Fall Term – 2013
Woodrow Wilson School 585b

Living in a Greenhouse: Technology and Policy

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Phil Hannam, AI

Week Eight Supplementary material:
November 8, 2013

1. **Kanter on food, N2O, Guest, 2012**
2. **Creutzig on biocarbon, Guest, 2012**

David Kanter
WWS 585b – November 28, 2012

Agriculture and Climate Change

Impacts, contributions and implications for feeding 9 billion people

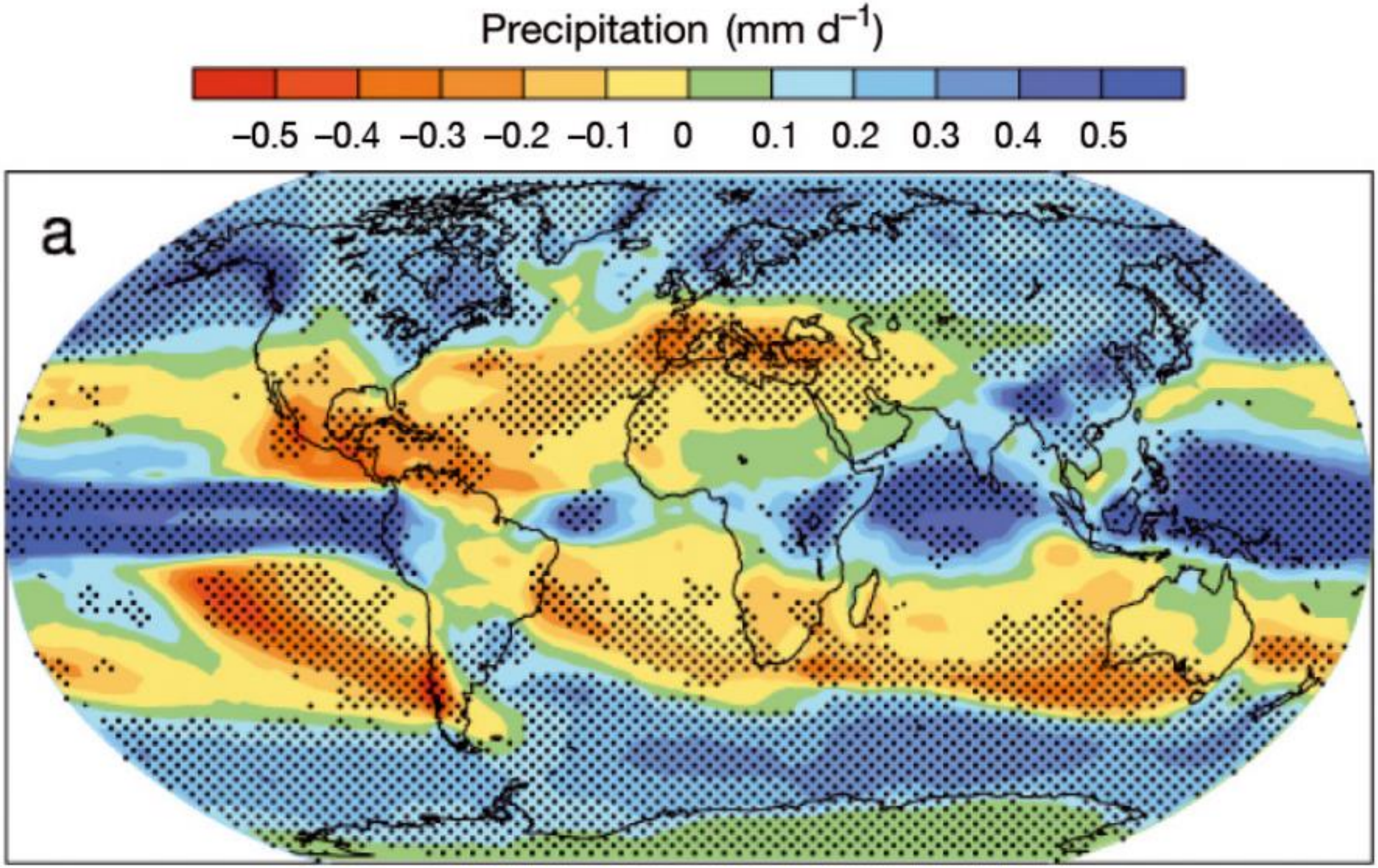
Outline

- Climate change → Agriculture
- Agriculture → Climate Change
- Deep dive – Agricultural N_2O
- Implications for global food security
- Diverse areas of overlap:
  - Geoengineering
  - Immigration
  - GMOs

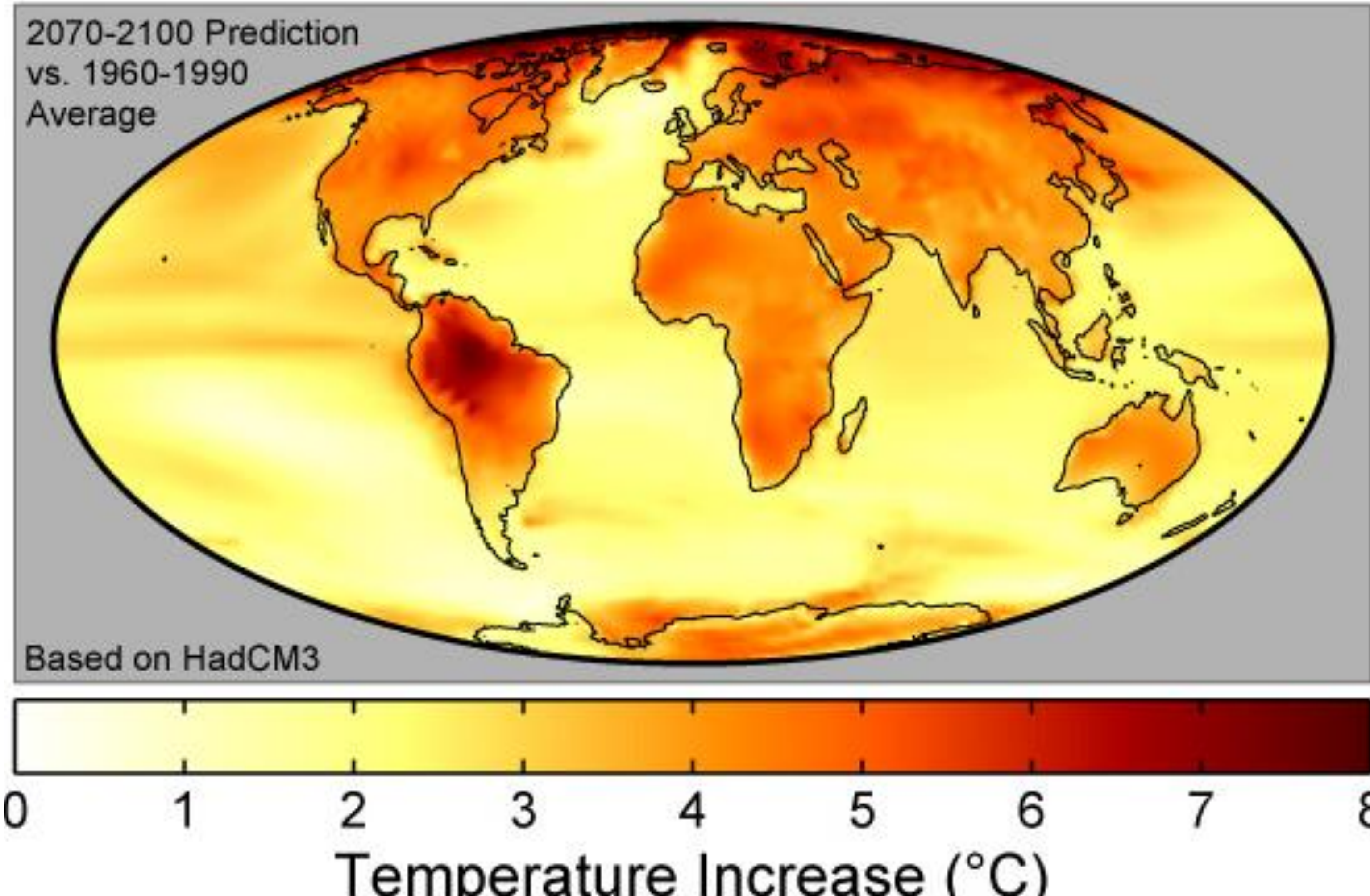
Climate change → Agriculture

- Shifting precipitation patterns
- Temperature increases
- Sea level rise
- CO_2 fertilization
- Tropospheric ozone
- Impacts vary, with the poorest most vulnerable

Precipitation

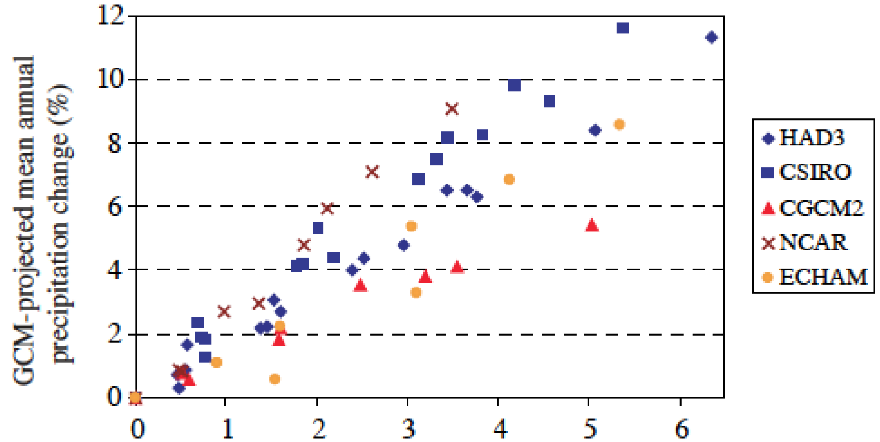


Temperature

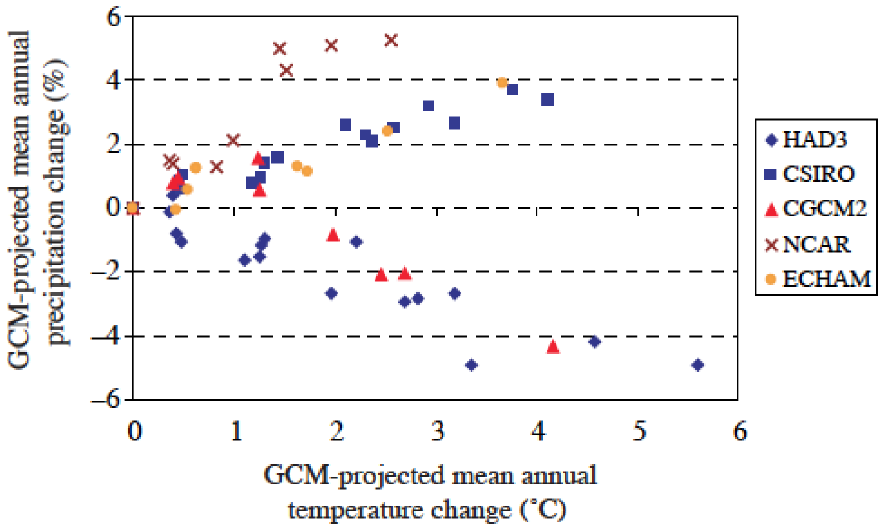


Linked – Temp. & precip.

Developed countries

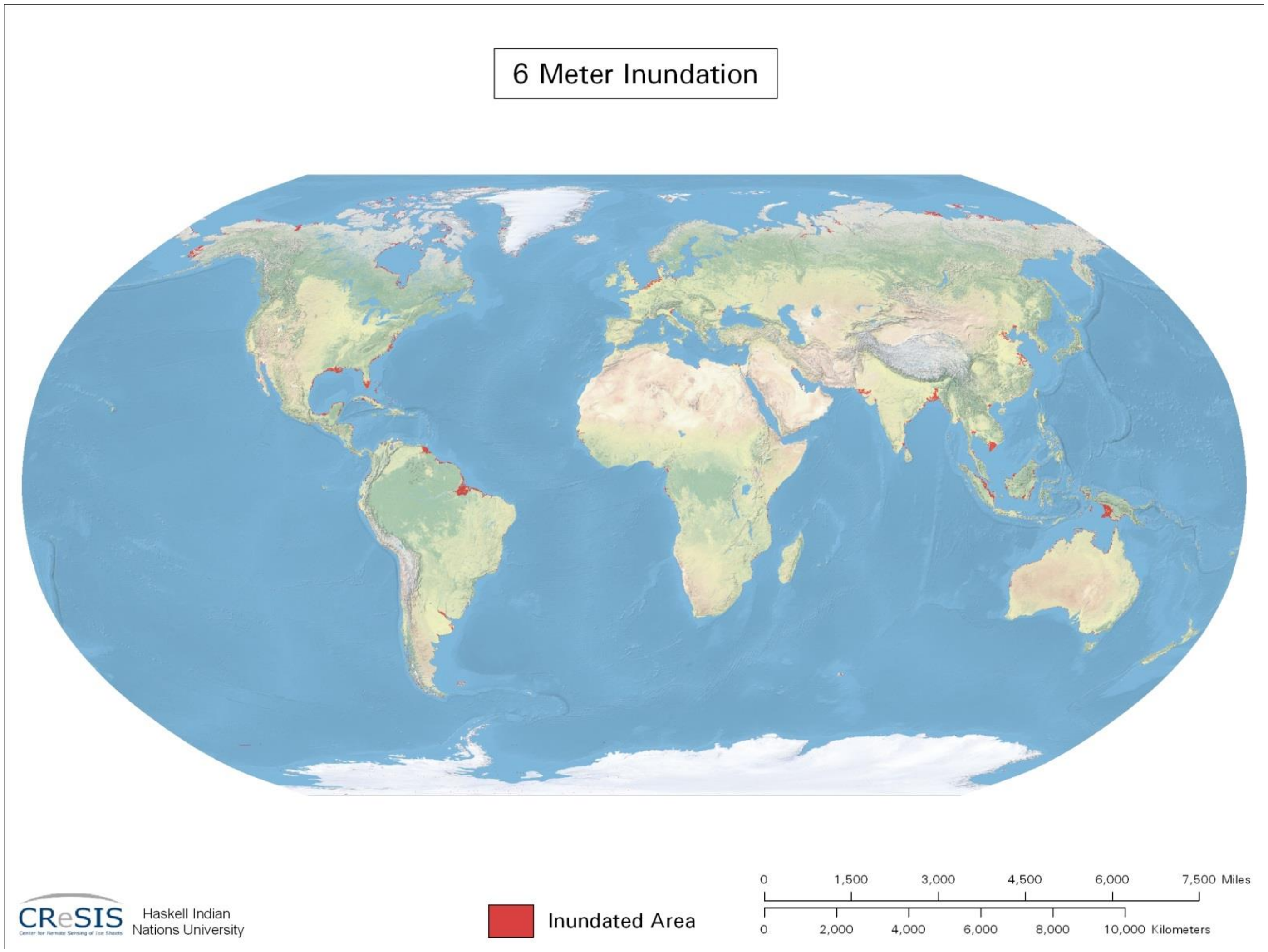


Developing countries



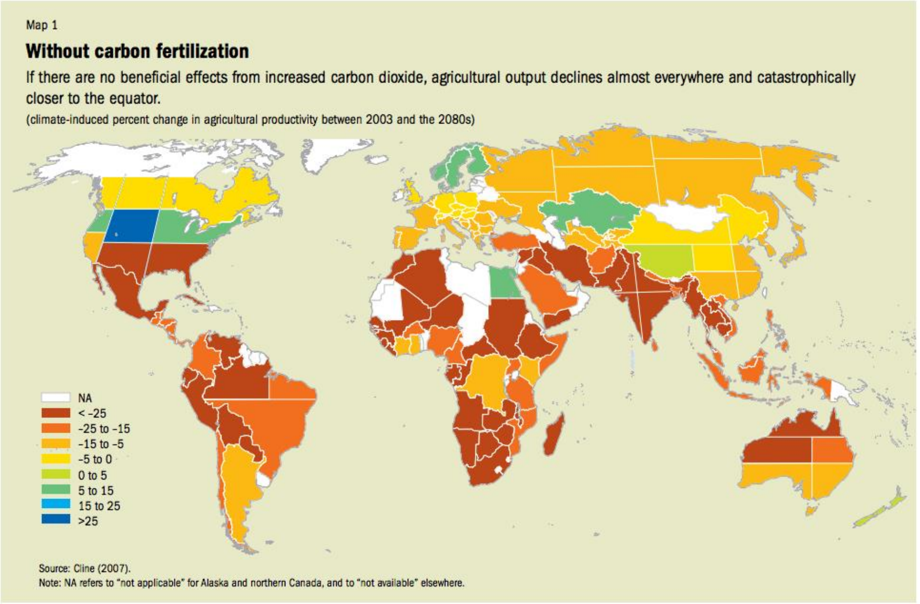
Fisher et al. 2005

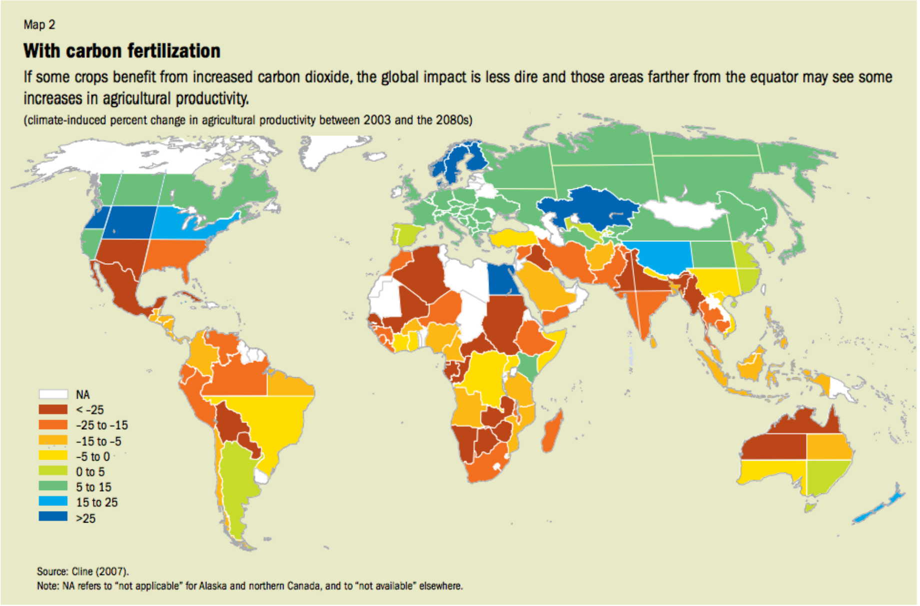
Sea level rise



https://www.cresis.ku.edu/data/sea-level-rise-maps

CO_2 fertilization



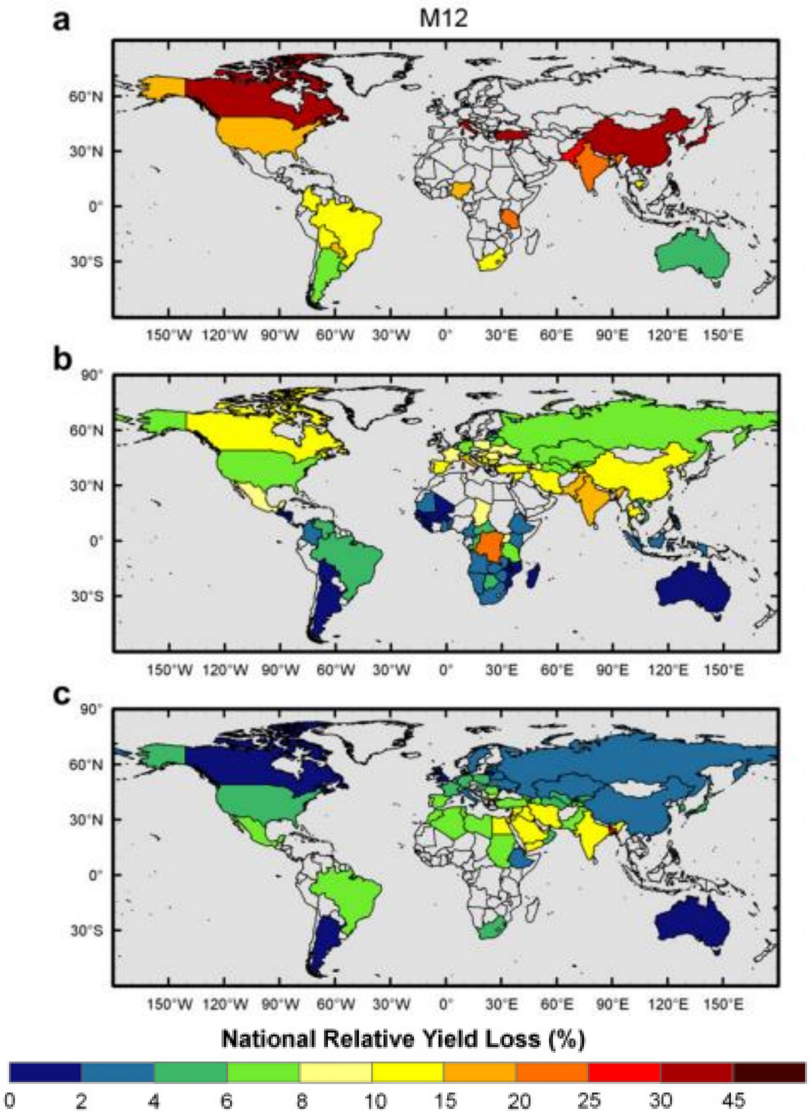


Tropospheric ozone

Soybean

Maize

Wheat



Using IPCC SRES high emissions (A2) scenario, 2030 relative yield loss compared to zero O_3 damage:

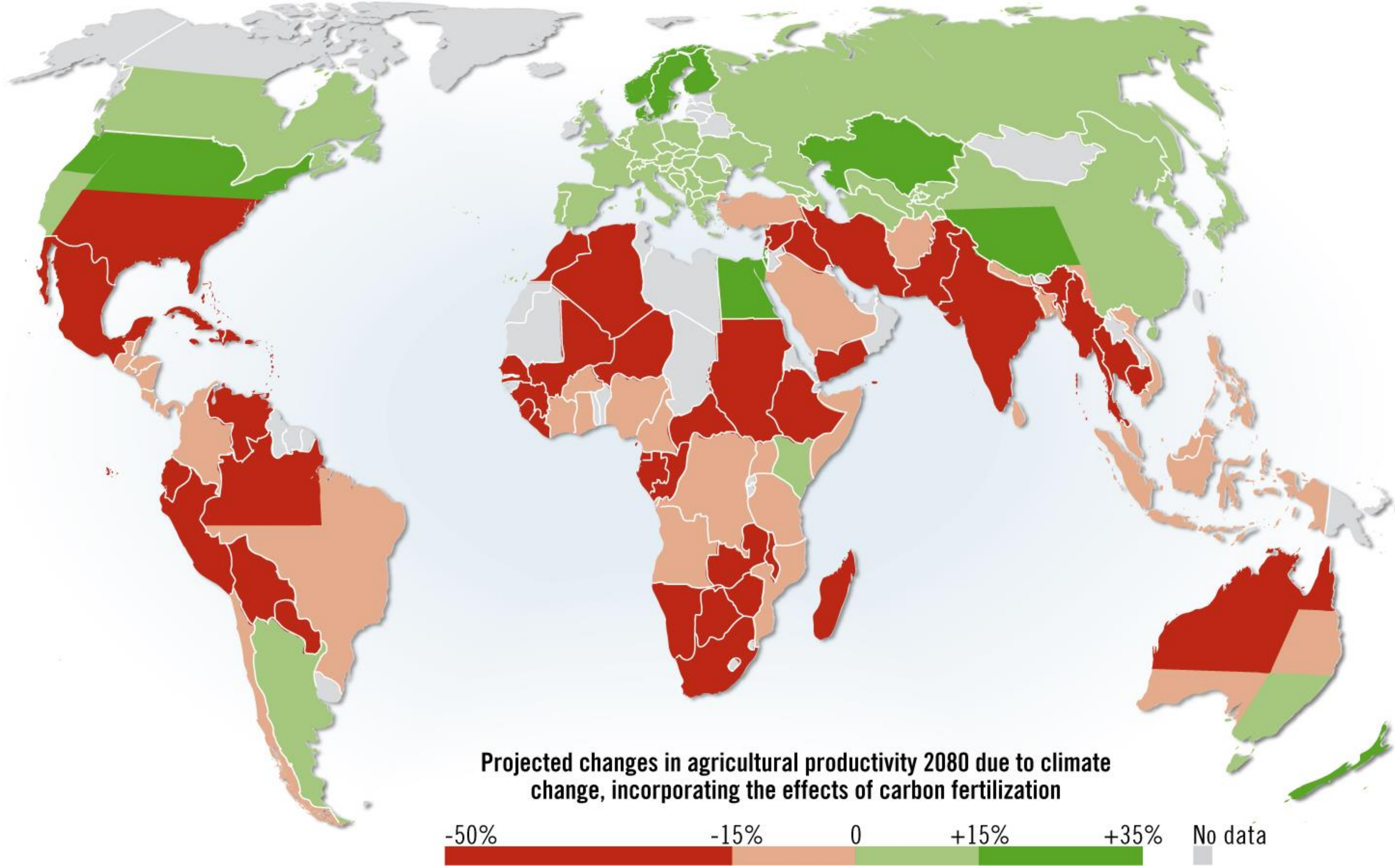
- Wheat: 5.4-26%,
- Soybean : 15-19%
- Maize: 4.4-8.7%
- Total losses: $17-35 billion USD2000 annually

Using SRES low emissions (B1) scenario, 2030 relative yield loss:

- Wheat: 4.0-17%
- Soybean: 9.5-15%
- Maize: 2.5-6.0%
- Total losses: $12-21 billion annually

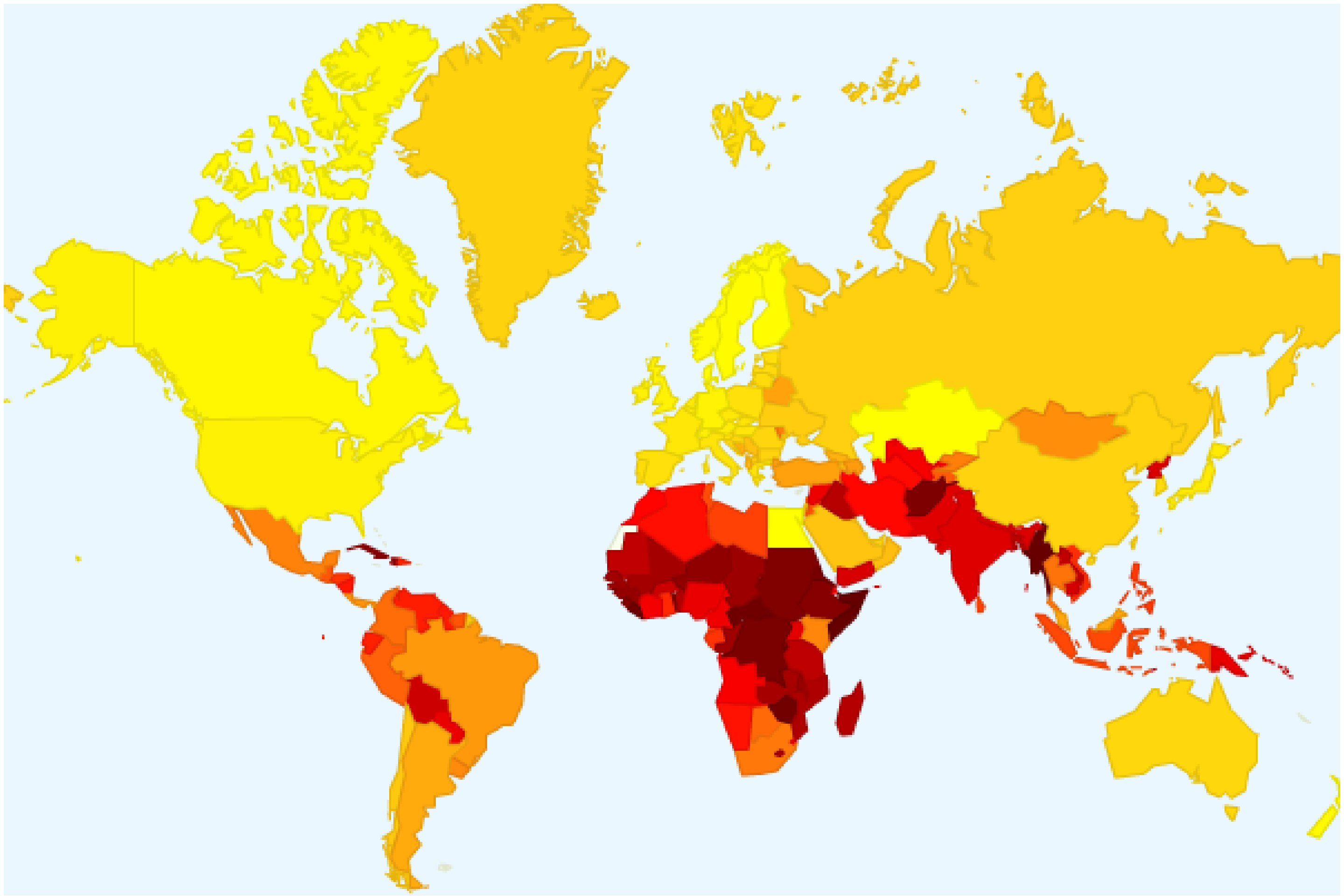
Avnery et al. 2011

Impacts will vary



UNEP/GRID-Arendahl, 2007

Poorest most vulnerable



Rank 1 ▇▇▇▇▇▇ 169

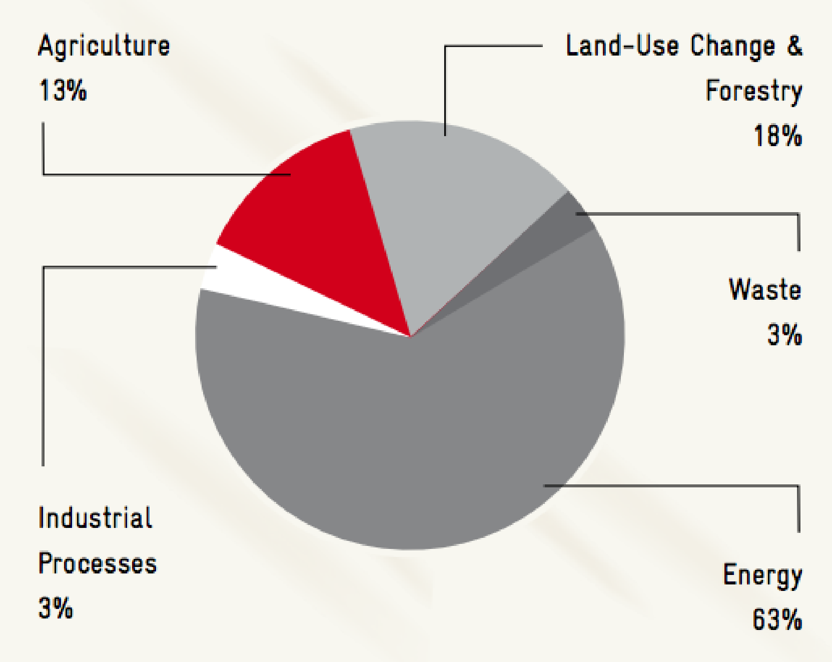
Agricultural Productivity Loss Overall Vulnerability:
Physical Impacts Adjusted For Coping Ability

1. Somalia
2. Myanmar
3. Burundi
4. Liberia
5. Central African Republic
6. Zimbabwe
7. Eritrea
8. Guinea-Bissau
9. Congo, Dem. Rep.
10. Afghanistan
11. Sudan
12. Sierra Leone
13. Ethiopia
14. Togo
15. Cuba
16. Rwanda
17. Niger
18. Guinea
19. Haiti
20. Malawi

Center for Global Development – Mapping the Impacts of Climate Change

Agriculture → Climate Change

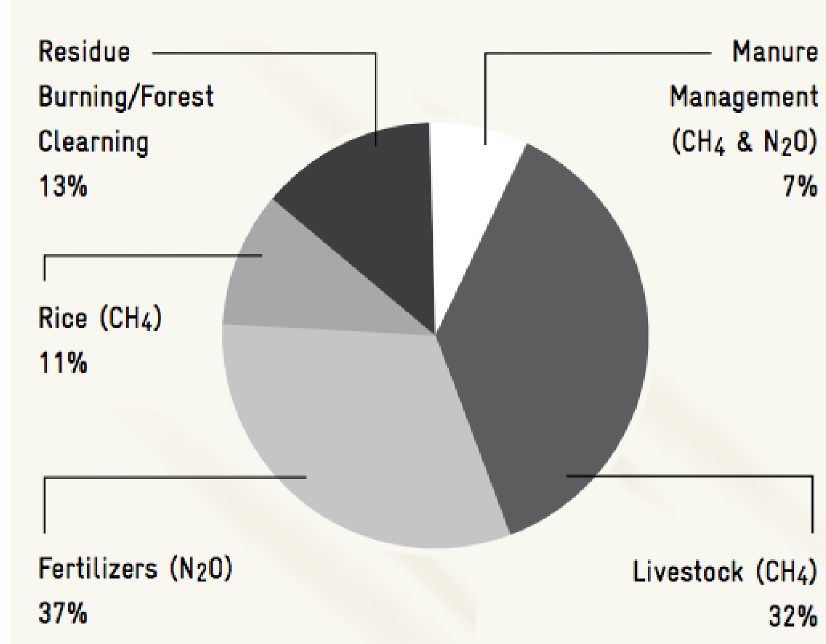
Fig. 1



Share of global GHG emissions by sector, year 2000

Source: Drawn from data from WRI (2008)

Fig. 2



Sources of emissions from the agricultural sector (2000)

Source: Drawn from data presented in USEPA (2006)

GTZ (2008) "Climate Change & Agriculture"

Mitigation

- Soil carbon sequestration (highest mitigation potential) e.g. conservation tillage, soil and woodland restoration…
- Nutrient management e.g. improved fertilizer use efficiency
- Livestock management e.g. better diet formulation
- Consumer behavioral changes e.g. less food wastage and meat consumption

Smil 2002; *IPCC AR4 WGIII* 2007

Adaptation

- Shift planting dates and crop varieties to match shifting climate trends
- Diversifying farm products where possible
- Improved water management e.g. expanding irrigation systems
- Increase use of climate forecasting to help farmers prepare

Howden et al. 2007

Deep dive –N_2O

- Responsible for ~ 7% of our climate impact (excluding BC)
- Sources – ½ natural, ½ antropogenic. Anthropogenic emissions have increased 40%-50% since 1860.
- Lifetime: 114 years; GWP_{100}: 298 (*IPCC* 2007)
- Recently identified as largest remaining anthropogenic threat to stratospheric ozone layer. Part of tightly coupled nitrogen cycle or 'cascade' (*Galloway et al.* 2003).

Emissions & mitigation opportunities

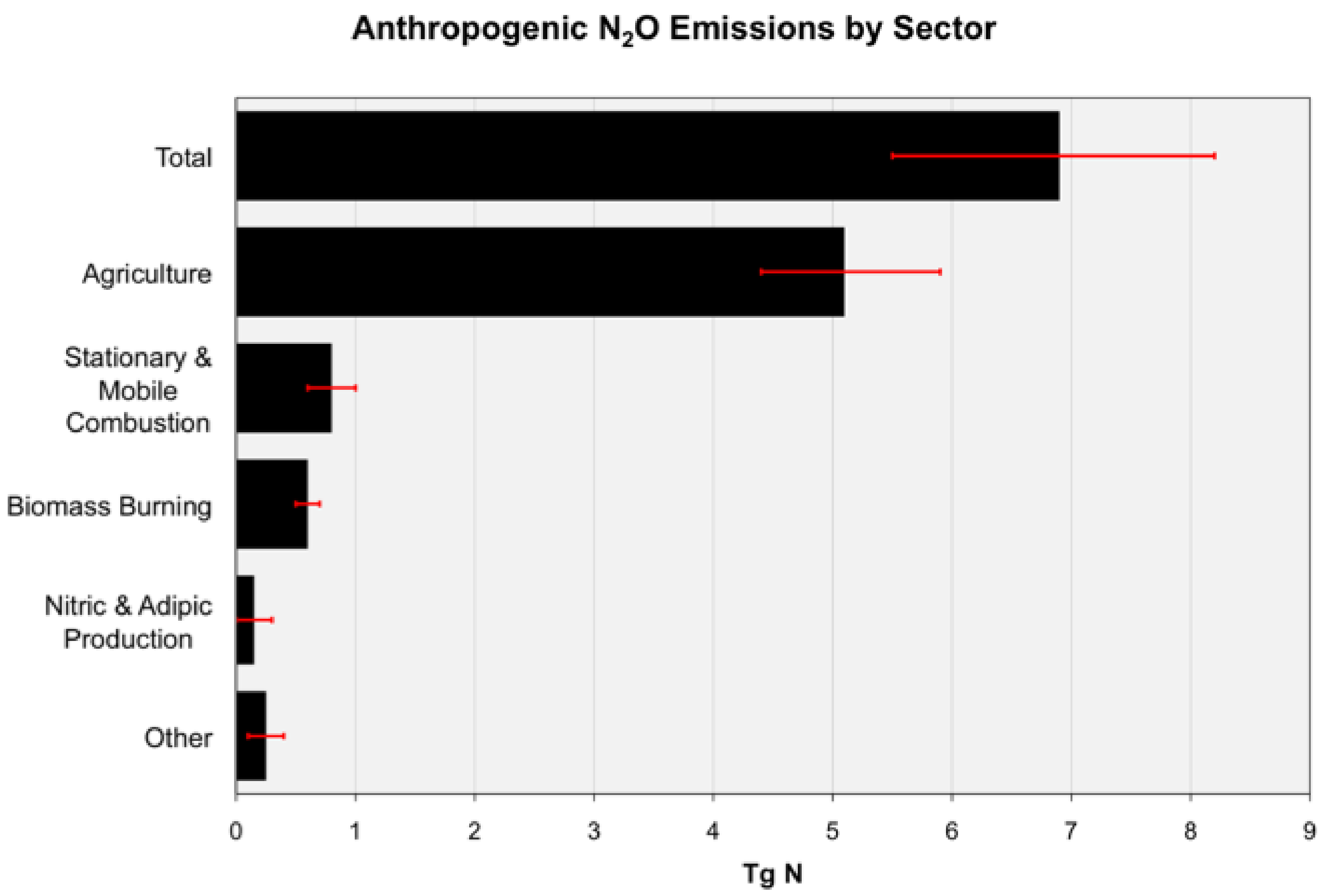


Fig. 2 Sector-by-sector contribution to anthropogenic N_2O emissions in 2005. Smaller sources such as wastewater treatment and aquaculture are included in the "Other" bar. Error bars represent the range of leading estimates, taken from USEPA (2006) (5), Davidson (2009) (8), Syakila & Kroeze (2011) (9), and Crutzen et al. (2008) (11).

Agriculture - Behavior

- Fertilizer best management practices (*Robertson & Vitousek* 2009):
  - Crop residue recycling & use of cover crops
  - Precision & split fertilizer application
  - Watershed management
  - Livestock management
  - 4Rs: Right product, right rate, right time, right place (*IFA*, 2007)
- Consumer behavioral changes – food wastage, meat consumption…

Agriculture - Technology

Technology	Mitigation potential	Current use	Mitigation co-benefits
Nitrification inhibitors	~35%	High value crops, ~12% US corn cropland	NO_3^-, NH_3, NO_x
Controlled-release fertilizer	~40%	High value crops, <1% of US corn cropland	NO_3^-, NH_3, NO_x
Genetically engineered crops/breeding	~30%	NA	NO_3^-, NH_3, NO_x

References – *Mosier et al.* (2004), *Akiyama et al.* (2009), *O'Brien & Mullins* (2009), *Shrawat et al.* (2008)

Meat production is increasing and uses fertilizer less efficiently

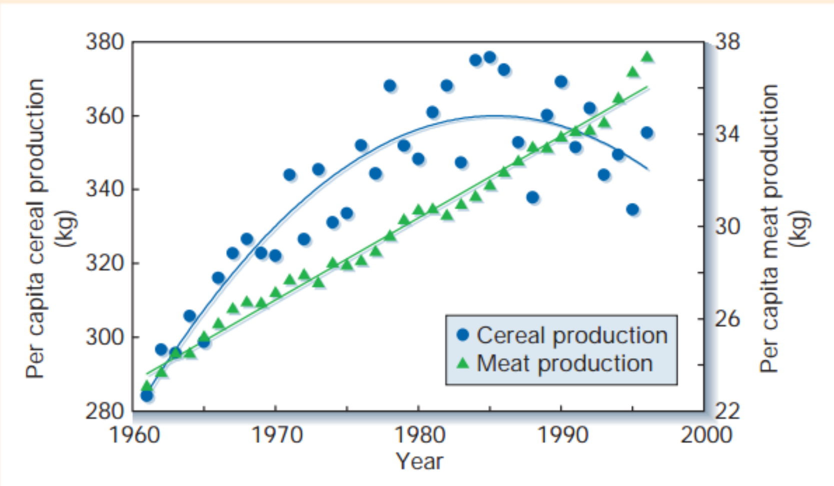
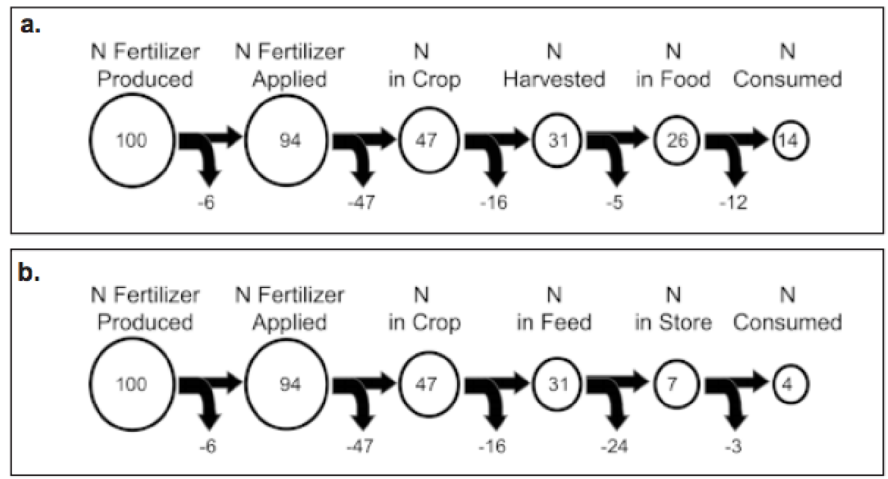


Figure 3 Long-term trends in average per capita food supply. Average annual per capita production of cereal grains and of slaughtered livestock, calculated as total global production for a given year divided by total global population for that year[2].

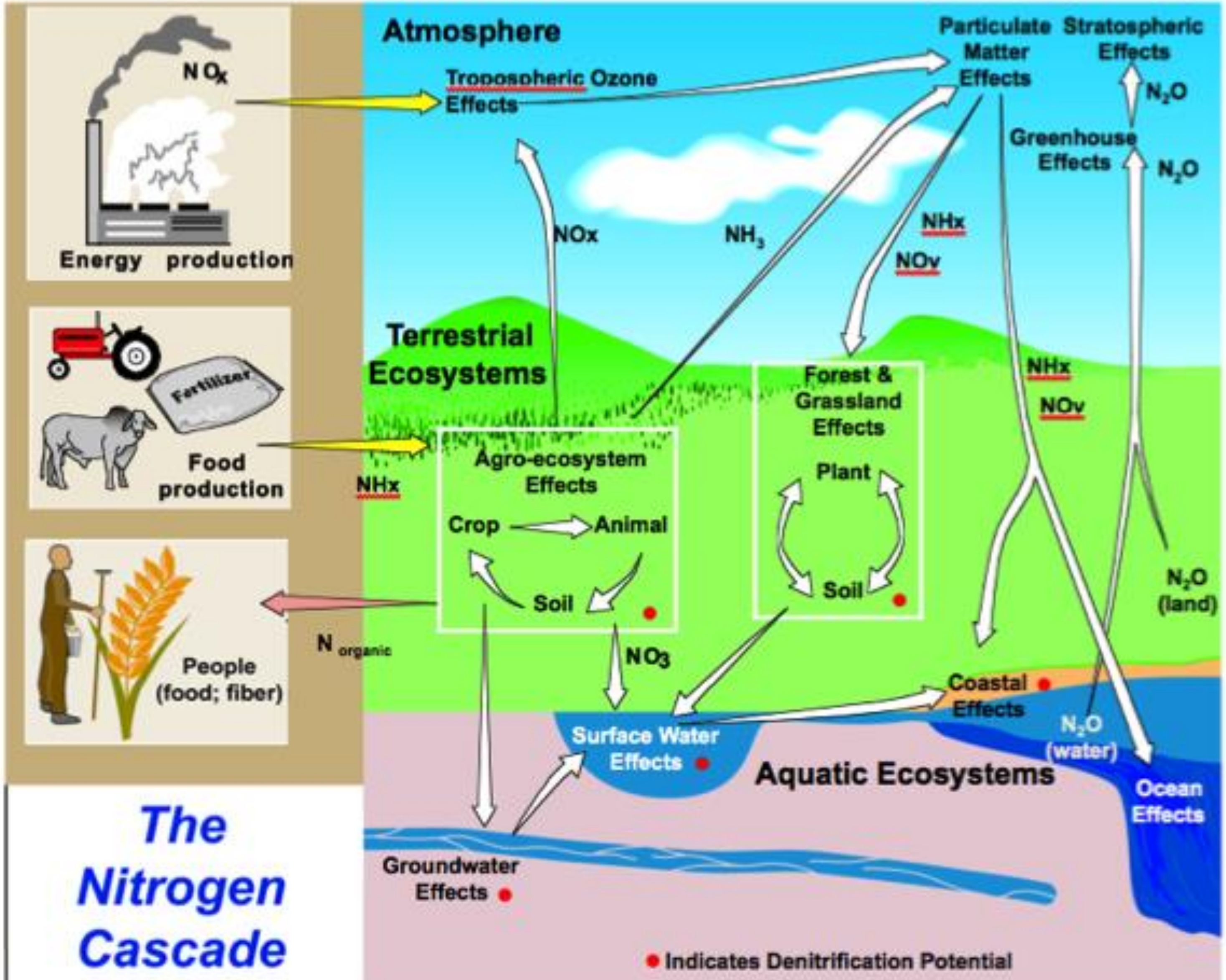
Tilman et al. 2002



Galloway et al. 2002

Challenges & opportunities to managing agricultural N_2O

- Food security
  - How to preserve and increase crop yields while reducing N_2O?
- **Equity**
  - How to allow regions that vastly under-fertilize to increase fertilizer use while globally reducing N_2O?
- **Nitrogen cascade**
  - Tight coupling of N cycle means that one atom of nitrogen can cascade through a variety of chemical forms, each with a different impact on environment



Examples of existing international policies managing parts of the nitrogen cascade:

Greenhouse and stratospheric effects (N_2O):

1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change

Particulate matter, tropospheric ozone, surface and groundwater effects (NH_3, NH_x, NO_x, NO_y, NO_3^-):

1988 Sofia Protocol to the Convention on Long Range Transport of Air Pollution

1999 Gothenburg Protocol to the Convention on Long Range Transport of Air Pollution

Ocean and coastal effects (NO_3^-):

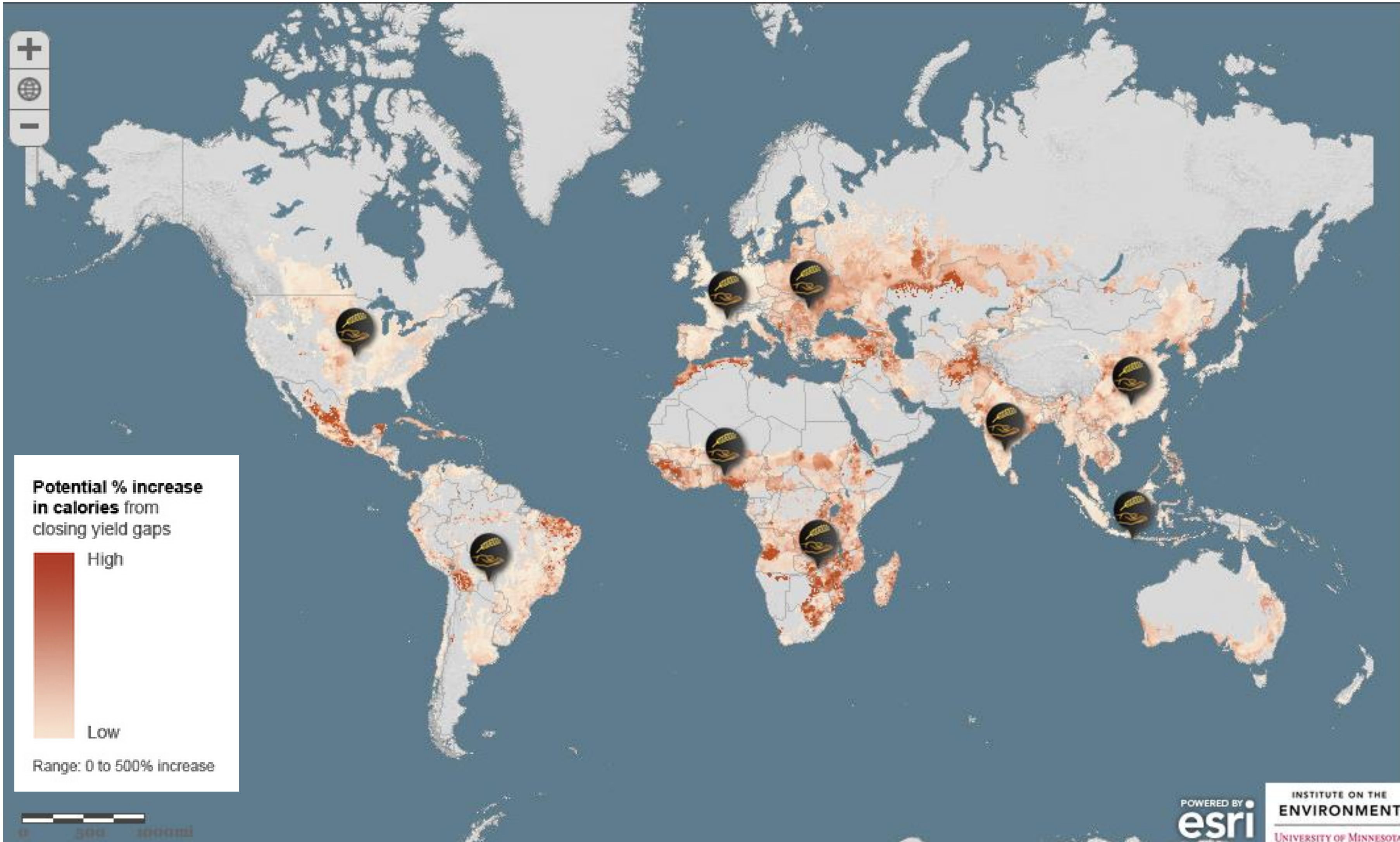
1972 Convention for the Prevention of Marine Pollution from Land Based Sources

Fig. 1 Illustration of the nitrogen cascade showing the sequential effects that a single atom of N can have in various reservoirs after it has been converted from nonreactive N_2 to a reactive form (yellow arrows) and examples of existing international management policies. Abbreviations: NH_3, ammonia; NO_3^-, nitrate; NOx, nitrogen oxide; N_2O, nitrous oxide. Adapted from Galloway et al. 2003 (7).

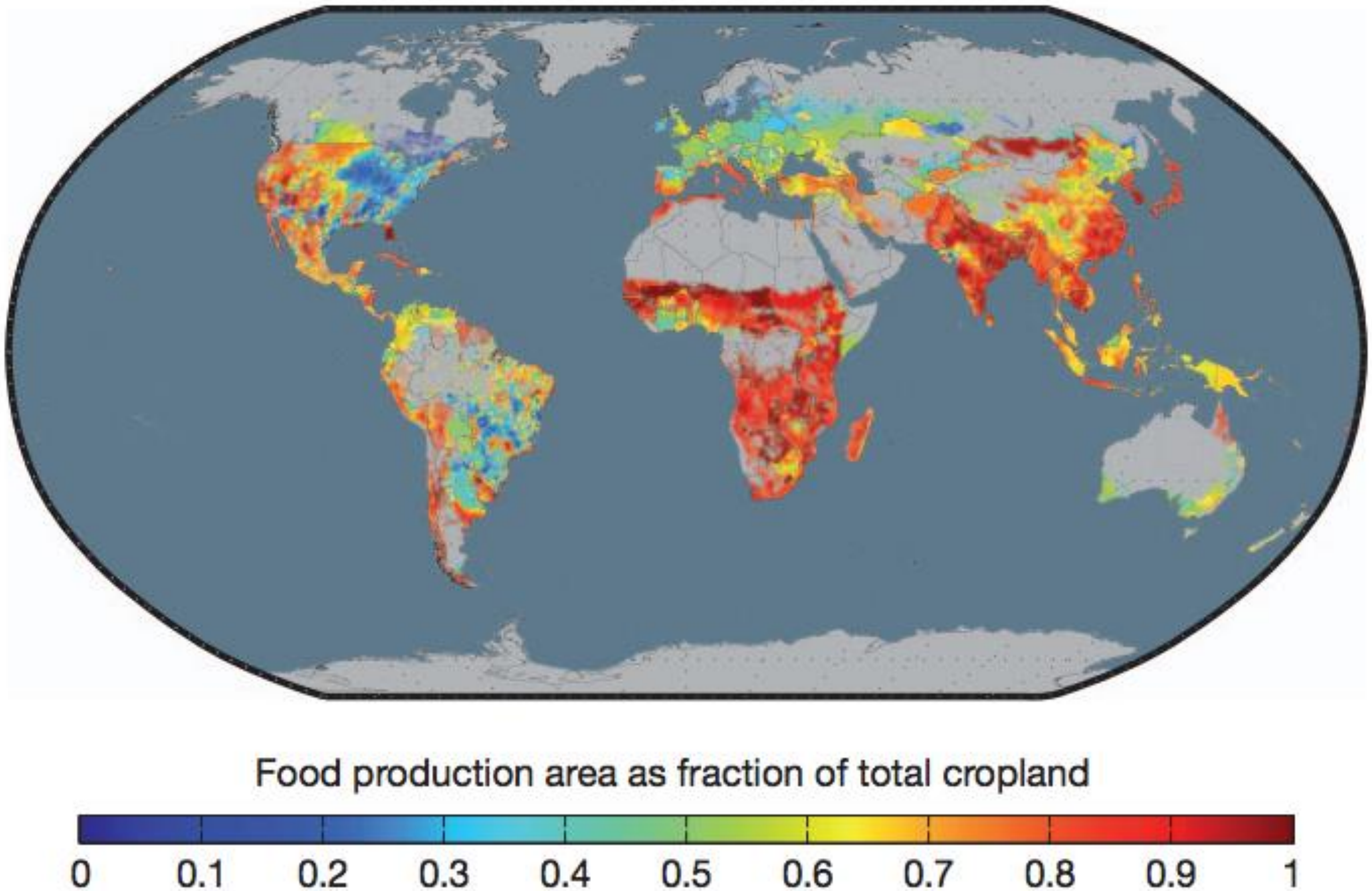
Food security

- Can we feed 9 billion people in an increasingly warm, wealthy world without increasing agricultural pollution, deforestation and food prices (the latter potentially partly due to increased bioenergy production) or reducing biodiversity?

Closing the yield gap

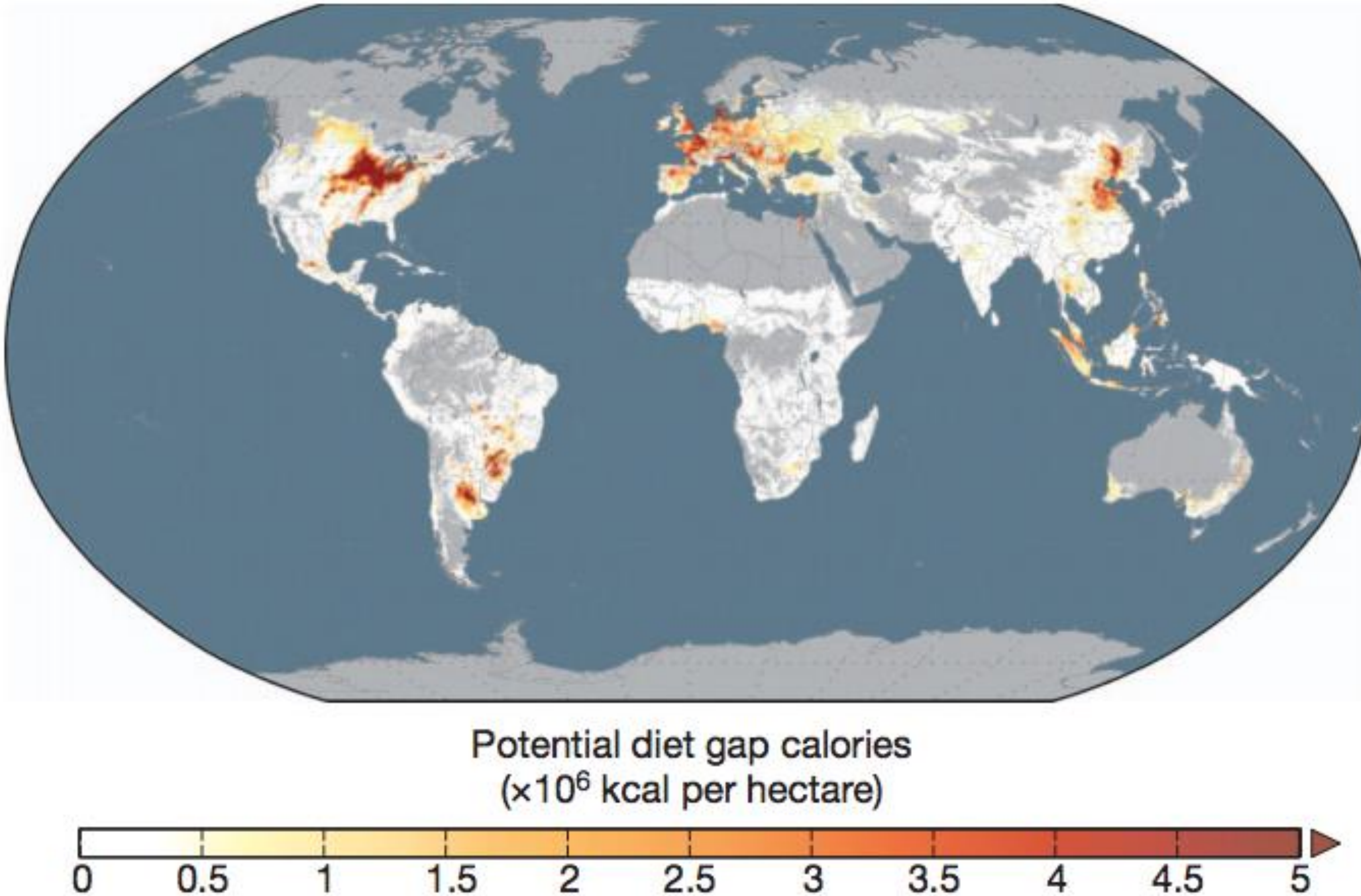


Current food production



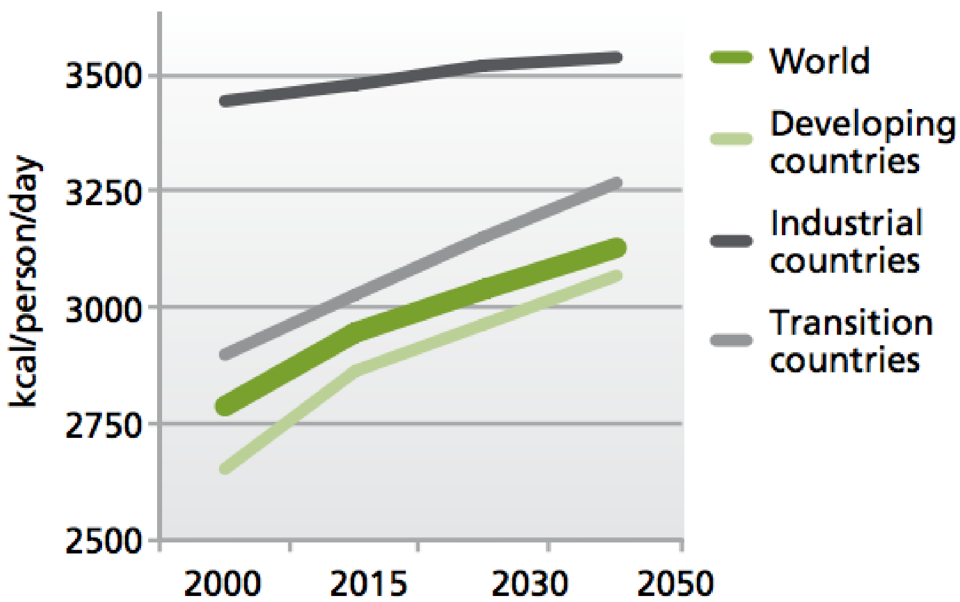
Foley et al. 2011

Diet gap

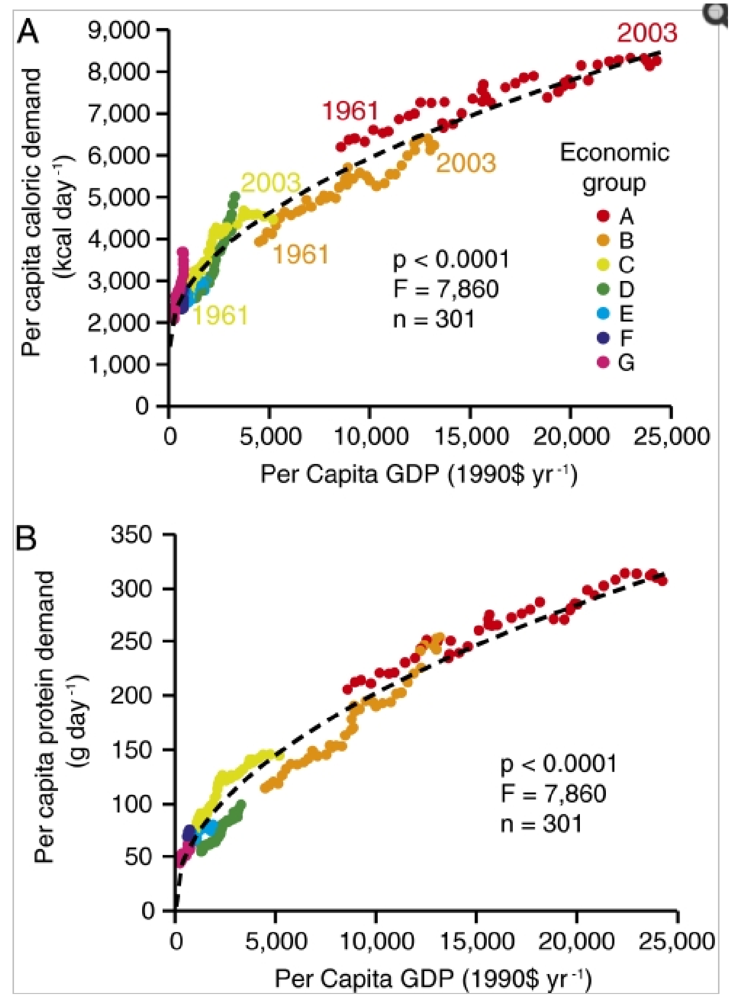


Foley et al. 2011

Population *and* per capita consumption projected to increase

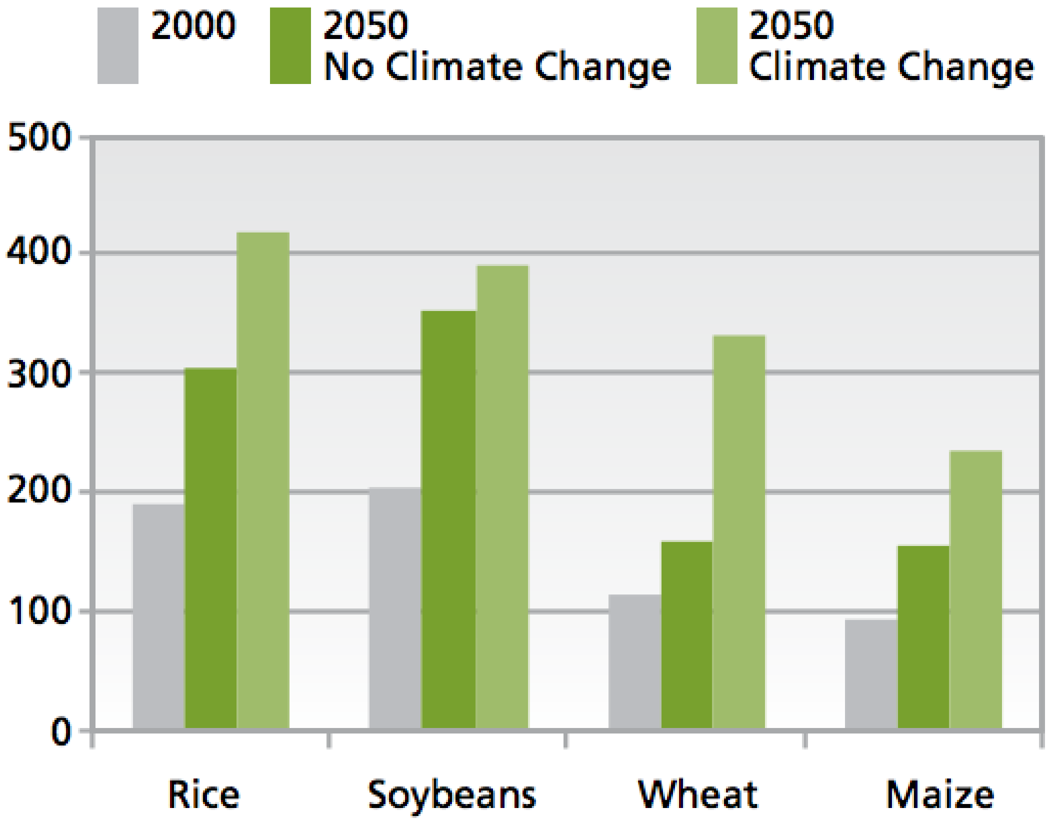


By 2050, people will be eating 60 percent more food, increasing the demand for, and prices of, agricultural products. Source: FAO, 2006[1]



Meridian Institute, 2011; *Tilman et al. 2011*

Food prices – with & without climate change



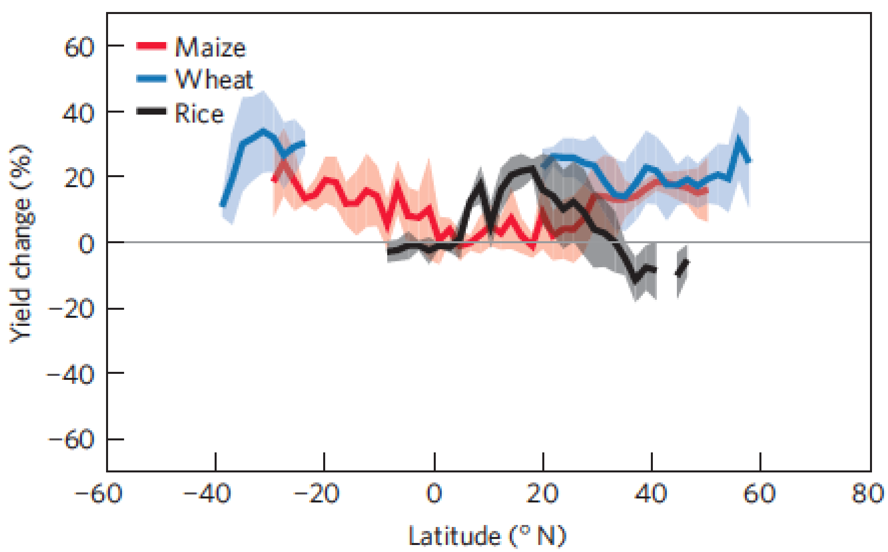
Source: FAO 2010[44]

Meridian Institute, 2011

Geoengineering

Crop yields in a geoengineered climate

J. Pongratz[1]*, D. B. Lobell[2], L. Cao[1] and K. Caldeira[1]



- Authors conclude that solar-radiation management in a high-CO_2 climate generally causes crop yields to increase, largely because temperature stresses are diminished while benefits of CO_2 fertilization are retained.

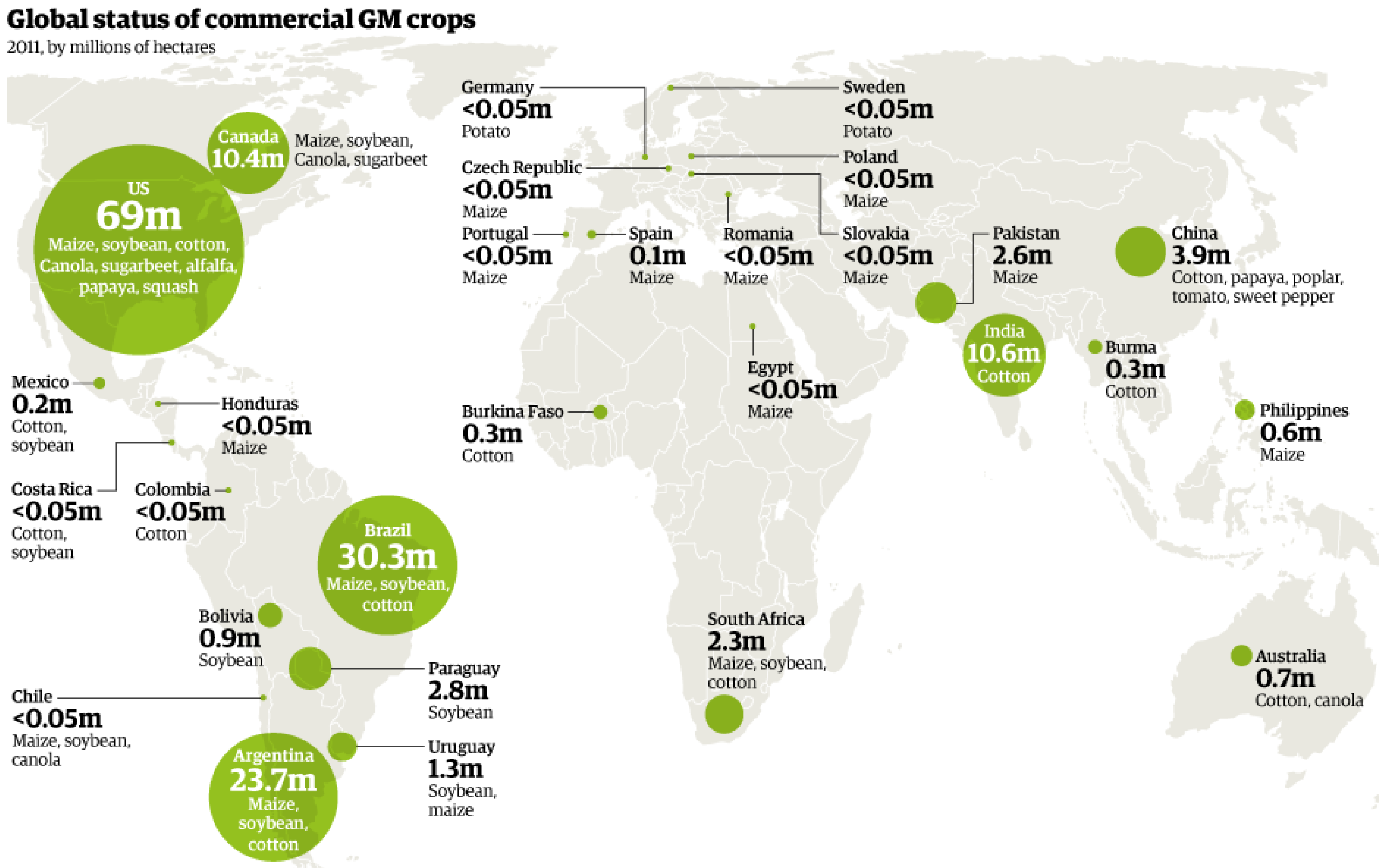
Immigration

Linkages among climate change, crop yields and Mexico–US cross-border migration

Shuaizhang Feng[a,b], Alan B. Krueger[a,c,d], and Michael Oppenheimer[a,e,1]

- Estimated that a 10% reduction in crop yields would lead to an additional 2% of Mexican population to emigrate to US
- By 2080, climate change is estimated to induce 1.4 to 6.7 million adult Mexicans (or 2% to 10% of current population aged 15–65 y) to emigrate as a result of declines in agricultural productivity alone.

GM crops



The Guardian – February 9, 2012

Table 1. Examples of current and potential future applications of GM technology for crop genetic improvement. [Source: (*18*, *49*)]

Time scale	Target crop trait	Target crops
Current	Tolerance to broad-spectrum herbicide	Maize, soybean, oilseed brassica
	Resistance to chewing insect pests	Maize, cotton, oilseed brassica
Short-term (5–10 years)	Nutritional bio-fortification	Staple cereal crops, sweet potato
	Resistance to fungus and virus pathogens	Potato, wheat, rice, banana, fruits, vegetables
	Resistance to sucking insect pests	Rice, fruits, vegetables
	Improved processing and storage	Wheat, potato, fruits, vegetables
	Drought tolerance	Staple cereal and tuber crops
Medium-term (10–20 years)	Salinity tolerance	Staple cereal and tuber crops
	Increased nitrogen-use efficiency	
	High-temperature tolerance	
Long-term (>20 years)	apomixis	Staple cereal and tuber crops
	Nitrogen fixation	
	Denitrification inhibitor production	
	Conversion to perennial habit	
	Increased photosynthetic efficiency	

Godfray et al. 2010

Bioenergy as a climate change mitigation technology

Felix Creutzig

Outline

- Introduction
  - Why relevant: Desperate search for climate change mitigation technologies
  - Difference to other renewables: land-use
  - Challenge of assessment: complexity of issue
- Energy Potential
  - Technical potential
  - Economic/sustainable potential
  - Different sources
- Technologies/processes
  - First-generation/ Sugarcane
  - Advanced biofuels
  - End-use: transport vs co-generation
  - BECCS
- Climate mitigation potential
  - ALCA insights
  - CLCA insights
  - Uncertainty
  - IAM insights – aggregate potential
- Sustainability and Equity
  - Land-use carbon risks and opportunities
  - Land-use biodiversity risks and opportunities
  - Food and water security
  - Land-use livelihoods risks and opportunities
- Conclusions
  - Difficulty in evaluating the future
  - Conditionality statements
  - Robust and adaptive pathways

Complex issues in a high-dimensional world

WHY BIOENERGY

Alternative energies & land use

Table 8
Input and outcomes of case study.

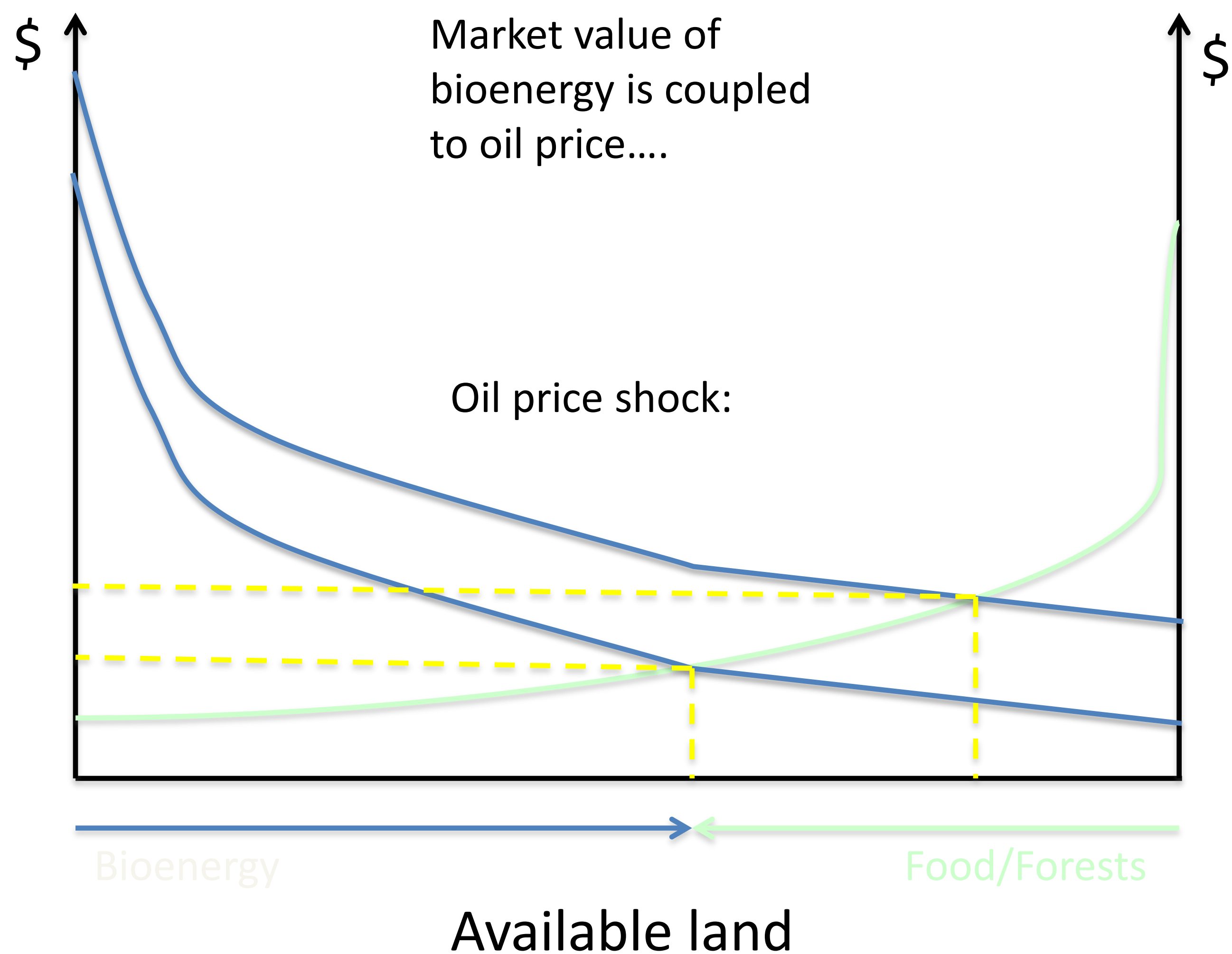
Region	Input		NED GJ/ha/y	Distance driven[a] 10^4 km
Bioethanol from sugar beet				
SE	47[b]	t/ha/y	10.9	0.55
NL	62[c]	t/ha/y	15.5	0.78
ES	27[d]	t/ha/y	4.8	0.24
Biodiesel from rapeseed				
SE	2.9[e]	t/ha/y	18.8	1.1
NL	3.7[c]	t/ha/y	24.6	1.5
ES	1.3[f]	t/ha/y	7.2	0.43
Electricity from wood				
SE	2.4[g]	t/ha/y	12.3	2.0
NL	2.8[h]	t/ha/y	14.4	2.4
ES	0.5[i]	t/ha/y	2.5	0.41
Electricity from wind				
SE	7.0[j]	m/s	978	160
NL	6.8[j]	m/s	927	151
ES	5.1[j]	m/s	490	80
Electricity from solar PV				
SE	824[k]	kWh/kWp	356	58
NL	873[k]	kWh/kWp	421	69
ES	1473[k]	kWh/kWp	1213	198

Dijkman & Benders, 2010:
Energy density (GJ/ha/a) much higher for wind and solar than for bioenergy

	Indicative area requirement (km^2/PJ/yr)	Potential sustainability issues
Bioenergy crops	50–500	Impacts on C balance, ecosystems, soils and food systems can be positive or negative, depending on management
Bioenergy residues	Almost no additional area	No or little additional area required if residues or wastes can be used; possible impacts of removal of residues on soil fertility and the soil C balance need to be considered
Solar energy	1–6	Land needed for infrastructure; excess heat can be used for grain drying
Geothermal energy	≈10	Land required for infrastructure and transmission
Hydropower	<1–100	Impacts are highly site-specific and include positive (e.g., irrigation, flood control) as well as negative aspects (e.g., biodiversity and ecosystems, resettlement during construction)
Wind power	1–32	Land for wind power plants plus transmission, affects landscapes; rotors may kill birds
Oil	<1	Land required for infrastructure and transport
Natural gas	<1	Land required for infrastructure and transport
Coal	≈1	Land required for infrastructure and transport, soil contamination
Nuclear energy	<1	Land for infrastructure and transmission; potentially much larger land areas contaminated in case of an accident

Source: GEA (Ch. 20), 2012

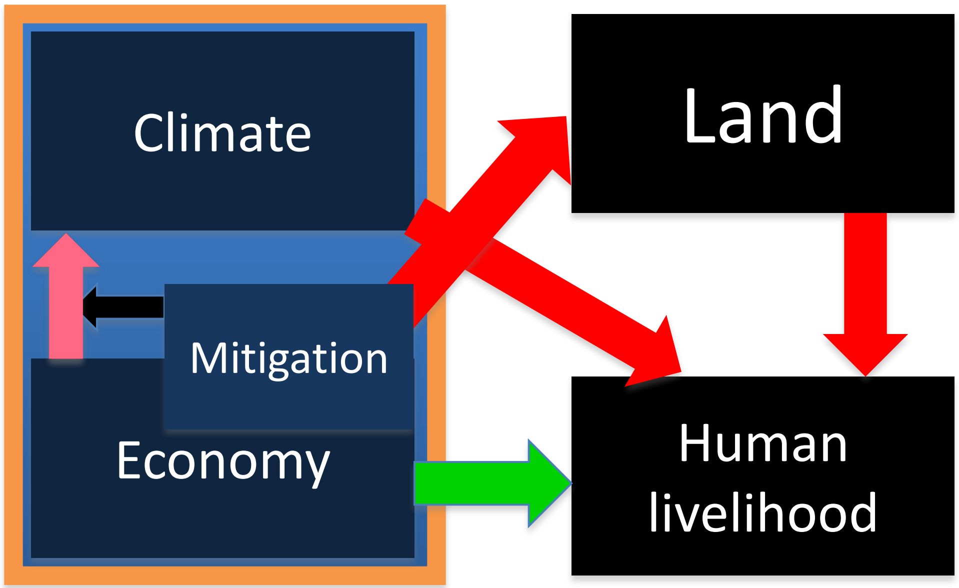
Coupling of energy and land markets



Variability, Complexity, Uncertainty

- Various resources: energy crops, wood, solid waste, residuals, etc.
- Various processing routes: various refinery options, technological development paths
- Various end-uses: transport fuels, co-generations, household fuel, …
- Various climate effects: soil carbon, land use change, fertilizer, processing, …
- Various ecological issues: biodiversity, water, landscape change, …
- Various socio-economic challenges: food security, water provision, livelihoods, economic development, …

System boundaries in sustainability sciences



"Scientific approach": Well-defined system boundaries

Sustainability science: system boundaries are not well-defined

→Operationalisibility
→Reproducibility

→ Interpretation is subject to structural uncertainty and remains ambiguous

How much bioenergy could be deployed?

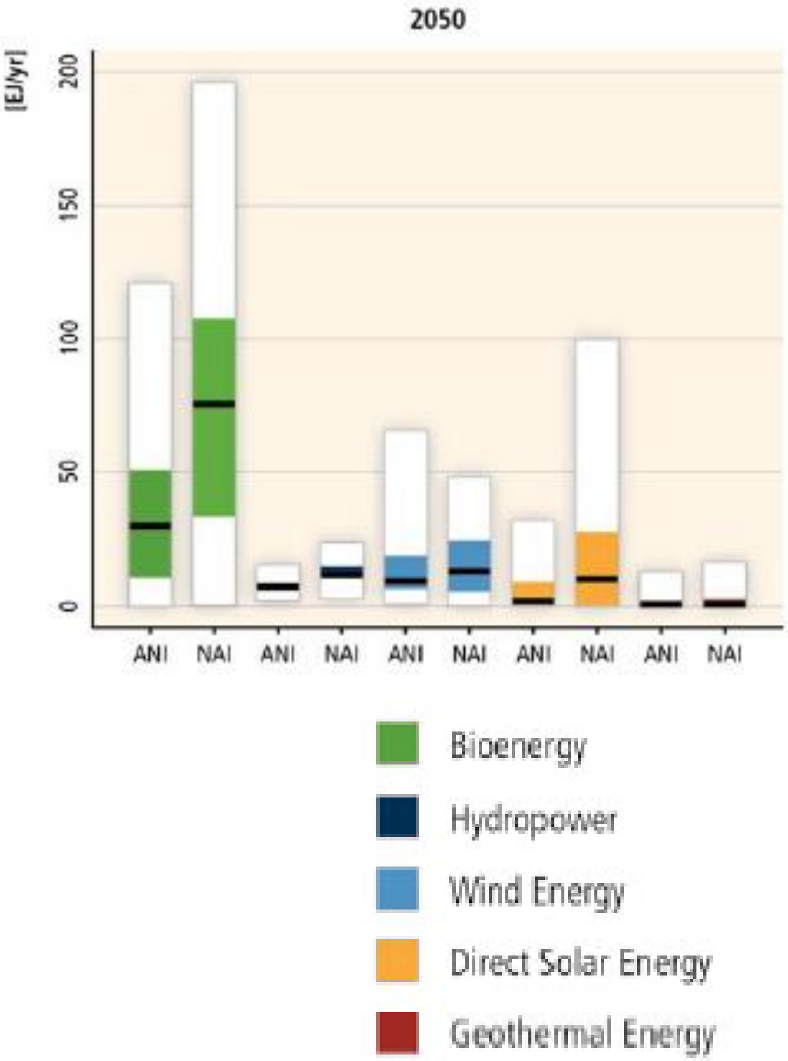
POTENTIAL

Net primary production – technical potential

- Benchmark: Current annual global energy consumption: 500 EJ, growing
- Currently: ca. 50 EJ from biomass
- Carbon cycle: 2000 EJ in carbon absorbed by terrestrial plants every year, another 2000 EJ by marine plants (algae)
- This carbon is returned to the atmosphere via respiration, rot, wildfires, etc.
- The question is which part of this carbon cycle can be accessed economically, and without destroying crucial ecosystem services, and food production

Bioenergy from forestry residues	Biomass from silvicultural thinning and logging, and wood processing residues such as sawdust, bark and black liquor. Dead wood from natural disturbances, such as storms and insect outbreaks, represents a second category. Environmental effects of primary residue removal depend on land management practice and local conditions, and removal rates need to be controlled considering local ecosystem, climate, topography, and soil factors.
Bioenergy from forest unutilized forest growth	Biomass from growth occurring in forests judged as being available for wood extraction, which is above the projected biomass demand in the forest industry. Includes both biomass suitable for, e.g., pulp and paper production and biomass that is not traditionally used by the forest industry.
Bioenergy from forest plantations and agroforestry	Includes biomass from woody plants grown in short-rotation coppice or single stem plantations (e.g., willow, poplar, eucalyptus, pine). Both monoculture plantations and mixed production systems including agroforestry are included.

Bioenergy from crop residues	Use of crop residues for Bioenergy; Use of by- products associated with crop production and processing, both primary (e.g., cereal straw from harvesting) and secondary residues (e.g., rice husks from rice milling) to produce bioenergy.
Bioenergy from dedicated crops	Cultivation of high yielding crops specifically designed for energy end use. Includes cultivation of both conventional agriculture crops and bioenergy feedstock plants such as oil crops (e.g., Jatropha), grasses (e.g., switchgrass, Miscanthus).
Bioenergy from manure mgt (Biogas)	Animal dung from confined livestock production. Currently dung is often burned directly as a cooking fuel in many developing countries. Dung can be converted to biogas in biodigesters.
Bioenergy from Organic Wastes	A heterogeneous category that can include, e.g., organic waste from households and restaurants, discarded wood products such as paper and demolition wood, and wastewaters suitable for anaerobic biogas production.



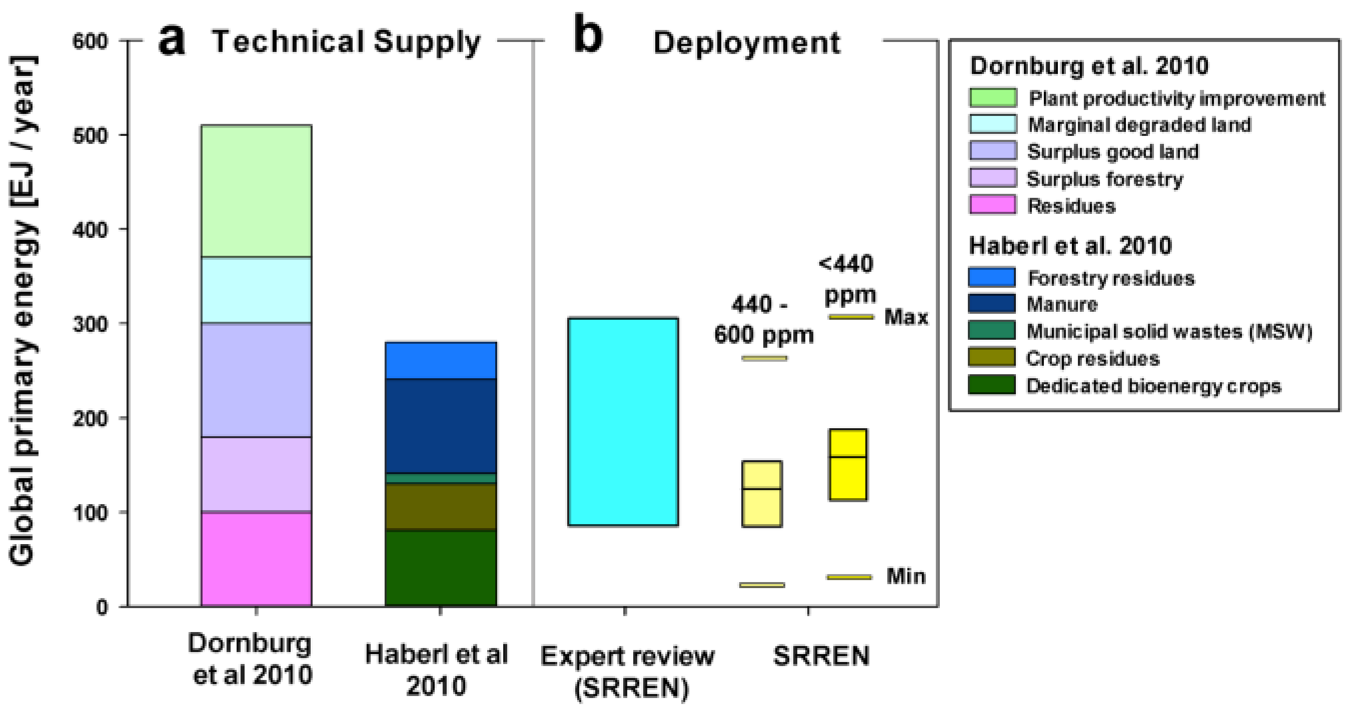
Krey & Clarke, 2011/ SRREN 10.2

Source	Potential in EJ
GEA KM 7	114-239
GEA KM 11	200-500
GEA KM 17	145 60-70 (strict sust) 65 (agrar residues)
GEA KM 20	44-133 EJ (energy crops)
SRREN Ch 2	100-400 EJ
SRREN CH 10	60-160 EJ
Haberl et al. 2010	160-270 81 (energy crops) 127 residues/foresty
Vuuren et al. 2009	65-115 (sust)

Potential = Land area X yield

Huge uncertainty, not visible in individual studies.

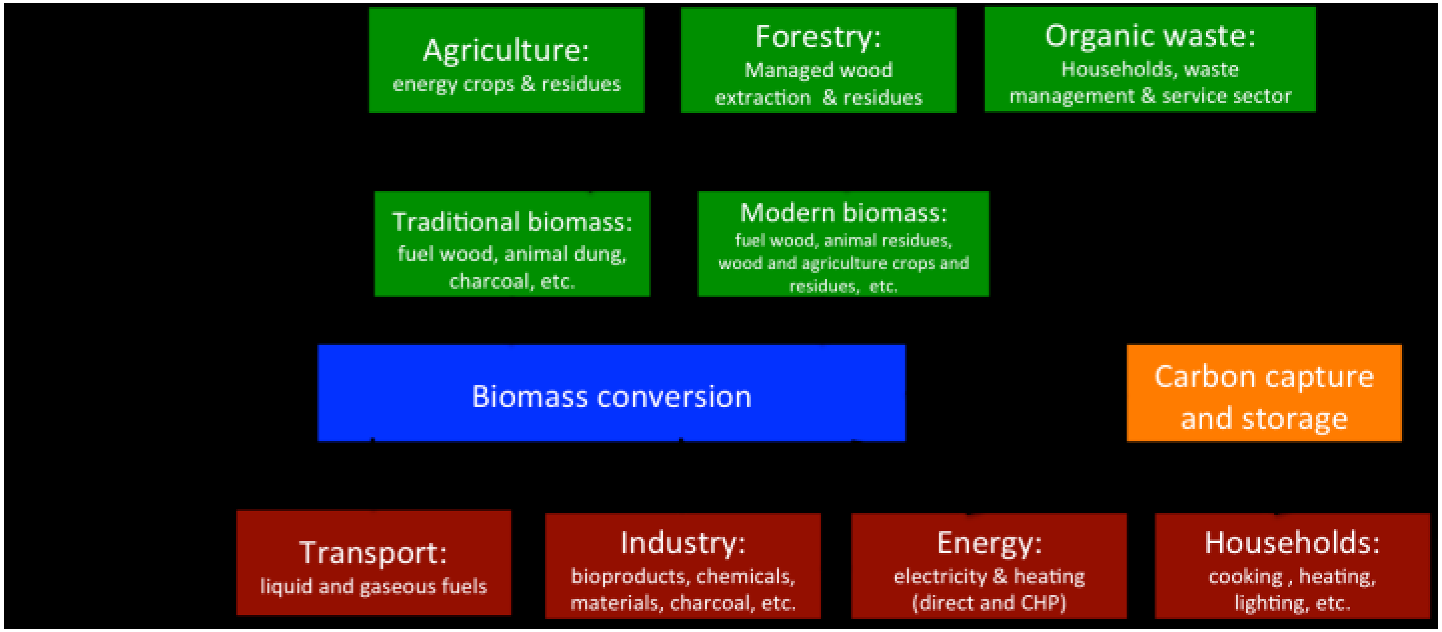
IAMs see bioenergy as being CO2-neutral.



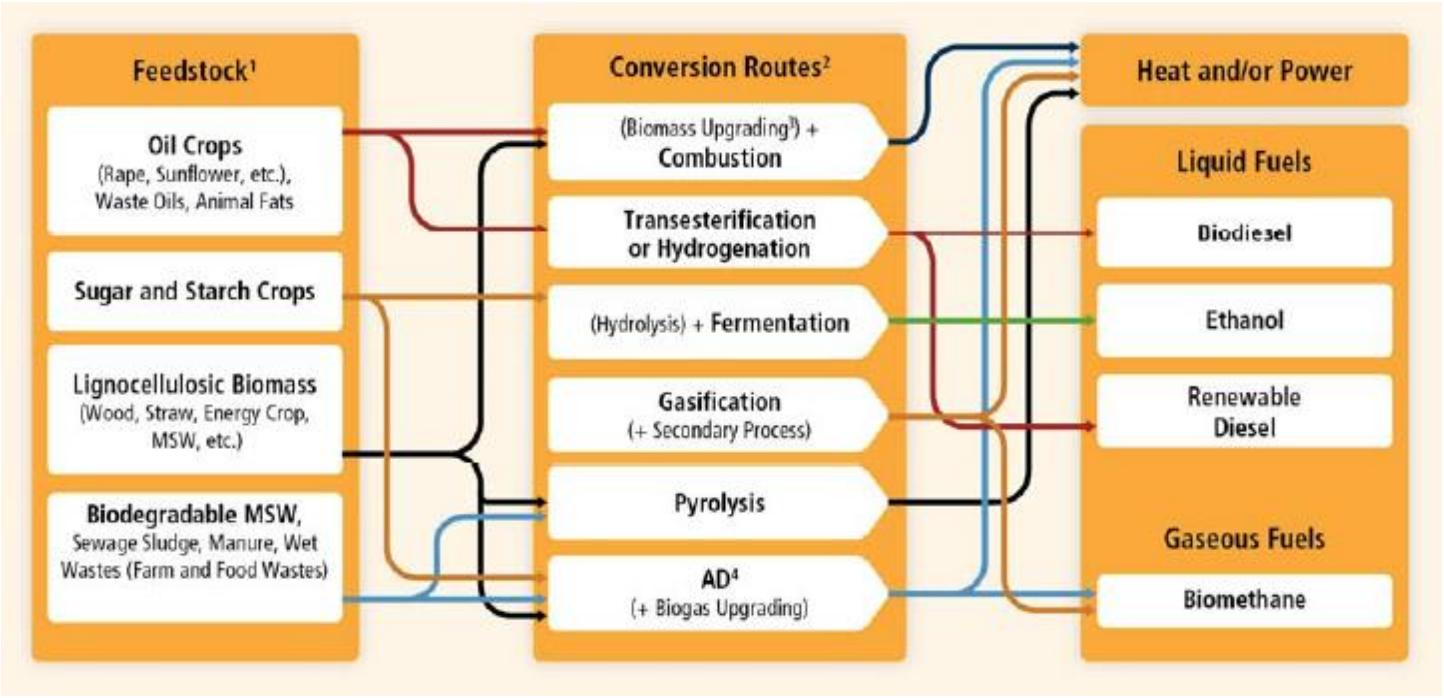
Creutzig et al., 2012

TECHNOLOGICAL OPTIONS

Bioenergy pathways

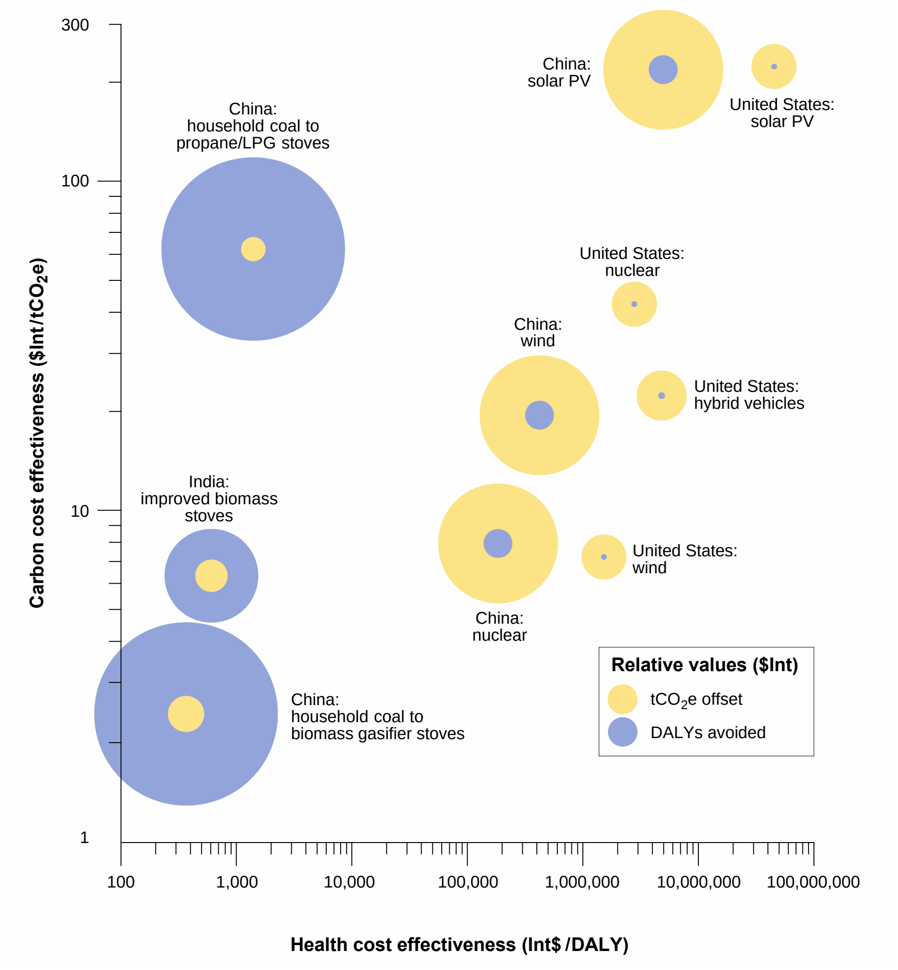


Bioenergy pathways



Improved cookstoves

- 2.7 billion people rely on traditional biomass for cooking
- 800 million of those currently using some sort of improved cookstoves
- Improved cook stoves can deliver fuel saving of 30-60%, and 90% in pilot studies
- High cobenefits: GHG emission reduction, black carbon reduction, less indoor air pollution, less firewood collection of women and children, cost savings

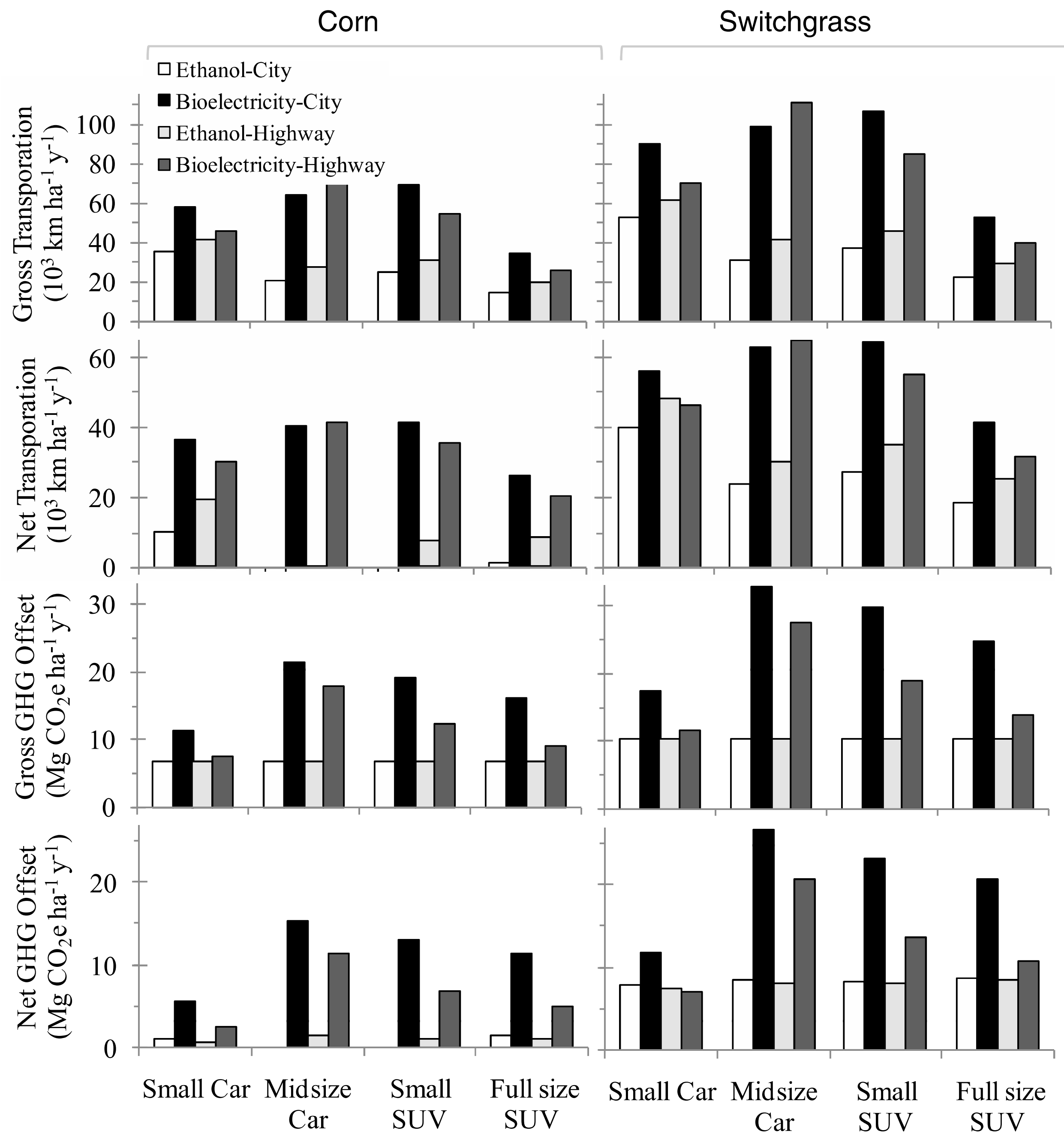


Smith and Haigler, 2008

Cogeneration

- Use heat as byproduct of power generation
- 60-90% efficiency possible
- Example: sugar mills operate on burning of bagasse and possibly cogenerate electricity
- Up to 5% of Brazil’s electricity produced by bagasse cogeneration

Electric cars



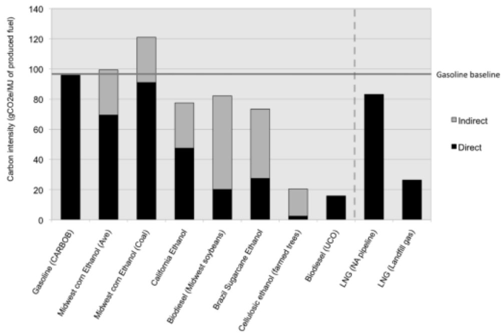
Campbell et al., 2009

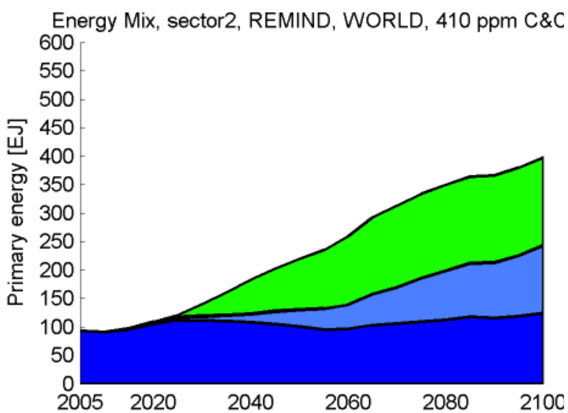
BECCS

- BECCS: Bioenergy Carbon Capture and Storage
- Produce energy from biomass and store the CO2 emissions underground
- High uncertainty on costs and storage availability

MITIGATION POTENTIAL

LCA/land-use model studies warn of biofuel GHG emissions >= gasoline





IAM studies project bioenergy as crucial mitigation strategy

present
first generation
3rd worst world

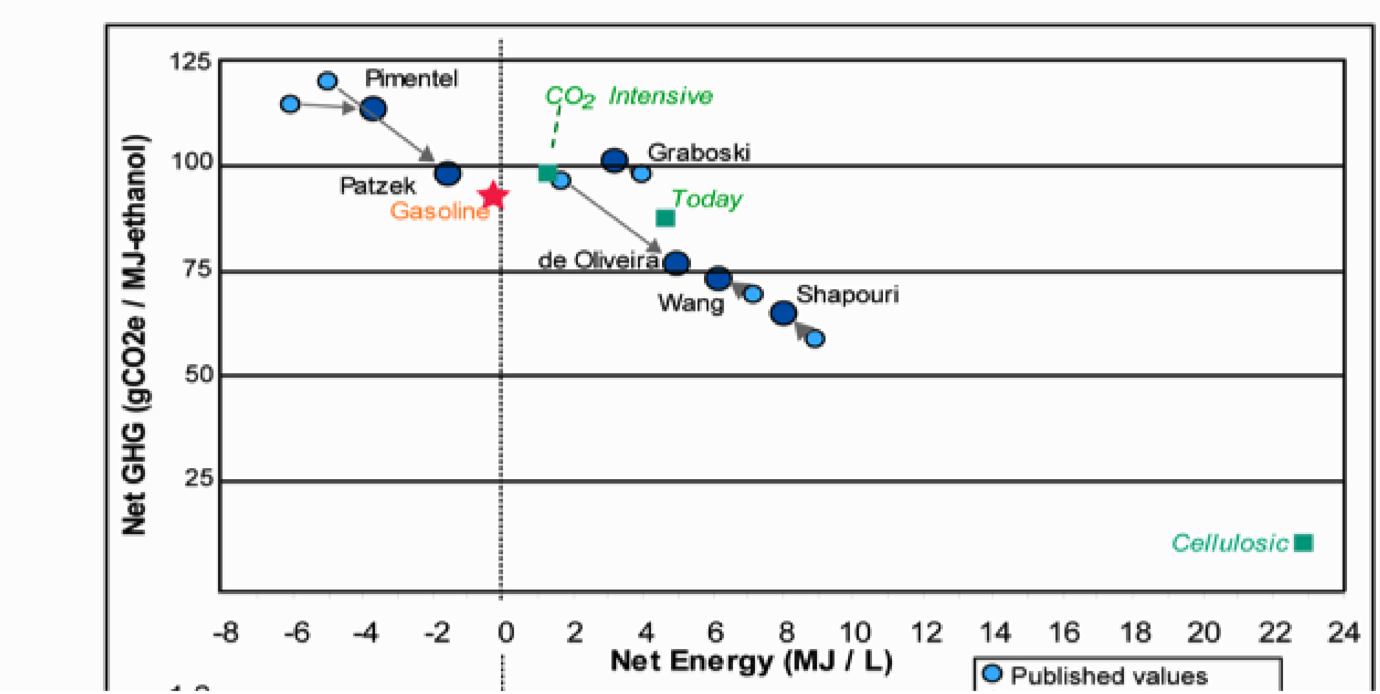
CO2e/MJ
inductive
part+gen equilib

In global reviews (SRREN 2011; GEA 2011) no coherent picture emerges; inconsistencies/ lack of science-science communication

future
2nd generation
1st best world

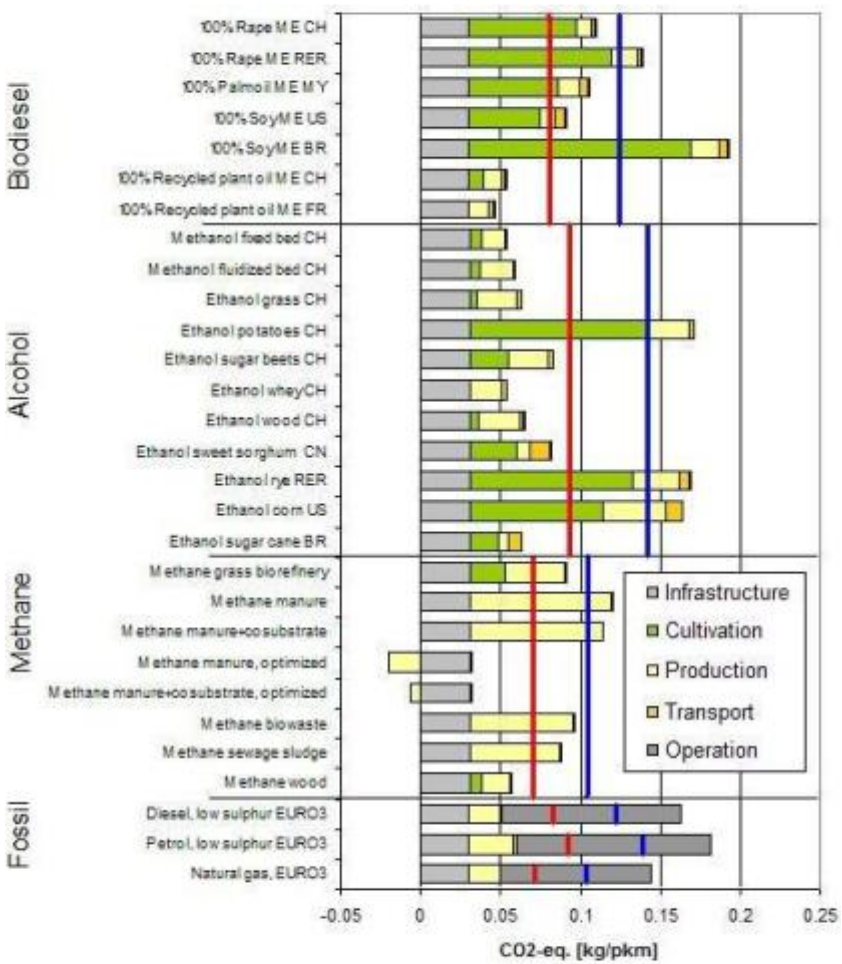
EJ
deductive
general equilib

Attributional LCA



Net energy and net GHG estimates for 6 studies of corn ethanol, as well as 3 cases. Gasoline is shown for reference. The cellulosic case is switchgrass grown on prime crop land. Adapted from - Farrell et al, 2006

Variability across biofuels

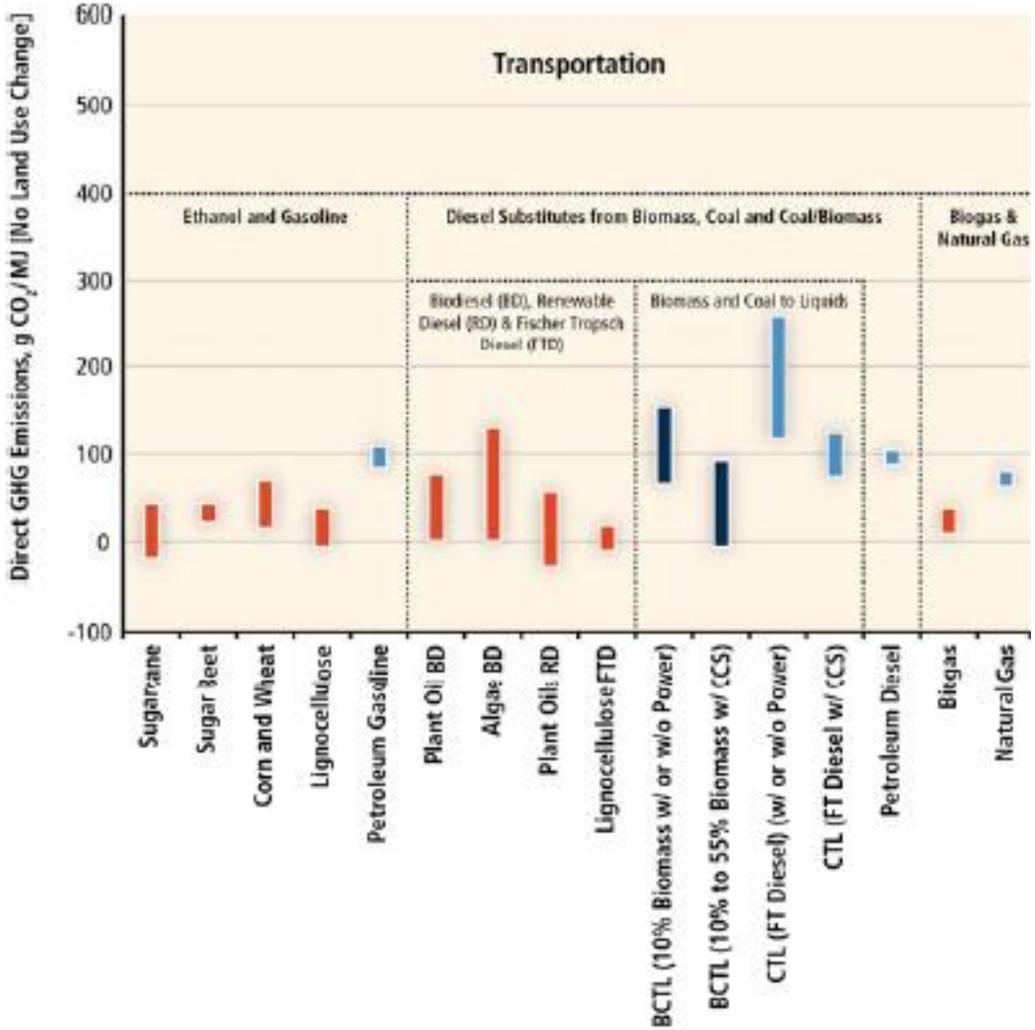


<u>Major point here:</u>

GHG emissions of biofuel crucially depend on feedstock and processing, and can vary by order of magnitudes.

→ **Variability (or stochastic uncertainty)**

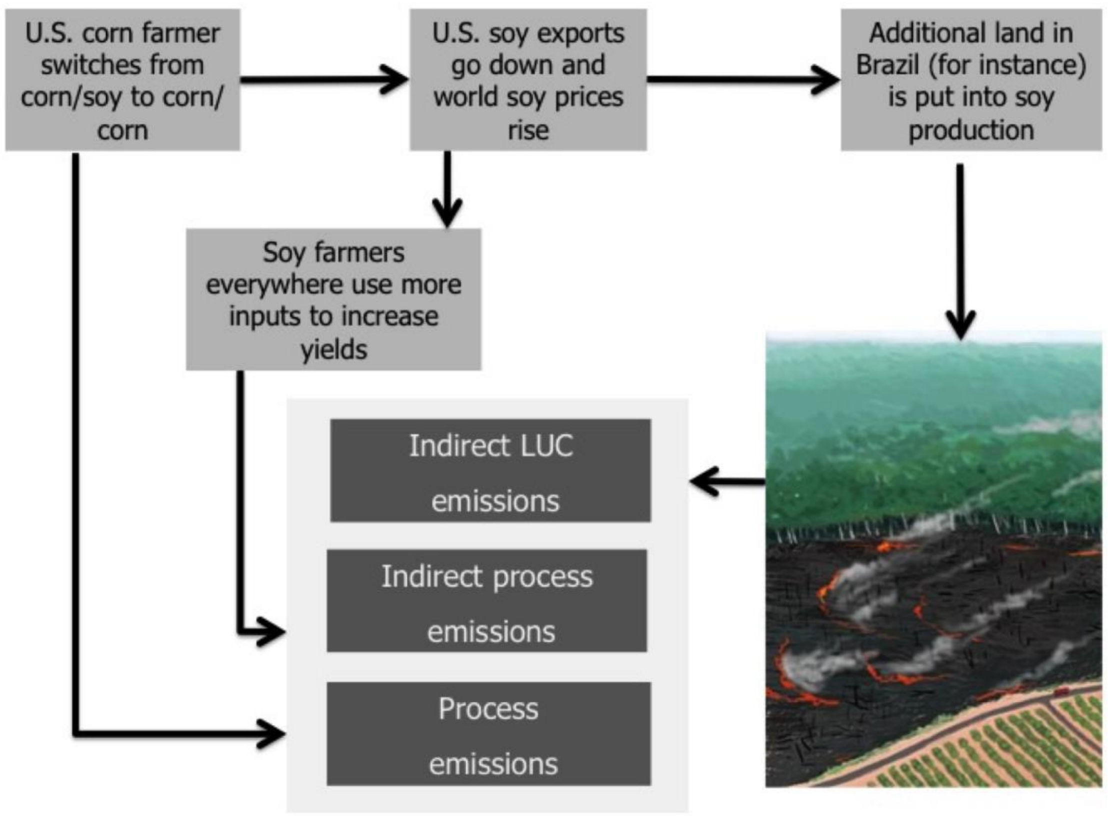
ALCA summary



<u>LCA perspective:</u>

In attributional LCA, GHG emissions from bioethanol are high but lower than gasoline emissions.

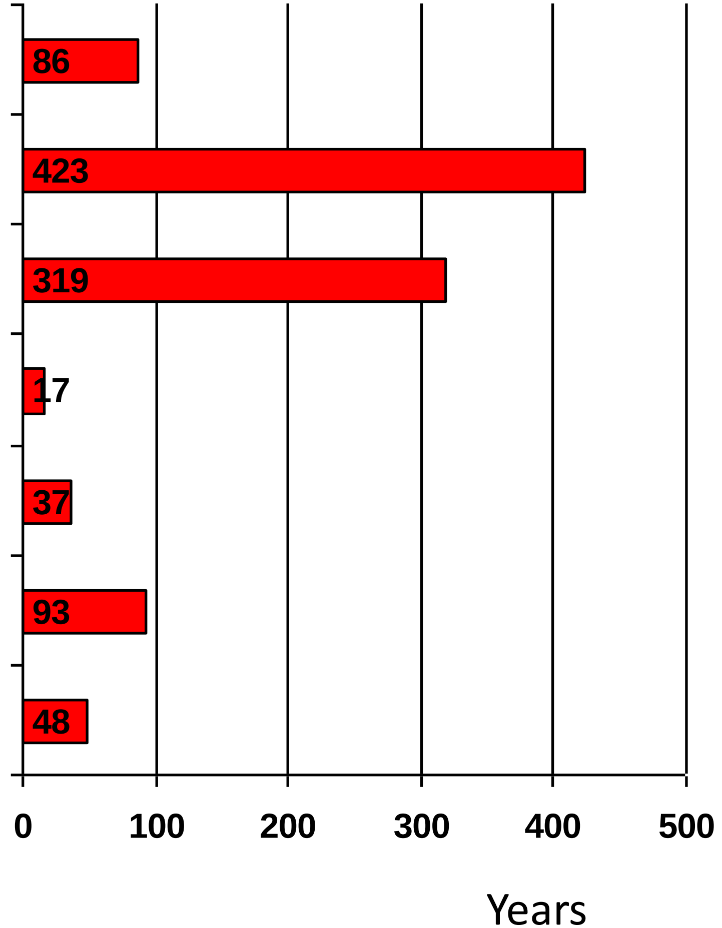
Globally integrated markets



F. Creutzig, D. Kammen. The Post-Copenhagen Roadmap Towards Sustainability: Differentiated Geographic Approaches, Integrated Over Goal. Innovation 4(4): 301-321

Time to repay carbon debt

Tropical rainforest	Palm biodiesel (> 85% of global palm production)	Indonesia/ Malaysia
Peatland rainforest		
Tropical rainforest	Soybean biodiesel	Brazil
Cerrado wooded	Sugarcane ethanol	
Cerrado grassland	Soybean biodiesel	
Central grassland	Corn ethanol	US
Abandoned cropland		



Land Clearing and the Biofuel Debt, Fargione et al., 2008. Slide courtesy by Heiner von Bothmer.

Livestock intensity determines emission effects of sugarcane ethanol

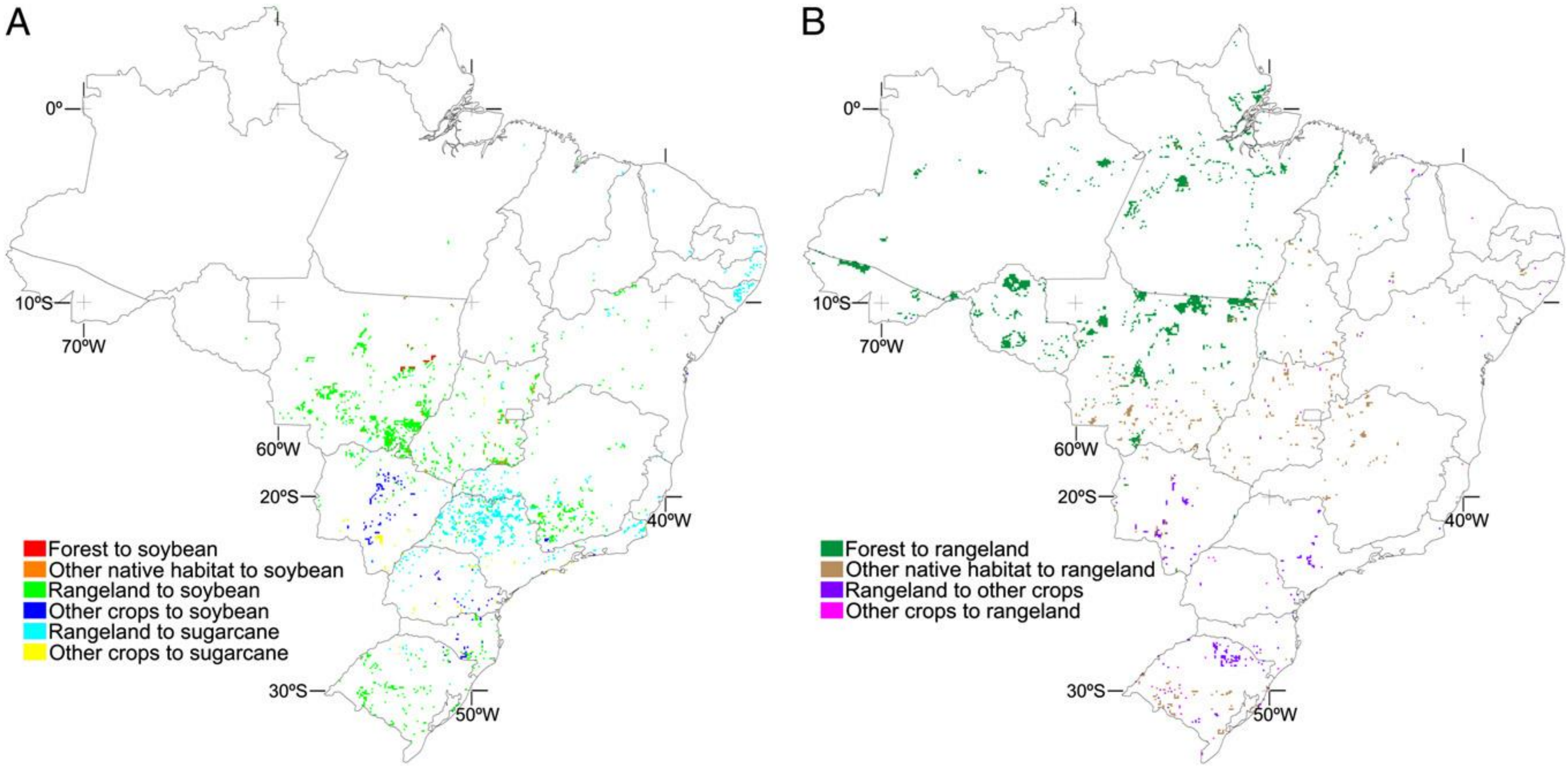


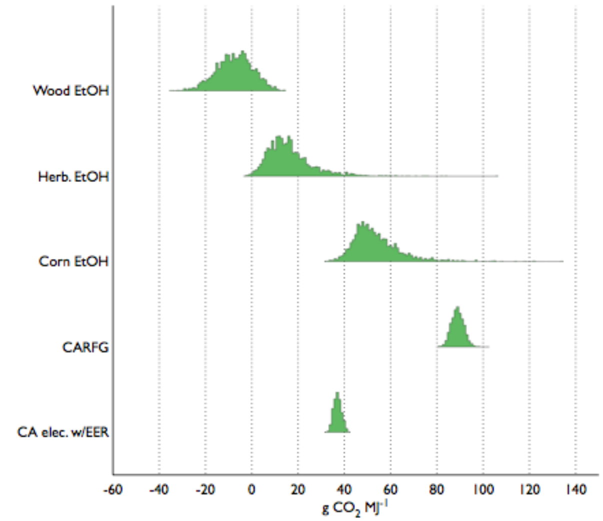
Fig. 1. Modeled direct (*A*) and indirect (*B*) LUC caused by the fulfillment of Brazil's biofuel (sugarcane ethanol and soybean biodiesel) production targets for 2020.

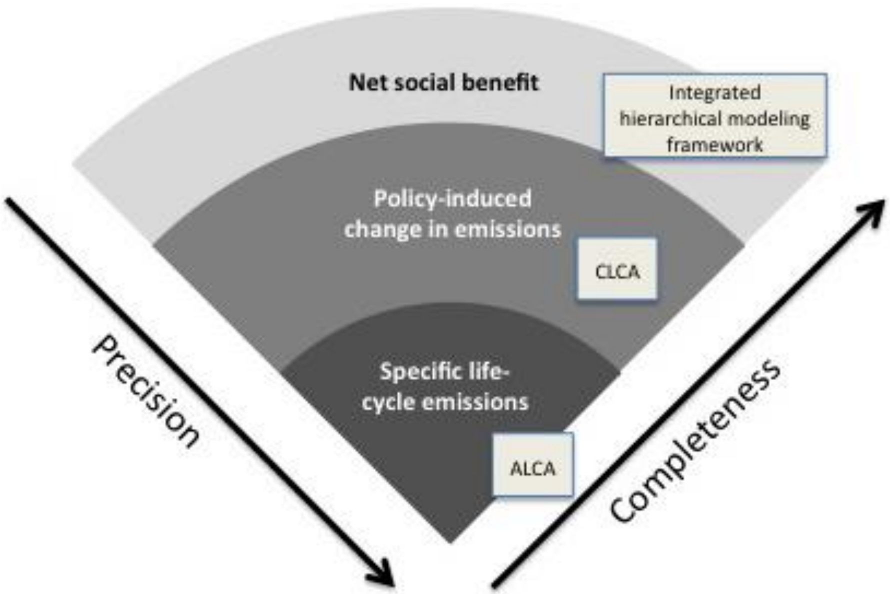
This kind of results are usually not covered by global land-use/energy IAMs, but are probably highly relevant

Lapola et al., 2010 (PNAS)

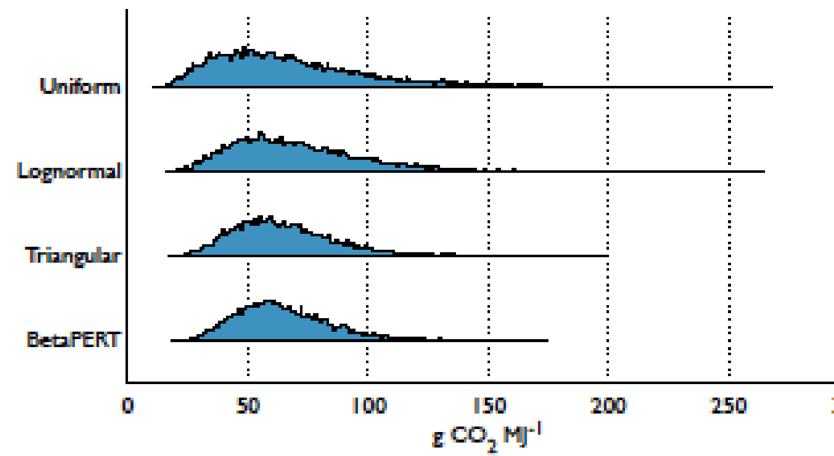
Uncertain of direct LCA emissions

Richard Plevin, PhD thesis, 2010

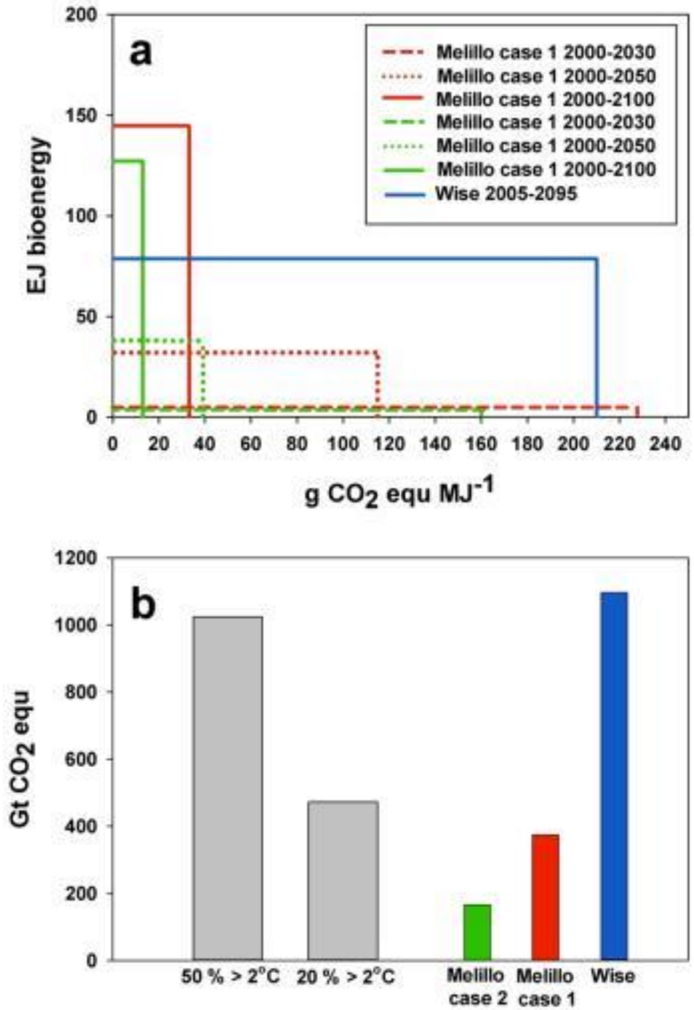




Creutzig et al., 2012



Uncertainty of ILUC emissions

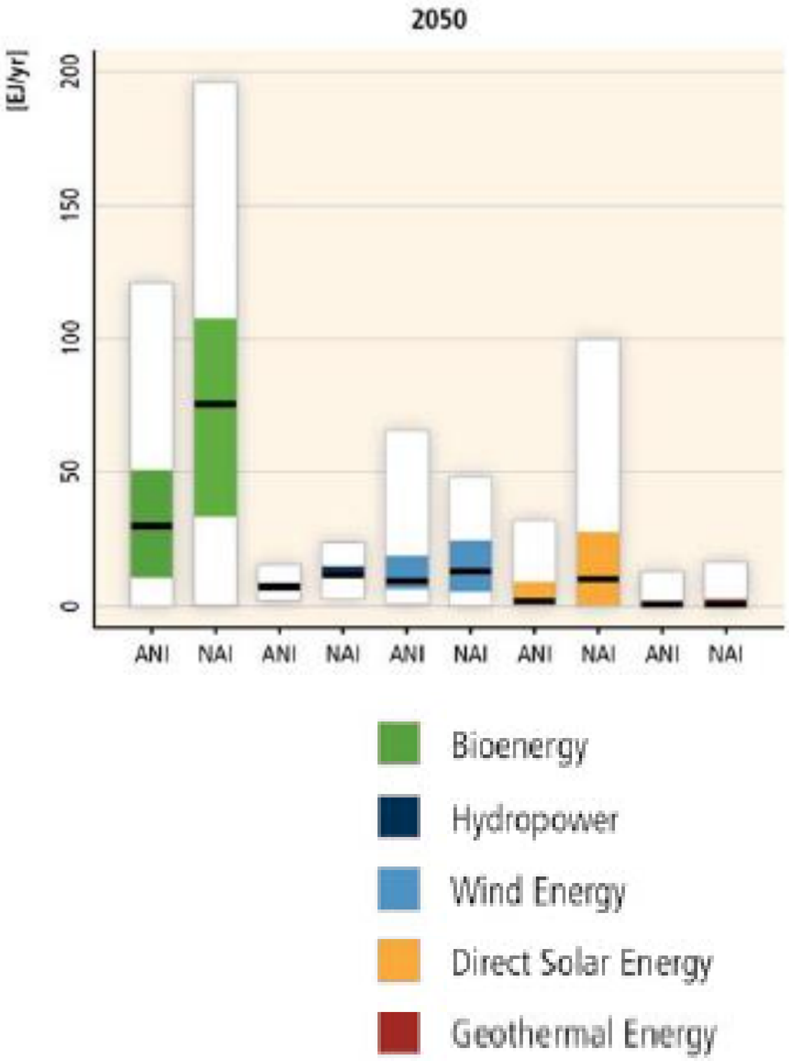


If there is no perfect forest protection, ILUC emissions can result in a catastrophic outcome of bioenergy deployment.

Bioenergy deployment alone can eat up the remaining GHG budget.

Real-world dynamics: Cheaper sources of biomass tend to be higher carbon.

Creutzig et al., 2012, based on Wise et al., 2009; Melillo et al., 2009; Meinshausen et al., 2010)



If assumed to be climate neutral, possibly including negative emissions, very high mitigation potential

Krey & Clarke, 2011/ SRREN 10.2

SUSTAINABILITY CONSIDERATIONS

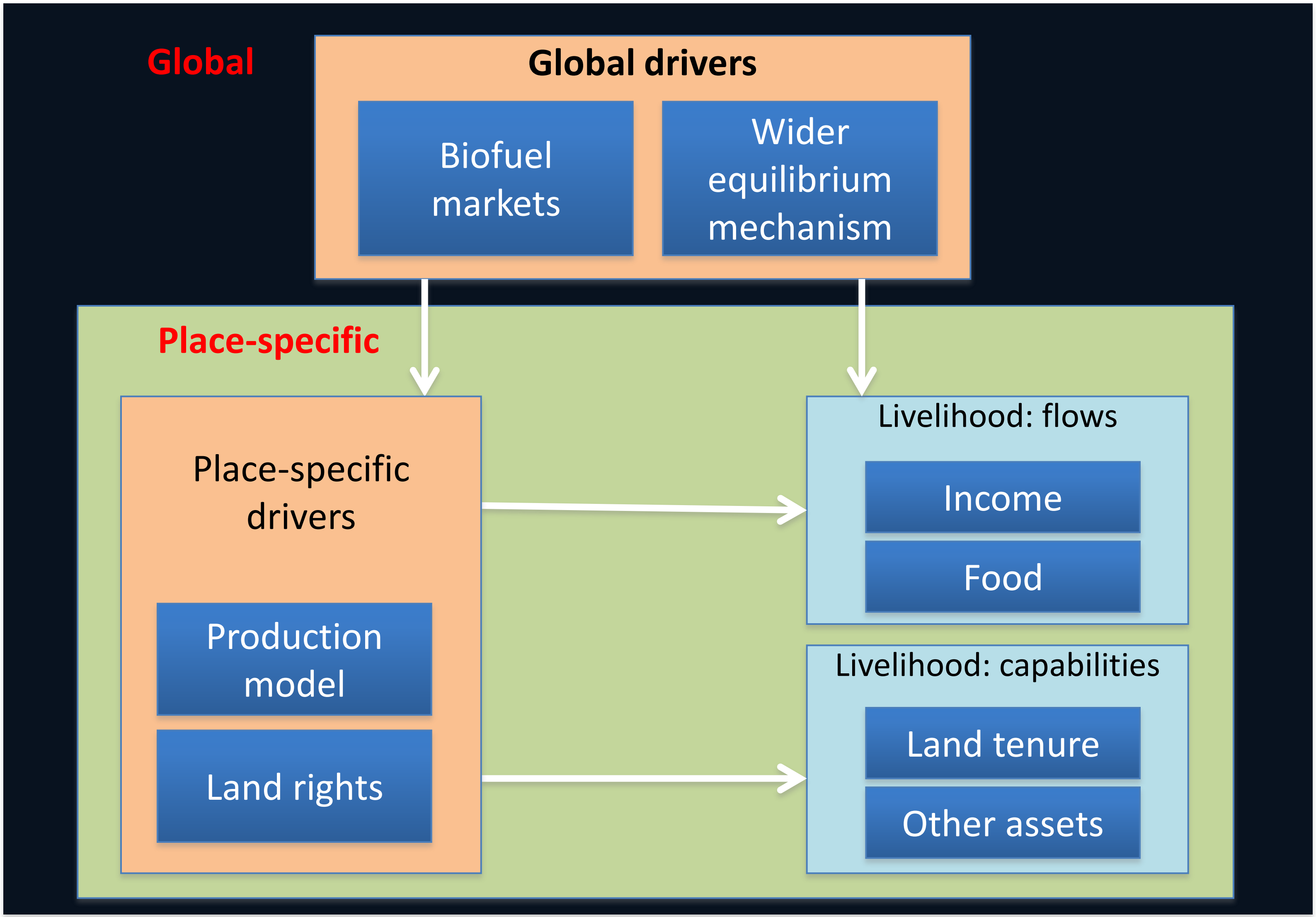
Food insecurity

Corn prices in 2008:

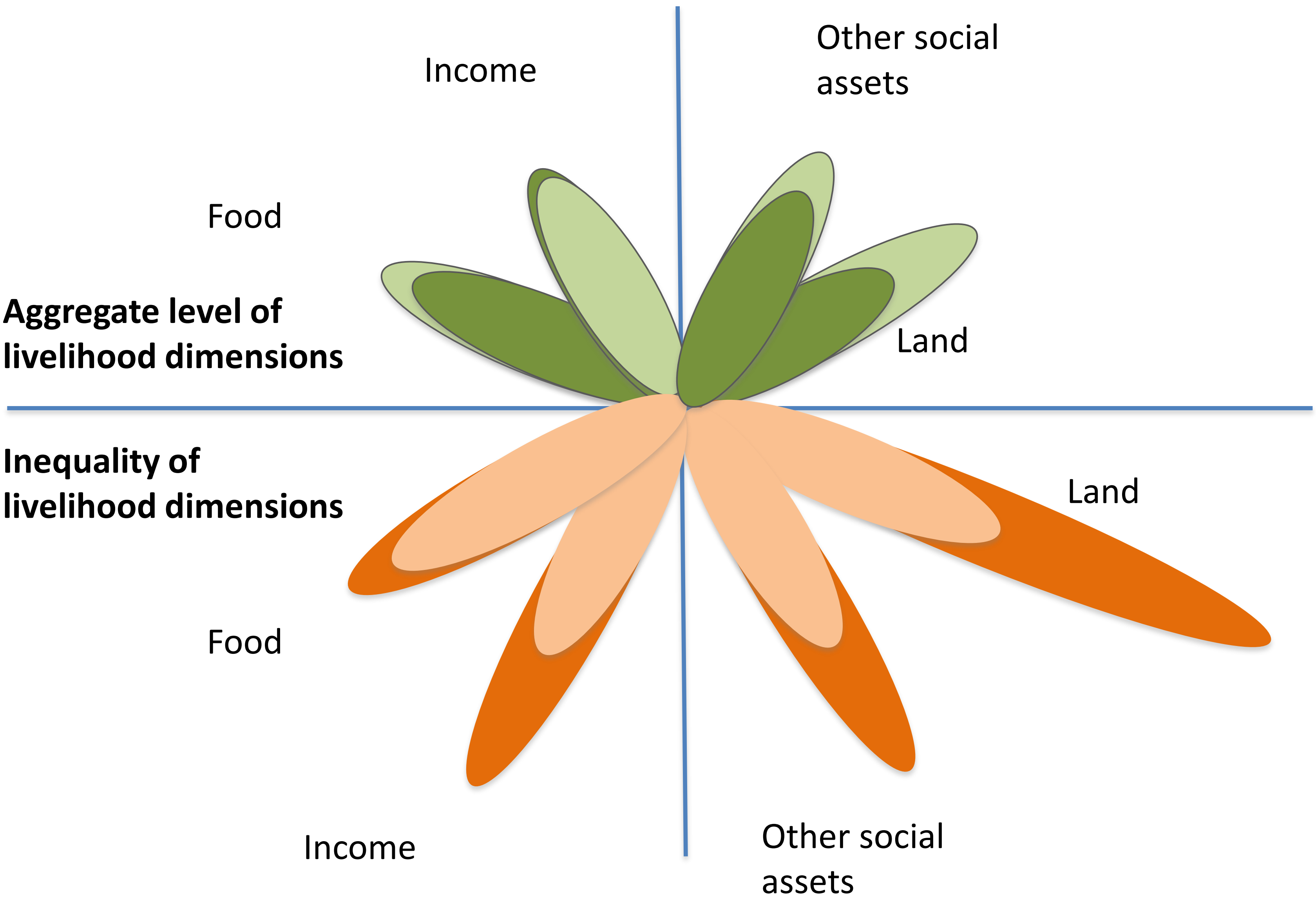
Biodiversity loss

Deforestation

Bioenergy and Livelihoods



Plantation (Schoneveld et al. 2011)



Summary: bioenergy impacts

	Benefits	Harms
green house gases	low	high
poverty	• more jobs, • improved infrastructure	• less food/ food insecurity, • little labour needed, • if hired - low salaries,
environment	• upgrade marginal/ in-fertile land	• biodiversity loss, • land use change (deforestation, drainage of wetlands etc.), • soil degradation, • influence of pesticides
energy security	• resource "land" more or less available in all parts of the world (in contrast to fossil fuel)	

Sustainability spillover

As one sustainability problem (e.g., climate change) is targeted to be solved by industrial-scale technologies, the sustainability challenge may spill over to other domains.

Examples are biodiversity and nitrogen.

While each (un)sustainability domain can be defined by itself, the coupling, in many cases, might be induced via land use.

CONCLUSIONS

High complexity and uncertainty

- Numerous pathways and options
- Can significantly contribute to climate change mitigation
- Can also cause additional climate change via land-use emissions
- Embedded in numerous highly relevant and sensitive sustainability issues

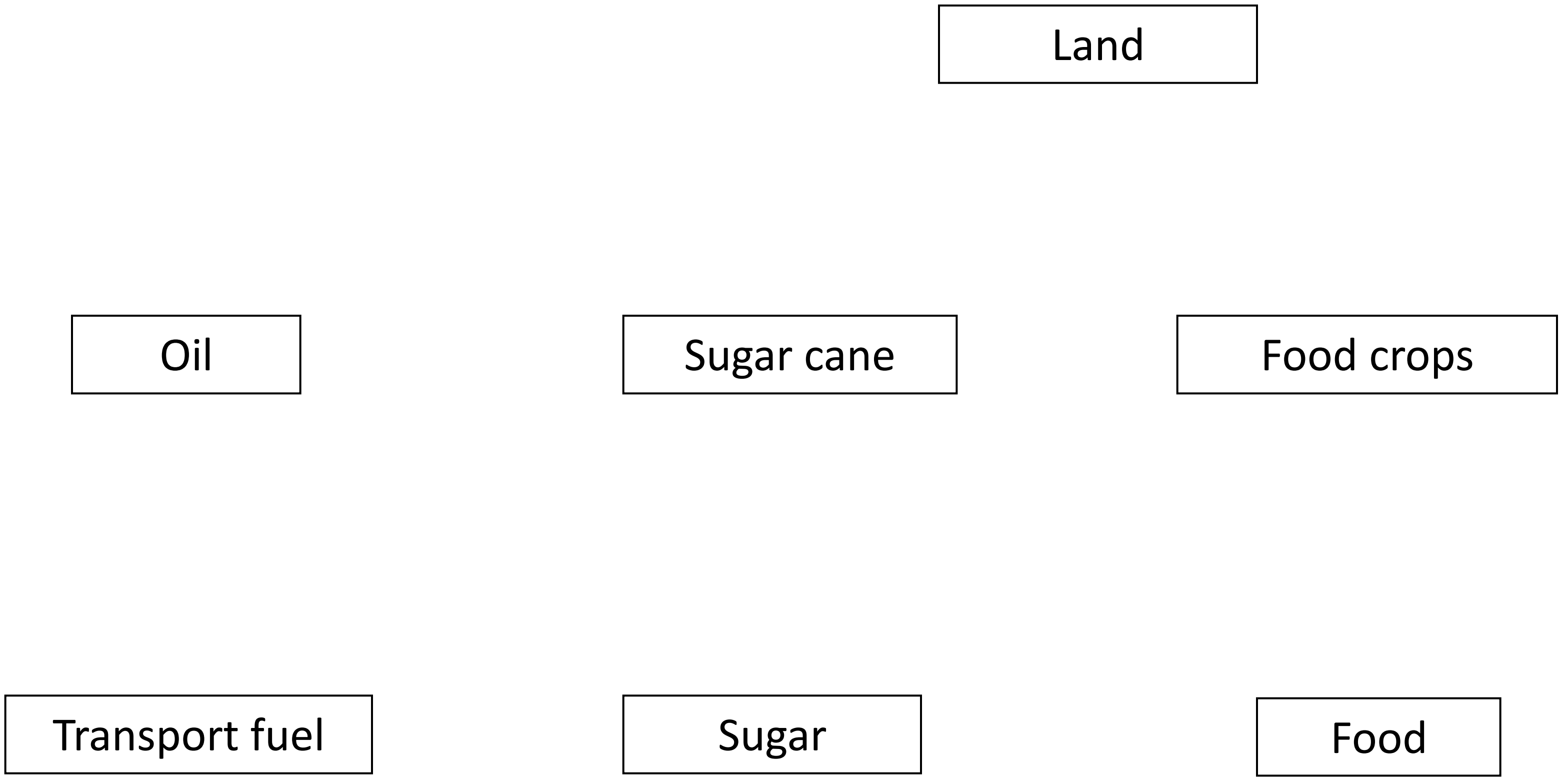
Key conditionalities

	Condition	Failure of condition
Land-intensity	Produce bioenergy by land-intensive biomass, not by land expansion	• Land carbon loss • Biodiversity loss • Competition with food
Food demand	Reduce consumption of red meat	• Less land available for bioenery crops • →see above
Costs	Reduce costs of cellulosic biofuels	• Not economically viable OR • False options chosen • → see above
Regulation	Global forest/peatland protection	• Very high risks of "leakage" • → see above
Labor and value chain	Rural communities take part in value chain, get labor, ownership & keep land rights	• Disempowerment • Inequality • Exclusion

Robust and adaptive pathways

- Invest into learning of options
- Enable re-evalution
- Invest into land-saving technologies
- Keep land carbon on ground
- Safety valve to food markets

GARBAGE


Land
Oil
Sugar cane
Food crops
Transport fuel
Sugar
Food