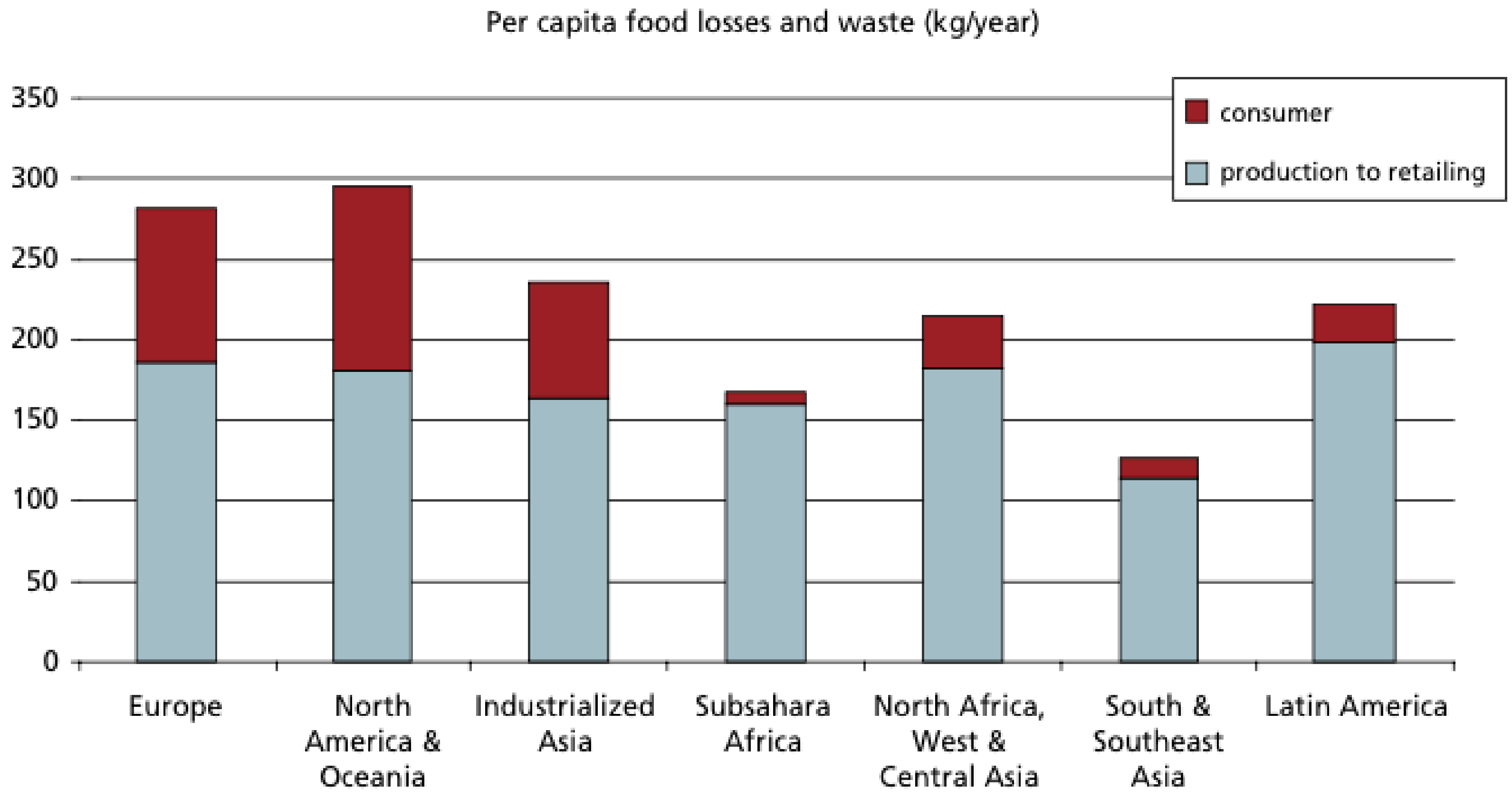
- **Feed 825 million people more**
- **Reduce water use by 12%**

Reduce Food Waste

Can the Food Waste Cycle be Broken?

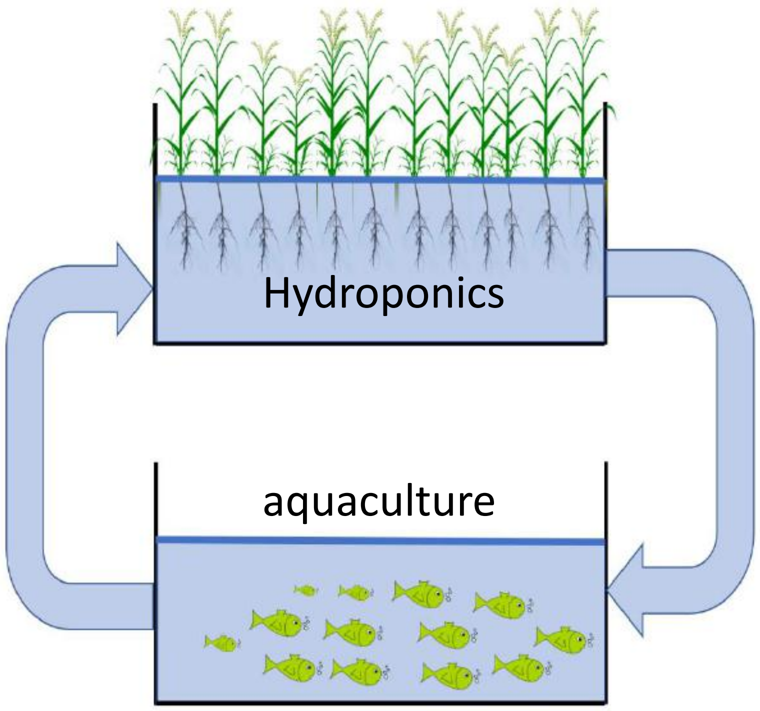
- One third of all food produced for human consumption in the world is lost or wasted
  (Gustavsson et al. 2011)

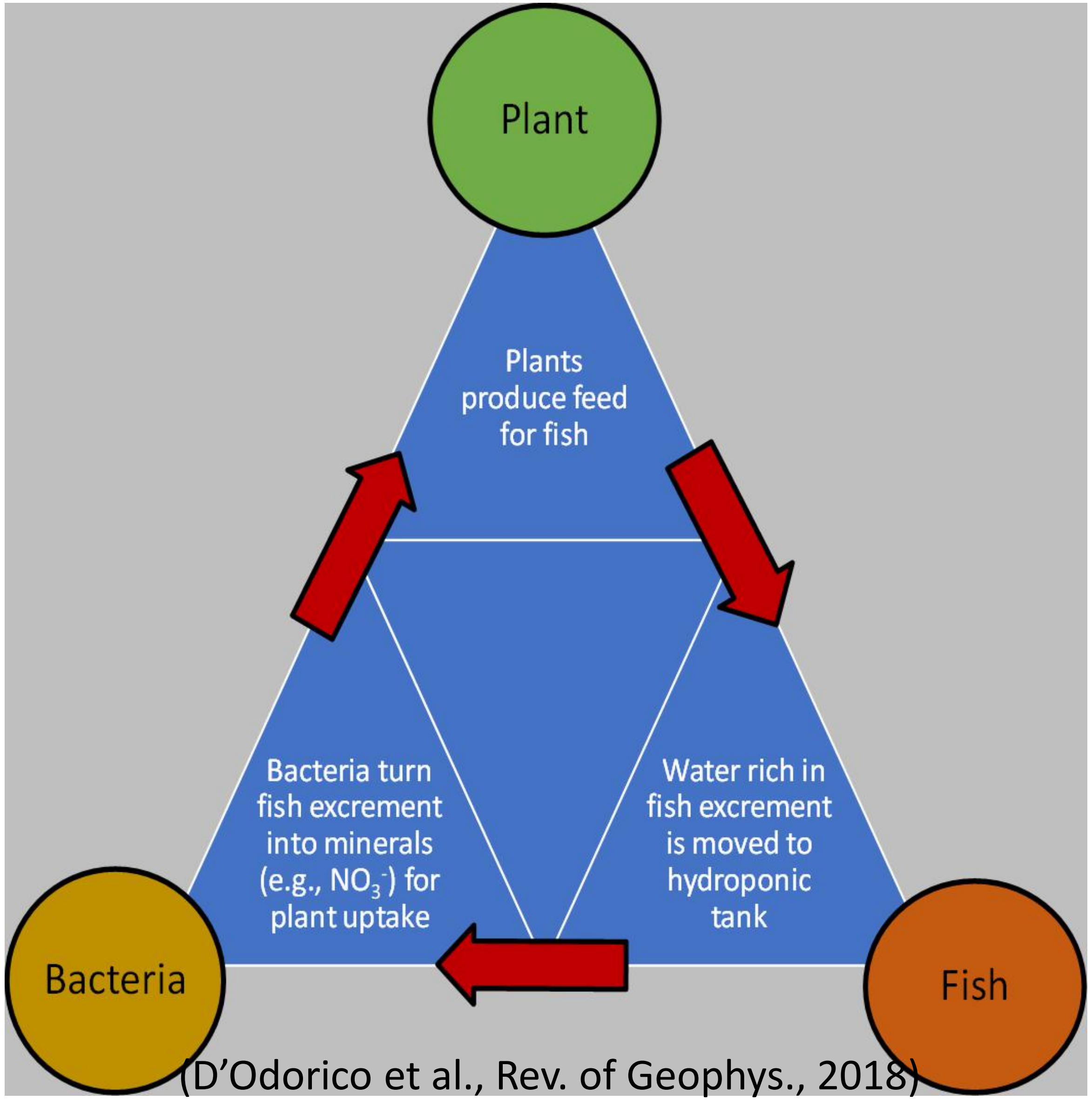
- 25% of the water used in agriculture goes in food waste
  (Kummu et al. 2012)



High Technology Solutions

- Aquaponics





(D'Odorico et al., Rev. of Geophys., 2018)

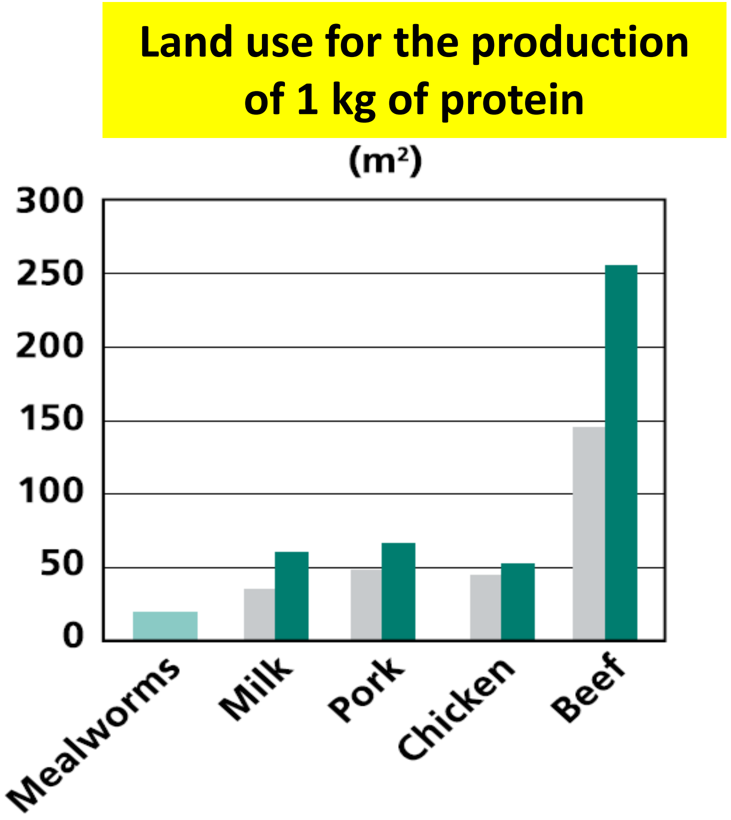
Pros:

- Plants grow faster
- Take less space
- Don't need to invest much in root growth to find nutrients
- Efficient nutrient regulation

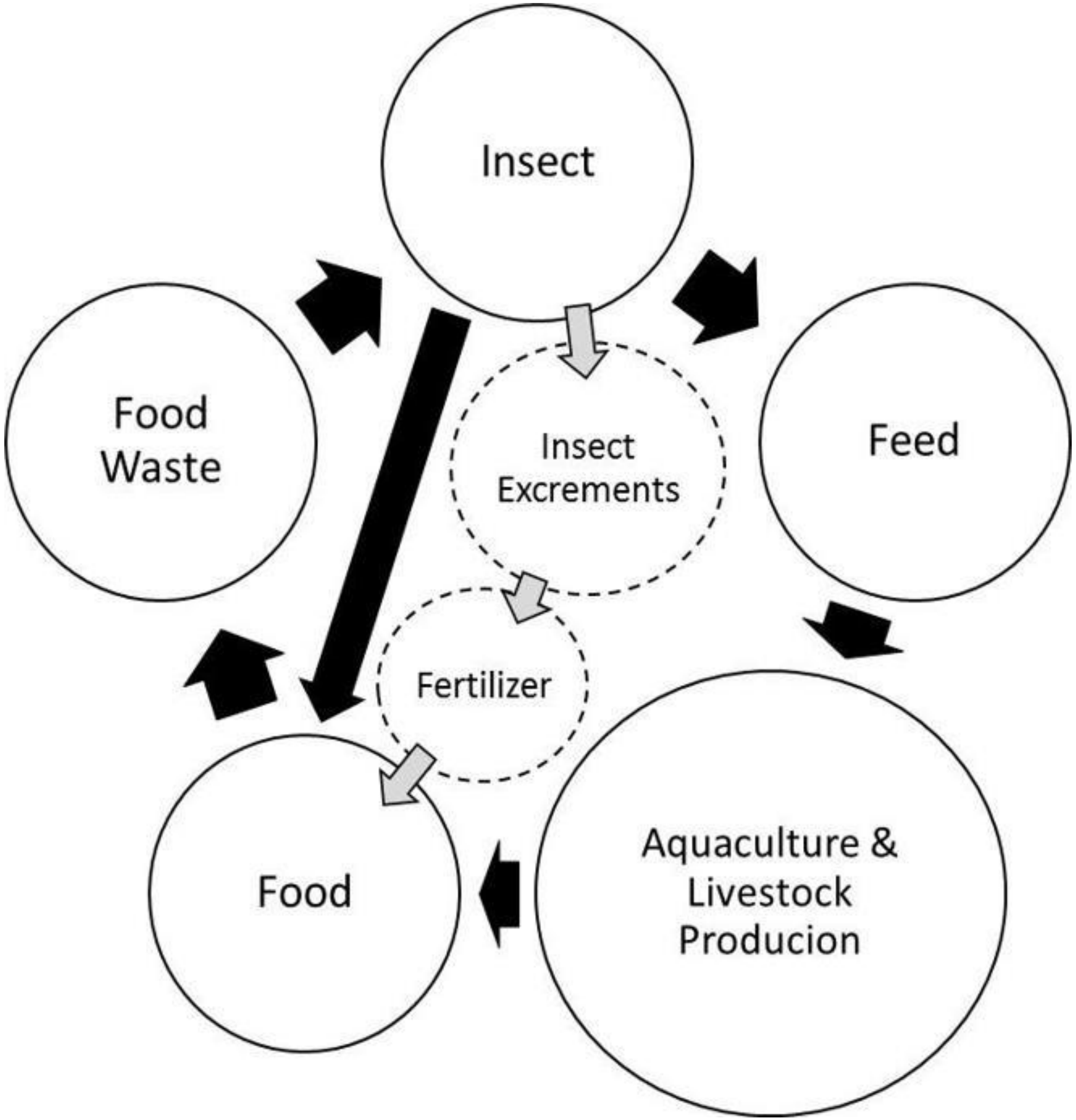
Cons:

The cost of the system, maintenance, and energy requirement

Circular Economy of Insects
(low technological inputs)



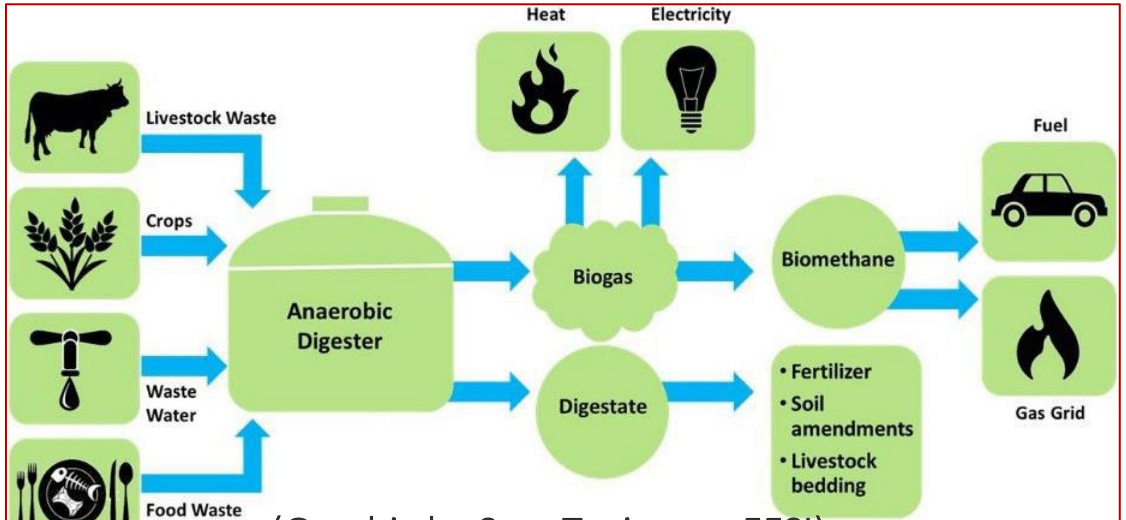
Van Huis, 2013; van Huis et al., 2013)



(D'Odorico et al., Rev. of Geophys., 2018)

Other Examples

- Biogas production from food waste

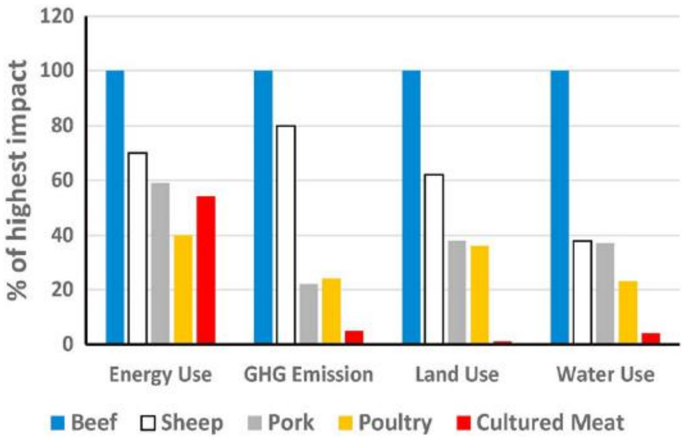


(Graphic by Sara Tanigawa, EESI)

- Fertilizer production from wastewater treatment

Decreased Reliance on Animal Products

Cultured Meat



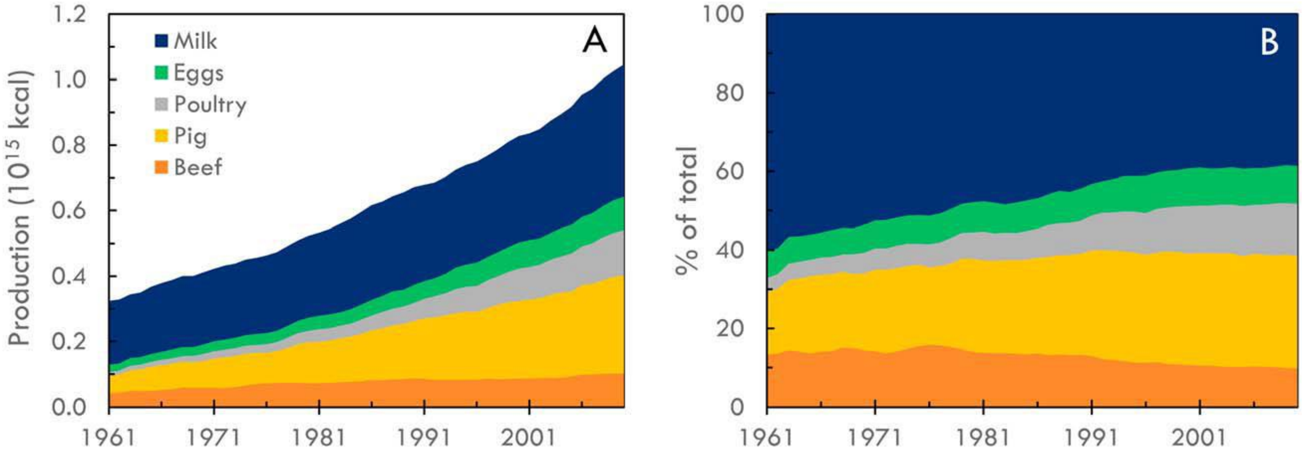
(data source: Tuomisto & Teixeira de Mattos, 2011)

Pros
- Smaller Footprint
- Less exposure to zoonotic diseases
- Animal wellbeing

Cons
- Costs
- Cultural barriers

Artificial Meat, Milk, Eggs

Changes in Diet
- Less Animal Products
- Livestock Transition (from Beef to Pork and Pultry)



(D'Odorico et al., Rev. of Geophys., 2018)

Increase water availability

- Treated water
- Production water
- Desalination

Is Salty Water the Solution?

What are the costs?

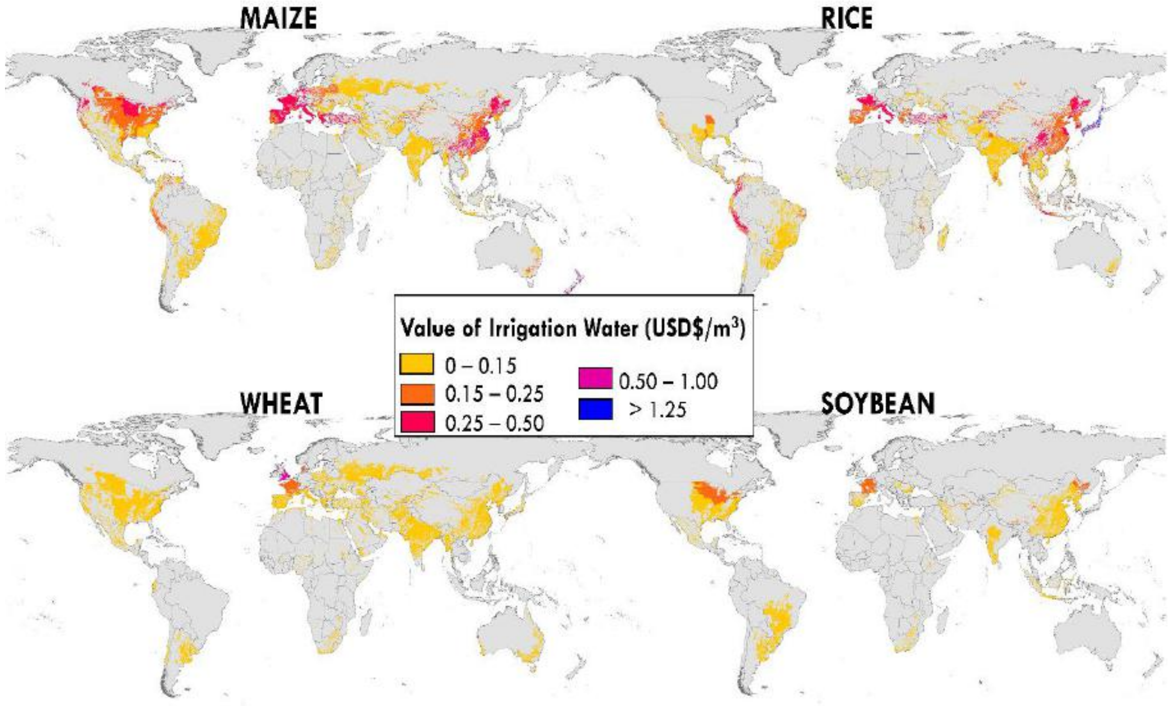
The use of this water depends on its added value in the production process.

- median global values in agriculture of US$ 0.13 /m^3
- Farmers would not pay more for water
- The oil industry pays more (US$0.80-2.5/$m^3$)

Cost of treated Water ($/m3)

Technology	Capacity in m^3/d (mgd)			
	3785 (1)	18,925 (5)	37,850 (10)	189,250 (50)
MSF (PR = 12)	2.746	1.925	1.582	1.339
MED (PR = 12)	2.146	1.455	1.336	1.128
MVC	1.333	0.926	0.867	–
SWRO	1.401	0.893	0.820	0.716
BWRO	0.712	0.447	0.380	0.297

S. Bhojwani et al. STOTEN, 651 (2019)



The global value of water in agriculture

Paolo D'Odorico[a], Davide Danilo Chiarelli[b], Lorenzo Rosa[a], Alfredo Bini[a], David Zilberman[c,1], and Maria Cristina Rulli[b]

(D'Odorico et al, PNAS, 2020)

Conclusions

- Water constrains food & energy production
- Crop yields and irrigation expansion are limited by water availability
- The expansion of irrigation strongly depends on water storages
- Use of treated water in agriculture
- Consumption moderation, food & water waste reduction, circular economy of food wand water