Bioenergy and Earth Sustainability: Session on Scenarios: Ideas for integrating

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Agriculture plays a fundamental, dual role in global change with a strong linkage to energy futures.

Agriculture has raised wide concerns as a key human sector and its exposure to and dependence on climate change over the coming decades.

Agriculture is a major user and significant producer of energy.

It is a major source and sink of greenhouse gases via land use changes, land management and livestock production.

Fuel production on agricultural land may compete with food production.

Ultimately, farmers will have to adapt and mitigate at the same time.
Ecological-Economic Analysis

1. Development scenario
2. Climate model
3. Climate impact response relations
4. Production
5. Demand
6. World Market
7. Trade
8. Global Food System
Land Resources & Agro-ecological Zoning:

- FAO and IIASA have developed a spatial analysis system that enables rational land-use planning on the basis of an inventory of land resources and evaluation of biophysical limitations and production potentials of land.

- The AEZ methodology follows an environmental approach; it provides a standardized framework for analyzing synergies and trade-offs of alternative uses of agro-resources (land, water, technology) for producing food and energy, while preserving environmental quality.

Current LUC projects:

- Global Agricultural Zones Assessment (GAEZ 2007)
- Harmonized World Soil Database (HWSD)
- Exploiting Information on Global Environmental Risks – Agriculture (EIGER-Agri)
Spatial Distribution and Intensity (percent) of Cultivated Land, year 2000

Note: calibration of GLC2000 class weights starts from estimated reference weights and is based on an iterative scheme to match national/sub-national statistics of year 2000 (FAO AT2015/2030 adjusted cultivated land).

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Normalized difference index, suitability of rain-fed cereals, HadCM3-A1FI, 2080s.
Water and Agriculture:

- Irrigated area has expanded to over 270 million ha worldwide, about 18% of total cultivated land. **Agriculture is the largest user of water** among human activities: irrigation water withdrawals are 70% of the total anthropogenic use of renewable water resources.

- Agriculture is in competition with other water users and has impacted negatively on the environment.

**Current LUC projects:**

- Water and Global Change (WATCH)
- Water Scenarios for Europe and for Neighboring States (SCENES)
Global Map of Irrigated Areas

Source: GMIA ver 4, FAO/University of Frankfurt (2007)
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Impacts of climate change on regional net irrigation water requirements in 2080

- 271 million ha irrigated out of total 1540 million ha cultivated (~ 18 %).
- Agriculture uses 2630 billion m³ out of 3816 billion m³ annual water withdrawals (~ 70%).
- On average, annual global crop water deficit is 500 mm (i.e., 1350 billion m³ in 2000); about 970 mm water per irrigated hectare were applied.
Impacts of climate change on regional net irrigation water requirements in 2080

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Mexico: Climate Change Impacts (% change) on Indicators of Agricultural Water Use – 2080

<table>
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<tr>
<th></th>
<th>Precipitation</th>
<th>Crop Water Requirements</th>
<th>Crop Water Deficits</th>
<th>Internal Water Resources</th>
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</table>

Note: percent change relative to respective reference projection without climate change. Crop water requirements calculated as crop-specific potential evapotranspiration (plus special allowance for paddy).

- 6.3 million ha irrigated out of total 27.3 million ha cultivated (~ 23 %)
- Agriculture uses 60.3 billion m³ out of 78.2 billion m³ annual water withdrawals (> 75%)
- On average, annually about 1000 mm water per irrigated hectare applied
Message 1:

- While atmospheric changes (CO₂ fertilization) may initially increase productivity of current agricultural land, climate change, if not halted, will have a clearly negative impact in the second half of this century.

- Impacts of climate change on increasing net irrigation water demand could be as large as changes projected due to socio-economic development in 2000-2080 (~400 Gm³ vs ~600 Gm³, compared to 1350 Gm³ in 2000).
The International Linkage in the World Food System Model

18 national models, 2 country-group models, 14 regional models

Commodities: wheat, rice, coarse grains, protein feed, bovine & ovine meat, dairy products, other animal products, other food, non-food agriculture, non-agriculture.

Linkage: trade, world market prices and financial flows
Food and Agriculture Outlook

1. Cereal production, scenario A2r, 2000 to 2080

2. Pork & poultry production, scenario A2r, 2000 to 2080

Source: LUC World food system simulations of GGI scenarios, IIASA (2005).
Food and Agriculture Outlook

<table>
<thead>
<tr>
<th>Growth of</th>
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</thead>
<tbody>
<tr>
<td>Arable land</td>
<td>12%</td>
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<tr>
<td>Cereal production</td>
<td>69%</td>
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<tr>
<td>Ruminant meat</td>
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<td>Other meat</td>
<td>85%</td>
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<tr>
<td>Agriculture</td>
<td>86%</td>
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</table>

Sources of growth in agricultural production, Scenario A2r, 2000-2050

- 75% Yield increases
- 13% Increases in cropping intensity
- 12% Arable land expansion

Food and Agriculture Outlook

<table>
<thead>
<tr>
<th>Growth 2000-2050</th>
<th>Scenario B1</th>
<th>Scenario A2r</th>
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<td>81%</td>
<td>86%</td>
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Sources of growth in agricultural production, 2000-2050

Arable land expansion

Increases in cropping intensity

Yield increases

Intensification

3. Total agricultural production, revised A2r scenario, 2000 to 2080

4. Cultivated land, projected for different socioeconomic pathways, 1990 to 2080

Source: LUC World food system simulations of GGI scenarios, IIASA (2005).
## Major land use by region, scenario A2r, year 2000 and 2050

<table>
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<tr>
<th>Region</th>
<th>2000</th>
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Source: IIASA-GGI, 2008

Global Development: Science and Policies for the Future

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Net changes of major land uses in LDC regions, Scenario A2r, 2000 to 2050

<table>
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<tr>
<th>REGION</th>
<th>TOTAL</th>
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Source: IIASA-GGI, 2008
Simulated Impacts of Climate Change on World Crop Prices – 2080s

Note: percent changes relative to A2r reference projection without climate change. The diagram is based on food system simulations using climate projections obtained from HadCM3 and CSIRO climate models for the IPCC SRES B1, B2, A2 and A1FI emissions scenario.
• The role of bio-energy has been strongly enhanced by its consideration in the **climate change** debate, as well as opportunities it may create for **rural development** and improved **energy security**.

• **Land use competition** with food and feed production is considered a potential **key barrier** to exploiting the bio-energy production potential.

**Current LUC projects:**

- Global Assessment of Bio-energy Potentials
- Renewable Fuels for a Sustainable Europe (REFUEL)
- Effective and Low-disturbing Bio-fuel Policies (ELOBIO)
Price Transmission: Energy to Agriculture

Retail food price:

\[ p_{i_{\text{food}}} = p_{i_{\text{raw}}} + \text{prm}_{i_{\text{food}}} \cdot p_n \]

Retail energy price:

\[ p_{i_{\text{energy}}} = (p_{i_{\text{raw}}} + \text{prm}_{i_{\text{energy}}} \cdot p_n) \cdot c_i \]

As the energy market is much bigger than agricultural market and assuming that markets are well integrated, substitution will take place on demand and supply side, etc., energy demand creates a floor and ceiling price:

Ceiling on (long-term) food prices:

\[ p_{i_{\text{food}}} = p_{i_{\text{energy}}} / c_i + (\text{prm}_{i_{\text{food}}} - \text{prm}_{i_{\text{energy}}}) \cdot p_n \]
Bio-fuel Feedstocks

Feedstock groups:

- Oil crops
  - Rapeseed; Sunflower; Soybean; Oilpalm
- Sugar crops
  - Sugarcane; Sugar beet; Sweet sorghum
- Starch crops
  - Wheat; Rye; Triticale; Maize; Sorghum
- Herbaceous lignocellulosic plants
  - Miscanthus; Switch grass; Reed canary grass
- Woody lignocellulosic plants
  - Poplar; Willow; Eucalyptus

Figure 1. Fuel production pathways

Source: adapted from BMU (2006) and Hamelinck and Faaij (2006)
Bio-fuel Feedstock Yield Potential

(a) Attainable energy yields of (1st generation) starch crops, sugar crops and oil crops (GJ/ha, biofuel equiv.)

(b) Attainable energy yields of (2nd generation) woody and herbaceous lignocellulosic feedstocks (GJ/ha, biofuel equiv.)

Source: Land Use Change and Agriculture Program, 2007
Figure 8. GHG emissions of biofuels related to their gasoline or diesel alternatives and overall environmental impact assessment.

Message 2:

- Most conventional agricultural feedstocks perform inadequately for environmental criteria, especially if cultivation leads to additional conversion of grassland or forest.

- Second generation lignocellulosic technologies (also recycling and using wastes) hold a promise of doing much better (both land use efficiency and GHG savings).

- A substantial contribution of agricultural biomass to energy sources would require:
  (a) Focus on sustainable production increases on current agricultural land (beyond BAU);
  (b) Tapping into resources currently not or only extensively used.
Global Use of Arable Land, year 2000

<table>
<thead>
<tr>
<th>Land in consumption</th>
<th>World mln ha</th>
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</thead>
<tbody>
<tr>
<td>Crops (excl feed)</td>
<td>1005.4</td>
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<tr>
<td>Cereals</td>
<td>536.9</td>
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<tr>
<td>Other crops</td>
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<tr>
<td>Feed use</td>
<td>514.1</td>
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<tr>
<td>Cereals</td>
<td>214.2</td>
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<tr>
<td>Other crops</td>
<td>94.4</td>
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<tr>
<td>Fodder crops</td>
<td>205.5</td>
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<table>
<thead>
<tr>
<th>of which</th>
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<tbody>
<tr>
<td>Ruminants</td>
<td>307.7</td>
</tr>
<tr>
<td>Other livestock</td>
<td>206.4</td>
</tr>
</tbody>
</table>

MDCs: 619 mln ha

LDCs: 900 mln ha
Total land ...

Note: The map indicates the share of each grid-cell that is available for use.

Source: GAEZ 2007, IIASA-LUC/FAO
... subtracting cultivated land

Note: The map indicates the share of each grid-cell that is available for use.

Source: GAEZ 2007, IIASA-LUC/FAO
... subtracting forest areas

Note: The map indicates the share of each grid-cell that is available for use.

Source: GAEZ 2007, IIASA-LUC/FAO
... excluding non-vegetated areas

Note: The map indicates the share of each grid-cell that is available for use.

Source: GAEZ 2007, IIASA-LUC/FAO
... excluding protected areas

Note: The map indicates the share of each grid-cell that is available for use.

Source: GAEZ 2007, IIASA-LUC/FAO
... excluding climatically unsuitable or very marginal areas

Note: The map indicates the share of each grid-cell that is available for use.

Source: GAEZ 2007, IIASA-LUC/FAO
How much land is available?

Source: IIASA-LUC, 2007

1 ... Total land (excl. Antarctica and Greenland)
2 ... excluding built-up land
3 ... excluding arable and perennial cropland
4 ... excluding forests
5 ... excluding barren land & water
Climatic suitability for herbaceous and woody lignocellulosic plants …

… on available grass-scrub-wood land

Source: GAEZ 2007, IIASA-LUC/FAO
Intensity of grass/scrub/wood land (percent)

Density of ruminant livestock (cattle equiv./ha)

Excluding from a total land area (excl. Antarctica & Greenland) of 13.1 billion hectares current cultivated land, forests, built-up land, water and unvegetated land (desert, rocks, etc,) results in some 4.5 billion hectare (35%).

Excluding from these lands the very low and unproductive areas (e.g. tundra, arid land) a remaining area of 2.1 billion hectares is estimated (currently grassland & pastures, shrubs and woodland).

Constructing detailed country-level livestock feed balances, we estimate that in year 2000 about 60-70 percent of the available biomass was used for animal feeding.

Hence with current use, the land potentially available for bioenergy production is 600 – 800 million hectare, with a wide range of productivity.
• The charts show the distribution of grass-scrub-wood-land areas and potential production by bio-productivity class.
• Protected land and land with steep slopes is shown in red; Very low productive areas are indicated as grey.
• Number of cattle, sheep and goat is shown by bio-productivity class respectively for areas where grass/scrub/woodland cover exceeds 1/3 of total (green) and for less than 1/3 (yellow).
Some Key Research Questions

• How do different scenarios of socio-economic development impact land use for food, feed and fiber, and built-up land?

• How much and where do climate impacts matter? What adaptation strategies need to be implemented? With what consequences to land and water resources, availability of land for energy production, emissions of GHGs?

• How do different scenarios of socio-economic development and climate change impact the ability to mitigate within land-based sectors?
Some Key Research Questions

• What are the options, trade-offs and impacts of a future high demand for biofuels?
  – Feasibility of such demand under different socioeconomic pathways?
  – Are there low-input ways of growing biomass? Under what conditions do they stand the economic test?
  – Is there a trade-off between ‘efficiency’ and ‘local value’?
  – What are the trade-offs in ecosystem services?
Some Key Research Questions

• How well do social transitions fit with technological and land use transitions in different scenarios?

• What transition pathways from 1\textsuperscript{st} to 2\textsuperscript{nd} generation technologies exist in terms of land use and feedstocks? What could be successful models for transition? How do they depend on environmental setting, socio-cultural conditions and development stage?

• Can a scenario be constructed where bio-energy becomes the cause of development?