Land Use in the integrated Population-Economy-Technology-Science (iPETS) Model: Data and Model Linkage

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ABSTRACT

Land use and land cover change play an important role in the climate change issue both as a driver of climate change and as a component of response options including mitigation and adaption. Land as an input to production is currently being added to the iPETS integrated assessment model at NCAR, and this technical note provides an overview of the data involved in modeling land use within that framework. It includes a discussion of land use data included in the GTAP dataset in both physical and economic terms, its use in iPETS, and how iPETS could link with terrestrial system models such as the Community Land Model (CLM).

KEY WORDS: Land use, Land use data, iPETS model, integrated assessment

1.0 Introduction

Land use and land cover change plays an important role in global climate change. For example, about 20% of the human caused CO_2 emissions in the 1990s were due to deforestation (Denman et al, 2007) and land use is also central to evaluating impacts and adaption options, for example related to agriculture, forestry, or biodiversity. Previous analyses with the integrated Population-Economy-Technology-Science (iPETS) model have not incorporated land use (e.g., O'Neill et al., 2010; O'Neill et al., 2012). An important step in adding the capability to model land use in iPETS is to examine available data sources and adapt them to be consistent with the data used by the existing iPETS model.

The economic core of iPETS uses economic data from the Global Trade Analysis Project (GTAP), currently version 7 with a base year of 2004, representing economic transactions among 226 regions and 57 sectors, including production, consumption, bilateral trade, transportation, and taxes (Fuchs et al., 2009). For the sake of consistency with these data, it is an obvious choice to adopt the land use data also developed by GTAP. The GTAP land use data base, GTAP_LU, documents global land cover, land uses and land rents by Agro Ecological Zone (AEZ) classifications developed by the Food and Agricultural Organization (FAO) and the International Institute for Applied System Analysis (IIASA; FAO, 1996; Fischer et al, 2002). An Agro-Ecological Zone (AEZ) is a land resource mapping unit and the level of detail, or the resolution of AEZ, may vary according to the scale of the soil map and the objective of the study (FAO, 1996). In the GTAP_LU dataset, AEZs are differentiated by biophysical characteristics of the land, including climate, soil and topography characteristics. The version of this data base we use is GTAP_LU 2.1 (Lee et al, 2005) and this data set includes land cover, crop use and yield, managed forest area, land rent, carbon stock, and CO_2 and non–CO_2 GHG emissions[1].

This technical note provides an overview of the land use related data in GTAP_LU 2.1, discusses the development of data consistent with the economic data used by iPETS, and sketches a basic framework to link the land use output from the iPETS model with terrestrial system models such as the Community Land Model (CLM; Oleson et al., 2010).

2.0 GTAP LU Dataset

2.1 Physical Land Data

The GTAP_LU 2.1 data set contains physical land areas for seven different land cover categories for 18 AEZs for each region (see next section), intended to describe conditions in 2001[2]. It also contains harvested area for 175 crops and timberland area. These data are from various sources originally at different resolutions. The global land cover and cropland data are from Ramankutty and Foley (1999), Ramankutty et al (2008) and Monfreda et al (2008), and the forestry data are from Sohngen et al (2009a). A summary of the definitions, original resolution and sources of these different land cover and land uses is presented in Table 1.

[1] Currently, we only employ the land use data and will ignore the emission data in this technical note.
[2] The physical land data are actually for year 2000. To be consistent with the economic data which describe year 2001, the physical land distribution for 2001 is assumed to be the same as 2000.

Ramankutty et al (2008) developed a global spatially detailed dataset of cropland and pasture at 5 min resolution for year 2000 using a technique called "data fusion" to integrate satellite data on land cover and inventory data on land use. They combined two satellite-based global land cover datasets, MODIS (Moderate resolution Imaging Spectometer, Friedl et al, 2002) and GLC2000 (Global Land Cover 2000, Bartholome and Belward, 2005), with national and sub-national census/inventory data on cropland and pasture. Following the FAO definition, cropland includes temporary and permanent crops, temporary fallow land, and fruit trees, while pasture refers to permanent pasture (see the full description in Table 1).

The cropland area data developed by Ramankutty et al (2008) contain only one category of crop and counts crop area once even if it is cropped multiple times in a year. Monfreda et al (2008) then fused this dataset with Agro-MAPS (FAO/IFPRI/SAGE/CIAT, 2003) along with other national censuses and surveys to create a more extensive database on crop yields and areas. This dataset comprises harvested area and yield information at 5 min resolution for 175 types of crops for year 2000. The harvested crop area developed by Monfreda et al (2008) counts a given area multiple times if it is cropped multiple times during a year, and therefore differs from physical cropland area as reported in Ramankutty et al (2008).

Figure 1 compares harvested area with physical cultivated cropland across AEZs for India, showing that harvested area is typically larger than cropland area. However, in certain AEZs harvested area is smaller because the cropland area includes fallow land while harvested area does not. The ratio of the two values indicates the average number of harvests per hectare. However, it is not possible to determine the distribution of fallow land, single-cropped land, or multiple-cropped land within each AEZ. The GTAP LU database contains both types of area information and they form the basis of this version of dataset.

Another type of land cover that involves human activities in the GTAP data is urban area, referred to as "built-up area"[3] and it was developed based on two data sources, DMSP/OLS (Defense Meteorological Satellite Program, Operational Linescan System) Nighttime Lights developed by the National Geophysical Data Center at National Oceanic and Atmospheric Administration (NOAA) and the IGBP (International Global Biosphere Programme) land cover characterization data set. .

The global land cover map also requires data for land areas that have no or very little human impact. Ramankutty and Foley (1999) developed a global dataset of 15 natural vegetation types, including eight types of forest/woodland, savanna, grassland, two types of shrubland, tundra, desert and polar desert/rock/ice at a 5 min resolution. This dataset is derived by combining the DISCover land cover dataset (Loveland and Belward, 1997) and the vegetation data set of Haxeltine and Prentice (1996). This dataset represents the "potential" vegetation of the world in the absence of human activities. The actual areas of these land use categories are calculated by subtracting crop, pasture, and built up area from total potential vegetation for a given grid cell.

The original datasets contain data for 175 types of crops and 15 natural vegetation types at 5 min resolution. To make it usable for a CGE model, Monfreda et al (2008) aggregated the land cover data into 18 Agro Ecological Zones (AEZs) at the country/region level for year 2001 using the approach decribed in the next section.

[3] This set of data is not used in PET model application. For more details, please refer to http://www.sage.wisc.edu/atlas/maps.php?datasetid=18&includerelatedlinks=1&dataset=18

Another important dataset in GTAP LU 2.1 is the forestry data. The physical land cover data in GTAP LU 2.1 contains physical area for "forest" developed by Ramankutty and Foley (1999), which counts the area for all forestland. However, only forestland that is available for wood production*i.e.,* accessible forestland, should be used in an economic analysis. Sohngen et al (2009a) provide data on accessible forest areas for 14 forest types for each AEZ at country or region level for 1990 to 2000. They developed total forest areas for different countries/regions by combining various sources of country specific data and FAO inventory data. Then the forest land in each country/region is divided into accessible and inaccessible forest area as defined by FAO (2001) where accessible forest is defined as forest area within 10 kilometers of infrastructure (including rivers)[4].

A comparison between the forest area developed by Ramankutty and Foley (1999) and the accessible forest area by Sohngen et al (2009a) for the US is shown in Figure 2. Across all the AEZs, forest areas are larger than accessible forest area, as would be expected. Most forest in AEZ 12 is accessible, while AEZ 13 to AEZ 15 contain mostly inaccessible forest since they are in boreal regions where there is little infrastructure. In terms of forest coverage, most forest is distributed in temperate (AEZ 10 to AEZ 12) and boreal (AEZ 14 and AEZ 15) regions.

2.2 Agro-Ecological Zone

In the GTAP_LU 2.1 dataset, all land-related data, including physical areas and land rents, are grouped into 18 Agro Ecological Zones (AEZs) for each region based on Length of Growing Period (LGP) from the Global AEZ (GAEZ) resource database developed by IIASA and FAO (Fisher *et al*, 2002) and climatic zones defined by Ramankutty and Foley (1999).

An agro-ecological zone, by its original definition, is a land resource mapping unit "comprised of all parts of gridcells on a georeferenced map that have uniform soil and climate characteristics"[5]. The AEZ methodology has been developed over the past 30 years by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) to evaluate the suitability of the production of various crops in each zone under different input/management scenarios based on the condition of the climate, terrain and soil types of that particular zone. In the GAEZ dataset, the spatially explicit attainable (i.e., maximum possible) and actual yields of the main food and fiber commodities are determined not only by climate, soil, terrain and land cover information, but also by different levels of input/management for various crops (Fisher *et al*, 2002).

However, the GTAP-LU database uses a definition of AEZs that depends only on biosphysical information. That definition combines two factors: Length of Growing Period (LGP), with the categories defined in Monfreda et al. (2008), and climatic zone, with the categories defined in Ramankutty and Foley (1999). We assume this approach was taken because the larger GTAP dataset specifies inputs to agriculture and forestry as well as the level of technology used for crop production, so that AEZs should reflect only biosphyscial information, and LGP is the main agro-climatic determinant for crop growth and development.

[4] Some adjustments are applied to this rule. For example, for the USA, forest that is within 30 km of infrasture is accessible (Sohngen et al 2009a)

[5] http://www.fao.org/nr/land/databasesinformation-systems/aez-agro-ecological-zoning-system/en/

Monfreda et al (2008) assign crop-specific harvested area to six land categories defined by Length of Growing Period (LGP) as a biophysical indicator for potential land productivity. Length of Growing Period (LGP) is generated by the Climatic Analysis Module of the model used to produce the GAEZ dataset. It is determined as the number of days when the average daily temperature is above 5^oC and the actual evapotranspiration (ET_a) is equal to or above half of the reference evapotranspiration (ET_0) (IIASO/FAO, 2012). The Climatic Analysis Module uses monthly climate data[6], including temperature and precipitation, from 1901 to 1996 at 0.5 degree resolution developed by the Climate Research Unit of the University of East Anglia (New et al., 2000). The rate of evapotranspiration is crop specific and a hypothetical reference crop[7] is used to calcuate both ET_0 and ET_a. The reference evapotranspiration (ET_0) is calculated based on the Penman-Monteith equation (FAO, 1992) and is determined by climatic information including temperature, humidiy, wind speed, sunshine hours, latitude and elevation of a particular grid cell. The actual evapotraspiration (ET_a) is estimated by a water –balance model and is determined not only by the climate, but also by the soil's physical and chemical characteristics and effective soil depth or volume which are taken from the Digital Soil Map of the World; (DSMW; FAO, 1995). By comparing the actual evapotranspiration and the potential evapotranspiration, along with the average daily temperatures, LGP can be calculated for each grid cell.

In Ramankutty and Foley (1999), the world is divided into three climatic zones based on annual absolute minimum temperature (t_{min}, ^oC) and Growing Degree Days (GDD). The absolute minimum temperatures dataset was provided by Pat Bartlein through personal communication. Growing Degree Days (GDD) is a heat index that measures the growth rate of plants, insects and other organisms related to temperature[8], and is usually calculated by comparing the average temperature to the reference/base temperature. Ramankutty and Foley (1999) calculated the Growing Degree Days using a 5^oC base (GDD_5) with the monthly average temperature from Cramer and Leemans (2001). For both parameters, the original data were at 0.5 degree resolution and then interpolated into 5 min resolution. The rules for the three climatic zones are: If $t_{min} > 0^oC$ then it is a tropical zone; else if $t_{min} > -45\ ^oC$ and $GDD_5 > 1200$, then it is temperate; else it is boreal.

To develop the 18 land types in GTAP_LU 2.1, the GAEZ dataset was first aggregated into six categories based on LGPs: 1) LGP1: 0-59 days, 2) LGP2: 60-119 days, 3) LGP3: 120-179 days, 4) LGP4: 180-239 days, 5) LGP5: 240-299 days, 6) LGP6: more than 300 days (Monfreda et al., 2008). By overlaying the six land categories with the three climatic zones defined in Ramankutty and Foley (1999), a global map of 18 AEZs is developed. The spatial physical land use data were then aggregated into 18 AEZs and the economic data were developed based on the physical land distribution.

2.3 Land Rents Data

Land rents (i.e., annual economic return on a land using activity by hectare, e.g. in $ per hectare per year) are very important in the GTAP_LU dataset since CGE models represent the economy in terms of economic value flows. Lee et al (2009) provide a detailed description of their approach to developing AEZ-specific data on land rents for the production of crops, livestock and forestry. GTAP LU 2.1 is

[6] The monthly climate data are converted to daily parameters by interpolation.
[7] The reference crop is assumed to have a height of 12 cm, a fixed canopy resistance of 70 ms-1 and albedo of 0.23. This is close to an extensive surface of green grass. (IIASO/FAO, 2012).
[8] http://en.mimi.hu/meteorology/growing_degree_day.html

developed based on GTAP 6.0 which represents the economy for the year 2001[9] and contains factor inputs (capital, unskilled labor, skilled labor, natural resources and 18 AEZ land types) in value terms for 58 sectors in 87 regions. Land-using sectors consist of eight crop sectors, three animal product sectors and one forestry sector. Since land rents by AEZ are not readily available, the data are constructed by splitting land input values for a single type of land, either from GTAP or from separate estimates depending on data availability, and allocating them to each AEZ.

The allocation process differs slightly across sectors because of different data sources and the data structure in GTAP. For crop sectors, the land rents for different AEZs are calculated by multiplying the single land input value (from GTAP 6.0) by the share of production value (i.e., the value of output) originating from each AEZ. For a certain crop sector, the share of production value for each AEZ is the ratio of AEZ-specific production value to the total production value of that crop across all AEZs in that region. The AEZ-specific production value is calculated as the output price (single value for one region) multiplied by harvested area (AEZ specific) and yield (AEZ specific). The harvested areas are used here because the land rents refer to the economic value of production generated from the activity on a given piece of land for one entire year, not just one season.

There are four livestock sectors in the GTAP database: ruminants (cattle, sheep and goats), dairy production, wool, and non-ruminants (pigs and poultry)[10]. Since there are no readily available data for AEZ-specific harvested areas, production, yields or prices, Lee et al (2009) estimate the land rents for ruminant production based on estimates of forage production by AEZ. Since the productivity of forage crops across AEZ is not available, the average yield of coarse grain is used as an approximation. The land input value for ruminant production is calculated by multiplying the yield of coarse grain by the grazing land cover area developed by Ramankutty et al (2008) for each AEZ for each region. By assuming the share of each AEZ is the same across livestock sectors that use land, and using the single land input value for each sector in GTAP 6.0, the land rent for each livestock sector is allocated into 18 AEZs in each region.

The process of constructing land input for the forest sector in each AEZ requires a major modification of the data compared to other sectors. In fact, there is no land input to the forest sector in GTAP 6.0. Instead, land use was treated as natural resource input in this sector (Dimaranan, 2006) and the share is unrealistically small. It was applied to produce reasonable partial equilibrium characteristics; i.e., a reasonable aggregate supply response in the forestry sector. GTAP LU takes an alternative approach. Based on GTAP 6.0 and an estimation from Gouel and Hertel (2006), the land rent accounts for 61% of the total value-added in global forestry production. By assuming this relationship holds in each region, the total land rent for the forestry sector at the national/regional level is determined. Sohngen et al (2009a)

[9] Note that after adding the AEZ land rents in the I-O table, the value added inputs for land use sectors from GTAP LU are different from those in the standard GTAP 6.0.

[10] The non-ruminant sector (sector "oap" = pigs and poultry) is assumed to have no direct land input in GTAP LU. Thus the land input in GTAP 6.0 for this sector is redistributed into capital and labor inputs. Then all the value-added inputs in agricultural sectors (all crops and livestock sectors in GTAP LU) are scaled up or down to preserve the region-specific shares of agriculture value-added and agriculture-wide labor/capital ratio. As a result, the value-added inputs in these sectors are different in GTAP LU and GTAP 6.0.

provide data on timberland rent by tree type and country, and timberland area by tree type, age, AEZ and country. Appropriate aggregation and simple calculations generate AEZ-specific timberland rent shares. The AEZ-specific land rents for the forestry sector are then calculated by combining these rent shares and the total land rent for forestry from Gouel and Hertel (2006).

3.0 Land Use in the iPETS Model

3.1 Base Year Data

The I-O tables used in iPETS are based on GTAP 7.0 which represents the economy of 2004 with land inputs that are not AEZ-specific, while GTAP LU 2.1 is based on GTAP 6.0, which represents 2001. We combine the GTAP LU 2.1 data with GTAP 7.0 to create a single consistent dataset, adopting an approach that keeps the shares and values of inputs as close as possible to the GTAP 7.0 data.

We first aggregate the GTAP LU 2.1 data into the iPETS model regions and sectors[11]. The 12 sectors that use land in GTAP LU are aggregated into four iPETS sectors: Rice, Other Crops, Animal Products, and Forestry (see Table 2 for sector definitions). For the sectors without substantial input structure changes between GTAP LU and GTAP 7 (Rice, Other crops, and Animal Products), we keep the GTAP 7.0 value-added data for land, labor, capital, and natural resources, and use the shares of AEZ-specific land inputs from GTAP LU to allocate the single land input value in GTAP 7.0 across AEZs. The forestry sector in GTAP LU has been modified significantly relative to the GTAP data, which does not include land as an input to forestry. For this sector, we apply the shares of each value-added input from GTAP LU (i.e., not only land shares but also labor, capital, and natural resources) to the total value added from GTAP 7.0 to calculate the value of each input, including AEZ-specific land input.

For physical land use data, we assume that the land cover doesn't change between 2001 and 2004, so that the physical land cover in 2004 is the same as what is reprensented in the GTAP LU 2.1 dataset. Curently, the aggregations of physical land cover data used in iPETS are areas for managed forest, rice production, other crop production and pasture. The physical area for managed forest is directly from the timberland area developed by Sohngen et al (2009a). The area for pasture is adopted directly from the pasture land area by Ramankutty et al (2008). Physical areas for rice and other cropland require additional assumptions to be made since Ramankutty et al (2008) don't distinguish crop types and Monfreda et al (2008), although they include land areas for 175 types of crops, report harvested area, which includes multiple cropping, rather than physical cultivated area. It is reasonable to use harvested areas in determining land rents, but here we are interested in physical land cover. We assume the share of the harvested area of rice in total harvested area of all crops from Monfreda et al (2008) is the same as the share of physical cultivated area of rice in total physical cropland. This assumption implies that rice has the same degree of multiple cropping as the average of all other crops. With this assumption and the total cropland area from Ramankutty et al (2008), we disaggregate the land cover for rice from other crops.

3.2 Land Supply Data

The GTAP LU dataset provides the land use data for the base year of the iPETS model. As a dynamic CGE model, land supply for each AEZ over the time horizon of a simulation is also required. Land supply in iPETS, which represents managed land used for production, is modeled with Constant Elasticity of

[11] See Fuchs et al (2009) for detailed discussion for implementing the iPETS model with GTAP production data.

Substitution functions with two inputs: total available land for each AEZ and Materials, a sector in iPETS that includes everything in the economy except for energy and the four land use sectors defined in Table 2. This approach implies upward-sloping supply curves for managed land that allow new land to be brought into production at some cost when necessary. The total available physical land area for each AEZ is exogenous and can be obtained from a biophysical model, such as CLM or ISAM (and in principle can be influenced by a changing climate). Our typical approach is then to calibrate the model to an existing scenario including managed land to serve as our baseline. With a calibrated baseline, we are able to evaluate land use changes that would occur in variants of the baseline scenario.

Currently, the 100-year projections of total land use developed from the IIASA integrated assessment framework (Rokityanskiy et al, 2007) is used as our baseline manged land scenario, although in principle we can use any suitable target scenario as a baseline. The IIASA projection contains ten different land use types, listed in Table 3, for 18 AEZs. Among these land use types, the land use categories that are relevant to iPETS are cropland (CROP), managed forest (FOHUM), and pasture (Grass 3 & Grass 4). Other land use categories are not considered in iPETS at this point. IIASA separated pasture land into 4 different categories based on the intensity of usage, and we assume that the two categories with the highest use intensity are defined as pasture in iPETS. This assumption is based on a comparison we carried out of the sums of different combinations of grassland categories from IIASA with GTAP data. The sum of the Grass 3 and Grass 4 categories is closest to the pasture data from GTAP.

The land use projection from IIASA starts from year 2000 and is projected to 2100 in decadal time steps. As noted before, although the economic data for iPETS is for 2004, the physical land use data is actualy for 2000[12], the same as the starting point of the IIASA projection. However, we can still see some differences between the two sources for total managed land in 2000, as shown in Figure 3. The total managed land area is about 5.9 billion hectares based on GTAP while it is about 5 billion hectares in the IIASA model. In general, the land use distribution across AEZ is similar in that temperate regions have the most land use and there is relatively little land use in boreal regions.

Due to the differences between the two data sources, either one or the other must be adjusted to make the base year data consistent with the initial year of the projection. We choose to adjust the projection, since our base year GTAP LU data are part of the full set of consistent GTAP data for all economic activity in the base year. We therefore use the physical land use data from GTAP LU 2.1 as our base year land cover[13], and then apply the absolute land change in the IIASA projection for each AEZ to the base year data. Table 4 demonstrates this adjustment for global land use, although this is implemented in iPETS at the regional level. Table 4-A shows projected land use from IIASA in decadal changes across AEZs. In 2000, total managed land area begins with 5 billion hectares and it is projected to grow to 5.7 billion hectares in 2100. While total land use rises globally, it decreases in certain AEZs, such as AEZ 11 which is in the temperate zone and AEZ 13 in the boreal zone. Among the three climate zones, the tropics has the largest land use gain over the century. The absolute decadal changes in Table 4-A in each AEZ are applied to the GTAP benchmark data to obtain the exogenous land use scenario used in iPETS (Table 4-B), resulting in total land use that begins with 5.9 billion hectares and grows to 6.6 billion hectares in

[12] Note the physical land data are originally for 2000 and it is assumed that the land distribution in 2001 is the same as 2000.

[13] Again, we assume that there was no land cover change or the change was negligible from 2000 to 2004.

2100. Following the same pattern as the IIASA projection, AEZ 11 and AEZ 13 show decreased land supply.

3.3 Land Application

Currently in iPETS we aggregate the 18 AEZs into six land types distinguished by length of growing period. We assume that within each land type the available land is homogenous in terms of physical characteristics and unit costs, and can be used by three industries that require land as an input: agriculture, animal products, and foresty, at each time period. When land is brought into production (*i.e.*, becomes managed land), additional costs are incurred by producers and these costs differ for different land uses. In iPETS, the total available land for each land type in each region over time is exogenous. In addition, exogenous assumptions are made about the productivity of different types of land for each land use, across regions, and over time. These assumptions are scenario specific and reflect changes in inputs and management practices. iPETS simulates endogenously the projected distribution of managed land by different use (i.e., crops vs. pasture vs. managed forest) within each region for each land type, as a function of demand, total land supply, and sector-specific productivities.

As a CGE model, the outcomes from iPETS are in monetary values. To convert outcomes for land use into physical units, we follow typical practice for CGE models and use the ratio of land values to physical hectares in the base year as a conversion factor. Here we sketch our basic approach; a detailed explanation is provided in the appendix. Although the model operates in value terms, it can be interpreted as operating in quantity terms but using monetary values as a quantity unit. The base year ratios between the physical quantities and the values, *i.e.*, number of physical units per dollar, define the quantity units we choose for the model and are kept constant over time. Although it might seem that land rents can vary due to technical change or management improvement for the same amount of land, the changes in technology and management are captured by the land productivity parameters. The land input values themselves are still treated as quantities in the model with the same units as in the base year.

There is one complication for tracking the physical land distribution. For cropland, the land values we use in the base year were developed from harvested areas, so we are able to track the harvested areas over time easily. However we are principally interested in physically cultivated areas, which differ from harvested areas (Figure 1). The ratio between the two represents the degree of multi-cropping, which can be scenario dependent. For pasture and managed forest, we assume there is no multi-cropping and the ratios between the land values and physical areas for each land type in every region in the base year are used over the whole time period. One additional related issue is that, in addition to managed forest area, we are also interested in the timber harvest area. In principle, this can be complex to track in a CGE framework, since it depends on age distributions of trees. We follow a method proposed by Sohngen et al (2009b). Based on the assumption of an even rotation age harvest rule, timber harvest area is simply the managed forest areas divided by the optimal rotation age (see appendix).

4.0 Future Development

4.1 Linkage to CLM

The incorporation of land use in iPETS is at an early stage. An important goal is to couple iPETS with terrestrial system models such as CLM or the spatial terrestrial component of ISAM. In general, such coupling would begin with an iPETS simulation of demand for different land types, for alternative land uses, over time and across model regions. A downscaling method would then allocate aggregate region- and AEZ-specific demand for land into grid cells. With this information, CLM or ISAM would generate land cover maps in terms of Plant Functional Types (PFTs),[14] implement these within a simulation of the Community Earth System Model (CESM), and evaluate the influence of land use change on climate. In turn, information on climate change influences on the land surface could be transmitted to iPETS to affect the supply of land.

To achieve this coupling, a number of important issues need to be addressed. Among them is to make data compatible among models. iPETS and CLM have different definitions of land use/cover categories. Table 5 summarizes a comparison of land use/cover types and resolution between the two models. iPETS only considers managed land areas for forest, crop and pasture at the regional level. CLM operates at grid cell level and includes not only land cover associated with these land uses, but also primary land cover categories (i.e., land cover not subject to human intervention) including primary forest and primary grass/shrub area.

The spatial resolution differences will be resolved by a downscaling process currently under development. A preliminary structure of a mapping and linkage scheme for different land use/cover categories is shown in Figure 4. Note that the elements in the dotted boxes are those that have not yet been developed. The upper panels are for primary land cover, which is not accounted for in iPETS. Primary land cover would be generated separately from a potential vegetation calculation or some other available dataset, and then interpreted in terms of CLM PFTs. The lower panel is for the secondary land use categories (managed forest, cropland and pasture) as well as for wood harvest. After downscaling to the grid cell level, these types of land cover will also be converted into CLM PFTs. In addition, wood harvest would be mapped to grid cells containing either primary or secondary land cover. The mapping methods of land use/cover categories from iPETS to CLM will be adapted from Lawerence and Chase (2007). Note that CLM also accounts for glaciers, lakes, wet lands, and urban areas, which are not showed in Figure 4. Those areas are all assumed be constant over time.

4.2 Limitations and Future Development

Given that the incorporation of land use in iPETS is at an early stage, many aspects of the approach can be improved. First, land-related parameter assumptions should be re-examined. In particular, for cropland, the spatial land cover map resulting from iPETS simulations with downscaling will be in terms of physical areas, while the land rent values used in iPETS are calculated based on harvested area. Thus, using conversion factors for land rent to physical area (or *vice versa*) based on initial conditions will assume that the intensity of multiple cropping is constant across crops and over time, which is a fairly strong assumption. The most detailed data readily available are from FAO and provide only total aggregated harvested area but without crop-specific multiple cropping information. Conversion factors

[14] Plant Functional Types (PFT) is a general term that groups plants according to their function in ecosystems and their use of resources (http://www.arcticatlas.org/glossary/pft/). CLM uses it to present flexible and ecologically consistent representation of vegetation (Bonan et al, 2002).

could be further refined by examining country/region-specific surveys or by deriving indices from physical process models.

Another important type of parameter is represented by the technical coefficients for land use. These coefficients represent the productivity of land for different land uses and, while they do not have large effects on the overall economy, they do strongly affect the distribution of land cover. With the development of a downscaling method and progress in linking with the terrestrial system model, developing more realistic productivity scenarios and transforming them into technical parameters will become increasingly important.

Finally, it may become important to include the effects of urban expansion on land cover. The demographic component of iPETS includes urbanization in terms of population defined as urban, but not yet in terms of urban land cover. Accounting for possible expansion of urban land, at the expense of primary or secondary land, may be a useful future addition to our treatment of land use.

References

Bartholome, E., and A. S. Belward, 2005: GLC2000: A New Approach to Global Land Cover Mapping from Earth Observation Data. *International Journal of Remote Sensing*, 26, 1959–77.

Bonan, G., S. Levis, L. Kergoat and K. Oleson, 2002: Landscapes as Patches of Plant Functional Types: an Integrating Concept for Climate and Ecosystem Models. *Global Biogeochemical Cycles*, 16(2), 1021-43.

Cramer, W. P., and R. Leemans, 2001: Global 30-Year Mean Monthly Climatology, 1930-1960, Version 2.1 (Cramer and Leemans) Data set. Available on-line [http://www.daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. doi:10.3334/ORNLDAAC/416

Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S Ramachandran, P.L. da Silva Dias, S.C. Wofsy and X. Zhang, 2007: Couplings Between Changes in the Climate System and Biogeochemistry. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Dimaranan, B.V., (Ed) 2006: *Global Trade, Assistance, and Production: The GTAP 6 Data Base*. Center for Global Trade Analysis, Purdue University.

FAO, 1992: Report on the Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements. Land and Water Development Division, FAO, Rome,Italy.

FAO, 1995: Digital Soil Map of the World and Derived Soil Properties (Version 3.5). CD-ROM, FAO, Rome, Italy.

FAO, 1996: Agro-Ecological Zoning: Guidelines. FAO Soils Bulletin 73, Soil Resources, Management and Conservation Service, FAO Land and Water Development Division, FAO, Rome, Italy. available at: http://www.fao.org/docrep/W2962E/W2962E00.htm

FAO. 2001: Global Forest Resources Assessment 2000, main report. FAO Forestry Paper 140, FAO, Rome, Italy.

FAO/IFPRI/SAGE/CIAT (2003) AgroMAPS: A Global Spatial Database of Agricultural LandUse Statistics Aggregated by Sub-national Administrative Districts, Food and Agriculture Organization (FAO), United Nations; International Food Policy Research Institute (IFPRI); Center for Sustainability and the Global Environment (SAGE), University of WisconsinMadison; International Center for Tropical Agriculture (CIAT). Website: http://www.fao.org/landandwater/agll/agromaps/interactive/index.jsp.

Fischer G., H. van Velthuizen, M. Shah and F. Nachtergaele, 2002: Global Agro-ecological Assessment for Agriculture in the 21 Century. IIASA Research Report. International Institute for Applied Systems Analysis, Laxenburg, Austria

Friedl, M.A, D.K. McIvera, J.C.F Hodgesa, X.Y. Zhanga, D. Muchoneyb, A.H. Strahlera, C.E. Woodcocka, S. Gopala, A. Schneidera, A. Coopera, A. Baccinia, F. Gaoa, and C. Schaafa, 2002: Global Land Cover Mapping from MODIS: Algorithms and Early Results. *Remote Sensing of Environment*, (83), 287–302.

Fuchs, R., S. Pachauri, and B.C. O'Neill, 2009: Production Data for the Population–Environment-Technology (PET) Model. Interim Report IR-09-025, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Gouel, C., and T. W. Hertel, 2006: Introducing Forest Access Cost Functions into a General Equilibrium Model. GTAP Research Memorandum No.8, Center for Global Trade Analysis, Purdue University.

Haxeltine, A., and C.I. Prentice, 1996: BIOME3: An Equilibrium Terrestrial Biosphere Model Based on Ecophysiological Constraints, Resource Availability, and Competition among Plant Functional Types. *Global Biogeochem. Cycles*, 10(4), 693-709.

IIASA/FAO, 2012: Global Agro-ecological Zones (GAEZ v3.0). IIASA, Laxenburg, Austria and FAO, Rome, Italy.

Lawrence, P.J. and T.N. Chase, 2010: Investigating the Climate Impacts of Global Land Cover Change in the Community Climate System Model. *International Journal of Climatology*, 30(13), 2066-87, doi: 10.1002/joc.2061.

Lee, H-L, T. Hertel, B. Sohngen, and N. Ramankutty. 2005: Towards An Integrated Land Use Data Base for Assessing the Potential for Greenhouse Gas Mitigation. GTAP Technical Paper No.25, Center for Global Trade Analysis, Purdue University.

Lee, H-L, T. Hertel, S. Rose, and M. Avetisyan. 2009: An Integrated Global Land Use Data Base for CGE Analysis of Climate Policy Options. In T. Hertel, S. Rose, R.Tol, ed. *Economic Analysis of Land Use in Global Climate Change Policy*, Routledge.

Loveland, T.R., and A.S. Belward, 1997: The IGBP-DIS Global 1 km Land Cove Data Set, DISCover: First Results, *International Journal of Remote Sensing*, 18, 3289-95.

Monfreda, C., N. Ramankutty, and J.A. Foley, 2008: Farming the Planet. Part 2: Geographic Distribution of Crop Areas, Yields, Physiological Types, and Net Primary Production in the Year 2000. *Global Biogeochemical Cycles* 22, GB1022, doi:10.1029/2007GB002947

New, M., M. Hulme, and P.D. Jones, 2000: Representing Twentieth Century Spacetime Climate Variability. Part 2: Development of 1901-96 Monthly Grids of Terrestrial Surface Climate. *Journal of Climate* 13: 2217-38.

Oleson, K.W., D.M. Lawrence, G.B. Bonan, M.G. Flanner, E. Kluzek, P.J. Lawrence, S. Levis, S.C. Swenson, P.E. Thornton, A. Dai, M. Decker, R. Dickinson, J. Feddema, C.L. Heald, F. Hoffman, J.-F.

Lamarque, N. Mahowald, G.-Y. Niu, T. Qian, J. Randerson, S. Running, K. Sakaguchi, A. Slater, R. Stockli, A. Wang, Z.-L. Yang, Xi. Zeng, and Xu. Zeng, 2010: Technical Description of version 4.0 of the Community Land Model (CLM). NCAR Technical Note NCAR/TN-478+STR, National Center for Atmospheric Research, Boulder, CO, 257 pp.

O'Neill, B.C., M., Dalton, L. Jiang, R. Fuchs, S. Pachauri, and K. Zigova, 2010: Global Demographic Trends and Future Carbon Emissions. *Proceedings of the National Academy of Sciences,* 107 (41), 17521-17526

O'Neill, B.C., X. Ren, L. Jiang, and M.G. Dalton, 2012: The Effect of Urbanization on Energy Use in India and China in the iPETS Model. *Energy Economics*, 34(Supplement 3), S339–S345.

Ramankutty, N and J.A. Foley, 1999: Estimating Historical Changes in Global Land Cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles*, 13(4), 997-1027.

Ramankutty, N., A.T. Evan, C. Monfreda, and J.A. Foley, 2008: Farming the Planet: 1. Geographic Distribution of Global Agricultural Lands in the Year 2000. *Global Biogeochemical Cycles*, 22, GB1003, doi:10.1029/2007GB002952.

Rokityanskiy, D., P.C. Benitez, F. Kraxner, I. McCallum, M. Obersteiner, E. Rametsteiner, Y. Yamagata, 2007: Geographically Explicit Global Modeling of Land-Use Change, Carbon Sequestration, and Biomass Supply. *Technological Forecasting & Social Change*, 74, 1057-1082.

Sohngen, B., C. Tennity, M. Hnytka, and K. Meeusen, 2009a: Global Forestry Data for the Economic Modeling of Land Use. In T. Hertel, S. Rose, and R.Tol, ed. *Economic Analysis of Land Use in Global Climate Change Policy*, Routledge.

Sohngen, B., Golub, A., and T. Hertel 2009b: The Role of Forestry in Carbon Sequestration in General Equilibrium Models. In T. Hertel, S. Rose, R. Tol, ed. *Economic Analysis of Land Use in Global Climate Change Policy*, Routledge.

Table 1 Descriptions, Units and Sources of Physical Land Types in GTAP_LU

	Description	Resolution	Source
1. Forest	Lands dominated by trees with a percent canopy cover >60% and height > 2 meters	5 min	Ramankutty and Foley (1999)
2. Savanna/Grassland	Sum of Savannas and Grassland a) Woody Savannas: Herbaceous and understory, forest canopy cover 30-60%, and >2m height b) Savannas: Herbaceous and understory, forest canopy cover 10-30%,and >2m height c) Grassland: Herbaceous cover. Tree and shrub cover < 10%	5 min	Ramankutty and Foley (1999)
3. Shrub	a) Closed Shrublands: Woody vegetation < 2m, with total canopy cover > 60% b) Open Shrublands: Woody vegetation < 2m , with total canopy cover 10-60%	5 min	Ramankutty and Foley (1999)
4. Cropland	Sum of arable land and permanent crops (by FAO definition). a) Arable land: "land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for arable land are not meant to indicate the amount of land that is potentially cultivable" b) Permanent crops: "land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but excludes land under trees grown for wood or timber" Multiple-cropping areas only count once	5 min	Ramankutty, Monfreda, and Foley (2008)

	Description	Resolution	Source
5. Pasture	Permanent pasture (by FAO definition): "land used permanently (5 years or more) forage crops, either cultivated or growing wild"	5 min	Ramankutty, Monfreda, and Foley (2008)
6. Built up	Urban area, contains a combination of modeled built-up areas (based on nighttime lights) and observed built-up areas (based on IGBP land cover data).	5 min	http://www.sage.wisc.edu/atlas/maps.php?datasetid=18&includerelatedlinks=1&dataset=18
7. Other	Potential vegetation class 13-15: tundra, desert, polar desert/rock/ice. The left-over areas from Ramankutty & Foley (1999).	5 min	Ramankutty and Foley (1999)
8. Harvested crop area	Annual total harvested area for 175 types of crops from statistics (AgroMap, FAOSTAT); Accounts for multiple cropping.	5 min	Monfreda, Ramankutty, and Foley (2008)
9. Accessible Forest	Accesssible forest (by FAO definition): "Forest within 10 kilometers of infrastructure (including rivers) for wood supply" (in the US, 30 kilometers); 14 timber types (hardwood, softwood, mixed etc)	Regional; AEZ	Sohngen, Tennity, Hnytka, and Meeusen (2009a)

Table 2 Definitions of Land Use Sectors in the iPETS Model

iPETS model	GTAP sectors
Rice	Paddy rice (pdr)
Other Crops	Wheat (wht); Cereal grains (gro); Vegetables, fruits, nuts (v_f); Oil seeds (osd); Sugar Cane, sugar beet (c_b); Plant based fibers (pfb); Crops nec (ocr)
Animal Products	Cattle, sheep, goat, horses (ctl); Raw milk (rmk); Wool, silk worm, cocoons (wol); Animal products (oap)*
Forestry	Forestry (frs)**

*: "oap" does not use land as input in GTAP LU dataset.

**: "frs" does not use land as input in standard GTAP dataset.

Table 3 Land Use Categories and Definition in IIASA Projection

Land use types	Definition
Crop	Cropland
FOPRI	Primary forest without human interaction
FOHUM	Secondary forest: managed forest
FOC	Timber harvest area
NON	Non-vegetated area (includes ice, rocks, barren lands)
Built	Urban plus roads and infrastructure
Grass 1	grass/woodland/shrubland share in grid cell < 10%
Grass 2	Low use intensity (used for areas where ratio energy required / energy supplied < 0.1)
Grass 3	Intermediate use intensity (used for areas where 0.1 < Energy required / energy supplied < 0.5)
Grass 4	Intensive use intensity (used for areas where ratio Energy required / energy supplied > 0.5)

Table 4 Total Future Land Use Projection

4.A Future Land Use Projection by IIASA (Million hectares)

Year	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	total
2000	74	128	173	206	267	882	147	502	832	746	414	625	24	6.8	6.8	0.0	5034
2010	78	133	184	217	274	913	150	511	845	753	416	633	24	6.8	6.8	0.0	5143
2020	83	135	213	244	280	922	149	518	826	794	412	648	23	6.5	7.5	0.0	5262
2030	93	145	222	273	292	920	142	505	837	818	391	685	23	6.9	7.6	0.3	5360
2040	98	147	239	295	307	926	140	504	861	823	398	681	22	6.8	8.4	0.2	5456
2050	105	163	268	304	318	915	137	486	829	855	386	703	22	6.0	8.4	0.6	5506
2060	108	167	275	313	325	928	138	490	832	858	386	705	22	6.0	8.4	0.6	5561
2070	110	169	280	320	330	938	140	494	833	859	385	707	22	5.9	8.3	0.6	5601
2080	114	174	289	325	333	943	144	504	832	859	385	706	22	5.9	8.3	0.6	5645
2090	116	177	296	334	340	961	146	508	833	861	385	709	22	5.9	8.3	0.6	5703
2100	117	179	301	341	346	973	147	511	834	861	384	711	22	5.9	8.3	0.6	5740

4.B Adjusted Total Land Use Projection Used in iPETS (Million hectares)

Year	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	total
2001	237	180	274	422	445	564	926	534	401	585	280	335	190	256	232	48.1	5912
2010	241	186	284	433	452	594	929	542	413	592	282	343	191	256	232	48.1	6021
2020	246	188	314	460	458	604	928	549	394	633	278	358	190	256	232	48.2	6139
2030	256	197	323	489	470	602	921	536	406	656	257	396	189	257	232	48.4	6238
2040	262	200	340	512	485	607	919	535	430	662	264	391	189	256	233	48.3	6333
2050	269	216	369	520	497	597	916	517	397	694	252	413	189	256	233	48.8	6384
2060	271	219	375	529	503	610	917	521	400	697	252	416	189	256	233	48.8	6438
2070	273	222	380	536	508	620	919	525	402	698	252	417	189	256	233	48.8	6479
2080	277	226	390	541	511	625	923	535	400	698	252	416	189	256	233	48.8	6523
2090	279	229	397	550	519	643	925	540	402	699	251	419	189	256	233	48.8	6581
2100	280	231	401	557	524	655	926	542	402	700	250	421	189	256	233	48.8	6618

Table 5 Land Use/Cover Types Used in Each Model

	iPETS	CLM
Land use / Land cover	Crop (rice & other crops) Pasture Managed Forest	Forest: (potential vegetation PFT & current day PFT) Needleleaf evergreen temperate Needleleaf evergreen boreal Needleleaf deciduous boreal Broadleaf evergreen tropical Broadleaf evergreen temperate Broadleaf deciduous tropical Broadleaf deciduous temperate Broadleaf deciduous boreal Herbaceous / Understory: (potential vegetation PFT & current day PFT) Evergreen shrub Deciduous temperate shrub Deciduous boreal shrub C3 Arctic grass C3 non-Arctic grass C4 Grass Crop Bare Glacier Lake Wetland Urban Wood harvest (primary & secondary)
Resolution	Regional	Grid Cell

Figure 1. Cropland Area vs. Harvested Crop Area

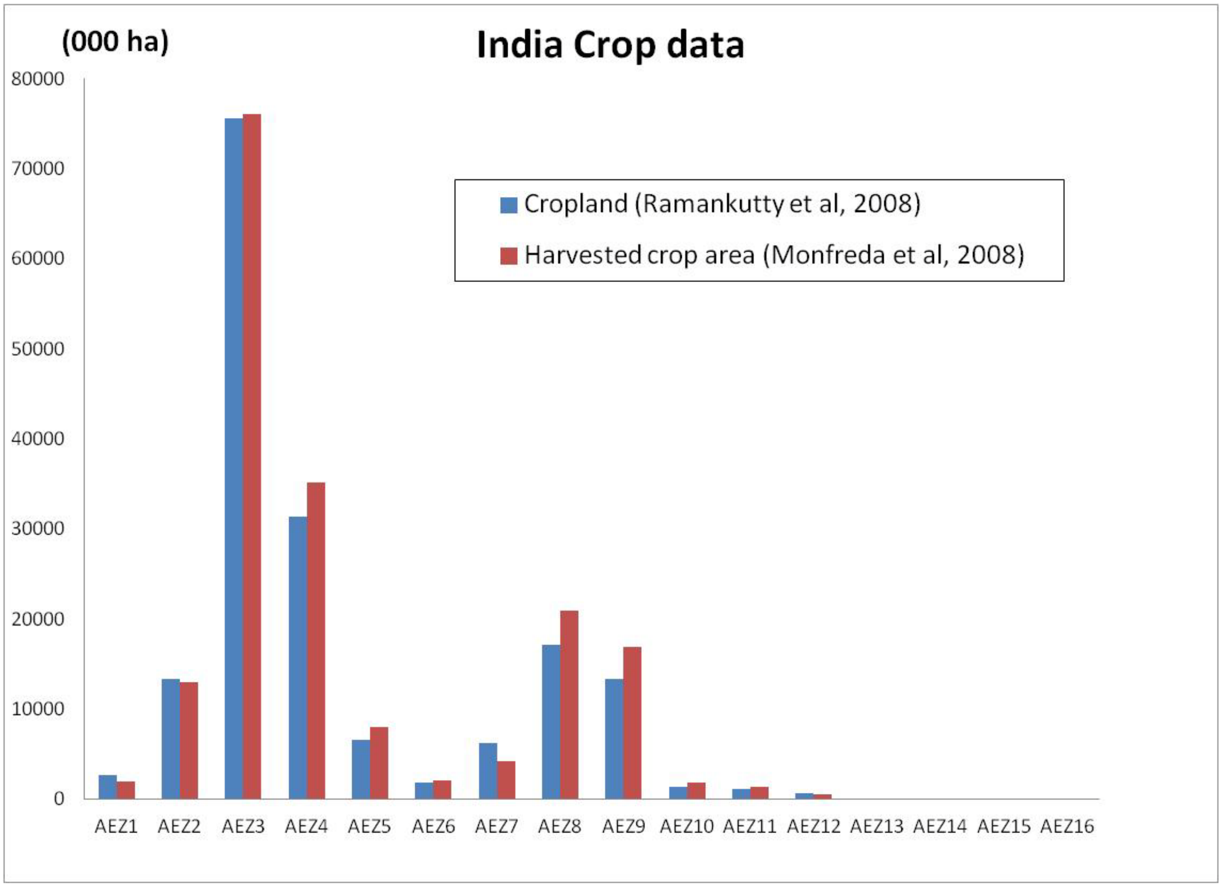


Figure 2 Comparison of Forest Area from Different Data Sources

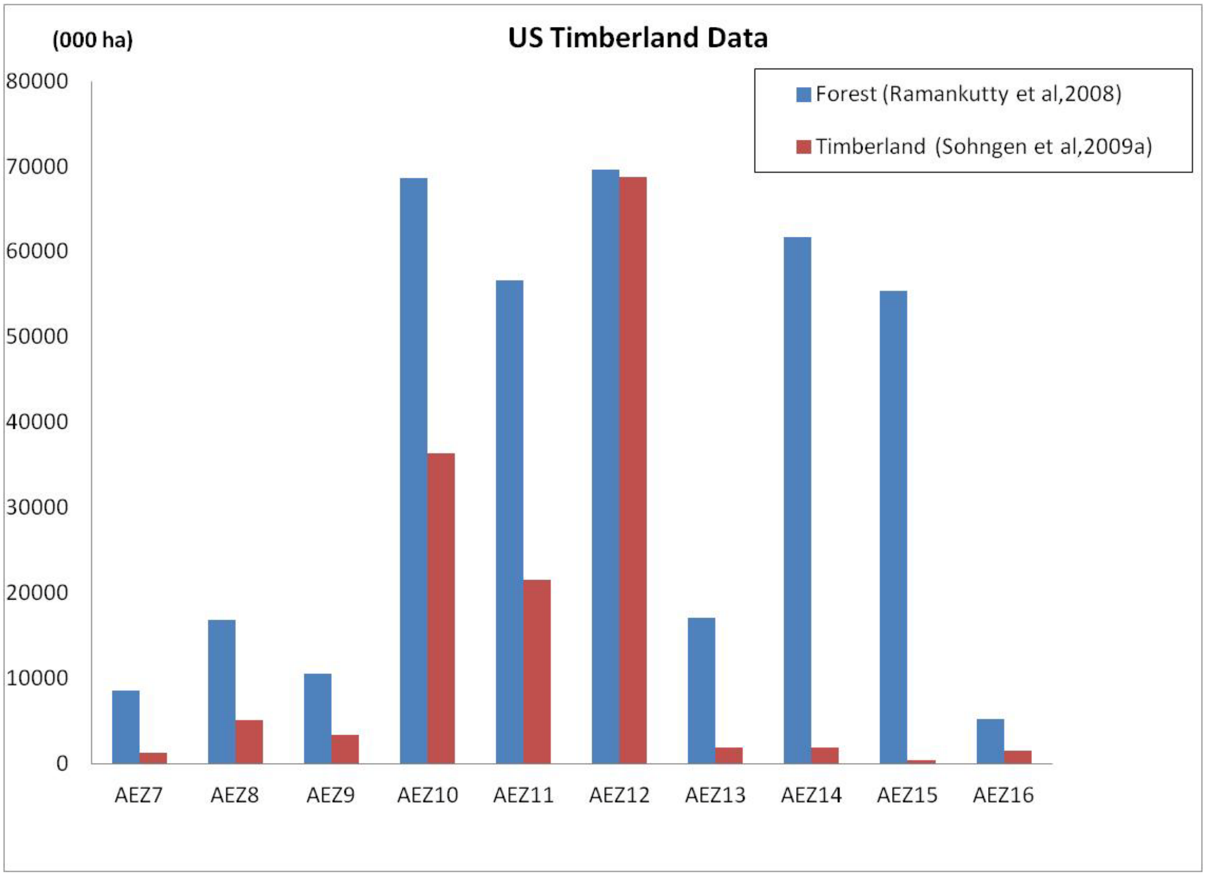


Figure 3 Total Managed Land Areas in GTAP vs. IIASA (year 2000)

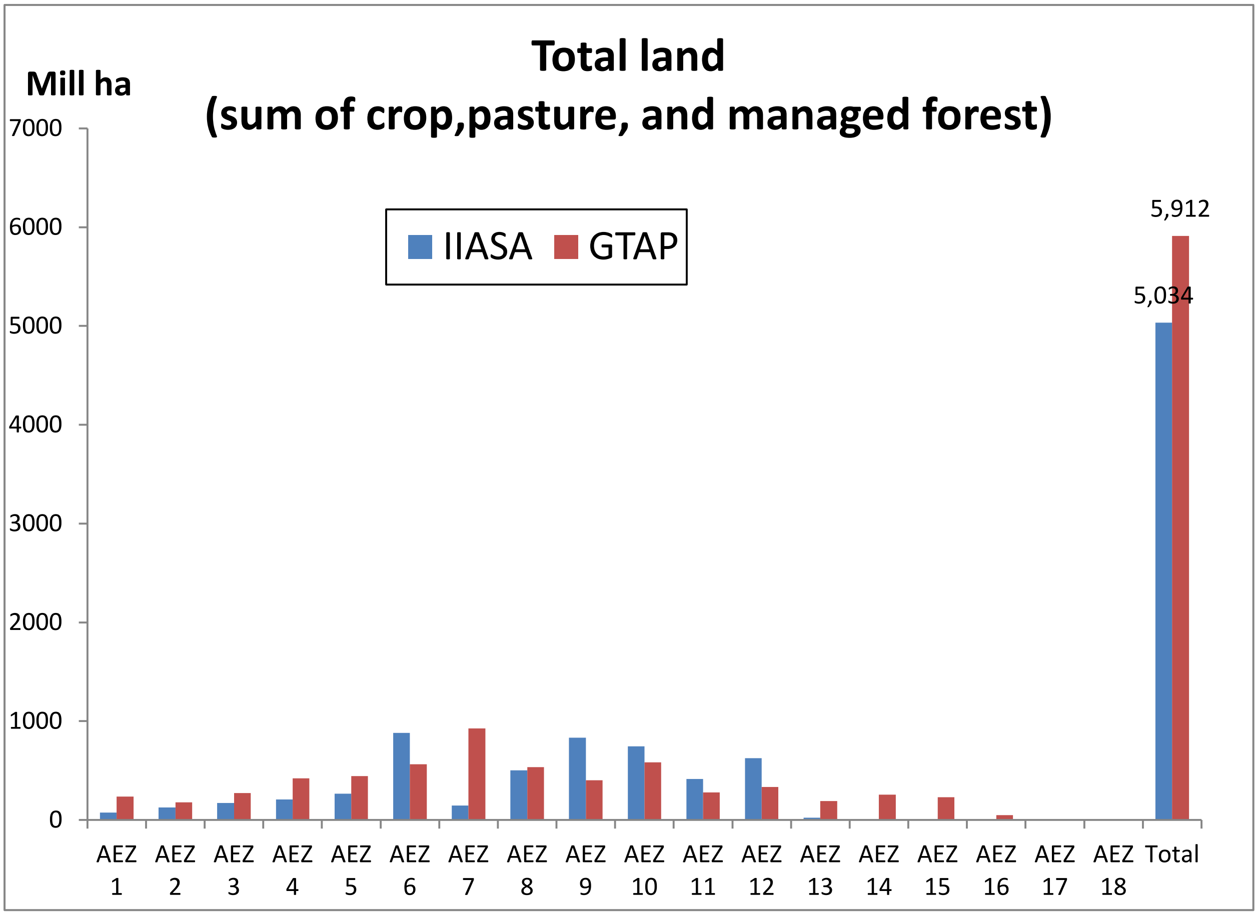
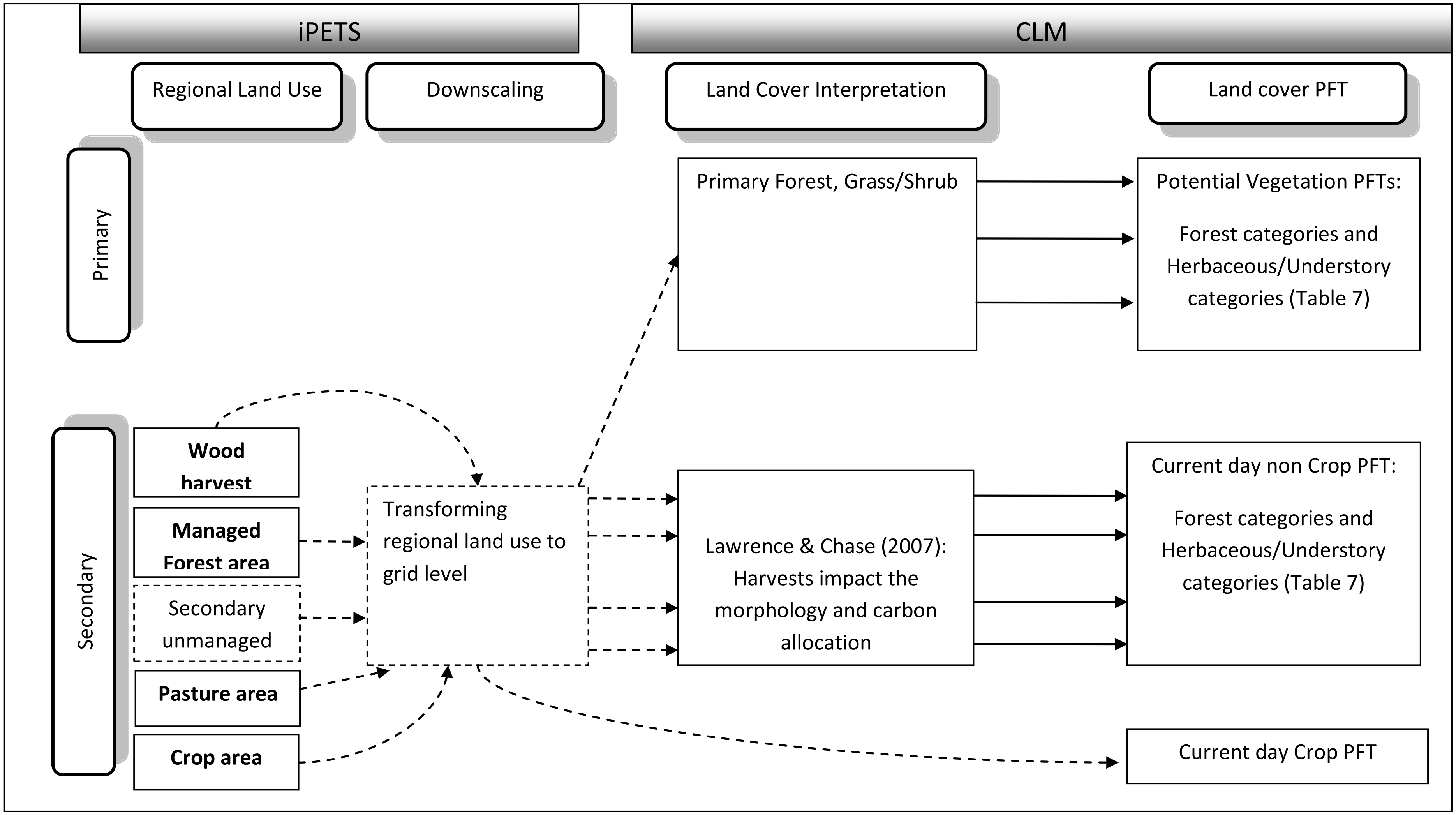


Figure 4 Land Use Linkage Scheme of iPETS to CLM



Appendix: Converting economic value of land to physical units in the iPETS model

As a general equilibrium model, iPETS treats all inputs to and outputs from industries in value terms. For land use, iPETS generates the land use distribution for each land type in every region over the time horizon in value terms. However, we are often interested in the physical land areas these value imply, especially when linking iPETS to a biophysical model of the land surface. To track the results in physical units, a proper approach is needed to convert the value terms into physical areas. Due to their different natures, different methods are applied to different land uses.

For cropland, the land input values in the GTAP data were derived from harvested areas, which can be written as:

$$(1) \quad H_{i,j,t}^{HA} = \alpha_{i,j} \cdot H_{i,j,t}^{V}$$

where

H^{HA} Harvested area

H^{V} Land inputs in value term

i Land use sector

j Land type

t Time

α Conversion factor that represents the harvested area per unit of economic value

As discussed in the main text, the conversion factor α defines the units used in iPETS, which can be interpreted as quantities even though they are measured in monetary terms. As a consequence, this factor should be constant over time.

The relation between harvested area and physical area can be written as:

$$(2) \quad H_{i,j,t}^{PA} = \frac{H_{i,j,t}^{HA}}{\beta_{i,j,t}}$$

where

H^{PA} Physical area

β Multi-cropping intensity

The conversion factor β represents the degree of multiple cropping. It can change over time as a function of management practices.

So the physical areas for cropland can then be calculated from land input values as

$$(3) \quad H_{i,j,t}^{PA} = \frac{\alpha_{i,j}}{\beta_{i,j,t}} \cdot H_{i,j,.t}^{V}$$

The base year values of the two conversion factors, α and β, can be easily calculated from the base year data as

$$(4) \quad \alpha_{i,j,0} = \frac{H_{i,j,t_O}^{HA}}{H_{i,j,t_O}^{V}}$$

$$(5) \quad \beta_{i,j,0} = \frac{H_{i,j,t0}^{HA}}{H_{i,j,t0}^{PA}}$$

Note that the aggregation levels for each variable need to match. In terms of the data used in iPETS, all variables are aggregated into the same level as the economic sectors: rice and other crops. It is very simple to aggregate the harvested areas to the desired aggregation level. However, the physical area for cropland reported in GTAP LU doesn't distinguish crop types and all cropland is aggregated together. As described in the main text, we assume that the degree of multi-cropping is equal across crop types, so that the physical area for crop *i* is

$$(6) \quad H_{i,j,t0}^{PA} = \frac{H_{i,j,t0}^{HA}}{\sum_{i=1,N} H_{i,j,t0}^{HA}} H_{j,t0}^{PA}$$

Combing equations (5) and (6), the multiple cropping intensity β is calculated as

$$(7) \quad \beta_{i,j,0} = \frac{\sum_{i=1,N} H_{i,t,t0}^{HA}}{H_{j,t0}^{PA}}$$

With the base year values and the assumptions on scenarios, we are able to define the values of α and β over the whole time horizon. Currently, we assume both of them are constant over time but in principle β can be scenario specific.

For pasture and managed forest, we assume that there is no multi-cropping since no data are available. Thus β=1 for both sectors and α is the ratio between the physical area and the land input value into the specific sector.

For forestry production, we are not only interestd in the physical area of accessible forest, but also the timber harvest area. The timber harvest area for year 2000 is provided by Sohngen *et al* (2009b) and we need to develop a method to project future timber harvest area. Unlike cropland and pasture, in the GTAP database, the land input for forestry is not the harvest area, but the total area of accessible timberland. Some studies have examined timber harvest areas but in a fairly simple way. For example, Ianchovichina et al (2001) use the difference between the percentage changes in forestland and the percentage changes in forest outputs to represent the percentage change in timber harvest rates. However, timber harvest is more complex than that and involves dynamic properties of forests. Those issues are difficult to address in a CGE framework. Recently, some attempts have been made to incorporate some forestry features, such as timber harvest, forest rotation, and management, into a CGE model (see Sohngen *et al* , 2009b, for a review). GTAP forest land data (Sohngen et al, 2009a) provides annual harvested area according to Sohngen *et al* (2009b). These data are derived from a calculation in which the timber harvest area is simply the accessible forest area divided by an estimate of the optimal rotation age (a^R). The optimal rotation age is based on timber yield, stumpage price, and cost for the year 2000 (Sohngen et al, 2009b). Then the even age rotation harvest rule is used to calculate the timber harvest area, simply expressed as

$$H^{HA}_{Forest,j,t} = \frac{H^{PA}_{Forest,j,t}}{a^{R}_{ijt}} \quad (8)$$

Equation (8) indicates that the factor β for timber production is the inverse of the rotation age ($1/a^R$). With current data, the rotation age is calibrated to be 40 years in iPETS model to match the timber harvest data from ISAM and IIASA at base year, as illustrated in Figure A. Future projection of timber harvest areas will be calculated based on this value and projected accessible forest areas.

Figure A Global Timber Harvest: IIASA .vs. ISAM .vs. Calculated from iPETS (Optimal Rotation Age = 40 years)