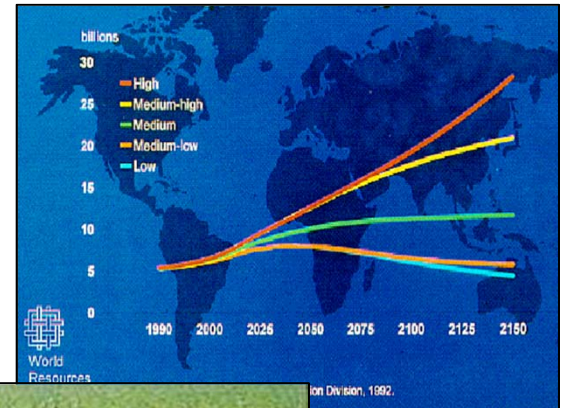
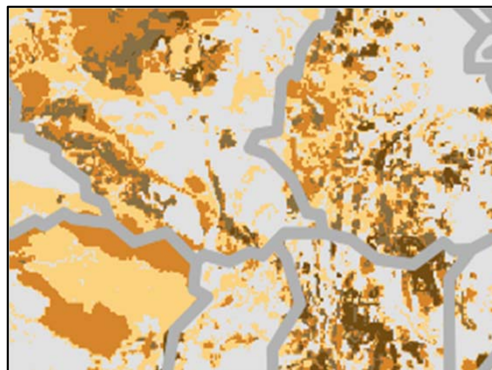
Food Security and Sustainable Resource Management

How will we provide a secure food supply for 10 billion people in 2050?

Food security … implies sustainable resource use





Demand

Resources for production

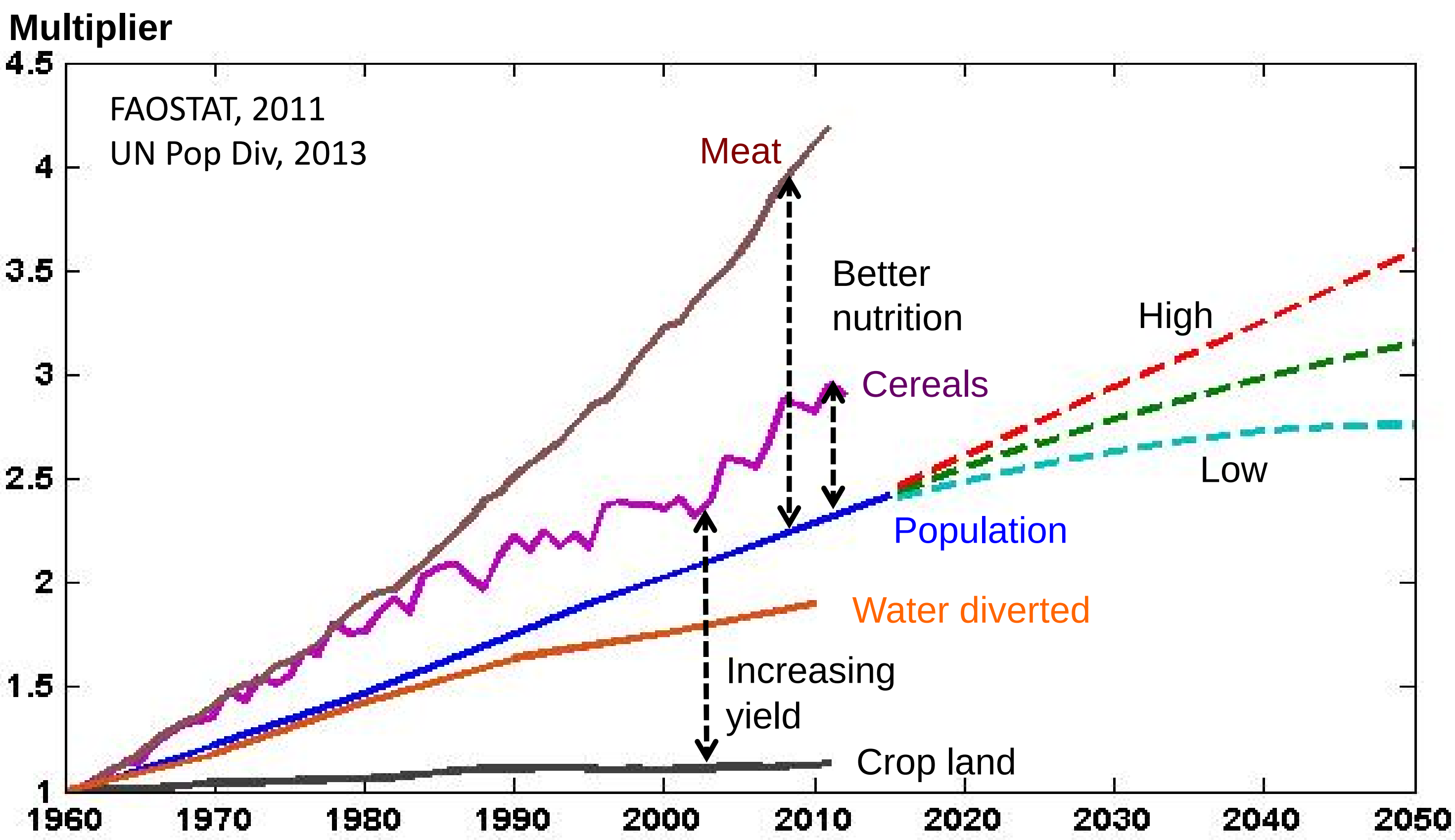
Land, water, nutrients

Environmental impacts

Assessing management options

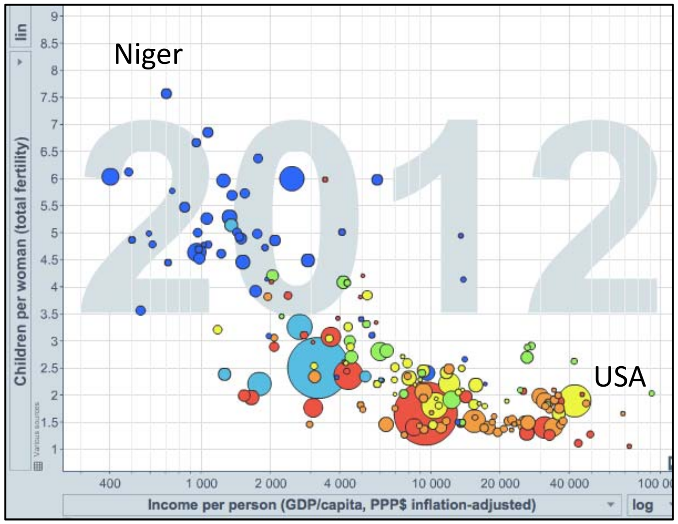
Demand
Population, diet, losses

Recent & projected demand



Production has grown faster than population and resource use.

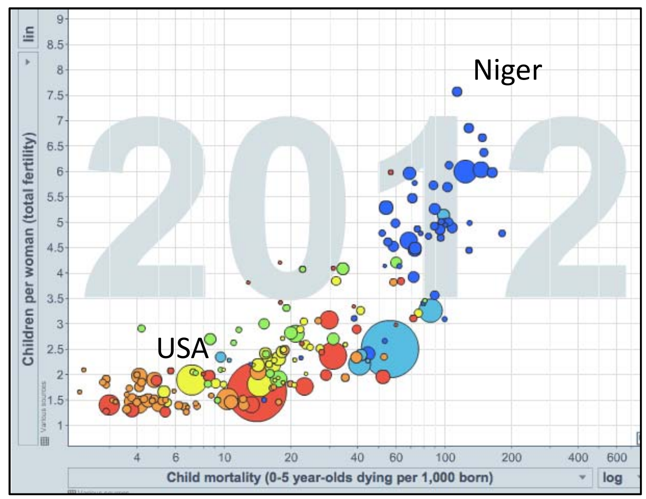
Influences on fertility – National scale



Dramatic decrease in children per woman with income

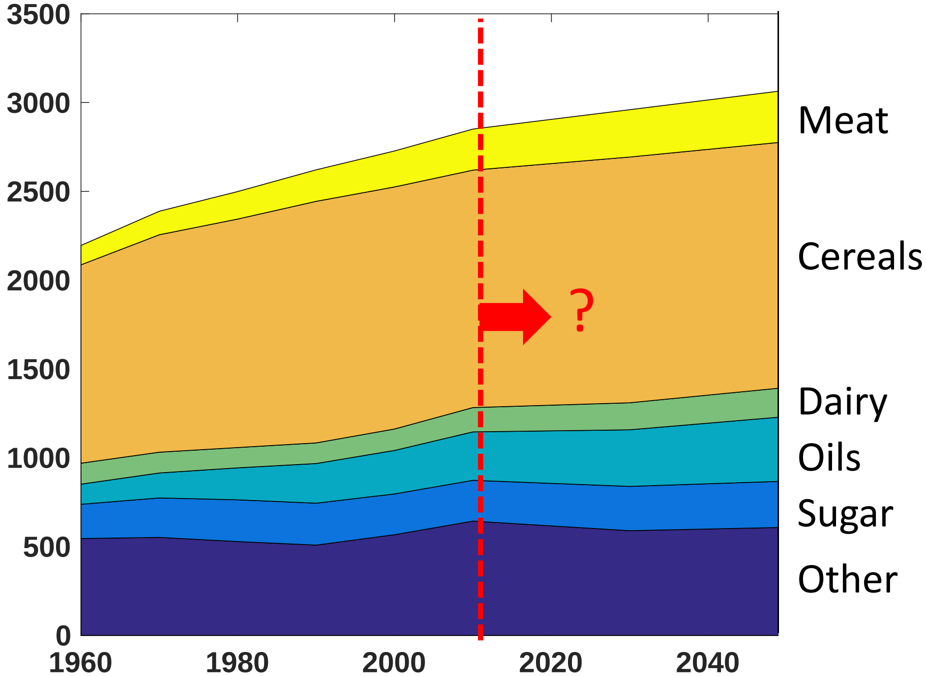
Gapminder, 2014

Dramatic increase with child mortality



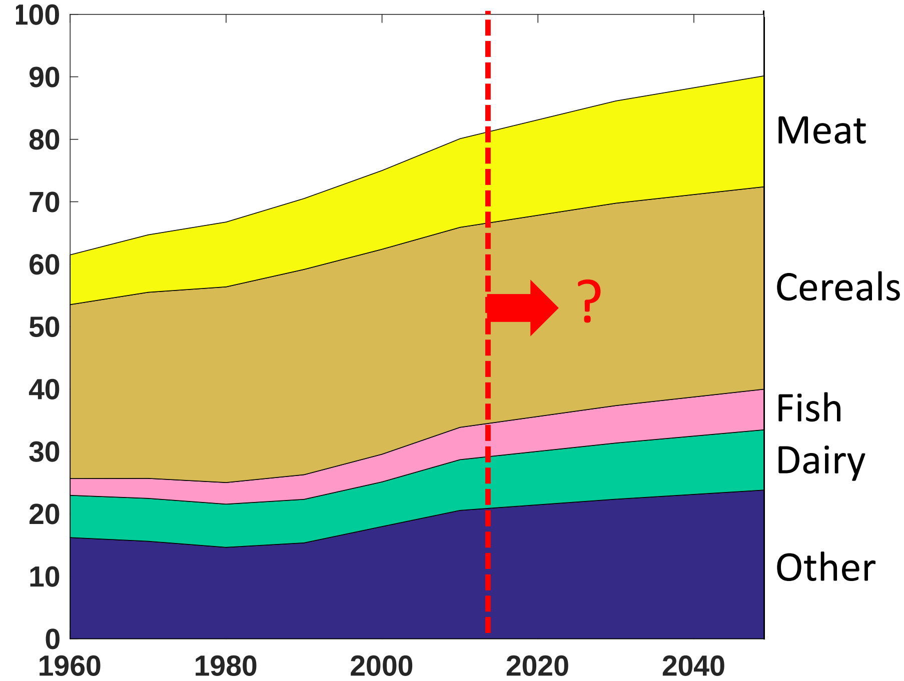
Trends in global average energy and protein

Calories – Meat, oil up



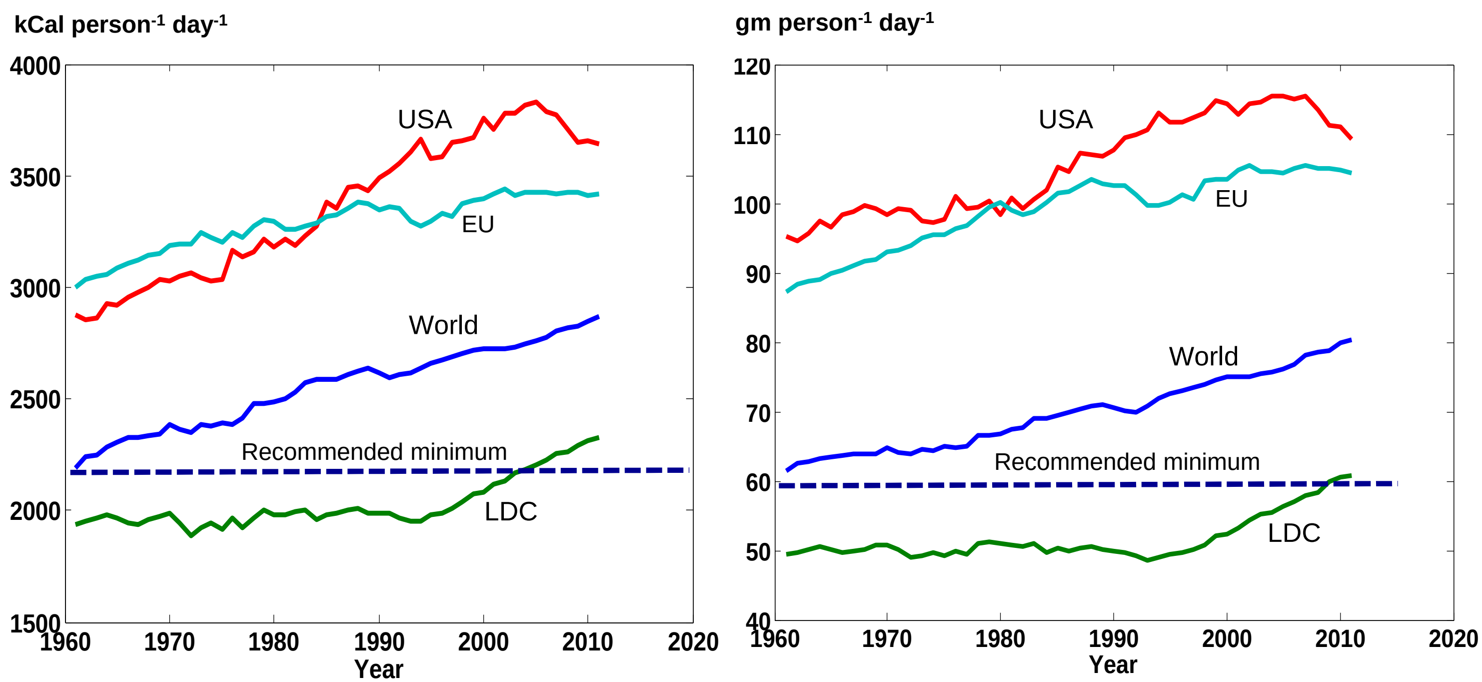
FAO, 2015
Alexandratos, 2012

Protein – Meat, dairy, fish up



What will future diets look like?

Regional comparison



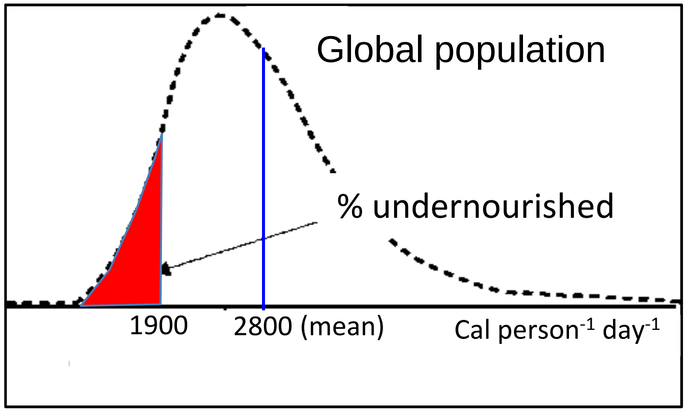
FAOSTAT, 2011

Overall, people are eating more.

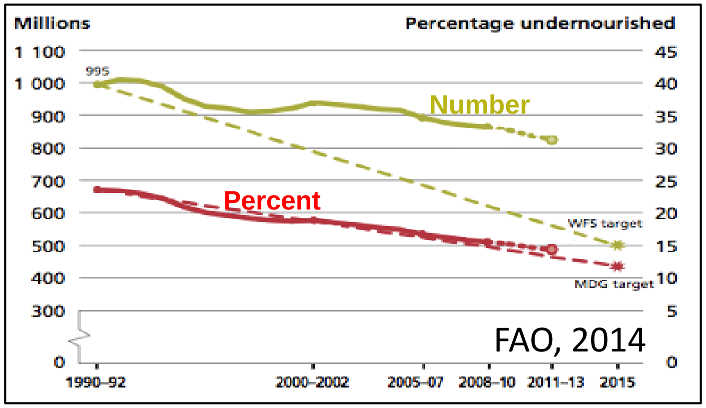
Average calorie & protein intake above minimal values

But … there is great disparity

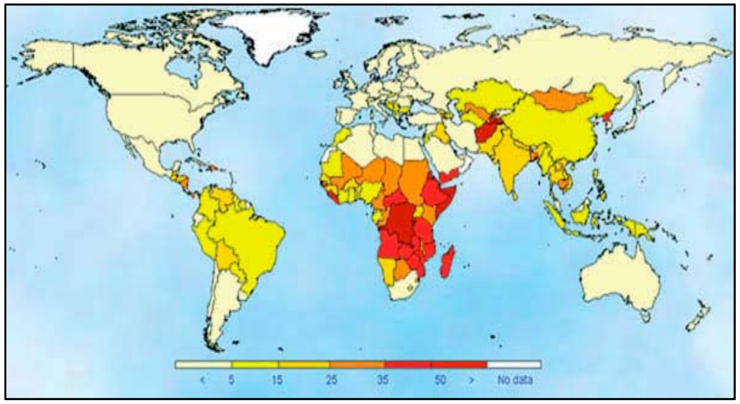
Undernourishment



Calorie distribution



Calorie trends



30-40% undernourished
(E. Africa, Haiti)

Critical micronutrient deficiencies: Iron, VitA, Iodine

Estimating 2050 global calorie demand

2010 Population: 6.9 billion
Calories $person^{-1}$ day^{-1}: 2900
Loss: 1.30

2050 Low -- Optimistic:

Demand = (2010 Demand) (Pop Δ)(Calorie Δ)(Loss Δ)

1.1X 1X (8.3 /6.9)(2900/2900)(1.20/1.30)

2050 Medium -- Neutral:

Demand = (2010 Demand) (Pop Δ)(Calorie Δ)(Loss Δ)

1.5X 1X (9.6 /6.9)(3200/2900)(1.25/1.30)

2050 High -- Pessimistic:

Demand = (2010 Demand) (Pop Δ)(Calorie Δ)(Loss Δ)

2.0X 1X (10.9 /6.9)(3600/2900)(1.30/1.30)

Resources for production
Land, water, nutrients
How much is available?

Satisfying projected food demands

Food demand: Increase by at least 1.5X … perhaps 2X

Resources needed:

$$Cropland = \frac{Production}{Yield} \qquad Water = \frac{Production}{WUE} \qquad Nutrient = \frac{Production}{NUE}$$

To satisfy 1.5X demand we can ….

- Use 1.5X more land, water, nutrients, pesticides
- Improve yield and efficiency by 1.5X
- Some combination (most likely)

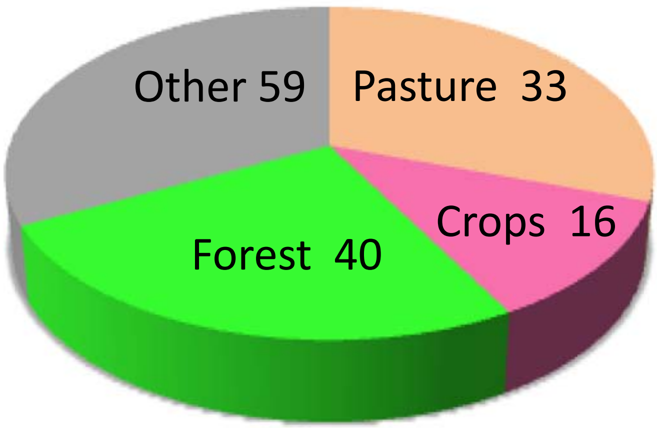
But is this sustainable?

Will environmental impacts threaten the resources needed to grow food?

Global land available?

Recent global land use

FAO (2010)



Total ice-free land:
130 10^6 km^2

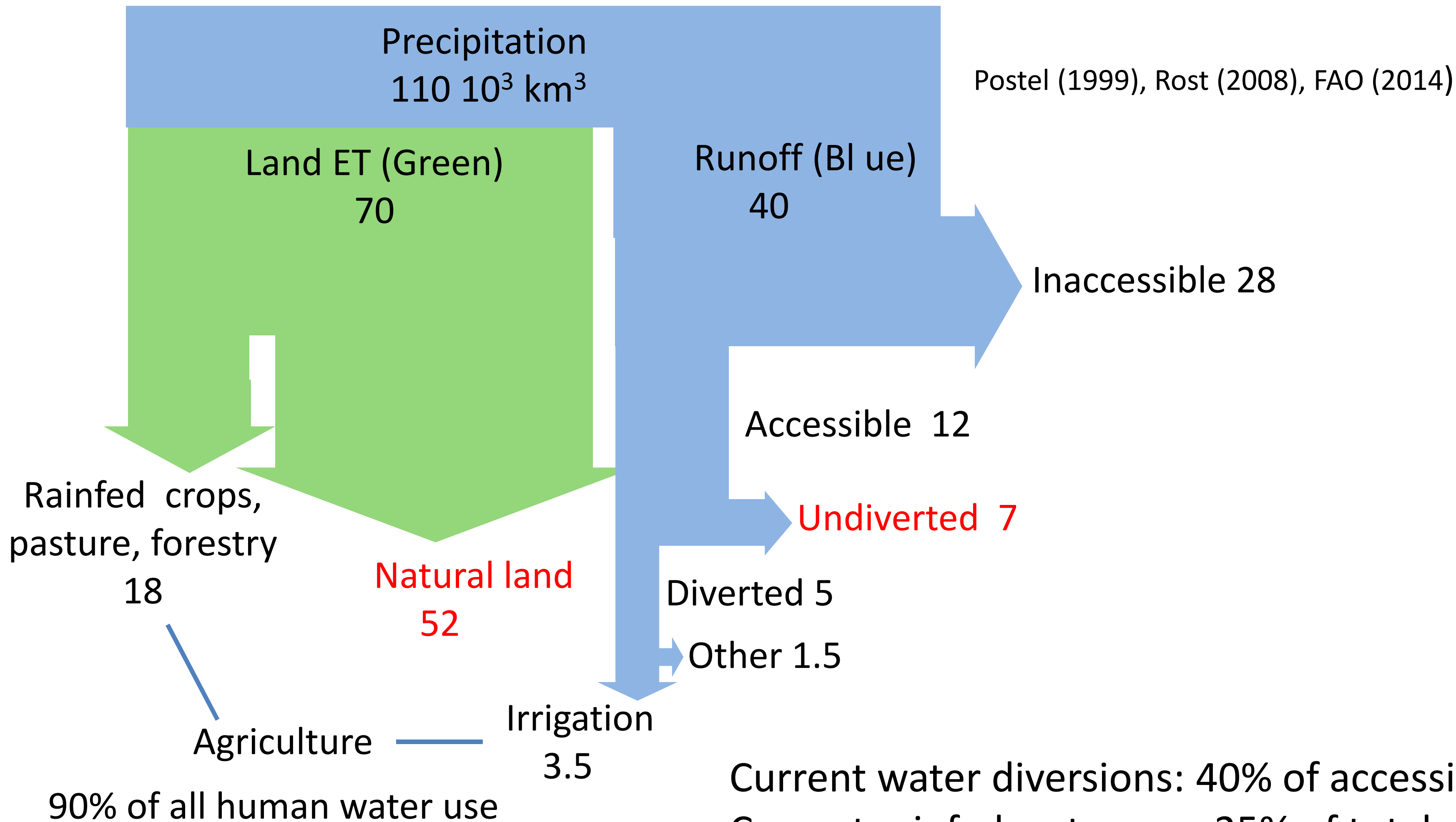
Land available for crops without deforestation:

Unprotected sparsely populated grassland: only 4 10^6 km^2 !

Primarily South American & African savannahs

Lambin & Meyfroid (2011)

Global water available?

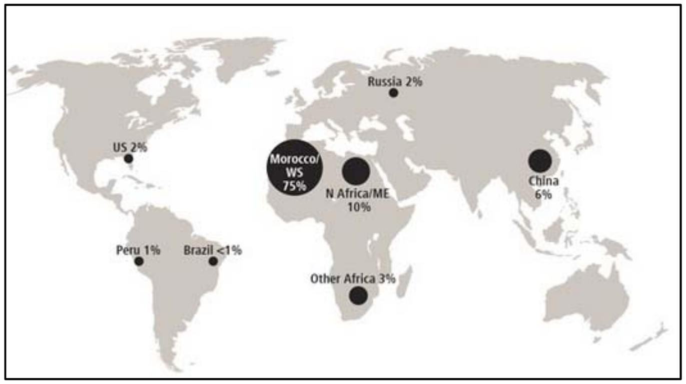


Current water diversions: 40% of accessible
Current rainfed water use: 25% of total
But there are other demands .....

Global nutrients available?

Nitrogen:

Atmospheric N2 is essentially unlimited ….
But Haber process ~1-2% of global energy use > wind +PV



Fixen (2009), USGS (2009)

Rock phosphate:

Limited mined sources … reserves are perhaps 300 years].
Agriculture disperses concentrated P

Potash (potassium):

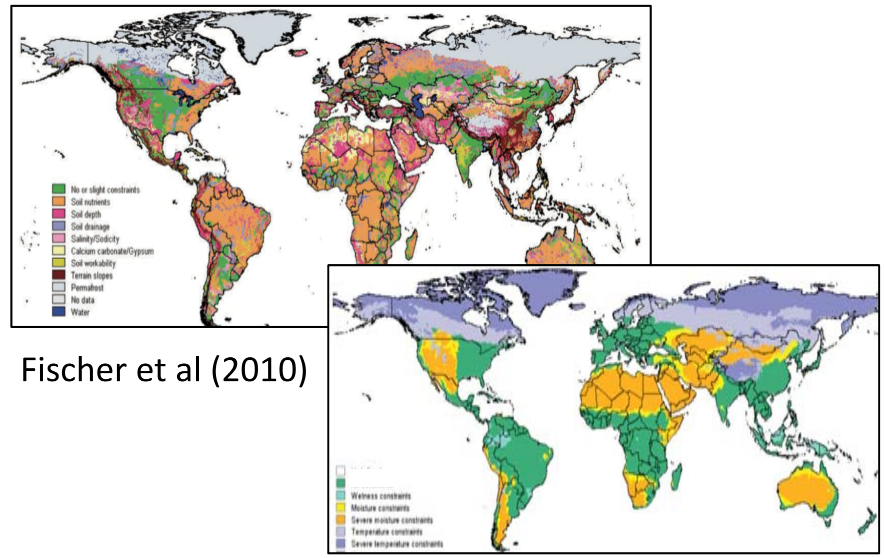
Limited mined sources … reserves are perhaps >300 years

Combining land, water, nutrients, ….

Consider all factors relevant to crop production:

- Soil properties, nutrients
- Terrain
- Water availability
- Temperature, other met variables
- Crop type
- (Population density, infrastructure)

Favorable Soil/terrain



Fischer et al (2010)

Favorable climate

Simplified estimates … Global land suitable for at least one crop:

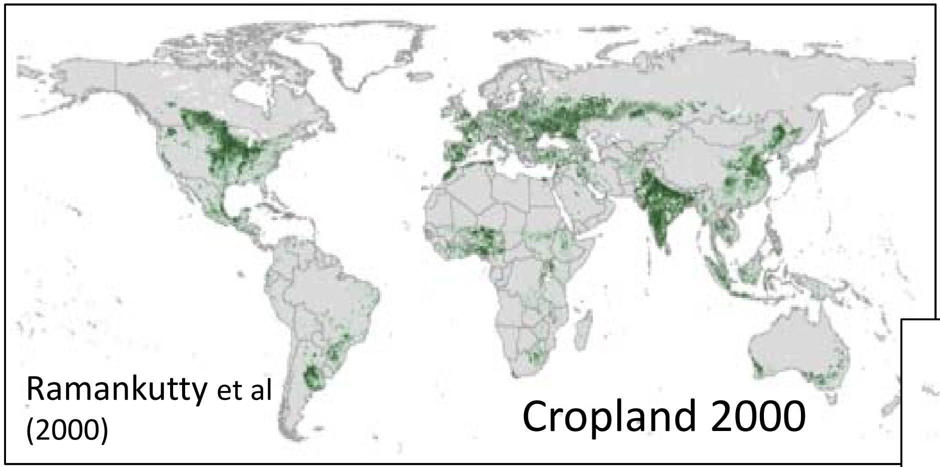
- Ramankutty Et al. (2000): 41 10^6 km^2
- IIASA/FAO (2000): 30
- Lambin & Meyfroid (2011): 40

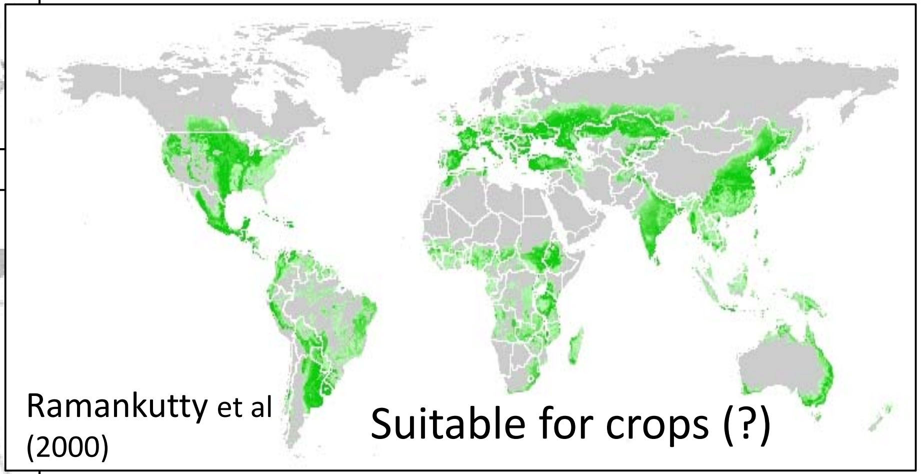
Compare to current cropland: 16-18 10^6 km^2

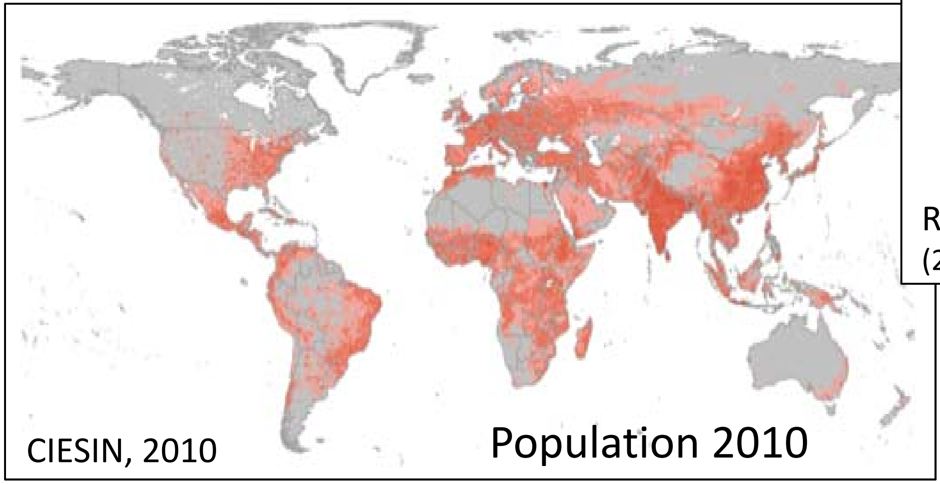
Spatial distribution -- Where can we grow food?

Current cropland is in the north while population growth is in the south.

Land expansion in the tropics?

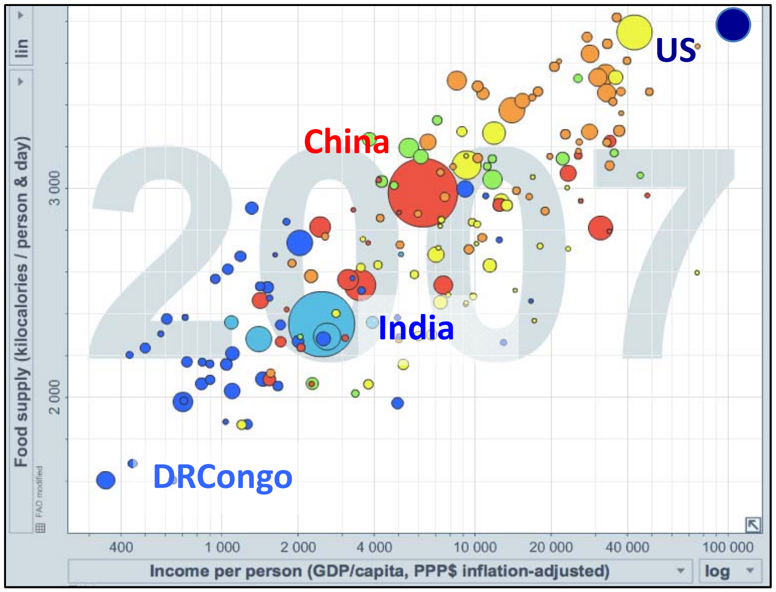


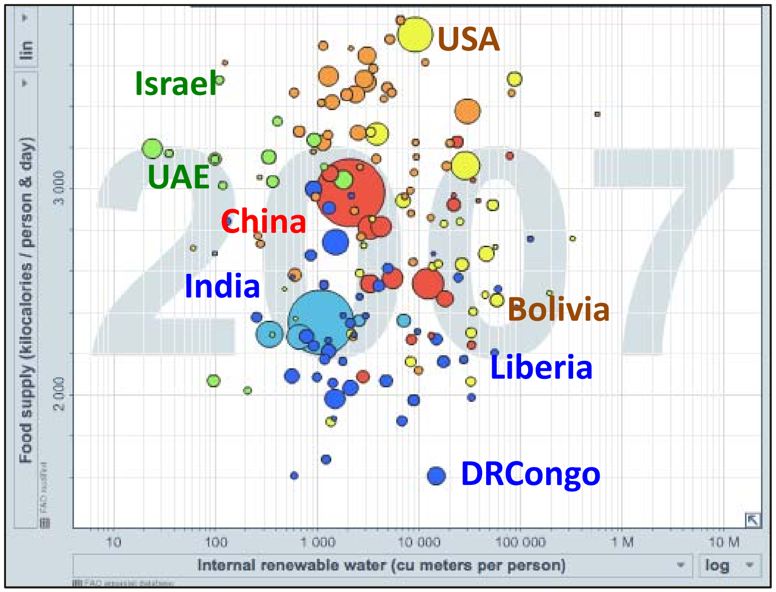




Connections between water and food scarcity

Gapminder, 2014





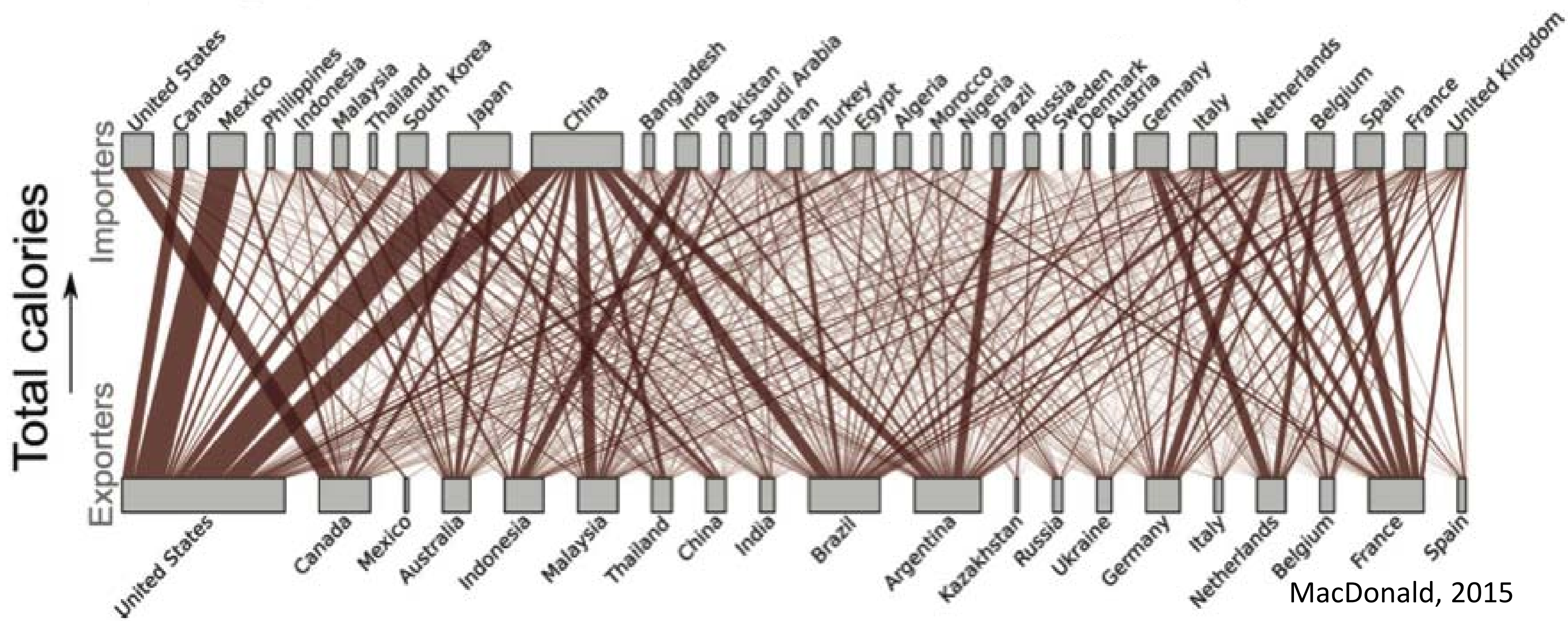
Calorie intake correlates strongly with income …..

But not with water availability

Richer countries can import water by buying food

Some poor countries have insufficient food production even if they have water

Global Food Trade



MacDonald, 2015

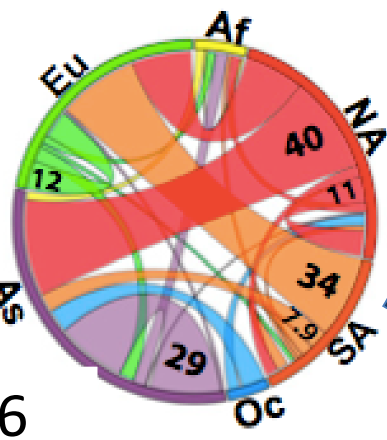
Food & fertilizer trade redistribute resources … land, water, nutrients

20% of global calorie production is imported/exported

Water Implications of Food Trade

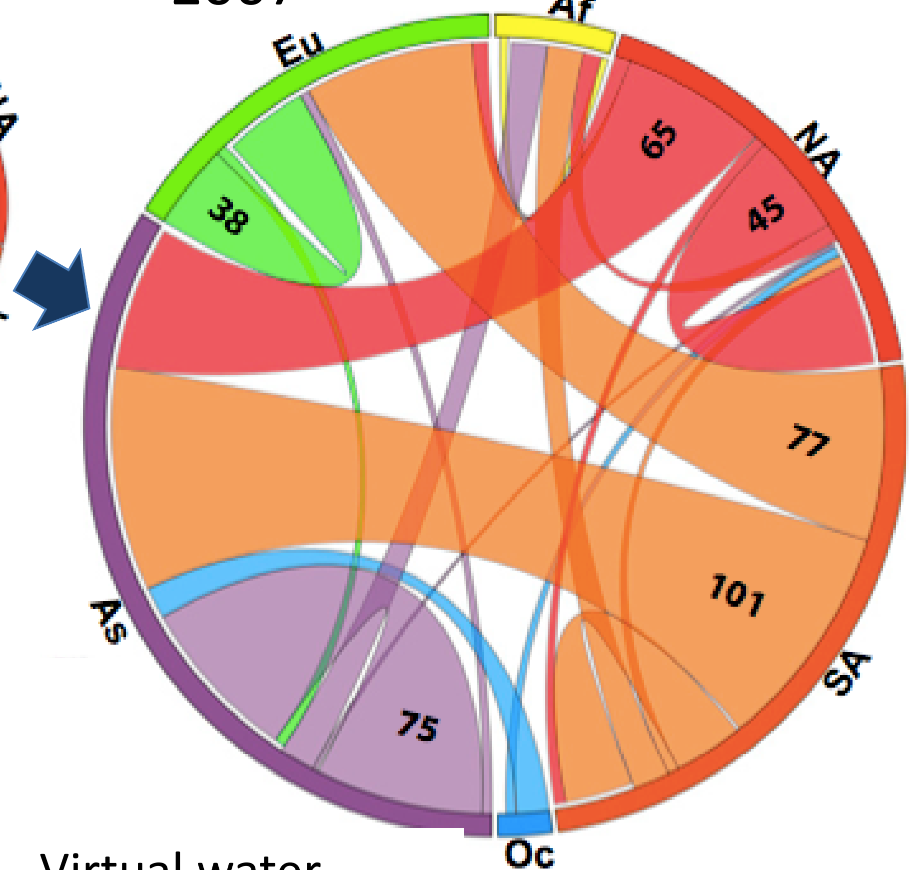
Food trade redistributes water … “virtual water”

2007



1986

Dalin et al, 2012



Virtual water transfers km^3

Environmental impacts of agriculture

Environmental impacts – Now and in the future

Irrigation

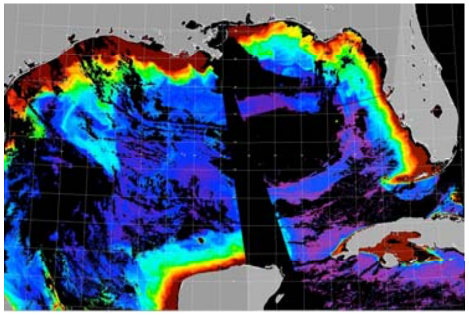
- Surface & groundwater depletion
- Riparian habitat change (wetlands, dams, …)
- Salination

Pesticides

- Human health effects
- Ecosystem changes (perhaps counterproductive)

Nutrient enhancement

- GHG emissions
- Energy consumption (e.g. Haber)
- Major changes in biogeochemical cycles
- Nutrient accumulation … algal blooms, … diversity loss



Cropland expansion

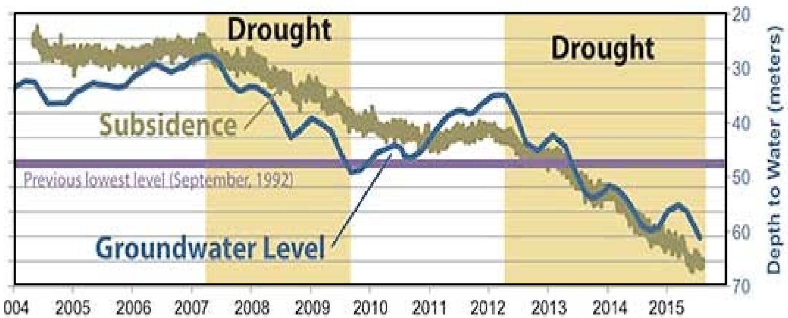
- Habitat change/loss of diversity
- Soil degradation, erosion/sedimentation,
- GHG emissions

Are there environmentally sustainable options?

Environmental sustainability – Is it really so hard to define?

Groundwater depletion is a good example:

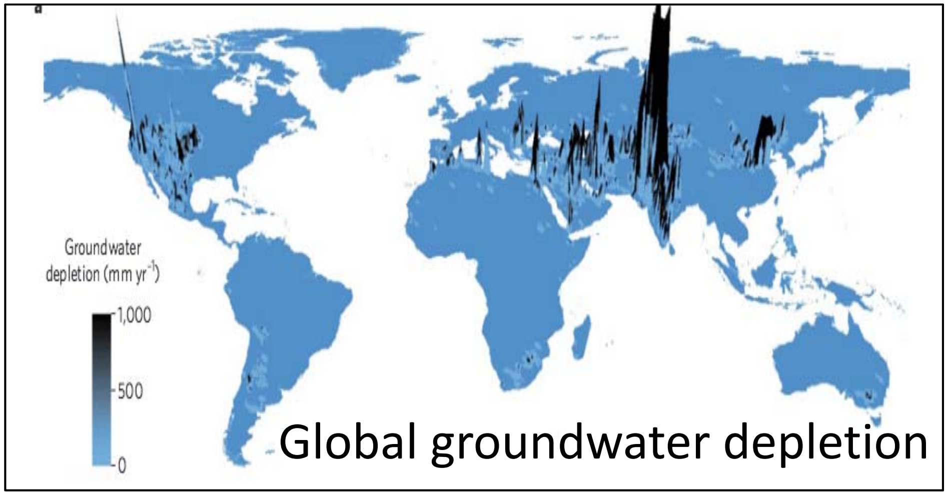
Δ Storage = Recharge - Pumpage



USGS, California Central Valley

A useful indicator of sustainability:
States & fluxes are in a dynamic steady state (no long term trends)

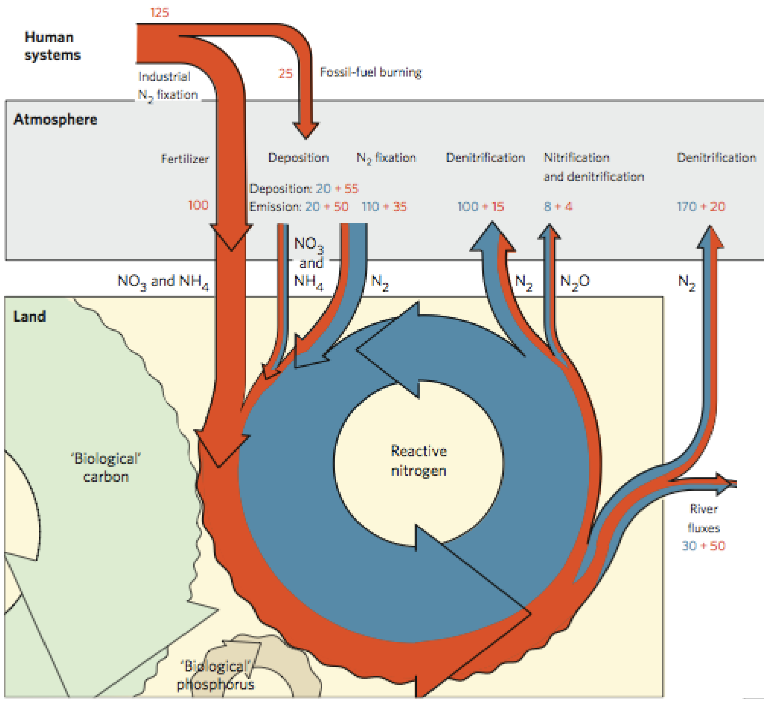
Hartig & Gleeson, 2012



Global groundwater depletion

Also applies to salt, nutrients, ecosystems, soil quality ...

Nitrogen and agriculture

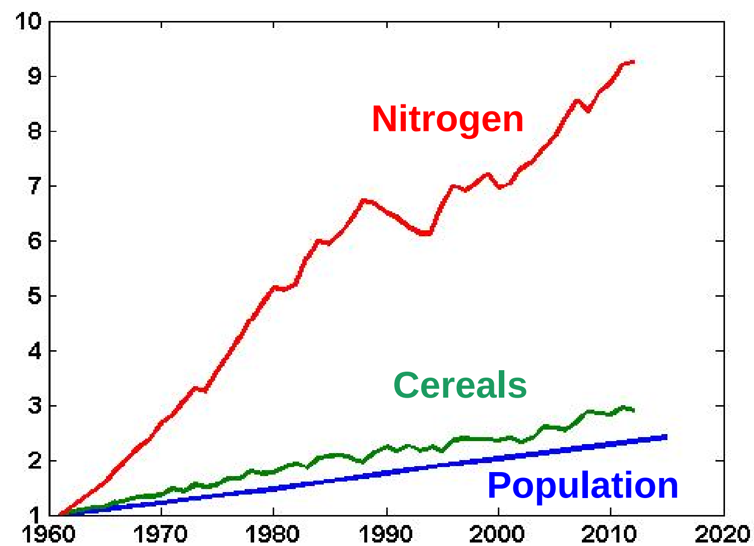


Gruber & Galloway, 2008

Nitrogen: DNA,RNA, Protein

$N_2 \rightarrow N_r$ Conversion to reactive form

Synthetic nitrogen fixation in early 20th century ~ 1/3 human protein



Terrestrial N fixation :

Natural: 110 Human: 135 10^6 tons yr^{-1}

Large amount of N_r recycled before $N_r \rightarrow N_2$

Assessing management options
Crop production, cost, environmental impacts

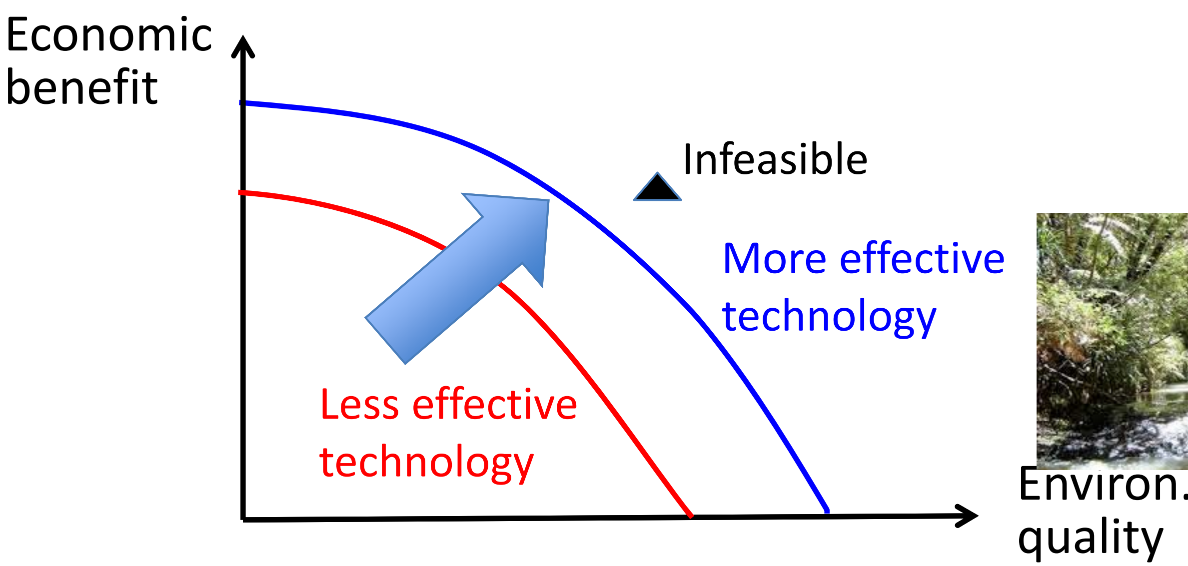
A multi-objective assessment perspective

Agricultural management as a multiobjective optimization problem :

Maximize: Economic benefit **and** Environmental quality

Subject to the constraints:

- Meet reasonable demand for nutritious food, equitable distribution
- Satisfy physical and resource constraints that relate management options to production, cost, and environmental variables



Some ways to group management options

Green Revolution II:

Raise yield, increase nutrient & water inputs, invest in precision agriculture to reduce resource demands & environmental impacts, continually adapt pest control, “land sparing”, larger farms ?

Agroecology:

Scale up low-input methods, emphasize biodiversity and soil quality, integrate livestock and cropping, invest in new equipment to improve yields & reduce labor, avoid pesticides, “land sharing”, smaller farms ?

Selective breeding, transgenics, conservation tillage:

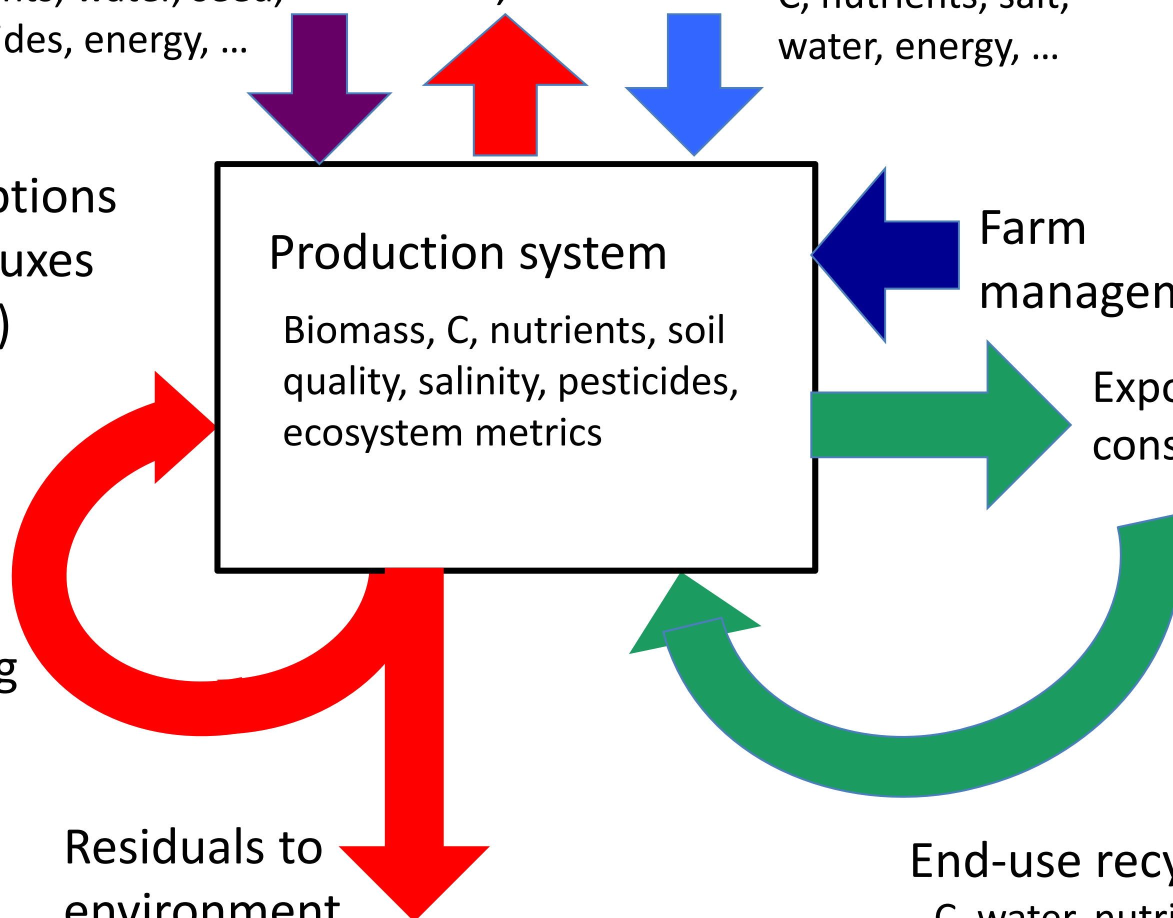
Could these be applied to either model?

How can we evaluate production, cost, environmental effects of a mix of options?

Analytical framework: mass & energy balance

Relate management options & impacts to system fluxes & states (sustainability)

Apply at farm, district & larger scales



Data or Models? Both !

Data fusion techniques can combine incomplete data & imperfect models

$$\underset{\text{Over all states \& fluxes}}{\textit{Minimize}} \left[\frac{\text{Datamisfit}}{\text{Model 1}} + \frac{\text{Datamisfit}}{\text{Model 2}} + \ldots \right]$$

Subject to the constraints:

- Mass & energy balances
- Resource limitations

Use best available crop/farm models (not just one) with best available data to assess:

Production, cost, environmental impacts

Goal is not to predict but to better understand the performance of different options.

A secure food supply for 10 billion people in 2050 ?

We have sufficient resources to meet reasonable demand for food.

The real question is whether higher production agriculture will be able to sustain these resources.

We have a range of options but (often) poor understanding of their performance & impacts.

We need better data & more experiments, guided by a flexible conceptual framework that connects production, cost, and environment.