Modeling Agriculture and Land Use within SGM and MiniCAM

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Model Development

- Path 1: Marginal abatement cost curves from other sources or models
  - Agricultural Sector Model (ASMGHG) to SGM
  - Non-CO_2 greenhouse gases (EMF-21) to SGM or MiniCAM
  - Analysis of emissions trading to 2020 or 2030
- Path 2: Endogenous land use and agriculture
  - Part of MiniCAM
  - Integration of land use, climate impacts, biomass, and energy system
  - Long term, global analysis

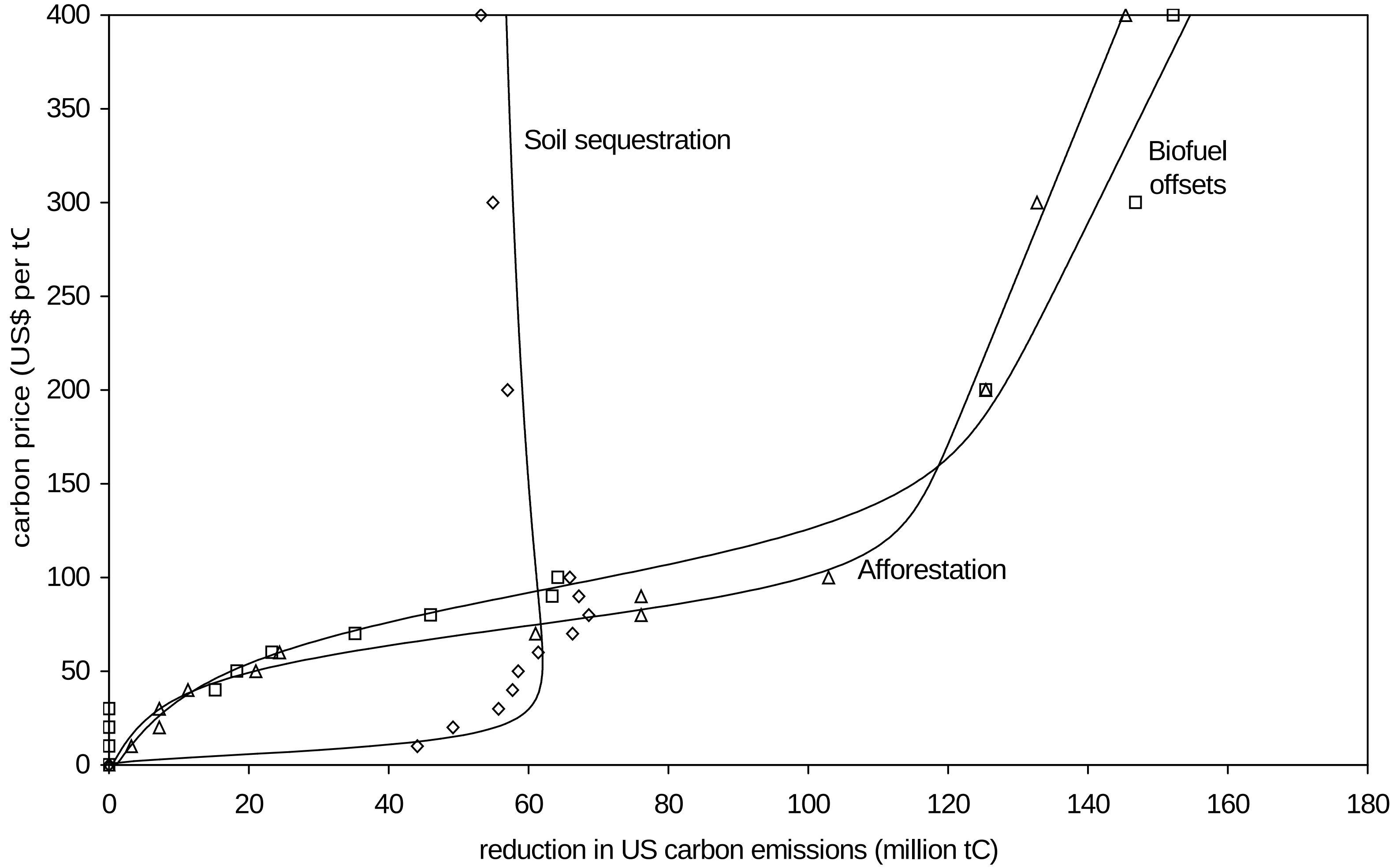
Overview

- Application #1: Use of marginal abatement cost curves from ASMGHG in Second Generation Model
  - Parameterization of ASMGHG cost curves
  - Combined with energy system cost curves from SGM
- Application #2: Determinants of global land use over the next century
  - Baseline production and land use
  - Carbon policy and biomass production
  - Climate impacts with link from biophysical models to AgLU
- Current research on AgLU
  - Disaggregate U.S. into subregions
  - Data requirements

Agricultural Sector Model

- Model characteristics
  - Nonlinear programming model of U.S. agricultural sector
  - 22 traditional crops, 3 biofuel crops, 29 animal products, 63 U.S. regions
- Mitigation options
  - Soil sequestration: carbon stored in agricultural soils related to cropping and tillage practices
  - Afforestation: expanded forest land area relative to 1990 base
  - Biofuel offsets: net reduction in carbon emissions by using biomass-based fuels instead of fossil fuels
- Interactions among options
  - Competition for land
  - Backward-bending supply curve for soil sequestration component

Reduction in carbon emissions from three activities simulated in the Agricultural Sector Model



Brief History of SGM

- Development began in 1991
- Cost of reducing carbon emissions in the U.S. and other countries
- Design
  - Top-down with broad economic coverage
  - Computable general equilibrium
  - Joint development with foreign partners

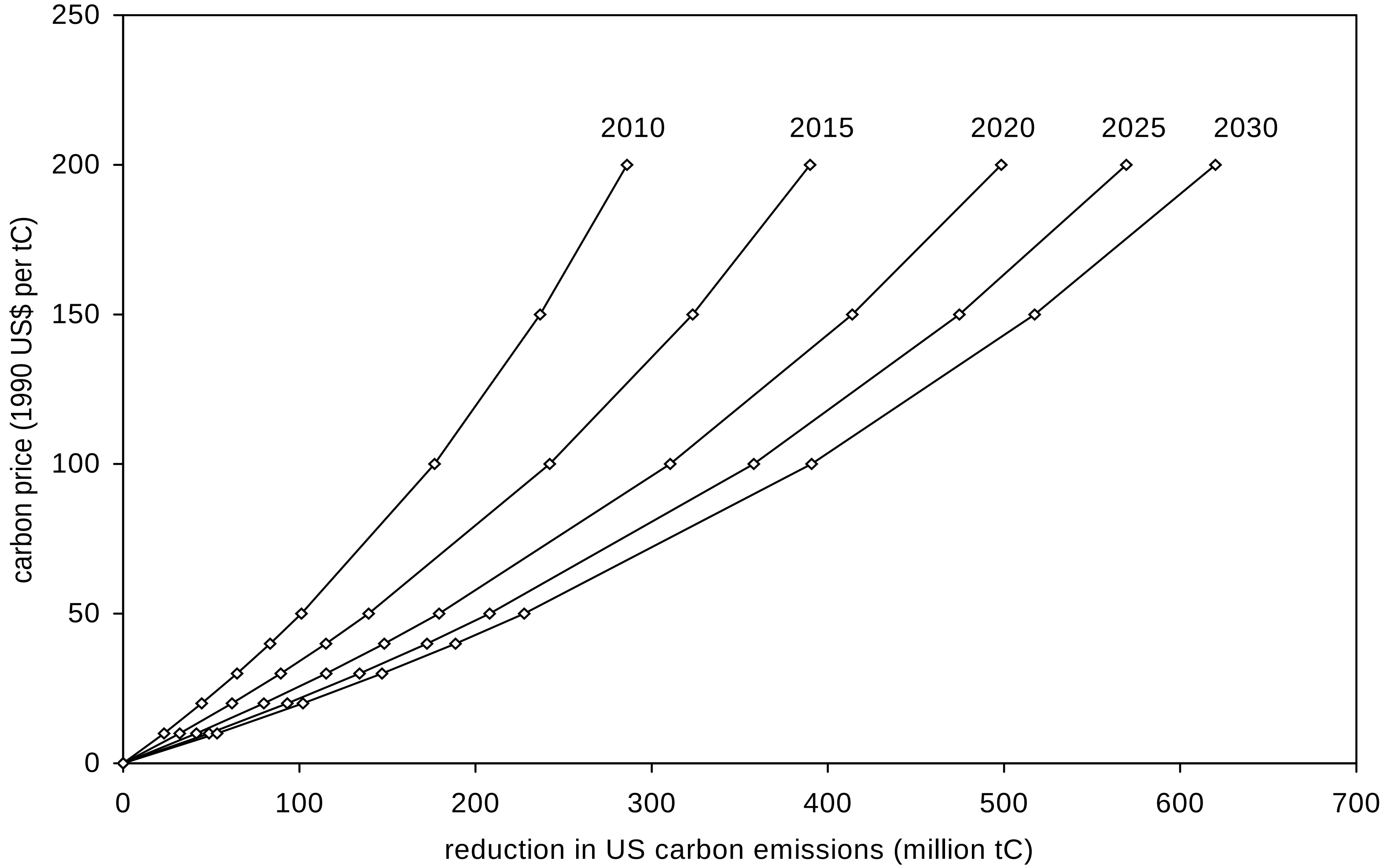
Second Generation Model

- SGM characteristics
  - Collection of computable-general-equilibrium (CGE) models for 14 world regions
  - Five-year time steps from 1990 through 2050
  - Capital stocks are industry specific with a new vintage for each model time step
- Marginal abatement cost curves for carbon
  - Generated using constant-carbon-price experiments
  - Outward shift (to the right) over time as economy grows and capital stocks turn over
- Following analysis focuses on United States

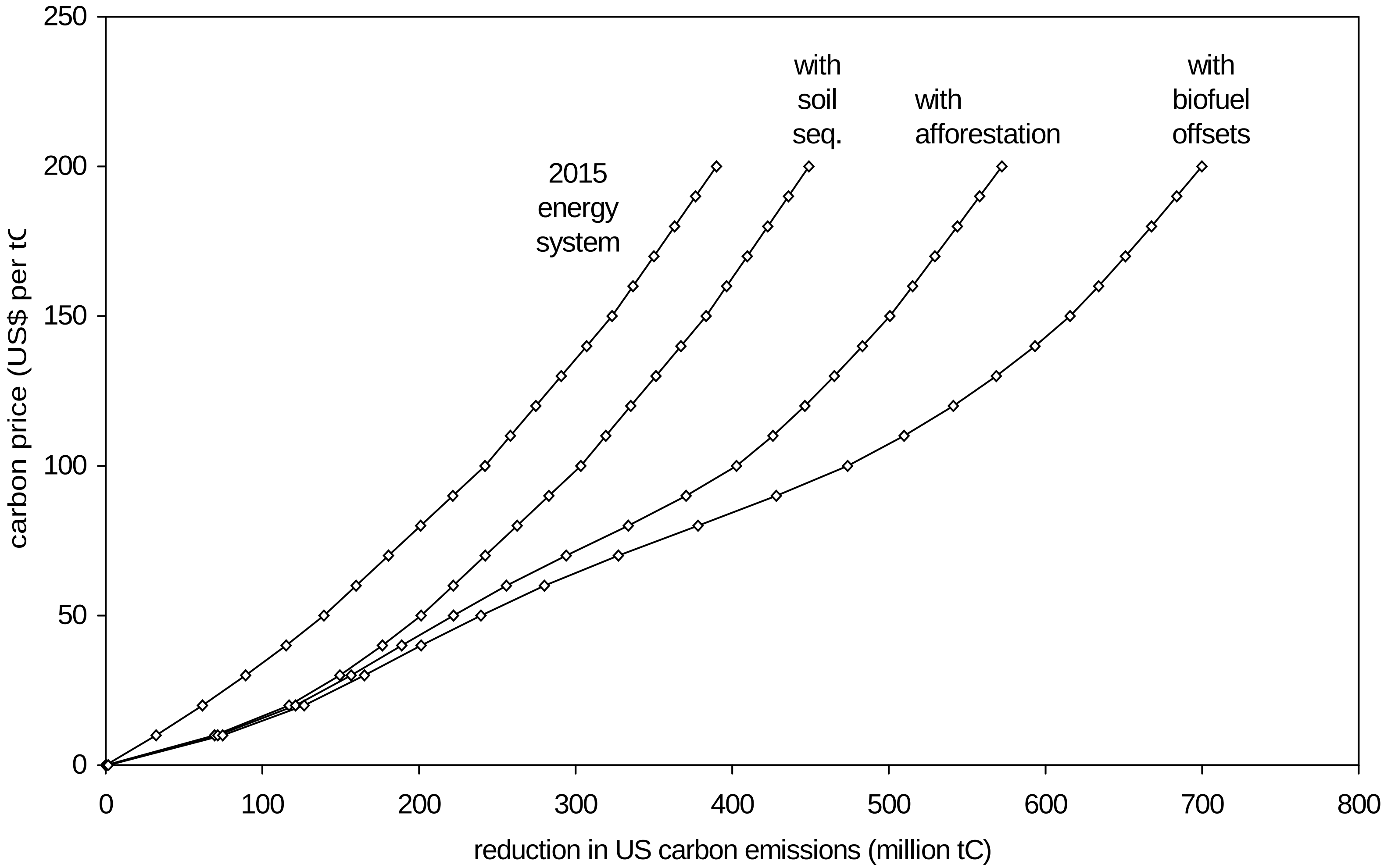
SGM Production Sectors

- Original Sectors
  - Agriculture
  - "Everything Else"
  - Oil Production
  - Gas Production
  - Coal Production
  - Electricity Generation
  - Oil Refining
  - Natural Gas Distribution
- Extended Sectors
  - Paper and Pulp
  - Chemicals
  - Cement
  - Iron and Steel
  - Non-Ferrous Metals
  - Other Industry
  - Passenger Transport
  - Freight Transport

Marginal abatement cost curves for carbon emissions from the U.S. energy system using PNNL Second Generation Model



Combined marginal abatement cost curves for the U.S. in 2015



Conclusions from Application #1

- Contributions from agricultural mitigation options
  - Below $50 per tC: mostly from soil sequestration
  - Above $100 per tC: reduction in net carbon emissions from three agricultural options combined is similar to that from energy system
- Agriculture options must be considered as a group and not in isolation
- Modeling challenges
  - Represent dynamics of saturation in marginal abatement cost curves
  - Demand for biofuels
  - Direct modeling of agriculture and land use in top-down economic models

Application #2: Determinants of Global Land Use over Next Century

- Agriculture and Land Use Model overview
- Global land use with and without carbon price
- Climate Impacts
  - Selection of climate scenarios
    - CO_2 at 365 ppmv and 560 ppmv
    - GCMs: UIUC, UIUC+sulfates, BMRC
    - Climate Sensitivity: 1.0° C and 2.5° C
  - Biophysical models used to simulate changes in U.S. productivity
    - EPIC (corn, winter wheat, soybeans, hay)
    - BIOME3 (grassland, forest)

Brief History of AgLU

- First version completed in 1996
- Design
  - Top-down
  - Partial equilibrium
  - Can be run stand-alone or as part of MiniCAM
- Studies
  - Role of biomass in carbon policy
  - Impact of ENSO on North America
  - U.S. climate impacts

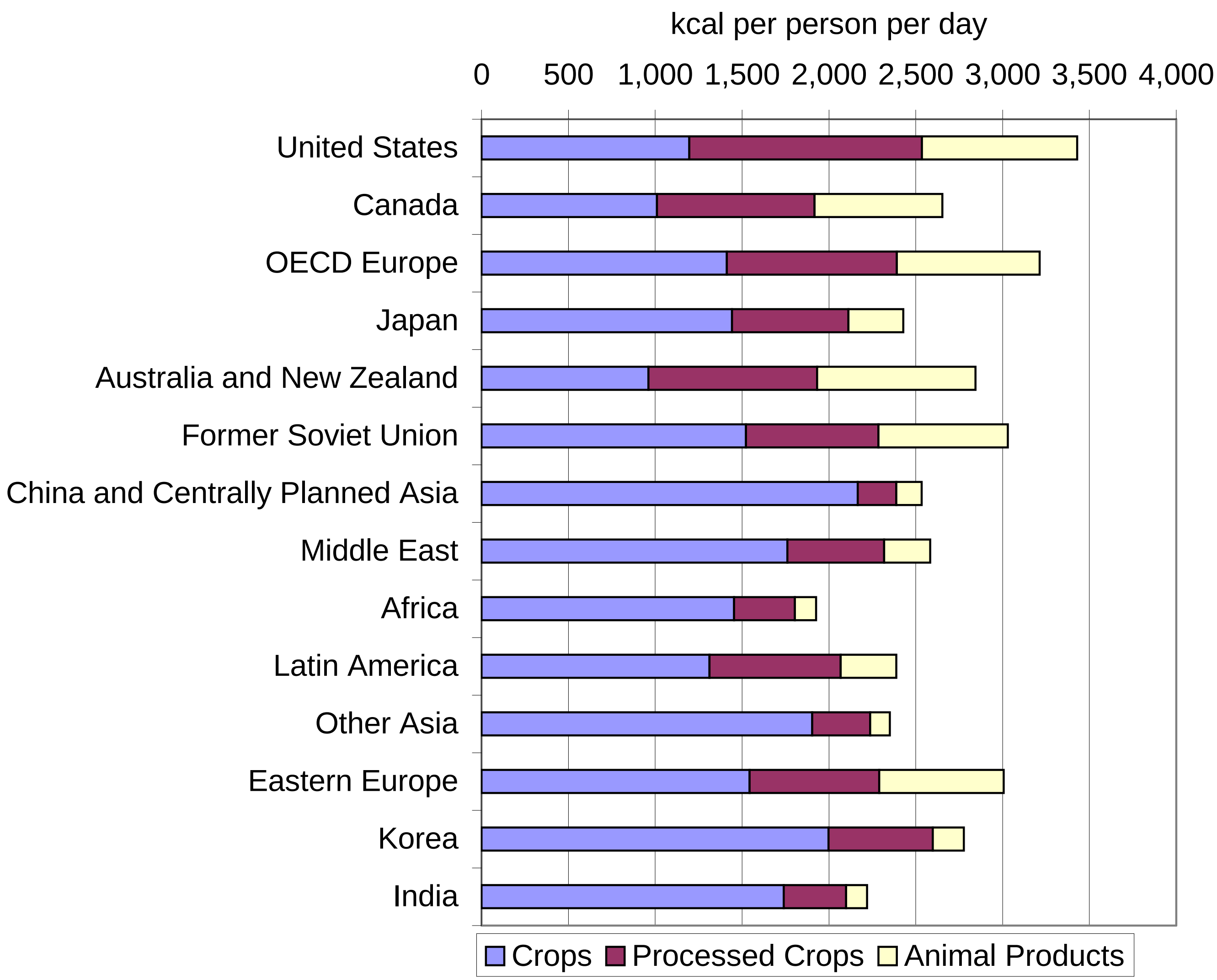
Methodology Highlights

- 15-year Time Steps from 1990 through 2095
- Land Allocation
  - Land owners compare economic returns across crops, biomass, pasture, and future trees
  - Underlying probability distribution of yields per hectare
- Forest Dynamics
  - Trees in AgLU grow for 45 years
  - Two forest markets (current and future) needed for model stability

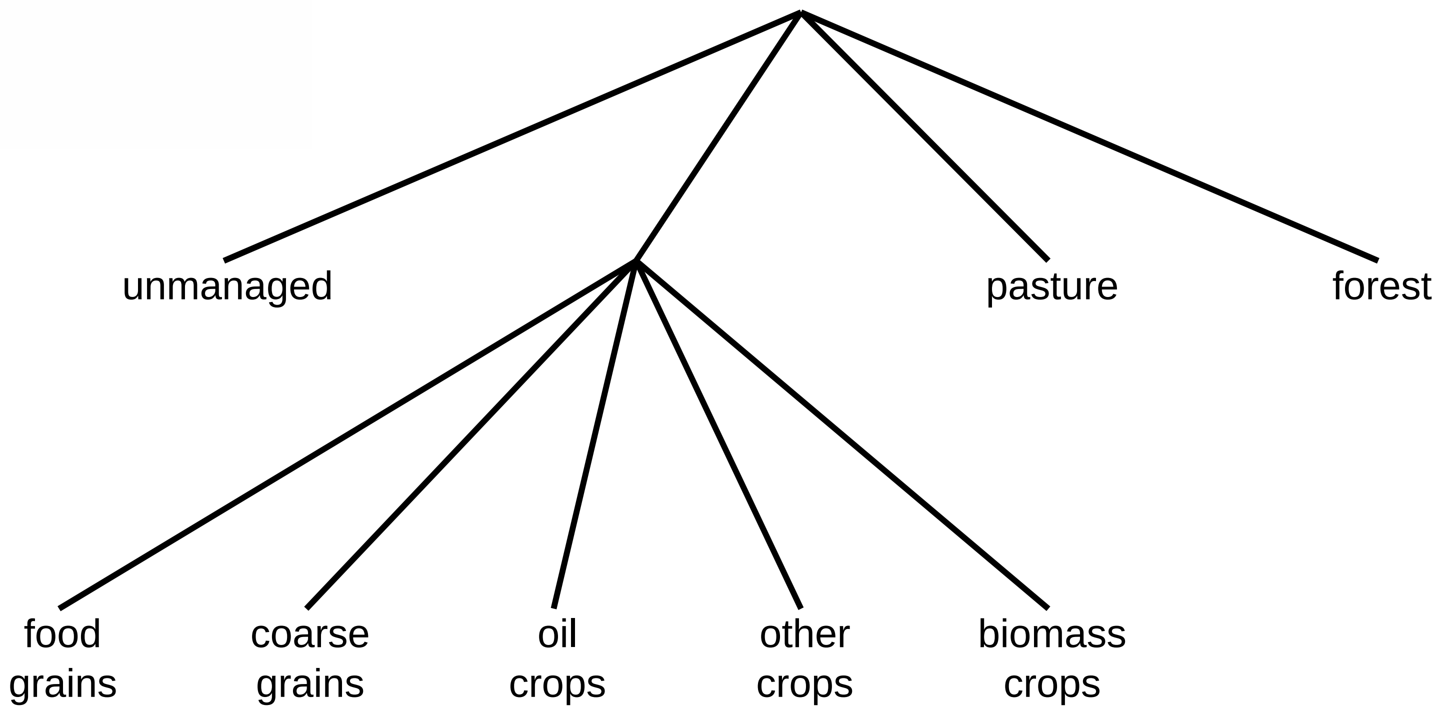
Products in AgLU

- Crops (calories)
  - Rice and Wheat
  - Coarse Grains
  - Oil Crops
  - Other Crops
- Processed Crops (calories)
  - Vegetable Oils
  - Sweeteners and Alcoholic Beverages
- Animal Products (calories)
  - Beef and other Ruminant Livestock
  - Pork and Poultry
- Commercial Biomass (calories or metric tons)
- Forest Products (cubic meters)

Daily Food Consumption in 1990



AgLU Land Allocation



Calculation of Land Shares

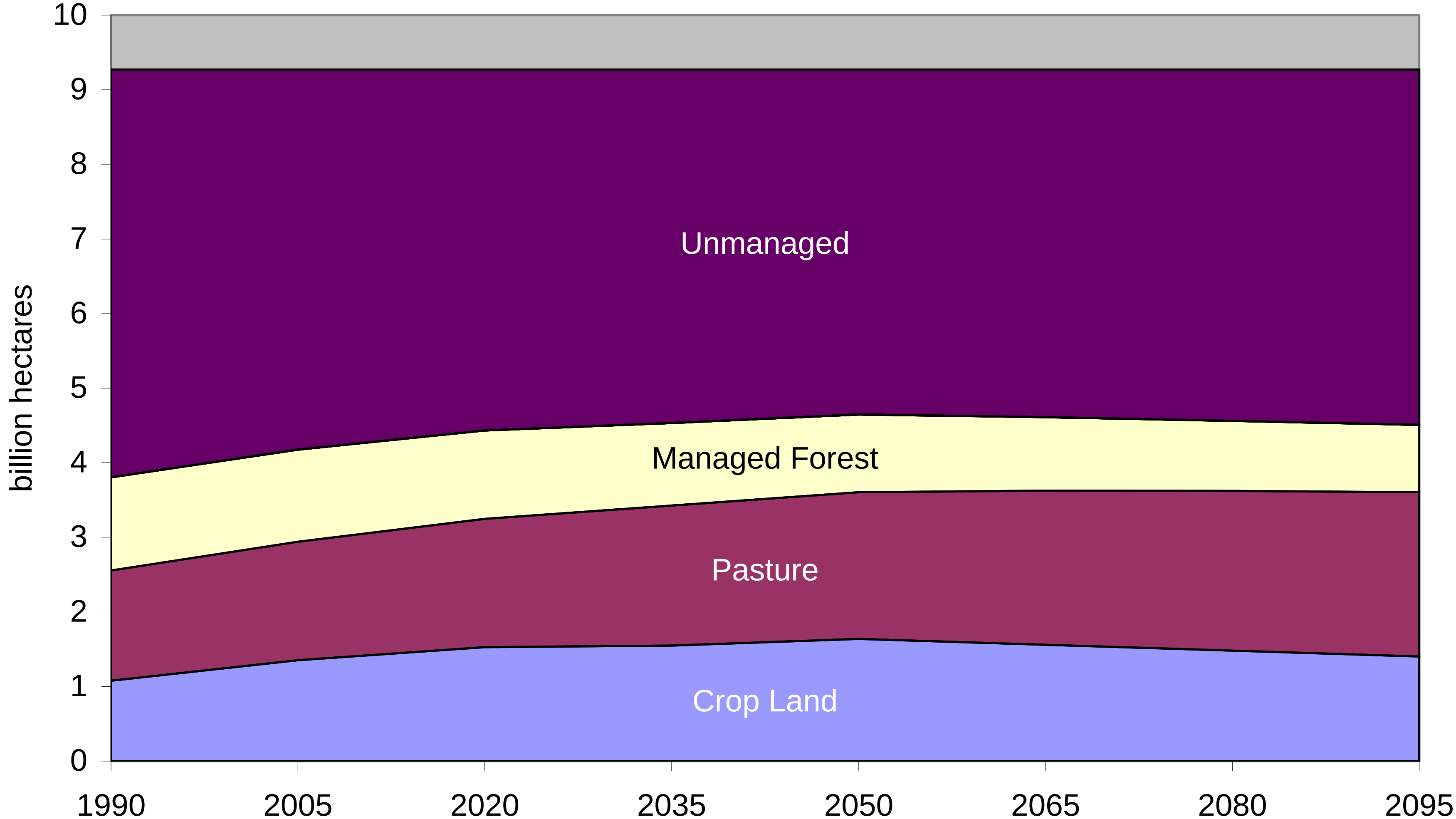
$$s_i = \frac{\bar{\pi}_i^{1/\lambda}}{\sum_k \bar{\pi}_k^{1/\lambda}}$$

Land share for land use i is an increasing function of profit rate (lambda is positive).

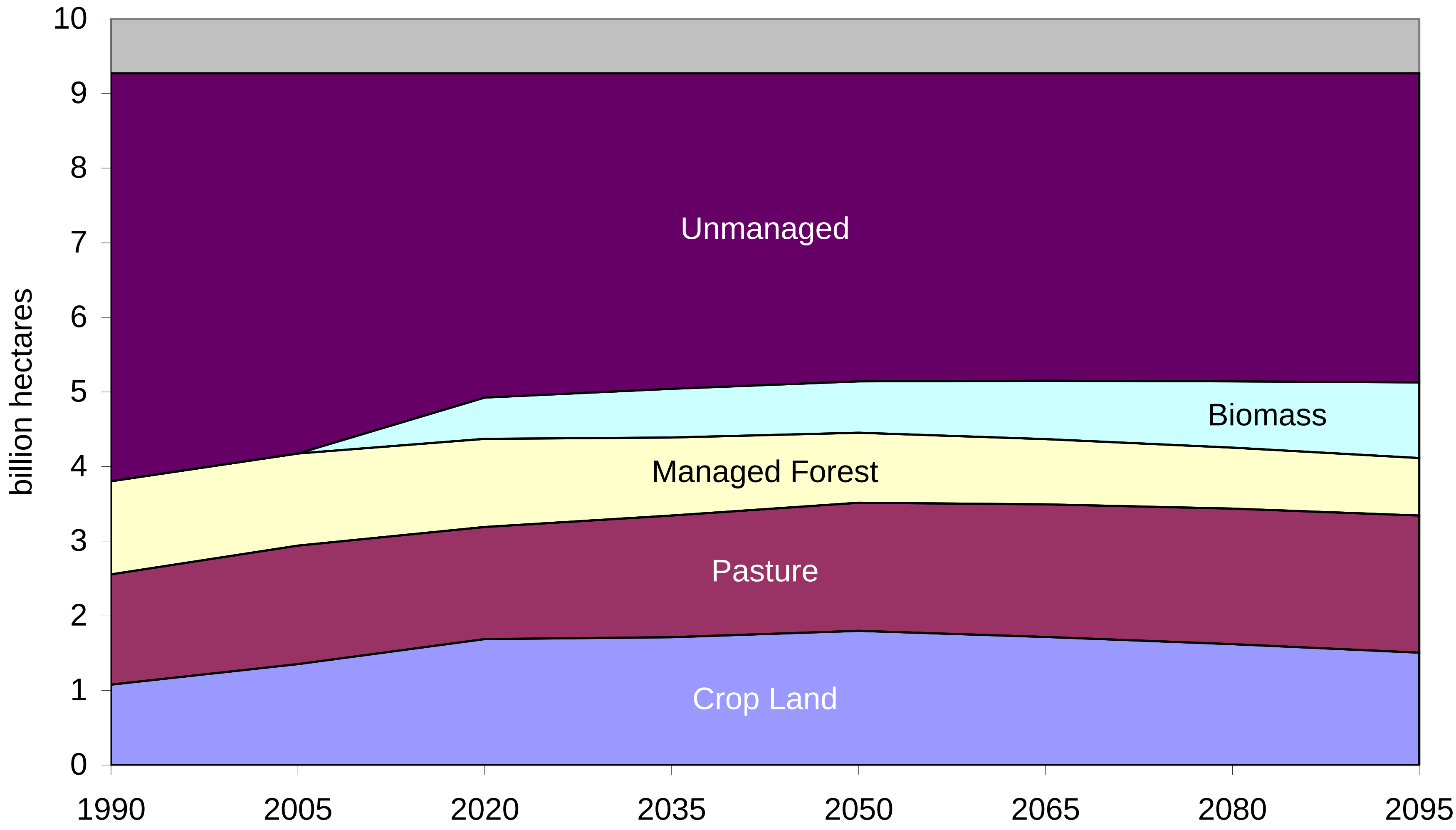
$$\bar{\pi}_i = \bar{y}_i \left(P_i - G_i \right)$$

Profit rate equals average yield times price received less non-land cost of production.

Land Use (without carbon policy)



Land Use (with carbon policy)

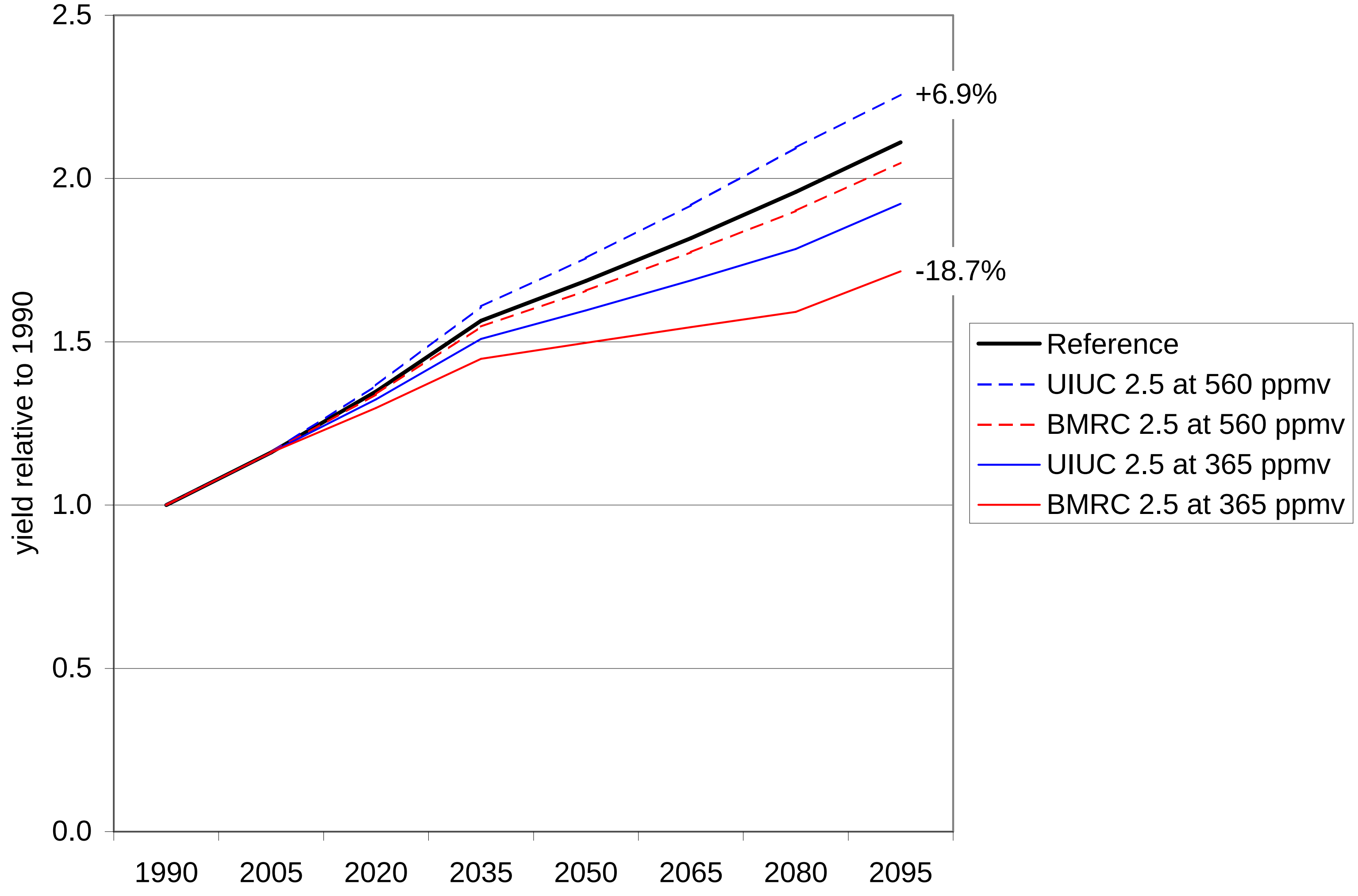


U.S. Soybean Yields (tons per ha)

	dryland		irrigated	
	365 ppmv	560 ppmv	365 ppmv	560 ppmv
Baseline	1.56	1.88	1.87	2.17
BMRC 1.0	1.45	1.76	1.80	2.10
BMRC 2.5	1.23	1.49	1.58	1.85
UIUC 1.0	1.53	1.84	1.80	2.09
UIUC 2.5	1.44	1.72	1.63	1.90
UIUC 1.0 + sulfates	1.53	1.84	1.80	2.09
UIUC 2.5 + sulfates	1.47	1.77	1.68	1.95

Yields are an average across 204 hydrologic unit areas in the United States, with agricultural land used as weights.

Soybean Yield Projections



Global Land Use

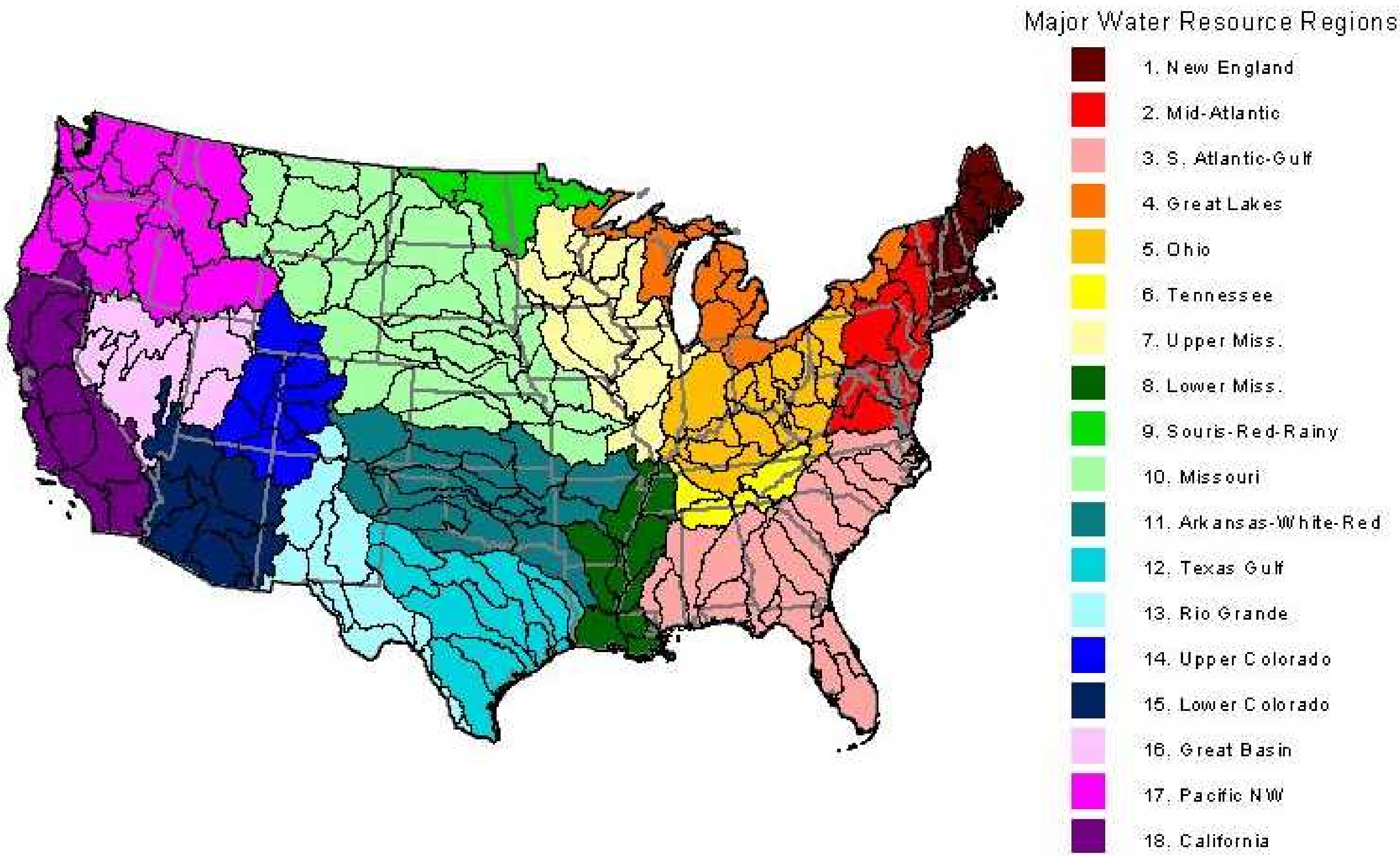
Scenario	Simulation Year	Wheat & Rice	Coarse Grains	Oil Crops	Misc. Crops	Total Crops
Baseline	1990	378	330	184	185	1,078
Baseline	2080	375	639	352	295	1,661
Change in US yields						
BMRC 2.5 at 365 ppmv	2080	381	653	360	292	1,686
UIUC 2.5 at 365 ppmv	2080	377	645	355	296	1,673
UIUC 2.5 at 560 ppmv	2080	373	646	348	298	1,665
US yield change applied globally						
BMRC 2.5 at 365 ppmv	2080	406	683	413	318	1,821
UIUC 2.5 at 365 ppmv	2080	407	662	377	309	1,754
UIUC 2.5 at 560 ppmv	2080	355	631	347	287	1,620

United States Summary by Sensitivity Scenario

Scenario	Simulation Year	Total Crops Production (Pcal)	Total Crops Land Use (million ha)	Land Rent (1990 = 1)
Baseline	1990	1,143	99.0	1.00
Baseline	2080	2,749	158.2	1.42
Change in US yields				
BMRC 2.5 at 365 ppmv	2080	2,698	193.5	1.15
UIUC 2.5 at 365 ppmv	2080	2,622	151.8	1.39
UIUC 2.5 at 560 ppmv	2080	2,711	145.4	1.56
US yield change applied globally				
BMRC 2.5 at 365 ppmv	2080	3,091	208.1	1.80
UIUC 2.5 at 365 ppmv	2080	2,899	180.7	1.46
UIUC 2.5 at 560 ppmv	2080	2,610	145.2	1.36

Model Development

- Improve theoretical description of statistical mechanism for land allocation
- Disaggregate U.S. by major water basin
- Embed AgLU in a computable general equilibrium model (SGM)
  - Full set of inputs to production
  - Land allocation rules replace land market
- Reflect carbon price in return to managed forests


Major Water Resource Regions
1. New England
2. Mid-Atlantic
3. S. Atlantic-Gulf
4. Great Lakes
5. Ohio
6. Tennessee
7. Upper Miss.
8. Lower Miss.
9. Souris-Red-Rainy
10. Missouri
11. Arkansas-White-Red
12. Texas Gulf
13. Rio Grande
14. Upper Colorado
15. Lower Colorado
16. Great Basin
17. Pacific NW
18. California

Data Requirements (1)

- Base-year land use
  - FAO data by country
  - US data by water resource region (NOAA)
- Land productivity
  - EPIC, historical crop yields
  - BIOME3
- Water Availability
  - Historical climate
  - HUMUS model for water runoff

Data Requirements (2)

- Carbon density by land use
- Net carbon emissions from managed agriculture (including biomass)
- Emissions of methane and nitrous oxide
  - Base year
  - Projections
  - Marginal abatement cost curves