

Incorporating Agro-Ecologically Zoned Land Use Data and Land-based Greenhouse Gases Emissions into the GTAP Framework

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ABSTRACT

The paper describes the on-going project of the GTAP land use data base. We also present the GTAPE-AEZ model, which illustrates how land use and land-based emissions can be incorporated in the CGE framework for Integrated Assessment (IA) of climate change policies. We follow the FAO fashion of agro-ecological zoning (FAO, 2000; Fischer *et al*, 2002) to identify lands located in six zones. Lands located in a specific AEZ have similar (or homogenous) soil, landform and climatic characteristics. The six AEZs range over a spectrum of length of growing period (LGP) for which their climate characteristics can support for crop growing. AEZ 1 covers the land of the temperature and moisture regime that is able to support length of growing period (LGP) up to 60 days per annum. On the other end of the LGP spectrum, lands in AEZ 6 can support a LGP from 270 to 360 days per annum. Crop growing, livestock breeding, and timber plantation are dispersed on lands of each AEZ of the six, whichever meets their climatic and edaphic requirements.

In GTAPE-AEZ, we assume that land located in a specific AEZ can be moved only between sectors that the land is appropriate for their use. That is, land is mobile between crop, livestock and forestry sectors *within, but not across, AEZ's*. In the

standard GTAP model, land is assumed to be transformable between uses of crop growing, livestock breeding, or timber plantation, regardless of climatic or soil constraints. The fact is that most crops can only grow on lands that is under certain temperature, moisture, soil type, land form, etc.. The same concern arises for land use by the livestock and the forestry sectors. Lands that are suitable for growing wheat may not be good for rice cultivation alike, even under transformation at a reasonable cost. The introduction of the agro-ecological zoning in GTAP helps to clear up the counterfactual assumption in inter-sectoral land transition, and permit a sound presentation of sectoral competition for land.

Table of Contents:

1.	Introduction.....	3
2.	The AEZ-identified Land Use Data.....	4
2.1	Agro-Ecological Zoning	4
2.2	The GTAP Land Use Data Base	5
3.	GTAP Greenhouse Gases Emissions Data	15
3.1	CO ₂	15
3.2	Non-CO ₂ greenhouse gases.....	15
4.	A brief overview of the GTAPE-AEZ model	18
5.	An Illustrative Simulations	24
5.1	Marginal abatement cost curves.....	26
5.2	Land transitions between uses under a 10% reduction of all GHGs.....	28
6.	Concluding remarks and future research agenda	30

1. Introduction

Land use, land-use change and forestry (LULUCF) activities have been perceived as a relatively cost-effective option to mitigate climate change due to the rapid buildup of greenhouse gases (GHGs) in the atmosphere. LULUCF may contribute to abatement of emissions by increasing carbon storage in forests (the so-called *sinks*: enhancing afforestation and forest management, while curbing deforestation). Article 3 of the Kyoto Protocol makes provision for the Annex I parties to take into account removals and emissions due to LULUCF activities since 1990 (e.g., afforestation, reforestation, deforestation and other agreed land use changes) to meet their commitment targets of greenhouse gas emission abatement. In the seventh Conference of the Parties (COP7) to the UNFCCC held in Marrakesh, October/November 2001, the parties finally agreed to include land-based carbon sequestration in their 2008-2012 GHG emissions reduction targets. The COP9, held in Milan, December 2003, has reached consensus for the rules of accounting for LULUCF projects in the Clean Development Mechanism (CDM) for the first commitment period (2008-2012) of the Kyoto Protocol. Along with such policy commitments, research on Integrated Assessment (IA) of climate change has recently been advancing towards the LULUCF embraced analysis.

At the 2002 MIT workshop (GTAP Website, 2002), co-sponsored by the U.S. Environmental Protection Agency (US-EPA), Massachusetts Institute of Technology (MIT), and the Center for Global Trade Analysis (GTAP), the idea of identifying agro-ecological zoning in the GTAP model (Hertel, 1997) was sparked in the discussion among the participating experts. The recognition of various agro-ecological zones (AEZ) is believed to be a more realistic approach in modeling land use change in GTAP, where land is mobile between crop, livestock and forestry

sectors *within, but not across, AEZ's*. In the standard GTAP model, land is assumed to be transformable between uses of crop growing, livestock breeding, or timber plantation, regardless of climatic or soil constraints. The fact is that most crops can only grow on lands that is under certain temperature, moisture, soil type, land form, etc.. The same concern arises for land use by the livestock and the forestry sectors. Lands that are suitable for growing wheat may not be good for rice cultivation alike, even under transformation at a reasonable cost. The introduction of the agro-ecological zoning in GTAP helps to clear up the counterfactual assumption in inter-sectoral land transition, and permit a sound presentation of sectoral competition for land.

We follow the FAO fashion of agro-ecological zoning (FAO, 2000; Fischer *et al*, 2002) to identify lands located in six zones of different agro-ecological feature. In section 2, we introduce the AEZ-identified land use data. In section 4, we introduce the GTAPE-AEZ model, which is based on the GTAP-E model (Burniaux and Truong, 2001). GTAPE-AEZ identifies six agro-ecological zones (AEZ) for the U.S., China, and rest of world. In Section 5, we present the selective results of the illustrative simulation with the GTAPE-AEZ model on the economic impact of carbon tax under the multi-gas mitigation scheme. Section 6 concludes the paper and points out future research direction.

2. The AEZ-identified Land Use Data

2.1 Agro-Ecological Zoning

The Food and Agriculture Organization (FAO) of the United Nations and the International Institute for Applied Systems Analysis (IIASA) pioneered in the Land

Use and Land Cover (LUC) project and have developed an agro-ecological zoning methodology during the past 20 years. Agro-ecological zoning refers to segmentation of a parcel of land into smaller units according to agro-ecological characteristics, e.g., moisture and temperature regimes, soil type, landform, etc. In other words, each zone has a similar combination of constraints and potentials for land use. The FAO/IIASA agro-ecological zoning methodology provides a standardized framework for characterizing climate, soil and terrain conditions pertinent to agricultural production (FAO and IIASA, 2000).

The key concept of “length of growing period” (LGP) is brought in to differentiate the agro-ecological zones by attainable crop productivity. The “length of growing period” (LGP) refers to the period during the year when both soil moisture¹ and temperature are conducive to crop growth. Thus, in a formal sense, LGP refers to the number of days within the period of temperatures above 5°C when moisture conditions are considered adequate (FAO, 2000).

2.2 The GTAP Land Use Data Base

Outlook of the GTAP land use data

In constructing the GTAP land use data base, we adopt the FAO/IIASA convention of agro-ecological zoning. Figure 1 shows the format of the GTAP land use data, which is proposed at the 2002 MIT workshop (GTAP Website, 2002). We identify land located in various agro-ecological zones (the rows in Figure 1) and the uses (sectors or activities) of land (the columns in Figure 1).

¹ Soil moisture is a function of precipitation, soil type, topography, etc.

Land use types in region r									
AEZs	Crop ₁	Crop _N	Livestock ₁	Livestock _H	Forest ₁	Forest _v
AEZ ₁									
....									
....									
AEZ _M									
Total									

Figure 1. GTAP land use matrix

Acreage and production data by AEZ

The GTAP AEZ-specific land use data are compiled from a set of land acreage and production provided by Dr. Navin Ramancutty of the Center for Sustainability and Global Environment (SAGE), University of Wisconsin-Madison, for the cropland and pasture land; and by Dr. Brent Sohngen of Ohio State University, for the forest land. The SAGE data cover 19 crops and 3 species of timber located in 18 agro-ecological zones (6 AEZs coupled with 3 climate zones—boreal, temperate, tropical). The 6 AEZs in the SAGE data follow the FAO/IIASA methodology of agro-ecological zoning. The 6 AEZs range over a spectrum of length of growing period (LGP) for which their climate characteristics can support for crop growing. AEZ 1 covers the land of the temperature and moisture regime that is able to support length of growing period (LGP) up to 60 days per annum. Lands in AEZ 2 can support LGP of 61 to 120 days per annum. On the other end of the LGP spectrum, lands in AEZ 6 can support a LGP from 270 to 360 days per annum. Figure 2 shows the SAGE global map of the 18 AEZs, by 0.5 degree grid cell. Table 3 shows the cropland distribution of China, as provided by SAGE. This table contains the harvested area data. It indicates that most of the crops are grown in temperate area (AEZs 7 to 12).

Harvested area v.s. physically cultivated area

When we split the GTAP sectoral land rents into AEZs, we thought we would need to convert the harvested area data of SAGE to physically cultivated area data due to the concern of multiple cropping. However, we later realize that we do not really need physically cultivated area data. In the GTAP Input-Output data, land rents are generated from the activity (or use) that is going on the given parcel of land during the calendar year. Furthermore, the fact shows that farmers may grow more than one crop on the same parcel of land at different intervals (or periods) of the calendar year. For example, farmers grow early double-crop rice from March to July, and then grow catch crops (e.g., vegetables) in the rest of the calendar year. As GTAP Input-Output data identify sector in terms of crops (e.g., the paddy rice sector, the cereal grain sector, the oil seeds sector, etc.), land rents of the crop sectors should accrue to the harvested area, which represents the activity of the given crop sector on the given parcel of land at certain interval of the year. In the abovementioned example, we should allot the land rent generated due to the growing of paddy rice to the GTAP paddy rice sector, and allot the land rent generated due to the growing of vegetables to the GTAP vegetables sector. In this example, land rent is tied to the harvested area, instead of the physically cultivated area. In addition, land based emissions (e.g., CH₄ emissions from paddy rice cultivation) are mostly tied to the harvested area (IPCC 1996 Guidelines). Fertilizer use is normally proportional to harvested area. So, we conclude that harvested area is the data we need to use for the GTAP land use data, rather than the physically cultivated area.

GTAP cropland rent data by 18 AEZs

We split the GTAP sectoral land rents into 18 AEZs according to the AEZ-specific production shares as derived from the data provided by SAGE and Sohngen. Table 4 shows the mapping between SAGE's 19 crops to GTAP's 8 crops. Equation 1 is the formula we use to split the GTAP sectoral land rents into 18 AEZs (L_{ca}). For region r ,

$$L_{ca} = L_c * \left[\sum_{i \in \text{SAGECROPS}=c} P_i * \frac{Q_{ia}}{H_{ia}} * H_{ia} / \sum_{a \in \text{AEZS}} \sum_{i \in \text{SAGECROPS}=c} P_i * \frac{Q_{ia}}{H_{ia}} * H_{ia} \right],$$

(Eq. 1)

where

L_{ca} is the land rent accrued to GTAP crop sector c in AEZ a ;

L_c is the land rent of GTAP crop sector c , with no AEZ distinction;

P_i is the per-ton price of SAGE's crop i ;

Q_{ia} is the production (ton) of SAGE's crop i in AEZ a ; and

H_{ia} is the harvested area of SAGE's crop i in AEZ a .

Set SAGECROPS contains SAGE's 19 crops;

set CROPS contains GTAP's crops, which are more aggregated than SAGE's.

Mapping CROP_SG2GT from SAGECROPS (index i) to CROPS (index c) (see Table 4).

The $\sum_{i \in \text{SAGECROPS}=c}$ operator in Eq. 1 means to aggregate over disaggregated crops i to the corresponding aggregated crop c .

Note that we assume the per-ton crop price (P_i) is homogenous across AEZs.

Data source of L_c = coefficients VFM and VDFA from the GTAP data base;

Data source of P_i = FAOSTAT;

Data source of Q_{ia} = tentatively self calculation based on SAGE's harvested area and FAO's yield data; SAGE data will be available a couple of months later;

Data source of H_{ia} = SAGE.

Since the SAGE production data will not have production estimates by AEZ at the national level until the second half of 2004, we need to split for AEZ-specific production ourselves. That is, we will calculate for Q_{ia} before SAGE's AEZ-specific production data become available. Below is the preliminary idea on how we calculate Q_{ia} , based on SAGE's harvested area and FAO's yield data.

Table 1. Mapping between FAO's LGP and Navin's 6 AEZs

FAO			Navins' AEZ
Class	Name	Moisture regime (LGP in days)	
AT1	Dry Semi-arid	75-119	AEZ2
AT2	Moist Semi-arid	120-179	AEZ3
AT3	Sub-humid	180-269	AEZ4
AT4-5	Humid	270+	AEZ5,6

Table 1 shows the mapping between FAO's LGP and SAGE's 6 AEZs. Table 2 shows the mapping between FAO crops and SAGE's. To get the AEZ-specific production data, we intend to apply to the FAO AEZ-specific (or LGP-specific) yield to SAGAE's AEZ-specific harvested area data.

$$NQ_{ia} = \alpha_i * \left[\frac{\sum_{s \in \text{FAOCROP}=i} FQ_{sa}}{\sum_{s \in \text{FAOCROP}=i} FH_{sa}} \right] * NH_{ia},$$

$i \in \text{SAGECROPS}; a \in \text{AEZS}; s \in \text{FAOCROPS}, \quad (\text{Eq.2})$

where NQ_{ia} is the AEZ-specific production by SAGE's crop and AEZ classifications; NH_{ia} is SAGE's AEZ-specific harvested area of 1992; FQ_{sa} is FAO AEZ-specific production; FH_{sa} is FAO AEZ-specific harvested area; and α_i is the factor between the 1998 and the 1992 crop-specific yield.

For short, we can write Equation 2 as follows:

$$NQ_{ia} = \alpha_i * FY_{ia} * NH_{ia}, \text{ where } FY_{ia} = \frac{\sum_{s \in \text{FAOCROP}=r} FQ_{sa}}{\sum_{s \in \text{FAOCROP}=r} FH_{sa}}. \quad (\text{Eq. 2a})$$

FAO data are for 1998, while SAGE's are for 1992. Supposed there exists a simple factor α_r between the 1998 and the 1992 crop-specific yield, α_r will be cancelled out when we substitute Equation 2a into Equation 1. Derivation is in Equation 1a.

$$\begin{aligned} L_{ca} &= L_c * \left[\sum_{i \in \text{DISAGCROPS}=c} P_i * \frac{NQ_{ia}}{NH_{ia}} * NH_{ia} / \sum_{a \in \text{AEZS}} \sum_{i \in \text{DISAGCROPS}=c} P_i * \frac{NQ_{ia}}{NH_{ia}} * NH_{ia} \right], \\ &= L_c * \\ &\quad \left[\sum_{i \in \text{DISAGCROPS}=c} P_i * \frac{\alpha_i * FY_{ia} * NH_{ia}}{NH_{ia}} * NH_{ia} / \sum_{a \in \text{AEZS}} \sum_{i \in \text{DISAGCROPS}=c} P_i * \frac{\alpha_i * FY_{ia} * NH_{ia}}{NH_{ia}} * NH_{ia} \right], \end{aligned}$$

c ∈ CROPS; i ∈ SAGECROPS; a ∈ AEZS. (Eq. 1a)

So, it is still viable that we use the FAO 1998 yield to calculate the AEZ-specific crop production from SAGE's AEZ-specific harvested area.

Table 2. Mapping between FAO crops to Navin's

No. FAO crops	No. Navin crops
1 WHEA	19 Wheat
2 RICE	12 Rice
3 MAIZ	5 Maize
4 BARL	1 Barley
5 MILL	6 Millet
6 SORG	14 Sorghum
7 OTHC	13 Rye
8 POTA	9 Potato
9 SPOT	8 Others
10 CASS	2 Cassava
11 OTHR	8 Others
12 BEET	16 Sugar beet
13 CANE	17 Sugar cane
14 PULS	10 Pulses
15 VEGE	8 Others
16 BANA	8 Others
17 CITR	8 Others
18 FRUI	8 Others
19 OILC	7 Oilpalm
20 RAPE	11 Rape
21 PALM	7 Oilpalm
22 SOYB	15 Soy
23 GROU	4 Groundnuts
24 SUNF	18 Sunflower
25 SESA	7 Oilpalm
26 COCN	8 Others
27 COFF	8 Others
28 TEAS	8 Others
29 TOBA	8 Others
30 COTT	3 Cotton
31 FIBR	8 Others
32 RUBB	8 Others

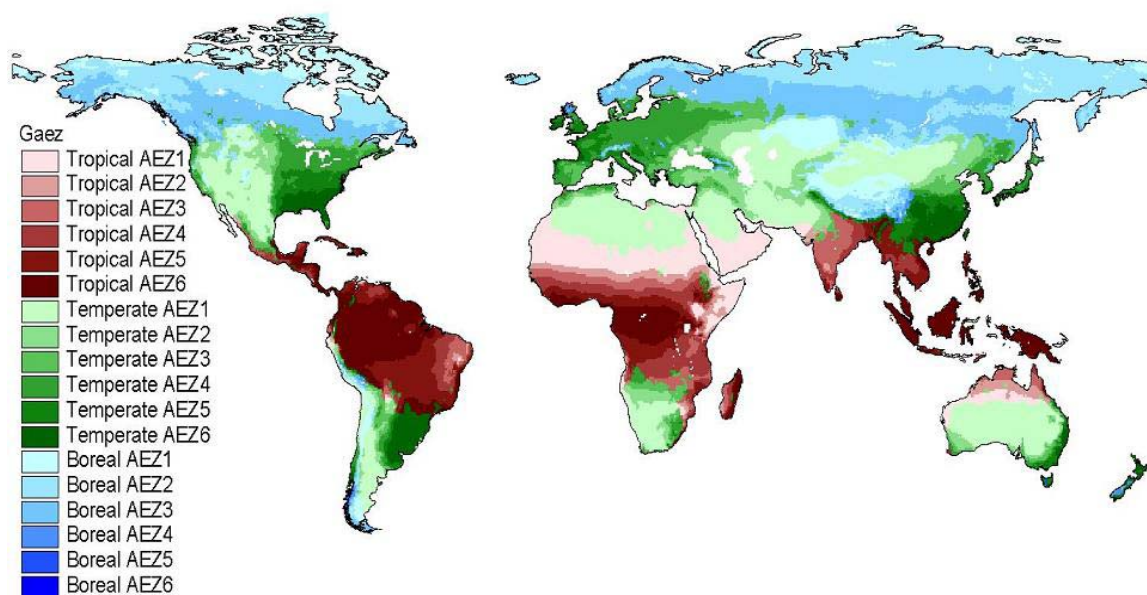


Figure 2. The SAGE global map of the 18 AEZs

Table 3. Cropland distribution: China, 1992

	China cropland (Unit: 1000ha)							
	1	2	3	4	5	6	7	8
	Paddy rice	Wheat	Cereal grains	Vegetables/fruit s/nuts	Oil seeds	Sugar cane/beet	Plant-based fibres	Crops N.E.C.
AEZ1	0	0	0	0	0	0	0	0
AEZ2	0	0	0	0	0	0	0	0
AEZ3	0	0	0	0	0	0	0	0
AEZ4	18	5	10	2	2	2	0	10
AEZ5	3699	69	367	284	547	497	1	2276
AEZ6	145	1998	1100	207	546	134	695	538
AEZ7	1418	6138	10340	1121	4956	587	457	5340
AEZ8	1491	6180	9256	1161	3906	286	1011	7733
AEZ9	1655	3707	5228	953	2760	242	452	3769
AEZ10	6417	6920	3934	1223	3110	182	1118	10049
AEZ11	28579	6314	6974	2753	7639	1654	884	19606
AEZ12	93	1507	482	143	526	64	439	337
AEZ13	88	971	237	77	415	15	13	266
AEZ14	275	944	472	113	502	34	8	378
AEZ15	256	404	227	54	131	15	10	330
AEZ16	17	9	13	3	4	2	0	14
AEZ17	0	0	0	0	0	0	0	0
AEZ18	0	0	0	0	0	0	0	0
Total	44149	35166	38639	8093	25044	3714	5086	50647

Table 4. Mapping of crops between SAGE and GTAP data

SAGE No.	SAGE code	GTAP No.	GTAP code	Description
1	barley	3	gro	Cereals grain n.e.c.
2	cassava	4	v_f	Vegetables, fruit, nuts
3	cotton	7	pfb	Plant-based fibres
4	groundnuts	5	osd	Oil seeds
5	maize	3	gro	Cereals grain n.e.c.
6	millet	3	gro	Cereals grain n.e.c.
7	oilpalm	5	osd	Oil seeds
8	others	8	ocr	Crops n.e.c.
9	potato	4	v_f	Vegetables, fruit, nuts
10	pulses	4	v_f	Vegetables, fruit, nuts
11	rape	5	osd	Oil seeds
12	rice	1	pdr	Paddy rice
13	rye	3	gro	Cereals grain n.e.c.
14	sorghum	3	gro	Cereals grain n.e.c.
15	soy	5	osd	Oil seeds
16	sugar beet	6	c_b	Sugar cane, sugar beet
17	sugar cane	6	c_b	Sugar cane, sugar beet
18	sunflower seeds	5	osd	Oil seeds
19	wheat	2	wht	Wheat
Reference: Concordance, HS96 to GSC rev. 2: concordance between the 1996 edition of the Harmonized System and revision 2 of the GTAP sectoral classification.				
http://www.gtap.agecon.purdue.edu/resources/download/582.txt				

Table 5. Mapping between FAO land classes (by LGP) and SAGE's AEZs

FAO			SAGE's AEZ
Class	Name	Moisture regime (LGP in days)	
AT1	Dry Semi-arid	75-119	AEZ2
AT2	Moist Semi-arid	120-179	AEZ3
AT3	Sub-humid	180-269	AEZ4
AT45	Humid	270+	AEZ5, 6

Proxies of AEZ-specific crop yields of countries not covered by FAO data

We run regression analysis to find out the relationship between yield of certain AEZ (or AT) and the average yield of the country (all AEZs). Table 6 shows the regression report of rice and wheat yields. Rice could not be grown in FAO land classes AT1 and AT2, so there is zero yield. Rice yield in irrigated land is about 5 times of yield in rainfed land class AT45. For wheat, rainfed land classes AT2 and AT3 are more productive. For each crop (if the country is producing it), we apply the statistically

significant coefficients to the country average yield of the corresponding crop so as to approximate AEZ-specific yield of the countries that are not covered in the FAO data. We multiply this estimated AEZ-specific yield with SAGE's AEZ-specific harvested area data to get the estimated AEZ-specific production. We later scale the estimated AEZ-specific production to attain the country total production of the crop as shown in the FAO data.

Table 6. Relationship of FAO land class specific yield against country average yield: paddy rice and wheat

	rice	wheat
AT1 v.s. country average	0.00	0.05
AT2 v.s. country average	0.00	0.21
AT3 v.s. country average	0.05	0.39
AT45 v.s. country average	0.24	0.14
AT67 v.s. country average	0.31	0.05
Irrigation v.s. country average	1.13	1.09

GTAP forest land rent data by 18 AEZs

The GTAP data base accounts land rent for agriculture land only. The forestry sector does not incur agriculture land rent, but it does incur natural resource rent (see Section 18.C of Chapter 18 in Dimaranan and McDougall, 2002). We move the “natural resource” rent to be the “land” rent for the forestry sector. We split the forestry land rent into 18 AEZs according to the rental shares by AEZ. We derive the AEZ-specific forestry land rent from Sohngen’s data of timberland rent by management type and hectare by management type and by AEZ.

3. GTAP Greenhouse Gases Emissions Data

The GTAP greenhouse gases emissions data (Lee, 2002; 2003) account for the six greenhouse gases as identified in the Kyoto Protocol. They are: (a) CO₂, (b) CH₄, (c) N₂O, and (d) F-gases, including HFC-134a, CF₄, HFC-23, and SF₆. We briefly describe below how the GTAP greenhouse gases emissions data are compiled.

3.1 CO₂

We follow the Tier 1 method as advised in the 1996 Revised IPCC guideline (IPCC/OECD/IEA, 1997) to estimate CO₂ emissions from fossil fuel combustion based on the GTAP energy volume data of 1997, which is derived from the IEA Energy Balances (OECE/IEA, 1999a; 1999b). We do not count emissions due to feedstock use (i.e., natural gas and petroleum products used by the petrochemical sector). We avoid double-counting of emissions from input use of coal, oil and gas by the coal transformation, the petroleum refinery and the gas distribution sectors. Emissions are accounted for use of coal products, petroleum products, and pipelined or bottled gas.

3.2 Non-CO₂ greenhouse gases

The CH₄, N₂O, and F-gases data are provided by the US Environmental Protection Agency (US-EPA). The data from EPA identify various sources of emissions. We further mapped the sources of emissions to GTAP sectors according to activities. Tables 7 to 9 show the mapping between emission sources of CH₄, N₂O, and F-gases, respectively, to GTAP sectors. Below we explain how we allocate each emission source to the multiple pertinent GTAP sectors.

CH₄ (see Table 7)

We allocate CH₄ emissions from mobile sources to the household sector and the transport sector of GTAP according to their consumption/output shares. We allocate CH₄ emissions from agriculture residue burning to the GTAP sectors coded as "PDR", "WHT", "GRO", and "C_B", according to the output shares. We allocate CH₄ emissions from enteric fermentation to the GTAP sectors of ruminants—i.e., "CTL" and "RMK"—according to their shares of capital (as a proxy of herd size). We allocate CH₄ emissions from manure management to the GTAP livestock sectors—i.e., "CTL", "OAP" and "RMK"—according to their shares of capital (as a proxy of herd size).

N₂O (see Table 8)

We allocate N₂O emissions from mobile sources to the household sector and the transport sector of GTAP according to their consumption/output shares. We allocate N₂O emissions from agriculture soil management (mainly due to fertilizer use) to the GTAP crop sectors—i.e., "PDR", "WHT", "GRO", "V_F", "OSD", "C_B", "PFB", and "OCR"—according to the output shares. We allocate N₂O emissions from manure management to the GTAP livestock sectors—i.e., "CTL", "OAP" and "RMK"—according to their shares of capital (as a proxy of herd size). We allocate N₂O emissions from agriculture residue burning to the GTAP sectors coded as "PDR", "WHT", "GRO", and "C_B", according to the output shares.

F-gases (see Table 9)

We allocate HFC-134a emissions from refrigerator and air conditioning to the household sector and all the manufacture and service sectors of GTAP according to their consumption/output shares.

Forest carbon stock

We use the AEZ-specific forest carbon stock provided by Sohngen, which is estimated by using information on the area of forests, the age class distribution, the merchantable yield functions, and the carbon conversion factor to convert merchantable forest stock to tons of carbon (Sohngen and Tennity, 2004).

Table 7. Mapping of CH₄ emission sources to GTAP sectors

Sources of CH ₄ emissions	Activity description	Mapping to GTAP sectors
Stationary Sources	Residential burning wood	Households
Mobile Sources	High way gasoline vehicles	Households and transport sector
Coal Mining	Coal mining industry	"15 COL": coal sector
Natural Gas Systems	Natural Gas exploit/mining industry	"17 GAS": natural gas sector
Petroleum Systems	Crude Oil exploit/mining	"16 OIL": crude oil sector
Waste Water treatment	Sanitary service industry	"56 OSG": sanitary service sector
Rice Cultivation	Flooded rice paddies	"1 PDR": paddy rice sector
Enteric Fermentation	Livestock & raw milk industry	"9 CTL": cattle, horses, sheep sectors "11 RMK": dairy sector
Ag Residue/Biomass Burning	Crop residue burning	"1 PDR": paddy rice "2 WHT": wheat "3 GRO": other grains "6 C_B": sugar cane and beet
Manure Management	Livestock & raw milk industry	"9 CTL", "10 OAP", "11 RMK"
Land-fills	Sanitary service industry	"56 OSG": sanitary service sector

Table 8. Mapping of N₂O emission sources to GTAP sectors

Sources of N ₂ O emissions	Activity description	Mapping to GTAP sectors
Stationary Sources	due to fuel-burning	Transport sector
Mobile Sources	High way gasoline vehicles	Households and transport sector
Industrial Process	Chemical industry	"33 CRP": chemicals sector
Ag. Soils Management	Ag. Soils Management	GTAP sector 1 to 8 (crop sectors)
Manure Management	Livestock & raw milk industry	"9 CTL": cattle, horse, sheep sector "10 OAP": other animals sector "11 RMK": dairy sector
Ag. Residue Burning	Crop residue burning	"1 PDR": paddy rice sector "2 WHT": wheat sector "3 GRO": other grains sector "6 C_B": sugar cane and beet
Human Sewage	Sanitary service industry	"56 OSG": sanitary service sector

Table 9. Mapping of F-gases emission sources to GTAP sectors

		HFC-134a	F-gases CF4	HFC-23	SF6
A. Emissions are released due to use of "inputs" which contain ODS substitutes					
Emissions of F-gases due to use of refrigeration application					
1	Refrigeration/AC (Gg HFC-134a Eq)	HH; IND's			
Emissions of F-gases due to use of ODS substitutes as INPUTs to industrial production					
2	Aerosols (MDI) (Gg HFC-134a Eq)	33 crp			
3	Aerosols (Non-MDI) (Gg HFC-134a Eq)	33 crp			
4	Solvents (Gg HFC-134a Eq)	33 crp			
5	Foams (Gg HFC-134a Eq)	33 crp			
6	Fire Extinguishing (Gg HFC-134a Eq)	33 crp			
7	Semiconductors				
8	CF4 (PFC) (Gg CF4 Eq)		40 ele		
9	C2F6 (PFC) (Gg CF4 Eq)		40 ele		
10	C3F8 (PFC) (Gg CF4 Eq)		40 ele		
11	NF3 (PFC) (Gg CF4 Eq)		40 ele		
12	HFC-23 (Gg CF4 Eq)		40 ele		
13	SF6 (Gg CF4 Eq)		40 ele		
16	Magnesium (Gg SF6 Eq)				36 nfm
17	Electric Trans. & Dist. (Gg SF6 Eq)				43 ely
18	Electric GIS Manufact. (Gg SF6 Eq)				
B. Emissions are proportional to sectoral "output"					
Emissions of F-gases as by-product of industrial production					
14	HCFC-22 Production (Gg HFC-23 Eq)			33 crp	
15	Aluminum (Gg CF4 Eq)		36 nfm		

4. A brief overview of the GTAPE-AEZ model

We build the GTAPE-AEZ model based on the GTAP-E model, which allows for substitution between capital and energy, and between various fuels in sectoral production (Burniaux and Truong, 2001). Figure 3 shows the nested production

structure in the GTAP-E model. Sectors may substitute energy for capital when energy price rises more than capital rental does. The inter-fuel substitution comprises of three sub-nestings: (a) electricity v.s. non-electricity composite; (b) coal v.s. non-coal composite; and (c) between oil, gas, and petroleum products. For example, sectors may substitute coal for non-coal fuel (a composite of oil, gas and petroleum products) when coal is more expensive than non-coal fuels.

In the GTAPE-AEZ model, we recognize a unique production function for each of the land-using sectors located in a specific AEZ. For example, the paddy rice sector located in AEZ 1 has a different production function from the paddy rice sector located in AEZ 6. This is to identify the difference in the productivity of land of different climate characteristics. Nevertheless, all the paddy rice sectors located in the six AEZs produce homogenous output to meet market demand.

We assume that transition of land in a specific AEZ can occur only between sectors that the land is appropriate for their use. This is a new concept beyond the standard GTAP model, in which land is assumed to be transformable between uses of crop growing, livestock breeding, or timber plantation, regardless of climatic or soil constraints. Facts show that most crops can only grow on lands that is under certain temperature, moisture, soil type, land form, etc.. We believe that the introduction of the agro-ecological zoning (AEZ) renders a sound presentation of sectoral competition for land.

In GTAPE-AEZ, we associate methane (CH_4) and nitrous oxide (N_2O) emissions to their emitting sources (or drivers). For example, we link methane emissions from paddy rice cultivation to the land used in the paddy rice sector. Following the approach of Hyman (2001), we treat methane emissions as input to the paddy rice

growing, and permit limited substitution of other input for emissions according to estimates of the marginal cost of abatement.

Figure 4 shows the production structure of the paddy rice sector located in AEZ 2. This paddy rice sector (“PDR_AEZ2”) uses land in AEZ 2 only, but no land from other AEZs. The paddy rice sector located in AEZ uses only land in AEZ 2. We associate CH₄ emissions with the land acreage of rice paddies, and assume CH₄ emissions are proportional to area harvested. We associate N₂O emissions to fertilizer use by the paddy rice sector and again assume fixed proportion between N₂O emissions and fertilizer use.

Figure 5 shows the production structure of the livestock sector located in AEZ 2. Again, this “LIV_AEZ2” sector uses only land in AEZ 2. We associated CH₄ emissions (due to enteric fermentation and manure management) to herd size (represented by capital in the GTAP data base), and assume fixed proportion between CH₄ emissions and herd size.

Figure 6 shows the outlook of the GTAPE-AEZ input-output data base. We associated emissions and thus emissions taxes to the pertinent drivers (inputs or output). We take the paddy rice as an example and show in Table 10 the cost structure of the paddy rice sectors in China. In the initial data base, emissions tax is not yet imposed, so there is no value for the emissions taxes that are tied to pertinent drivers. Among the rice paddies in the AEZs that is conducive to rice cultivation—i.e., AEZs 4, 5, and 6—the paddy rice sector in AEZ 6 (“pdr_6”) is relatively more productive. This can be attributed to the higher rainfall, which supports longer length of growing period (LGP). The “pdr_6” sector produces about 75% of the total paddy rice output.

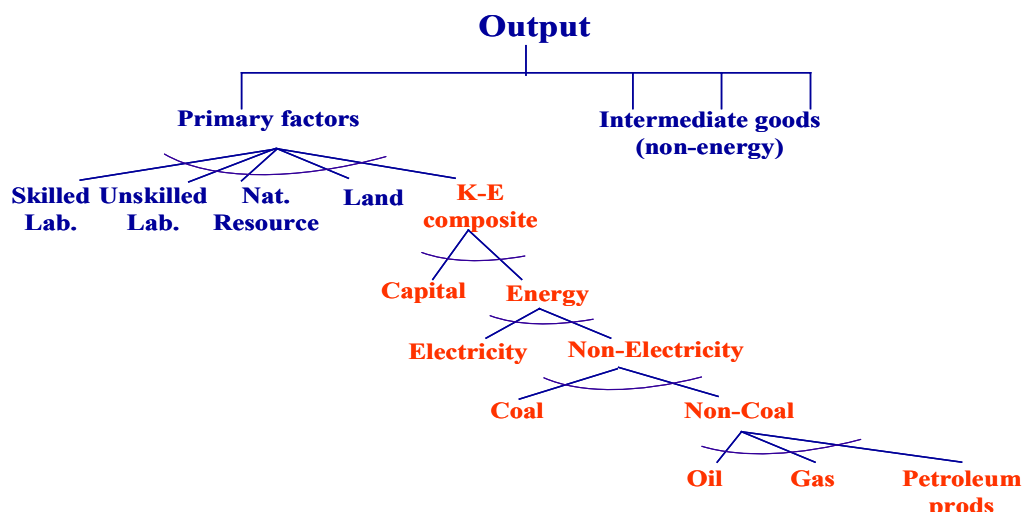


Figure 3. Production structure in GTAP-E

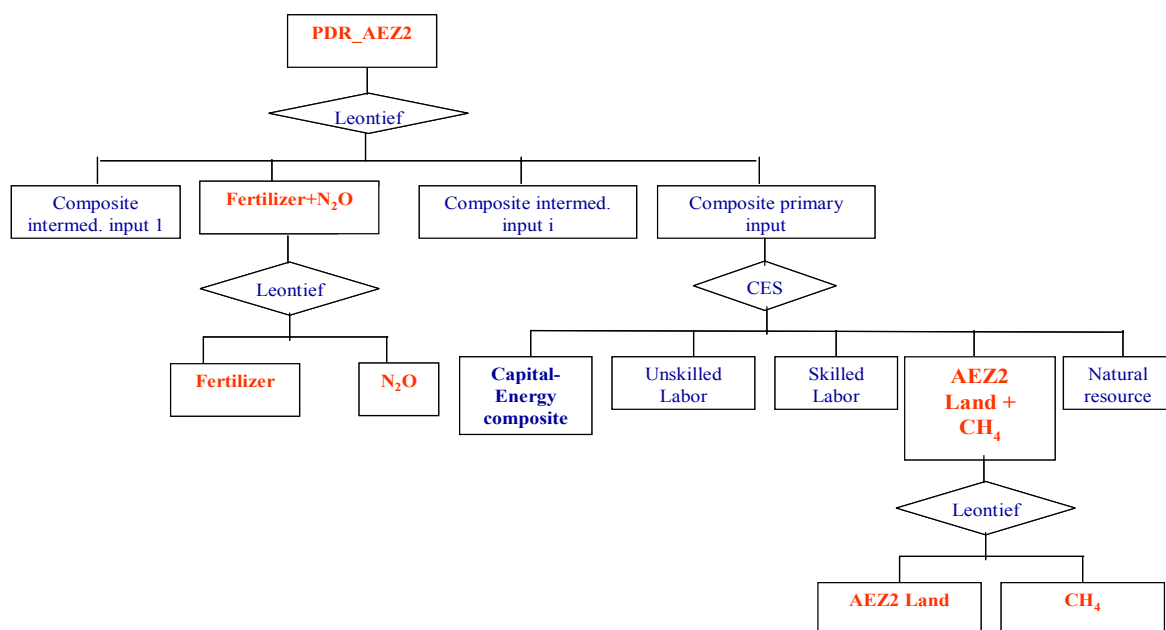


Figure 4. Production structure of the paddy rice sector in AEZ 2

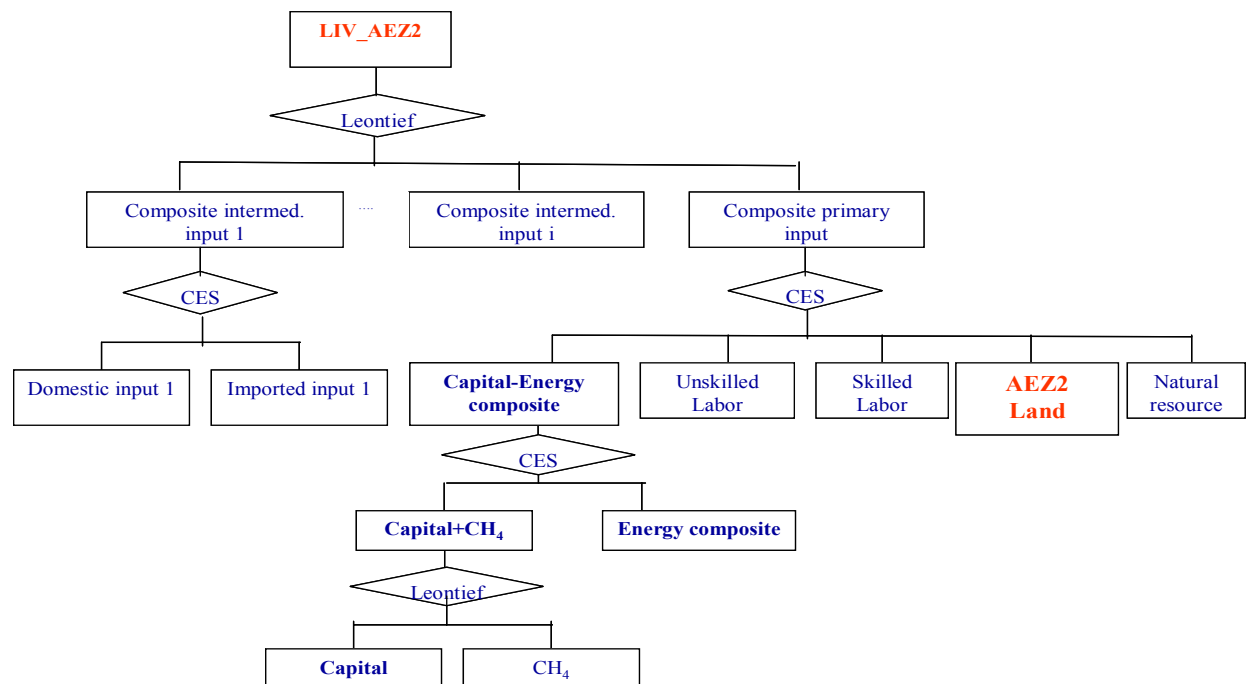


Figure 5. Production structure of the livestock sector in AEZ 2

		Absorption Matrix						
		1	2	3	4	5	6	
		Producers	Investors	Household	Export	Government	Int'l transport	Total
Sizes			1	1	1	1	1	1
Comm. Flows								
Emissions tax on inputs					N/A			
Land	6							
Emissions tax on land	6							
Tax/Subsidy on C sequestration	6							
Natural Resources	1							
Labour	2							
Capital	1							
Emissions tax on output	1							
Total Costs	1							
Production Taxes	1							

Figure 6. Outlook of the GTAPE-AEZ data base

Table 10. Cost structure: paddy rice, China

China_PDR	pdr_1	pdr_2	pdr_3	pdr_4	pdr_5	pdr_6	Total
Int'med. Inputs	0	0	0	936.3	1114.4	5575.8	7626.5
Land_pdr_1	0	0	0	0	0	0	0
Land_pdr_2	0	0	0	0	0	0	0
Land_pdr_3	0	0	0	0	0	0	0
Land_pdr_4	0	0	0	227.0	0	0	227.0
Land_pdr_5	0	0	0	0	621.1	0	621.1
Land_pdr_6	0	0	0	0	0	3435.2	3435.2
Unskilled Labor	0	0	0	1061.3	1263.1	6320.2	8644.6
Skilled Labor	0	0	0	8.6	10.2	51	69.7
Capital	0	0	0	217.6	259	1295.8	1772.4
Natural Resource	0	0	0	0	0	0	0
Total	0	0	0	2450.8	3267.8	16678.0	22396.5

5. An Illustrative Simulations

We run the GTAPE-AEZ model with an aggregated data base of three regions (i.e., the U.S., China, and rest of world), 23 commodities and 48 sectors ($=5*6 + 18$; each of the first five land-based sectors are further disaggregated into 6 AEZ-specific sub-sectors). Table 11 shows the sectoral aggregation scheme of the GTAP data base for the prototype GTAPE-AEZ model.

Table 11. Sectoral aggregation scheme of the prototype GTAPE-AEZ model

No.	New sector code	Sector description	Comprising old sectors:
1	PaddyRice	Paddy Rice	pdr
2	WheatGrains	Wheat and Grains	wht gro
3	Livestock	Livestock	ctl oap rmk
4	OthAg	Other Ag Production	v_f osd c_b pfb ocr
5	Forestry	Forestry (timber)	for
6	OthPrimInd	Other Primary Ind Production	wol fsh omn
7	Coal	Coal	col
8	Oil	Oil	oil
9	Gas	Gas	gas
10	CSGHMeat	Ruminant Meat	cmt
11	OthMeat	Other Meat	omt
12	OthFoodProd	Other Food Products	vol sgr ofd b_t
13	DairyProd	Dairy Products	mil
14	ProcsdRice	Processed Rice	pcr
15	OthManufact	Other Manufacture	tex wap lea fmp mvh otn ele ome omf wtr
16	WoodProd	Wood Products	lum
17	PaperProd	Paper Products	ppp
18	PetroleumProd	Petroleum Products	p_c
19	EI_Manufact	Energy Intensive Manufacture	crp nmm i_s nfm
20	Electricity	Electricity	ely
21	GasDistrib	Gas Distribution	gdt
22	Construction	Construction	cns
23	Service	Service	trd otp wtp atp cmn ofi isr obs ros osg dwe

We first run a set of simulations of various scenarios—abating CO₂ only v.s. multiple gases, coupled with various degrees of land mobility—and develop aggregate marginal abatement cost curve for each country. This is described in section 5.1. In section 5.2, we look at some selective sectoral results of a 10% reduction of all gases.

5.1 Marginal abatement cost curves

We run four experiments and develop aggregate marginal abatement cost curve for each country under the no emission trading scenario. In experiment (a), only CO₂ emissions from fossil fuel combustion are reduced, and forest carbon is not included. In experiments (b), (c), and (d), all greenhouse gases, plus forest carbon, are included in the abatement basket. We specify no land mobility between uses in experiment (b). We specify -1.0 and -5.0 of CET transformation elasticities of land between uses in experiments (c) and (d), respectively.

Figures 7 and 8 show the aggregate marginal abatement cost curves of the U.S. and China, respectively, under the four sets of scenarios. In the CO₂ only case, the marginal abatement cost curve (MAC) of the U.S. (Figure 7) is in line with the U.S. MACs as seen in the literature—for example, Ellerman and Decaux (1998), and other estimates by the EMF study as reported in IPCC (2001)—although a little bit lower. This is mainly because GTAPE-AEZ is currently a comparative static model, while the other MAC estimates are obtained from the dynamic model for the 2010 reduction target. Emissions abatement by 2010 is more costly than by 1997 due to economic growth, supposing that there is no dramatic improvement in clean development technology.

Comparing the MACs of experiments (a) and (b)—i.e., the CO₂ only v.s. the multi-gas with zero land mobility—we see that the marginal cost of multiple gases abatement is lower than that of the CO₂-only case, as there is efficiency gain in the multi-gas abatement. Initial abatement of non-CO₂ gases is normally cheaper. This also conforms with the results as other global CGE models estimate, e.g., Burniaux (2000), Reilly *et al.* (1999), Reilly, Mayer, and Harnisch (2000), Kets (2002), and Brown *et al.* (1999). Comparing the MACs of experiments (b), (c), and (d)—the

easier mobility of land among uses further helps reduce the abatement cost: about 30% lower when the land mobility parameter (CET elasticity) is -1.0, relatively to the zero land mobility; and about 70% lower when the CET elasticity is extremely large (-5.0).

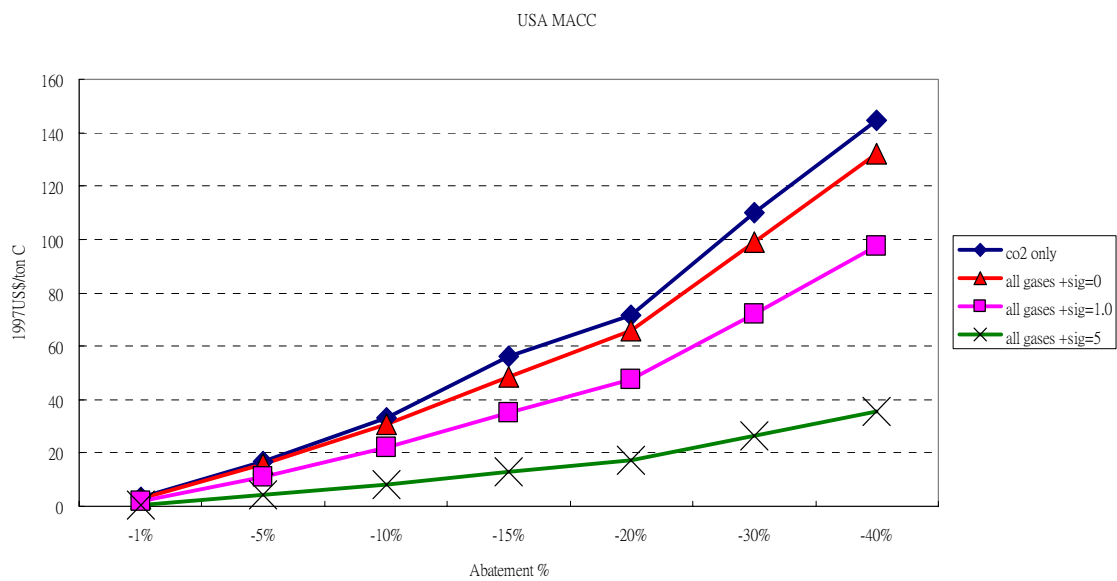


Figure 7. Marginal abatement cost curve of the U.S.

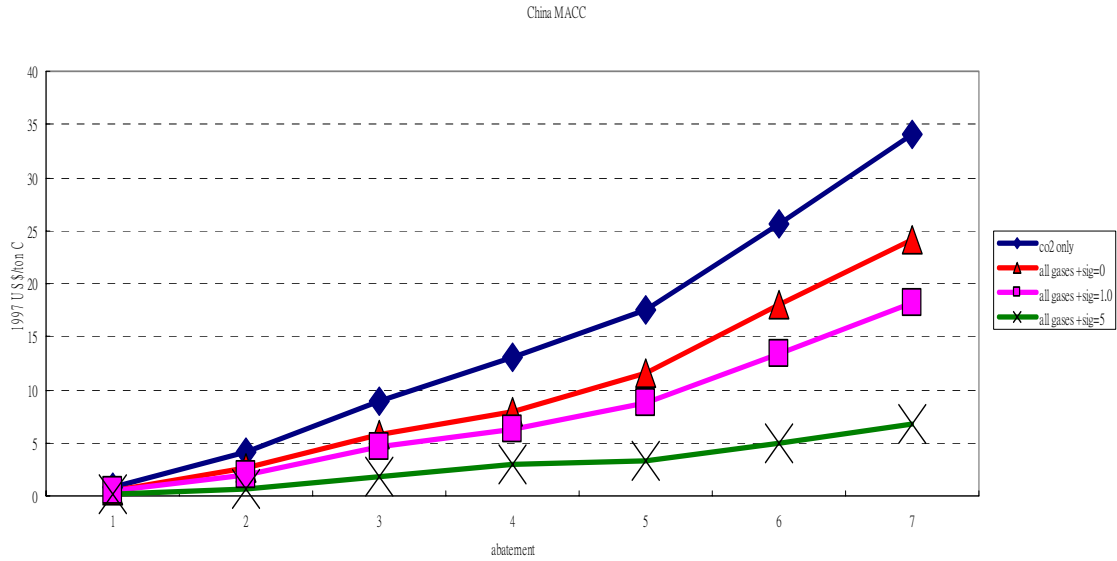


Figure 8. Mapping of CH₄ emission sources to GTAP sectors

5.2 Land transitions between uses under a 10% reduction of all GHGs

Table 12 shows the land transition between the land-based sectors of China. Most of the land-based sectors are reducing its land acreage, and the shifted land is absorbed by the forestry sector (“FOR”). To reduce land-based GHG emissions, a tax is imposed, and this tax raises the cost of, for example, rice production. The paddy rice sectors of all AEZs are subject to this tax. So, the supply curve of paddy rice shifts up, and thus the price goes up, which discourages demand. In turn, the decline in demand for paddy rice drives down the equilibrium price of paddy rice. The prices of other inputs also rise due to the carbon tax. Revenue is squeezed by the increase in input costs. Thus, land rent declines.

On the other hand, the forest sector is assumed to be able to absorb carbon. In GTAPE-AEZ, we assume that forest carbon stock is proportional to land acreage. The forestry sector is subsidized due to its credit in carbon absorption. The supply curve of

the forestry sector shifts outwards due to the subsidy. The increase in revenue boosts land rent of forestry. Within the same AEZ, land therefore flows to the forestry sector.

When we examine the sectoral land use results, we find that the AEZs where the crop is mostly grown are suffering most. For example, the rice paddy acreage of higher rainfall AEZs (e.g., AEZs 5 and 6) reduces more, compared to rice paddies in other AEZs. Note that we assume paddy rice sectors located in all AEZs are producing homogeneous product. The market price of paddy rice falls as a consequence of the carbon tax. All the paddy rice sectors (in the 6 AEZs) face the same market price. The higher rainfall AEZs—that are more productive and thus incur higher land rent—bear more of the revenue-cost squeeze. Furthermore, the higher rainfall AEZs of the paddy rice sector are relatively more CH₄-intensive. So we see more decline in land acreage of higher rainfall AEZs. The Other Crop sector (“OAG”) also has similar context as the paddy rice sector. The Wheat sector (“WHT”) is most located in AEZs 2 and 3. So its AEZs 2 and 3 acreage shrinks more than other AEZs.

As all land-based sectors are losing land, the forestry sector is gaining land, and thus absorbs more carbon (-8.24%). Table 13 shows the AEZ-specific contributions of the increase in forest land to its carbon absorption. Most of the contribution comes from AEZ 6 (6.26% out of 8.24% in magnitude). The paddy rice sector (“PDR”) and the Other Crop sector (“OAG”) are the key source of land supply to the forest sector.

Table 12. Land transition between sectors: China

China	PDR	WHT	LIV	OAG	FOR
Land_AEZ1(%)	0	-1.35	-1.8	-1.6	1.02
Land_AEZ2(%)	0	-3.0	-1.9	-1.8	2.35
Land_AEZ3(%)	0	-3.0	-2.4	-3.8	2.65
Land_AEZ4(%)	-1.8	-2.2	-1.8	-2.8	2.50
Land_AEZ5(%)	-2.6	-2.0	-1.5	-3.9	2.62
Land_AEZ6(%)	-2.9	-2.5	-2.0	-10.2	9.42
GHG emissions (%)	-2.3	-2.7	-2.1	-7.7	-8.24

**Table 13. Contributions of land use change to greenhouse gases
sequestration in forest: China**

China	Contribution to GHG emissions
Land_AEZ1(%)	-0.00
Land_AEZ2(%)	-0.25
Land_AEZ3(%)	-0.86
Land_AEZ4(%)	-0.57
Land_AEZ5(%)	-0.39
Land_AEZ6(%)	-6.26
GHG emissions (%)	-8.24

6. Concluding remarks and future research agenda

The paper describes the on-going project of the GTAP land use data base. We also present the GTAPE-AEZ model, which illustrates how land use and land-based emissions can be incorporated in the CGE framework for Integrated Assessment (IA) of climate change policies. We follow the FAO fashion of agro-ecological zoning (FAO, 2000; Fischer *et al*, 2002) to identify lands located in six zones. Lands located in a specific AEZ have similar (or homogenous) soil, landform and climatic characteristics. The six AEZs range over a spectrum of length of growing period

(LGP) for which their climate characteristics can support for crop growing. AEZ 1 covers the land of the temperature and moisture regime that is able to support length of growing period (LGP) up to 60 days per annum. On the other end of the LGP spectrum, lands in AEZ 6 can support a LGP from 270 to 360 days per annum. Crop growing, livestock breeding, and timber plantation are dispersed on lands of each AEZ of the six, whichever meets their climatic and edaphic requirements.

In GTAPE-AEZ, we assume that land located in a specific AEZ can be moved only between sectors that the land is appropriate for their use. That is, land is mobile between crop, livestock and forestry sectors *within, but not across, AEZ's*. In the standard GTAP model, land is assumed to be transformable between uses of crop growing, livestock breeding, or timber plantation, regardless of climatic or soil constraints. The fact is that most crops can only grow on lands that is under certain temperature, moisture, soil type, land form, etc.. The same concern arises for land use by the livestock and the forestry sectors. Lands that are suitable for growing wheat may not be good for rice cultivation alike, even under transformation at a reasonable cost. The introduction of the agro-ecological zoning in GTAP helps to clear up the counterfactual assumption in inter-sectoral land transition, and permit a sound presentation of sectoral competition for land.

In GTAP-AEZ, we recognize a unique production function for each of the land-using sectors located in a specific AEZ. For example, the paddy rice sector located in AEZ 1 has a different production function from the paddy rice sector located in AEZ 6. This is to identify the difference in the productivity of land of different climate characteristics. Nevertheless, all the paddy rice sectors located in the six AEZs produce homogenous output to meet market demand.

In GTAP-AEZ, we associate methane (CH₄) and nitrous oxide (N₂O) emissions to their emitting sources (or drivers). For example, we link methane emissions from paddy rice cultivation to the land used in the paddy rice sector of GTAP-AEZ. We treat methane emissions as input to the paddy rice growing, and permit limited substitution of other input for emissions according to estimates of the marginal cost of abatement, following the approach of Hyman (2001).

For future research, we plan to address the dynamics of forest carbon sequestration, which is closely related to forest growth and harvest. Biomass growth is a key factor to forest carbon stock. Biomass growth varies by age of trees and by management intensity of timberland. This in turn affects the forest carbon sequestration potential. On the other hand, timber harvest causes carbon emissions. These features of forest and carbon sequestration need to be tackled in a dynamic framework.

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