Week Eight Supplementary material:
November 8, 2013
1. Kanter on food, N2O, Guest, 2012
2. Creutzig on biocarbon, Guest, 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$_2$O
• 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

2070-2100 Prediction vs. 1960-1990 Average

Based on HadCM3

Temperature Increase (°C)
Linked – Temp. & precip.

Developed countries

Developing countries

Fisher et al. 2005
Sea level rise

[Image: Map showing 6 Meter Inundation with inundated areas highlighted.

https://www.cresis.ku.edu/data/sea-level-rise-maps]
CO$_2$ fertilization

**Map 1**
Without carbon fertilization
If there are no beneficial effects from increased carbon dioxide, agricultural output declines almost everywhere and catastrophically closer to the equator.
(climate-induced percent change in agricultural productivity between 2003 and the 2080s)

**Map 2**
With carbon fertilization
If some crops benefit from increased carbon dioxide, the global impact is less dire and those areas farther from the equator may see some increases in agricultural productivity.
(climate-induced percent change in agricultural productivity between 2003 and the 2080s)

Source: Cline (2007)
Note: NA refers to "not applicable" for Alaska and northern Canada, and to "not available" elsewhere.
Tropospheric ozone

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

Projected changes in agricultural productivity 2080 due to climate change, incorporating the effects of carbon fertilization

UNEP/GRID-Arendahl, 2007
Poorest most vulnerable

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

Rank 1

1. Somalia
2. Myanmar
3. Burundi
4. Liberia
5. Central African Republic
6. Zimbabwe
7. Eritrea
8. Guinea-Bissau
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
- Agriculture: 13%
- Land-Use Change & Forestry: 18%
- Waste: 3%
- Industrial Processes: 3%
- Energy: 63%

Source: Drawn from data from WRI (2008)

Fig. 2: Sources of emissions from the agricultural sector (2000)
- Residue Burning/Forest Clearing: 13%
- Rice (CH4): 11%
- Fertilizers (N2O): 37%
- Livestock (CH4): 32%
- Manure Management (CH4 & N2O): 7%

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 – N₂O

• Responsible for ~ 7% of our climate impact (excluding BC)
• Sources – ½ natural, ½ anthropogenic. Anthropogenic emissions have increased 40%-50% since 1860.
• Lifetime: 114 years; GWP₁₀₀: 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**

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**Fig. 2** Sector-by-sector contribution to anthropogenic N₂O 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

<table>
<thead>
<tr>
<th>Technology</th>
<th>Mitigation potential</th>
<th>Current use</th>
<th>Mitigation co-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrification inhibitors</td>
<td>~35%</td>
<td>High value crops, ~12% US corn cropland</td>
<td>NO$_3^-$, NH$_3$, NO$_x$</td>
</tr>
<tr>
<td>Controlled-release fertilizer</td>
<td>~40%</td>
<td>High value crops, &lt;1% of US corn cropland</td>
<td>NO$_3^-$, NH$_3$, NO$_x$</td>
</tr>
<tr>
<td>Genetically engineered crops/breeding</td>
<td>~30%</td>
<td>NA</td>
<td>NO$_3^-$, NH$_3$, NO$_x$</td>
</tr>
</tbody>
</table>

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

Galloway et al. 2002

Tilman 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
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$_2$O, 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

Potential diet gap calories
($\times10^6$ kcal per hectare)

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

Meridian Institute, 2011; Tilman et al. 2011
Food prices – with & without climate change

Source: FAO 2010

Meridian Institute, 2011
Geoengineering

Crop yields in a geoengineered climate

J. Pongratz\textsuperscript{1*}, D. B. Lobell\textsuperscript{2}, L. Cao\textsuperscript{1} and K. Caldeira\textsuperscript{1}

• Authors conclude that solar-radiation management in a high-\textsuperscript{CO}_2 climate generally causes crop yields to increase, largely because temperature stresses are diminished while benefits of \textsuperscript{CO}_2 fertilization are retained.
Immigration

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

Shuaizhang Feng\textsuperscript{a,b}, Alan B. Krueger\textsuperscript{a,c,d}, and Michael Oppenheimer\textsuperscript{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.
<table>
<thead>
<tr>
<th>Time scale</th>
<th>Target crop trait</th>
<th>Target crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>Tolerance to broad-spectrum herbicide</td>
<td>Maize, soybean, oilseed brassica</td>
</tr>
<tr>
<td></td>
<td>Resistance to chewing insect pests</td>
<td>Maize, cotton, oilseed brassica</td>
</tr>
<tr>
<td>Short-term (5–10 years)</td>
<td>Nutritional bio-fortification</td>
<td>Staple cereal crops, sweet potato</td>
</tr>
<tr>
<td></td>
<td>Resistance to fungus and virus pathogens</td>
<td>Potato, wheat, rice, banana, fruits, vegetables</td>
</tr>
<tr>
<td></td>
<td>Resistance to sucking insect pests</td>
<td>Rice, fruits, vegetables</td>
</tr>
<tr>
<td></td>
<td>Improved processing and storage</td>
<td>Wheat, potato, fruits, vegetables</td>
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<td></td>
<td>Drought tolerance</td>
<td>Staple cereal and tuber crops</td>
</tr>
<tr>
<td>Medium-term (10–20 years)</td>
<td>Salinity tolerance</td>
<td>Staple cereal and tuber crops</td>
</tr>
<tr>
<td></td>
<td>Increased nitrogen-use efficiency</td>
<td></td>
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<tr>
<td></td>
<td>High-temperature tolerance apomixsis</td>
<td></td>
</tr>
<tr>
<td>Long-term (&gt;20 years)</td>
<td>Nitrogen fixation</td>
<td>Staple cereal and tuber crops</td>
</tr>
<tr>
<td></td>
<td>Denitrification inhibitor production</td>
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<tr>
<td></td>
<td>Conversion to perennial habit</td>
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<tr>
<td></td>
<td>Increased photosynthetic efficiency</td>
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</tbody>
</table>
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

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Input</th>
<th>NED</th>
<th>Distance driven*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GJ/ha/y</td>
<td>10⁶ km</td>
</tr>
<tr>
<td><strong>Bioethanol from sugar beet</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>47⁴</td>
<td>10.9</td>
<td>0.55</td>
</tr>
<tr>
<td>NL</td>
<td>62³</td>
<td>15.5</td>
<td>0.78</td>
</tr>
<tr>
<td>ES</td>
<td>27⁴</td>
<td>4.8</td>
<td>0.24</td>
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<tr>
<td><strong>Biodiesel from rapeseed</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>2.9⁴</td>
<td>18.8</td>
<td>1.1</td>
</tr>
<tr>
<td>NL</td>
<td>3.7³</td>
<td>24.6</td>
<td>1.5</td>
</tr>
<tr>
<td>ES</td>
<td>1.3¹</td>
<td>7.2</td>
<td>0.43</td>
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<td><strong>Electricity from wood</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>2.4⁴</td>
<td>12.3</td>
<td>2.0</td>
</tr>
<tr>
<td>NL</td>
<td>2.8³</td>
<td>14.4</td>
<td>2.4</td>
</tr>
<tr>
<td>ES</td>
<td>0.5¹</td>
<td>2.5</td>
<td>0.41</td>
</tr>
<tr>
<td><strong>Electricity from wind</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>7.0¹</td>
<td>978</td>
<td>160</td>
</tr>
<tr>
<td>NL</td>
<td>6.8¹</td>
<td>927</td>
<td>151</td>
</tr>
<tr>
<td>ES</td>
<td>5.1¹</td>
<td>490</td>
<td>80</td>
</tr>
<tr>
<td><strong>Electricity from solar PV</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>824³</td>
<td>356</td>
<td>58</td>
</tr>
<tr>
<td>NL</td>
<td>873³</td>
<td>421</td>
<td>69</td>
</tr>
<tr>
<td>ES</td>
<td>1473³</td>
<td>1213</td>
<td>198</td>
</tr>
<tr>
<td>Source: GEA (Ch. 20), 2012</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Indicative area requirement (km²/PJ/yr)</th>
<th>Potential sustainability issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioenergy crops</td>
<td>50–500</td>
<td>Impacts on C balance, ecosystems, soils and food systems can be positive or negative, depending on management</td>
</tr>
<tr>
<td>Bioenergy residues</td>
<td>Almost no additional area</td>
<td>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</td>
</tr>
<tr>
<td>Solar energy</td>
<td>1–6</td>
<td>Land needed for infrastructure; excess heat can be used for grain drying</td>
</tr>
<tr>
<td>Geothermal energy</td>
<td>≈10</td>
<td>Land required for infrastructure and transmission</td>
</tr>
<tr>
<td>Hydropower</td>
<td>&lt;1–100</td>
<td>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)</td>
</tr>
<tr>
<td>Wind power</td>
<td>1–32</td>
<td>Land for wind power plants plus transmission, affects landscapes; rotors may kill birds</td>
</tr>
<tr>
<td>Oil</td>
<td>&lt;1</td>
<td>Land required for infrastructure and transport</td>
</tr>
<tr>
<td>Natural gas</td>
<td>&lt;1</td>
<td>Land required for infrastructure and transport</td>
</tr>
<tr>
<td>Coal</td>
<td>≈1</td>
<td>Land required for infrastructure and transport, soil contamination</td>
</tr>
<tr>
<td>Nuclear energy</td>
<td>&lt;1</td>
<td>Land for infrastructure and transmission; potentially much larger land areas contaminated in case of an accident</td>
</tr>
</tbody>
</table>
Coupling of energy and land markets

Market value of bioenergy is coupled to oil price....

Oil price shock:

Available land

Bioenergy

Food/Forests
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

Analytical framework

“Scientific approach”: Well-defined system boundaries

- Operationalisibility
- Reproducibility

Sustainability science: system boundaries are not well-defined

- 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
<p>| 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. |</p>
<table>
<thead>
<tr>
<th><strong>Bioenergy from crop residues</strong></th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bioenergy from dedicated crops</strong></td>
<td>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).</td>
</tr>
<tr>
<td><strong>Bioenergy from manure mgt (Biogas)</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Bioenergy from Organic Wastes</strong></td>
<td>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.</td>
</tr>
</tbody>
</table>
Huge uncertainty, not visible in individual studies.

IAMs see bioenergy as being CO2-neutral.
Creutzig et al., 2012
TECHNOLOGICAL OPTIONS
Bioenergy pathways

- **Agriculture:** energy crops & residues
- **Forestry:** Managed wood extraction & residues
- **Organic waste:** Households, waste management & service sector
- **Traditional biomass:** fuel wood, animal dung, charcoal, etc.
- **Modern biomass:** fuel wood, animal residues, wood and agriculture crops and residues, etc.
- **Biomass conversion**
- **Carbon capture and storage**
- **Transport:** liquid and gaseous fuels
- **Industry:** bioproducts, chemicals, materials, charcoal, etc.
- **Energy:** electricity & heating (direct and CHP)
- **Households:** cooking, heating, lighting, etc.
Bioenergy pathways

Feedstock
- Oil Crops (Rape, Sunflower, etc.), Waste Oils, Animal Fats
- Sugar and Starch Crops
- Lignocellulosic Biomass (Wood, Straw, Energy Crop, MSW, etc.)
- Biodegradable MSW, Sewage Sludge, Manure, Wet Wastes (Farm and Food Wastes)

Conversion Routes
- (Biomass Upgrading) + Combustion
- Transesterification or Hydrogenation
- (Hydrolysis) + Fermentation
- Gasification (+ Secondary Process)
- Pyrolysis
- AD (+ Biogas Upgrading)

Heat and/or Power
- Liquid Fuels
  - Biodiesel
  - Ethanol
  - Renewable Diesel
- Gaseous Fuels
  - Biomethane
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 $\geq$ gasoline

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

IAM studies project bioenergy as crucial mitigation strategy

present
- first generation
  - 3rd worst world

CO2e/MJ
- inductive
  - part+gen equilib

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

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

→ Variability (or stochastic uncertainty)
ALCA summary

LCA perspective:
In attributional LCA, GHG emissions from bioethanol are high but lower than gasoline emissions.
Globally integrated markets

### Time to repay carbon debt

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Biofuel Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical rainforest</td>
<td>Palm biodiesel (&gt; 85% of global palm production)</td>
<td>Indonesia/Malaysia</td>
</tr>
<tr>
<td>Peatland rainforest</td>
<td>Soybean biodiesel</td>
<td>Brazil</td>
</tr>
<tr>
<td>Tropical rainforest</td>
<td>Sugarcane ethanol</td>
<td></td>
</tr>
<tr>
<td>Cerrado wooded</td>
<td>Soybean biodiesel</td>
<td></td>
</tr>
<tr>
<td>Cerrado grassland</td>
<td>Corn ethanol</td>
<td>US</td>
</tr>
<tr>
<td>Central grassland</td>
<td></td>
<td></td>
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<tr>
<td>Abandoned cropland</td>
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</tbody>
</table>

Livestock intensity determines emission effects of sugarcane ethanol

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

Richard Plevin, PhD thesis, 2010

Uncertainty of ILUC emissions

Creutzig et al., 2012
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
SUSTAINABILITY CONSIDERATIONS
Food insecurity

Corn prices in 2008:
Biodiversity loss
Deforestation
Plantation (Schoneveld et al. 2011)

Aggregate level of livelihood dimensions

Inequality of livelihood dimensions
## Summary: bioenergy impacts

<table>
<thead>
<tr>
<th></th>
<th>Benefits</th>
<th>Harms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>green house gases</strong></td>
<td>low</td>
<td>high</td>
</tr>
</tbody>
</table>
| **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

<table>
<thead>
<tr>
<th></th>
<th>Condition</th>
<th>Failure of condition</th>
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</thead>
<tbody>
<tr>
<td>Land-intensity</td>
<td>Produce bioenergy by land-intensive biomass, not by land expansion</td>
<td>• Land carbon loss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Biodiversity loss</td>
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<tr>
<td></td>
<td></td>
<td>• Competition with food</td>
</tr>
<tr>
<td>Food demand</td>
<td>Reduce consumption of red meat</td>
<td>• Less land available for bioenergy crops</td>
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<td>• ( \rightarrow ) see above</td>
</tr>
<tr>
<td>Costs</td>
<td>Reduce costs of cellulosic biofuels</td>
<td>• Not economically viable OR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• False options chosen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ( \rightarrow ) see above</td>
</tr>
<tr>
<td>Regulation</td>
<td>Global forest/peatland protection</td>
<td>• Very high risks of “leakage”</td>
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<td>• ( \rightarrow ) see above</td>
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<tr>
<td>Labor and value chain</td>
<td>Rural communities take part in value chain, get labor, ownership &amp; keep land rights</td>
<td>• Disempowerment</td>
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<td></td>
<td></td>
<td>• Inequality</td>
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<tr>
<td></td>
<td></td>
<td>• Exclusion</td>
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</tbody>
</table>
Robust and adaptive pathways

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