Examples of Long-term Integrated Food System Analysis using IIASA’s Assessment Framework

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International Institute for Applied Systems Analysis, Laxenburg, Austria
Chinese Agricultural Transition: Trade, Social and Environmental Impacts

A three-year multidisciplinary international project to investigate the impacts of China’s economic transition on its agricultural economy, with a particular focus on:

- Consequences and prospects for international trade, especially between China and the European Union
- Impacts on social conditions in rural areas
- Environmental implications

The Research Consortium consists of:
SOW - CCAP - IIASA - SOAS - LEI - IFPRI

with funding from the European Union, under the Sixth Framework Programme for Research and Technological Development
Agriculture, Food and Water: Environmental Impacts and Linkages

The fast growth of consumption in China, meat in particular, has triggered intensification and concentration of production, requiring additional irrigation and leading to increased emission of pollutants, interacting with climate change and other environmental stresses:

- Water scarcity
- Climate change
- Non-point source pollution
- GHG emissions
- Ground-level ozone
Ground-level ozone

Air pollutant:
- Toxic to humans
- Toxic to plants
- Greenhouse gas

Photochemical formation depends on:
- Emission of precursors (e.g. NO$_x$, VOCs)
- Weather (e.g. radiation, temperature, wind)
21,400 premature deaths/year in EU are O₃-associated

Crop losses in 2000: US$ 6.7 billion/year in EU and US$ 14-26 billion global

Northern hemisphere [O₃] > 2x pre-industrial revolution

Northern hemisphere background ~35-40 ppb; Peaks > 100 ppb in metropolitan areas

WHO guidelines: 50 ppb; Plant damage: 40 ppb

O₃-precursor emissions were reduced in US, EU, Japan

Transboundary transport (global problem)

Climate change may exacerbate [O₃] formation
Ozone damage to plants

Well established reduction in photosynthesis

Impacts on:

- Food security (crop production)
- Carbon sequestration (tree growth)

Figure 1. Potato leaves showing: (a) no visible ozone damage, (b) moderate and (c) severe visible ozone damage (reprinted from Donnelly et al. 2001a with permission from Blackwell Publishing).
Ground-level ozone seasonality

Index: DEU649N0 (49°46’N, 7°03’E, 480 m.a.s.l.)

NOTICE:
All submitted data are plotted and no data selection is made by a data quality flag.
Assessing $O_3$ impact on crops with the AEZ methodology

Seasonal ozone concentration

TM5-JRC/Ispra Projections + APD-IIASA Emission Scenarios
Structure of integrated assessment for the analysis of O₃ impact on crops

- Chemical Transport Models (CTMs)
- Socio-economic/ emission scenarios (e.g. IPCC storylines)
- Global Circulation Models (GCMs)
- Climate Change \( \Delta (CO_2, T, P) \)
- \([O_3]\)
- \(\text{VOC}\)
- \(\text{NOx}\)
- GAEZ with O₃ functions

\(\Delta \text{ yield with O}_3\)
Methodology

1) AEZ determines (i) crop type, (ii) crop calendar and the (iii) sensitive period

2) AOT40 index is calculated from TM5 daily projections

3) AEZ estimates crop yields and the loss expected due to O$_3$ exposure
Using GAEZ to test adaptation to $O_3$

GAEZ estimates crop calendar for maximum yields without considering $O_3$ concentration and damage.

Radiation, temperature, and water are the main factors defining crop calendar.

GAEZ shifts calendar and/or tests crop types with different cycle length to maximize "ozone-damaged" yield.

GAEZ estimates 'adapted' crop calendar for maximum yields considering $O_3$ concentration and damage.

Trade-off between "new AOT40" and "new climatic conditions" for crop growth define the 'adapted' yield.

Rain-fed length of growth season (rain-fed calendars are tested) | Dry period | Irrigated length of growth season (irrigated calendars are tested)

Crop calendar: Sowing date | Harvest date

Ozone concentration (ppb h)
Crop sensitivity differs
AOT40 damage functions
China

Estimates of yield loss

Assumptions:

- TM5 runs with
- IIASA CLE emissions scenario
- AOT40 index
- Rain-fed and irrigated systems independent

Teixeira et al., (2008, forthcoming)
Royal Society Science Policy Report, October 2008:

Figure: Global and regionally aggregated relative yield losses in 2000 for rice, wheat, maize and soybean (van Dingeren et al. in press). The bars indicate average values using two different exposure indices (AOT40 and either M7 or M12) while the error bars give the range of values using the two indices.
Message:

- Ground-level ozone is estimated to have a substantial impact on China’s crop production;
- Wheat and soybean are much more affected than rice and maize;
- There are only very limited agronomic adaptation options to ground-level ozone;
- Avoiding precursors of ground-level ozone formation is the most effective mitigation measure.
AGRO-ECOLOGICAL IMPACTS OF CLIMATE CHANGE
Temperature response to increasing CO₂ concentrations (China)

Correlations between temperature increase and precipitation change (China)
Rain-fed Wheat

HadCM3, IPCC A2, 2050s

Reference, 1961-1990

Agronomically Attainable Yield
Irrigated Wheat
HadCM3, IPCC A2, 2050s

Reference, 1961-1990

Agronomically Attainable Yield
Percentage of cultivated land in grid cell; calibration to province data of year 2000
CHINA - Economic Regions and Provinces

Provinces
11 Beijing
12 Tianjin
13 Hebei
14 Shanxi
15 Inner-Mongolia
21 Liaoning
22 Jilin
23 Heilongjiang
31 Shanghai
32 Jiangsu
33 Zhejiang
34 Anhui
35 Fujian
36 Jiangxi
37 Shandong
41 Henan
42 Hubei
43 Hunan
44 Guangdong
45 Guangxi
46 Hainan
51 Sichuan
52 Guizhou
53 Yunnan
54 Tibet
61 Shaanxi
62 Gansu
63 Qinghai
64 Ningxia
65 Xinjiang
71 Taiwan
72 Hongkong

ECONOMIC Regions
- Central
- East
- North
- Northeast
- Northwest
- Plateau
- South
- Southwest
Climate Change Impacts on Rain-fed Wheat Production Potential of Cultivated Land

With climate change (as projected by Hadley Centre GCM) the national potential for rain-fed wheat production is decreasing, with reductions both in yield and suitable extents most pronounced in southern regions.

Calculation based on (i) spatial grid of climate, soil terrain data and cultivated land areas and (ii) FAO/IIASA AEZ crop yield estimation method.
## China: Climate Change Impacts (% change) on Rain-fed Wheat Production Potential Land

<table>
<thead>
<tr>
<th>Region</th>
<th>HadCM3 2050s</th>
<th>2050s, Irrig.</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adapted var.</td>
<td>Adapted var.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>without CO2</td>
<td>with CO2</td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>1</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Northeast</td>
<td>-14</td>
<td>-8</td>
<td>7</td>
</tr>
<tr>
<td>East</td>
<td>-5</td>
<td>1</td>
<td>-3</td>
</tr>
<tr>
<td>South</td>
<td>-37</td>
<td>-34</td>
<td>-62</td>
</tr>
<tr>
<td>Central</td>
<td>-26</td>
<td>-22</td>
<td>-28</td>
</tr>
<tr>
<td>Southwest</td>
<td>-20</td>
<td>-15</td>
<td>-10</td>
</tr>
<tr>
<td>Northwest</td>
<td>1</td>
<td>7</td>
<td>32</td>
</tr>
<tr>
<td>China</td>
<td>-11</td>
<td>-6</td>
<td>-2</td>
</tr>
</tbody>
</table>

Assumes full adaptation to best-suited wheat type.
Rain-fed Grain Maize

HadCM3, IPCC A2, 2050s

Reference, 1961-1990

Agronomically Attainable Yield
Climate Change Impacts on Rain-fed Maize Production Potential of Cultivated Land

With climate change (as projected by Hadley Centre GCM) the national potential for rain-fed maize production is increasing, mainly due to yield increases in Northeast, North and Northwest regions.

Calculation based on (i) spatial grid of climate, soil terrain data and cultivated land areas and (ii) FAO/IIASA AEZ crop yield estimation method.
## China: Climate Change Impacts (% change) on Rain-fed Grain Maize Production Potential Land

<table>
<thead>
<tr>
<th>Region</th>
<th>HadCM3 2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>local varieties without CO2</td>
<td>adapted var. without CO2</td>
</tr>
<tr>
<td>North</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Northeast</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>East</td>
<td>-7</td>
<td>-2</td>
</tr>
<tr>
<td>South</td>
<td>-27</td>
<td>-23</td>
</tr>
<tr>
<td>Central</td>
<td>-6</td>
<td>-4</td>
</tr>
<tr>
<td>Southwest</td>
<td>-10</td>
<td>-6</td>
</tr>
<tr>
<td>Northwest</td>
<td>39</td>
<td>42</td>
</tr>
<tr>
<td>China</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>

Assumes full adaptation to best-suited maize type.
Temperature change vs CO2 concentration

North Region

Precipitation change (%) vs Temperature change

Northeast Region
Share of irrigation in cultivated land
# Share of Irrigated Production in China

## Total in 2000; (percent)

<table>
<thead>
<tr>
<th>Region</th>
<th>RICE</th>
<th>WHEAT</th>
<th>MAIZE</th>
<th>SOYB</th>
<th>COTTON</th>
<th>CEREALS</th>
<th>CEREALS excl.RICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>R1</td>
<td>98.1</td>
<td>94.5</td>
<td>68.5</td>
<td>55.1</td>
<td>83.5</td>
<td>82.8</td>
</tr>
<tr>
<td>Northeast</td>
<td>R2</td>
<td>84.9</td>
<td>23.4</td>
<td>17.6</td>
<td>7.1</td>
<td>67.0</td>
<td>38.8</td>
</tr>
<tr>
<td>East</td>
<td>R3</td>
<td>99.9</td>
<td>86.5</td>
<td>47.8</td>
<td>46.3</td>
<td>70.7</td>
<td>90.6</td>
</tr>
<tr>
<td>Central</td>
<td>R4</td>
<td>100.0</td>
<td>68.1</td>
<td>21.9</td>
<td>36.1</td>
<td>56.3</td>
<td>94.0</td>
</tr>
<tr>
<td>South</td>
<td>R5</td>
<td>98.2</td>
<td>92.7</td>
<td>16.4</td>
<td>34.8</td>
<td>22.6</td>
<td>92.5</td>
</tr>
<tr>
<td>Southwest</td>
<td>R6</td>
<td>96.8</td>
<td>65.4</td>
<td>10.0</td>
<td>8.5</td>
<td>33.3</td>
<td>65.8</td>
</tr>
<tr>
<td>Plateau</td>
<td>R7</td>
<td>86.1</td>
<td>49.9</td>
<td>75.6</td>
<td>79.2</td>
<td>0.0</td>
<td>48.8</td>
</tr>
<tr>
<td>Northwest</td>
<td>R8</td>
<td>100.0</td>
<td>79.6</td>
<td>69.6</td>
<td>28.8</td>
<td>97.7</td>
<td>72.8</td>
</tr>
<tr>
<td>China TOT</td>
<td></td>
<td>97.9</td>
<td>86.8</td>
<td>44.8</td>
<td>29.4</td>
<td>80.1</td>
<td>78.9</td>
</tr>
</tbody>
</table>

Source: Model-based estimation using county statistics of year 2000
China: Climate Change Impacts (% change) on Indicators of Agricultural Water System

<table>
<thead>
<tr>
<th>Climate Scenario</th>
<th>Percent change in 2020s</th>
<th>Percent change in 2050s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PREC</td>
<td>CWR</td>
</tr>
<tr>
<td>HadCM3 A2</td>
<td>1.1</td>
<td>6.7</td>
</tr>
<tr>
<td>CSIRO A2</td>
<td>3.0</td>
<td>5.7</td>
</tr>
<tr>
<td>CGCM2 A2</td>
<td>0.2</td>
<td>11.0</td>
</tr>
<tr>
<td>ECHAM A2</td>
<td>-0.2</td>
<td>7.1</td>
</tr>
<tr>
<td>HadCM3 B1</td>
<td>4.0</td>
<td>2.2</td>
</tr>
<tr>
<td>CSIRO B1</td>
<td>4.2</td>
<td>6.5</td>
</tr>
</tbody>
</table>

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

In year 2000:
- 54 million ha irrigated out of total 128 million ha cultivated (~42%)
- Agriculture uses 427 billion m³ out of 630 billion m³ annual water withdrawals (~68%)
- On average, annually about 790 mm water applied
China: Climate Change Impacts on average Crop Water Requirements in Irrigated Areas

Calculation based on (i) spatial grid of climate and irrigated land areas and (ii) FAO/IIASA AEZ crop soil water balance method.

With climate change the share of irrigation in total water requirements as well as the total amount of water to be supplemented by irrigation increases; magnitude dependent on scenario and climate model.
Message:

- Climate change requires substantial adaptation of cropping systems in China’s regions;
- Crop production potential is shifting northwards with climate change;
- Positive temperature effects may be limited by soil moisture deficits;
- Crop water requirements projected to increase >10 percent by 2050; a growing fraction to be supplied by irrigation;
- High risk that water stress will increase with climate change. Magnitude of effects varies with GCM and emission scenario.
Eyes on the track, Mind on the horizon
From inconvenient rapeseed to clean wood:
A European road map for biofuels
planning the road ahead for biofuels
To develop an ambitious, yet realistic road map for an effective deployment of biofuels until 2030 in the EU25+

- Land availability
- Feedstock potentials
- (relative) costs of biofuels
- Impacts
- Strategy and policy issues
- Implementation issues
Three available European land cover databases (CORINE 2000, CORINE 1990, GLC2000 Europe) have been reclassified to twelve major land use classes for the purpose of determining spatial locations of arable land, grassland, forest and other areas. In this way a harmonized land use map was constructed for the Pan-European territory to permit spatially explicit estimation of land potentially available for bio-fuel production.

Source: Land Use Change and Agriculture Program, 2007
Bio-fuel Feedstocks

Feedstock groups:

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

Figure 1. Fuel production pathways

Source: adapted from BMU (2006) and Hamelinck and Faaij (2006)
Detailed feedstock supply and cost assessment

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

Summary baseline 2030

1 EJ (ExaJoule) = 24 Mtoe

planning the road ahead for biofuels
Methodology for assessment of biofuel feedstock potentials

Biofuel feedstocks considered:

1. **Woody ligno-cellulosic** plants – (2nd generation biofuels): Short rotation forestry management systems. Tree species considered include poplars, willows and eucalypts covering a wide range of ecological regions of Europe.

2. **Herbaceous ligno-cellulosic** plants - (2nd generation biofuels): Herbaceous plants selected included miscanthus, switchgrass and reed canary grass.

3. **Oil crops** – (1st generation biofuel for biodiesel production): The two selected oil crops are widely grown in Europe: rapeseed, sunflower.

4. **Starch crops** - (1st Generation biofuel for bioethanol production): Selected starchy crops are wheat, maize, rye and triticale.

5. **Sugar crops** - (1st Generation biofuel for bioethanol): Sugar beet is a widely grown crop in Europe, while sweet sorghum is regarded as a potential energy crop for the sugar to energy production pathway.

Source: Land Use Change and Agriculture Program, 2007
Biofuel 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 ligno-cellulosic feedstocks (GJ/ha, biofuel equiv.)

Source: Land Use Change and Agriculture Program, 2007
## POLAND – Suitability for biofuel feedstock

### Feedstocks

<table>
<thead>
<tr>
<th>Suitability index</th>
<th>SUITABILITY distribution on agricultural area (%)</th>
<th>Average YIELD (rainfed) in suitability class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VS  S  MS  ms  NS</td>
<td>VS  S  MS  Ms  Unit of Yield</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>33  10  18  0  39</td>
<td>17.1  13.3  9.4  5.4  ton d.w./ha</td>
</tr>
<tr>
<td>Woody</td>
<td>14  37  31  10  7</td>
<td>13.3  10.6  7.2  4.1  ton d.w./ha</td>
</tr>
<tr>
<td>Cereals</td>
<td>34  11  16  4  35</td>
<td>8.6  6.5  4.5  2.9  ton d.w./ha</td>
</tr>
<tr>
<td>Sugar crops</td>
<td>25  17  14  6  38</td>
<td>8.6  6.7  4.5  2.6  ton sugar/ ha</td>
</tr>
<tr>
<td>Oil crops</td>
<td>35  11  15  4  34</td>
<td>1.5  1.2  0.8  0.5  ton oil / ha</td>
</tr>
</tbody>
</table>

### Biofuel equivalent [GJ/ha]

![Percentage and GJ/ha graphs for different crop types](image)
Average potential biofuel energy yields for 1st and 2nd generation biofuel feedstocks on cultivated land for European countries (GJ/ha biofuel equivalent)

Note: 1st generation biofuel feedstocks include starchy crops (wheat, maize, rye, triticale), sugar crops (sugar beet, sweet sorghum) and oil crops (rapeseed, sunflower). 2nd generation ligno-cellulosic feedstocks comprise of woody species (willow, poplar, eucalyptus) and herbaceous species (switch grass, miscanthus, canary reed grass). In each grid-cell with cultivated land the best-performing species is selected (in terms of biofuel equivalent).

Source: Land Use Change and Agriculture Program, 2007
Policy issues:

**Competition** of energy crops with **food and feed** production is a key issue in the policy debate on expanding biofuel use.

The basic approach is to assess availability of agricultural land in excess of land required for food and feed production (‘Food first’):

- Land use model
- Per country
- Year 2000 – 2030
- Relates demand with production
- Scenario dependent productivity increases free up land in the future
- Differentiates arable land and pasture
- Maintains food/feed self-reliance level of baseline year
REFUEL Scenario Projections

Population

Food consumption

food use / capita

Vegetable food

from

Cereals

from

Other crops

Livestock products

from

Other LVST

from

Ruminants

CROPS Qty.

Dom. USE

CROPS Qty.

Dom. PROD

CULTIVATED
area requirements

ENERGY requirements

FEED crops requirements

Feed from

PASTURE

Pstr YIELD

PASTURE
area requirements

SSR

Dom.PROD

Other LVST

Dom.PROD

Ruminants

SSR

Crop YIELD

Dom. PROD

Other LVST

Dom. PROD

Ruminants

CROP YIELD

Dom. USE

Dom. PROD
Land required for food and feed and land potential available for biofuel feedstocks, 2030

The graph shows the use of current stock of cultivated land in 2030 for EU15, EU12, Ukraine and selected European countries assuming projected food and feed demand would be satisfied from domestic production at current aggregate European self-reliance levels for cereals, other crops, ruminant livestock products as well as other meat (variant ‘baseline’ scenario).
Trajectories of cultivated land potentially available for biofuel feedstock production

Potential area for growing BIO-CROPS in Western Europe

Source of potential cultivated land for growing BIO-CROPS in Europe, Baseline in 2030

Potential area for growing BIO-CROPS in Eastern Europe

Total = 65.1 million ha

Source: Land Use Change and Agriculture Program, 20
**Summary: Feedstock assessment**

- Detailed resource database available for assessing suitability of alternative biofuel feedstocks;
- CLC2000 land cover grid (at 100 m) used to determine current use of land potentially suitable for biofuel feedstock production;
- Suitability and bio-productivity assessment with AEZ model operating at 1 km resolution database;
- Aggregation of individual feedstock potentials to national or sub-national administrative units by major land cover class;
- Availability of land was assessed assuming (a) scenarios of demographic change and per capita consumption, (b) convergence of yields for WEC and CEEC, and (c) maintaining of current European levels of self-reliance for food and feed.
Conclusions & Policy implications

- Sufficient extents of agricultural land could become available for biomass production while satisfying food & feed demand.
- Regional differences – Importance of Eastern Europe
- By 2030, some 22 to 30 mio.ha cultivated land available in EU27 (+another 20 mio.ha in Ukraine). In addition some 15 mio. ha of pasture could be used for energy crops.
- With large areas to be used for bio-energy feedstock production, **efficiency** and **sustainability** of production will be crucial for public acceptance (crop rotations, agricultural intensity, biodiversity impacts, nitrogen losses, net GHG savings, …).
However first-generation fuels...

- Only moderate answer to the biofuels drivers
  - GHG savings 40-60%
  - Limited land efficiency
  - Moderate options for innovation, competitiveness
  - What if 10% is not sufficient?

*Second-generation biofuels score significantly better on all these criteria*
Quite a stormy year for biofuels

2008

“Biofuels bitter necessity”

“Sustainability Criteria”

“70% of the food crisis”

“...crime against humanity”

At the global scale, to achieve a significant contribution of agricultural biomass to energy sources, while

- Accomplishing substantial GHG savings
- Preserving highly biodiverse land, and
- Protecting land with high carbon stocks

would require:

- preserving current agricultural land
- focusing on sustainable production increases on current agricultural land (beyond BAU)
- tapping into (non-forest) resources currently not or only extensively used, and
- rapid development of alternative feedstocks on non-food land and 2\textsuperscript{nd} generation conversion routes.
IS THERE ENOUGH AGRICULTURAL LAND?
Estimated Use of Land in 2000*

<table>
<thead>
<tr>
<th>Land Type</th>
<th>Area (mln ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland</td>
<td>1562</td>
</tr>
<tr>
<td>Forests</td>
<td>3744</td>
</tr>
<tr>
<td>Grass/woodland</td>
<td>4560</td>
</tr>
<tr>
<td>Other land</td>
<td>3443</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>13309</strong></td>
</tr>
</tbody>
</table>

* excluding Antarctica
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
How much land is available?

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

Source: IIASA-LUC, 2007
Climatic productivity of herbaceous and woody lignocellulosic plants


Source: GAEZ 2007, IIASA-LUC/FAO
Climatic productivity of 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)

• 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 and for less than 1/3.
Message:

How much land could be available?

- 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.

- 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 needed for animal feeding.

- Hence with current use, the land potentially available for bioenergy production is 600–800 million hectare, with a wide range of natural productivity.
Policy to encourage …

- Maintaining high potential land in good conditions to facilitate sustainable production increases
- Promoting integrated cross-sectorial approaches to land use planning
- Using market signals to guide efficient allocation of scarce resources and production factors
- Applying strict sustainability criteria, regulation and monitoring to protect land and safeguard ecosystem services.
http://www.iiasa.ac.at/Research/LUC