Modelling Land Use Changes in GTAP

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Abstract

It is agreed by members in the 7th Conference of the Parties (COP7) to the UNFCCC held in November 2001 to take land-based carbon sequestration into account for the 2008-2012 greenhouse gas (GHG) emissions reduction targets. Activities such as afforestation, reforestation, and deforestation (ARD), forest management, crop management, grazing land management, and re-vegetation affect carbon sequestration. This provision has motivated more research efforts to consider land-use changes in integrated assessment (IA) of climate change issues. A need is elicited to count in greenhouse gas (GHG) emissions from all sources and sinks from land-based resources—land use, land use change and forestry (LULUCF) activities are specially focused.

In conventional CGE models, land is normally assumed sectoral-specific and is exogenous. To consider the context of LULUCF in the model, it is important to identify functions of land supply to sectors—especially sources of land supply, as emission coefficients vary to different uses of land. In this paper we introduce the GTAPE-L model (Burniaux, 2002), which recognizes sources of land supply via a "land transition matrix". GTAPE-L is based on the GTAP-E model, which extends the standard GTAP model to accommodate substitution between energy and between capital and energy.

GTAPE-L is designed to track inter-sectoral land transitions and to estimate sectoral *net* emissions due to land use changes. In GTAPE-L, we treat GHG emissions as part of the CES nested production structure, which takes into account complementary inputs to GHG abatement technologies. We calibrate the CES substitution elasticities to fit marginal abatement costs of

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engineering estimates. The land transition matrix shows changes of land status (or use) over a given period of time, for example, cropland being transformed into forest land (or afforestation). We derive inter-sectoral land use transitions from the estimation of the RIVM IMAGE 2.2 model (IMAGE Team, 2001). We also calculate net emissions associated with land transitions. For each type of land transition, we assign a specific net emission coefficient measuring the difference in emissions per unit of land between the two types of land uses. In the case of transforming cropland into forest, we can calculate the amount of carbon sequestered by multiplying units of land shifted from the agriculture sector to the forestry sector with the net emission coefficient pertaining to the cropland-forest transition. We associate tax instruments with net emissions due to land transitions so that GHG abatement policies could direct LULUCF activities to some conditionally optimized status.

We run illustrative simulations of a 30% reduction in GHG emissions of the US and the European Union under the two sets of scenarios: with and without counting in changes in emissions due to land use changes (or transitions). We analyze how the implementation of this abatement target affects the production and prices of the 11 aggregated sectors—rice, crops, livestock, forestry, coal, oil, gas, petroleum products, electricity, chemicals and rest of the economy—in 5 aggregate countries, including the Unite States (US), European Union (EU), Rest of Annex 1 countries, China and India, and Rest of World. We compare the two sets of results to see how the incorporation of land use changes and associated (net) emissions affect the marginal costs of GHG abatement. The results show that land use transitions do help reduce the marginal abatement costs—a 3% reduction for the US, and a 30% for the EU. Such substantial difference between the US and the EU could be explained by the relatively higher carbon intensity in agricultural production of the US and possible under-estimation of carbon sequestration potential as indicated in the net emissions matrix corresponding to land use changes.

In addition, we make an alternative version of the GTAPE-L model where sources of land supply are obscured. This is similar to the approach currently taken by the MIT Joint Program on the Science and Policy of Global Change in their EPPA model (Babiker *et. al.*, 2001). In this case, we sum up the sources of land supply of the land transition matrix so that only sectoral total land values are presented. For GHG emissions associated with land based activities, we are not able to recognize differences in emission intensity between activities (or sectors). Only sectoral gross emissions are presented. Comparing the results of the same simulation by the two versions of GTAPE-L, we find that neglecting the sources of land supply and thus net carbon emission/sequestration will lead to mis-measurement of economic costs and sectoral responses. For the US, the economic cost of GHG abatement is relatively higher due to the positive net emission rate associated with land use change. For the EU, the economic cost of GHG abatement is relatively lower due to the negative net emission rate (i.e., sequestration) associated with land use change.

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1. Introduction

In November 2001, participating members of the 7th Conference of the Parties (COP7) to the UNFCCC agreed to take land-based carbon sequestration into account for the 2008-2012 greenhouse gas (GHG) emissions reduction targets. Activities competing for use of land affect carbon sequestration—such as afforestation, reforestation, and deforestation (ARD), forest management, crop management, grazing land management, and re-vegetation. This provision has motivated more research efforts to consider land-use changes in integrated assessment (IA) of climate change issues. A need is elicited to count in greenhouse gas (GHG) emissions from all sources and sinks from land-based resources—land use, land use change and forestry (LULUCF) activities are specially focused.

Many quantitative assessments for the economic costs of the Kyoto Protocol compliance have been focusing mainly on carbon dioxide, while other GHGs (e.g., methane and nitrous oxide) and the carbon sinks potential are ignored. Information about costs of reducing non-CO_2 emissions and the cost of increasing carbon sinks by reducing the net-emissions from land-use changes has been limited. Few consent is received due to large uncertainty about the magnitude of net GHG emissions from agricultural and forestry activities. Furthermore, available information about net emissions from land-use changes (e.g., Houghton (1999) and McCarl (1998)) is not yet ready to be incorporated into Computable General Equilibrium (CGE) models, which have been playing an important role in integrated assessment (IA) models designed for climate change policy analyses (e.g., the IMAGE model developed by the RIVM team[1]; the MIT Integrated Global System Model (IGSM)[2].

Hence, the need is called forth upon an integrated data base for assessing GHG mitigation policies with a special emphasis on the link between land use changes and changes in net GHG emissions from agriculture and forestry. While constructing this data base, it is important to identify a methodological approach to integrate land-based activities and associated GHG emissions into CGE models. This serves as a blueprint for the construction of the land use data base.

In this paper, we introduce a prototype CGE model—named GTAPE-L, based on the GTAP-E[3] model (Burniaux and Truong, 2002)—which incorporates carbon sequestration from land use changes. Conventional CGE models normally assume land as sectoral-specific and as exogenous to policy shocks. Thus, demand of land determines rents. Relative sectoral land rents determine which sectors attract more land than others. However, we can not tell in this approach how much

[1] For instance, the RIVM (National Institute of Public Health and the Environment, The Netherlands) developed the Integrated Model to Assess the Global Environment (IMAGE), quantifying the relative importance of major processes and interactions in the society-biosphere-climate system under global change. The IMAGE model consists of a general equilibrium economy model—named WorldScan—of 17 world regions, a demographic model, the energy-industry system, the terrestrial environment system, and the atmospheric ocean system. For more details about the IMAGE model, visit the RIVM website at: http://arch.rivm.nl/index_en.html .

[2] The MIT Integrated Global System Model (IGSM) is developed to simulate global environmental changes caused by anthropogenic GHG emissions and uncertainties associated with projected changes, and to simulate the effect of proposed climate change policies (Prinn *et. al.*, 1999). The MIT IGSM includes: an economic model—named EPPA (stands for Emissions Prediction and Policy Analysis)—for analysis of greenhouse and aerosol precursor gas emissions and mitigation proposals (Babiker *et. al.*, 2001); a coupled model of atmospheric chemistry and climate; and models of terrestrial ecosystems.

[3] The GTAP-E model extends the standard GTAP model (Hertel, 1997) to accommodate substitution between energy and between capital and energy.

forest land, for example, has been transformed into agriculture land. Carbon sequestration is closely related to the reallocation of forestry land. To consider the context of LULUCF in the model, it is important to identify functions of land supply to sectors—specifically sources of land supply—as emission coefficients vary to different uses of land. In the GTAPE-L model, we recognize sources of land supply via a "land transition matrix". We introduce the GTAPE-L model in Section 2, and the land transition matrix and associated net emissions in Section 3. To show the advantage of GTAPE-L by incorporating land use changes and associated emissions, we run an illustrative simulation of a 30% reduction in GHG emissions of the US and the European Union under two sets of scenarios: with and without counting in changes in emissions due to land use changes. Comparison of the two sets of simulation results is in Section 4.

To reveal the advantage of tracking sources of land supply (as in the "land transition matrix"), we make another version based on GTAPE-L by aggregating the sources of land supply, and associated net emissions. We run the same 30% GHG abatement simulation and discuss how the results differ from the original GTAPE-L, where sources of land supply are explicit. This is in Section 5. Section 6 concludes the paper and notes research agenda.

2. Overview of the GTAPE-L model

The GTAPE-L model—L refers to land; E refers to energy—is developed on the basis of the GTAP-E model (Burniaux and Truong, 2002), which is an extension of the standard GTAP model (Hertel, 1997). With GTAPE-L, we aim to address policy assessment of carbon dioxide emissions from fossil fuel combustion, methane and nitrous oxide emissions, and land use change. We aggregate the GTAP version 5 data base for GTAPE-L to five regions/countries and 10 sectors (see Tables 1 and 2).

Like in GTAP-E, all sectors produce output from a number of non-energy intermediate inputs and of a composite "value-added + energy" input (see Figure 2). In all sectors, except in the crops sector (discussed later), the first level production nesting has a Leontief structure. The composite "value-added + energy" input is made up of land, natural resource, labor, and a composite "capital + energy" input. The third CES level describes the relationship between capital and a composite energy input. This specification potentially allows to distinguish a short-term technological response where capital and energy are complementary and a long-term response where they are substitutes. The fourth level allocates the aggregate demand for the composite energy input into electricity and a composite non-electricity input. In turn, the composite non-electric input is made up of coal and a composite energy input including the remaining fossil fuels (fifth level). Finally, the bottom level of the production function describes the inter-fuel substitution between crude oil, natural gas and refined petroleum products. The values of the substitution elasticities[4] for each level are reported between brackets on Figure 2.

2.1 New features in GTAPE-L

New features of GTAPE-L includes incorporation of: (a) non-CO_2 greenhouse gas emissions, (b) land use transition between sectors, and (c) net carbon emissions associated with land use changes. We give more description about the new features below.

[4] See Burniaux and Truong (2002).for a detailed discussion about these substitution elasticities.

(A) Non-CO_2 greenhouse gas emissions

In addition to CO_2 emissions, we account for methane (CH_4) and nitrous oxide (N_2O) in GTAPE-L. Data of CH_4 and N_2O emissions are drawn from the OECD GREEN model data base (Lee *et. al.*, 1994). However, not all emission sources of non-CO_2 emission sources are accounted in the prototype GTAPE-L model. In particular, CH_4 emissions from landfills, N_2O emissions from fossil fuel combustion and chemical processing, the chlorofluorocarbons, the tropospheric ozone and the other trace gases are not included.

Methane (CH_4)

In GTAPE-L, methane emissions are included as a production factor at the top of the CES nesting, as in Figure 1. Thus, for a number of sectors—rice, livestock, coal and natural gas—output is made up of methane emissions and a composite factor (the production structure is similar to the one shown in Figure 2. The value of the top level elasticity is chosen so as to best fit the engineering MAC (see Burniaux (2002)). Table 3 reports the value of the CES substitution elasticities that are used in the current version of the model for various non-CO2 sources[5]. These elasticities are small, ranging from 0.06 to 0.2. Burniaux (2002) reports additional information on the sources that have been used to establish the engineering MACs and how these fit with the CES-based MACs. In the current version of the model, all substitution elasticities related to emissions from land uses are equal to zero.

Nitrous Oxide (N_2O)

In GTAPE-L, we assume that nitrous oxide emissions are associated with the amount of chemicals input into the crops sector[6]. As Figure 3 shows, aggregate demand for chemicals by the crops sector is derived from the first level CES function. This demand is made up of N_2O emissions and a composite chemicals input net of emissions. In turn, this composite chemicals input is made up of domestic and imported chemicals as part of the Armington specification of the bilateral trade flows. We assume the amount of N_2O emissions per unit of chemicals used is constant (the second level elasticity is equal to zero in Figure 3).

(B) Land use transition

The structure of the land market in GTAPE-L is illustrated in Figure 4—taking the crops sector as an example. The second level CES nesting indicates that the crops producer decides the total amount of land as desired. The third CES level is to decide from which sectors (e.g., the livestock or forestry sectors) the crops producer acquires more land. Alternatively, the crop producer may choose to use crop land *more intensively*. By "*more intensively*", we mean that the crop producer reduces crop land acreage. The lowest part of Figure 4 shows how the cropland owner allocates the original cropland across different uses (including that remained for crop production purposes). We use a Constant Elasticity of Transformation (CET) function with the value of the transformation elasticity determining the degree of land mobility. Thus the model simultaneously determines demands and supplies for each bilateral land use across sectors as well as the equilibrium prices that equalize these demands and supplies.

The decision to allocate land to alternative competing uses (e.g., for growing wheat or for afforestation) is treated explicitly in this model. At this stage, we adopt the comparative static

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[5] At this stage, the same MAC is used for all regions of the model.

[6] The fertilizer sector is accounted in the Chemicals sector in the version 5 GTAP data base.

framework so as to keep the model structure simple and tractable. We intend to model the land transition dynamics at the next stage of the model development.

(C) Net carbon emission rates associated with land use transition

We distinguish the net emissions due to land use changes (i.e. from shifting a cropland into a forest plantation) from emission changes that are related to changes in land management practices (i.e. changing the tillage methods or the rate of fallow). Any carbon sequestration policy will imply large-scale changes of land uses. Most likely, this will induce price increases of agricultural, urban and recreational lands. In turn, the price rise of agricultural land will affect agricultural output and input mix and thus amount of GHGs emissions associated. For instance, higher cropland prices may prompt farmers to use more fertilizer, which will increase N_2O emissions. Higher cropland prices may shift cropland towards livestock sector, and therefore increases CH_4 emissions.

3. Data for the compilation of the land use transition matrix

3.1 Land use transition matrix

Figure 5 shows the accounting framework, on which the land market specification of GTAPE-L is based. This accounting framework reports all changes of land status over a given period of time. It tracks origins and flows of sectoral lands—changes of land use—during the period under consideration.

The land transition matrix reports, for instance, how many hectares of cropland are transformed into forest (i.e., afforestation); how many hectares of forest land are transformed into agricultural or urban land (i.e., deforestation). The diagonal flows of the land transition matrix correspond to the land that has not changed status during the period under consideration (e.g., the land that remains under cultivation in the crops sector, or the land that remains permanently covered by forests). The sum of the columns of the matrix gives the land allocation across sectors at the beginning of the period. The sum of the rows gives the land allocation at the end of the period.

We derive the inter-sectoral land transitions from the IMAGE version 2.2 model (henceforth, IMAGE 2.2) (Alcamo J., 1994; Leemans *et. al.*, 1998). The IMAGE 2.2 model is a dynamic integrated assessment modeling framework for global climate change, comprising a general equilibrium economic model (named WorldScan), a population model (named PHOENIX), an energy-industry system (abbreviated as EIS), a terrestrial environment system (abbreviated as TES), and an atmospheric ocean system (abbreviated as AOS).

WorldScan and PHOENIX feed economic and demographic development information of 17 world regions into the subsystem that links EIS, TES, and AOS. EIS calculates regional energy consumption, energy efficiency improvements, fuel substitution, supply and trade of fossil fuels and renewable energy technologies and emissions of greenhouse gases (GHG), ozone precursors and acidifying compounds). TES calculates land-use changes based on regional consumption, production and trading of food, animal feed, fodder, grass and timber, with consideration of local climatic and terrain properties and emissions from land-use changes, natural ecosystems and agricultural production systems, and the exchange of CO_2 between terrestrial ecosystems and the atmosphere. AOS calculates changes in atmospheric composition using the emissions and by taking oceanic CO_2 uptake and atmospheric chemistry into consideration, changes in climatic properties by resolving the changes in radiative forcing caused by greenhouse gases, aerosols and oceanic heat transport[7].

The land transition matrices used in this version of GTAPE-L refer land use changes occurred in 1995. It is derived from the IMAGE 2.2 simulation results using the B2 SRES scenario[8] (IPCC, 2001). This B2 scenario is characterized by moderate economic growth, emphasis on environmental protection and social equity, and decentralized solutions. It assumes that governance is effective at the national and regional level, not at the global level. We calculated land transitions on the basis of the land allocation changes reported in the B2 scenario in 1995. Table 4 shows the land transitions of the US and the EU[9] occurred in 1995, subject to some assumptions[10].

3.2 Land use change associated net emission rates

The GTAPE-L data base contains the annual average land area that is transformed from one sector to another. We also derive from the IMAGE 2.2 model net carbon emissions (in million tons of carbon equivalent, Ceq) associated with every land use change. However, land use change disturbs net carbon fluxes to the atmosphere for several years. For instance, after cutting a forest, the respiration flux from soil remains high for a few years, depending on the natural vegetation and the climate circumstances. On the other hand, it takes time before a newly planted forest generates substantial net sequestration. As this prototype model is designed under a static framework, we do not address the dynamic nature of carbon emissions and sequestration due to land use changes. Thus, it is appropriate to consider the *average* net emissions changes that are associated to the land transitions over a certain period of time rather than to use one-year emission rates.

The IMAGE 2.2 model has been used to simulate the land transitions observed in 1995 and to calculate the associated net emission changes over a period of 10 years. Four types of net emissions are considered:

(1) The net emissions from agriculture and extensive grasslands that are abandoned and turn back to natural vegetation:
Soil respiration of abandoned land generates carbon emissions that gradually turn into sinks as the natural vegetation re-grows. Over a period of 10 years, the average net emissions in the US and the EU are negative[11]. Clearly, the time span over which net emissions are averaged is critical in estimating a representative net emission rate for the land that returns to natural vegetation.

(2) The net emissions associated with the change from natural vegetation to agricultural land:

[7] See IMAGE Team (2001) for more detailed description of the IMAGE 2.2 model.

[8] The Intergovernmental Panel on Climate Change (IPCC) published a set of new scenarios in the Special Report on Emissions Scenarios (SRES) (IPCC, 2001). These scenarios are based on a thorough review of the literature, the development of narrative 'storylines', and the quantification of these storylines using six different integrated models from different countries. The IMAGE 2.2 model has been used to simulate these scenarios and the results are reported in detail on a CD-ROM (IMAGE Team, 2001).

[9] We mainly focus on the mitigation policies of the US and the European Union (EU) in this prototype model.

[10] For instance, that the natural vegetation that is harvested for timber extraction and then let abandoned for re-growing is accounted for in the diagonal of the transition matrix (i.e. permanent forest land).

[11] Though there are regions where letting agricultural lands to turn back to natural vegetation generates positive net emissions on average over a period of 10 years, as simulated by the IMAGE2.2 model.

The amount of these net emissions is definitely positive. The amount of carbon that is released from new agricultural land remains relatively high for several years after this land has been cleared.

(3) The emissions associated with the change from natural vegetation to extensive grasslands.

(4) The emissions associated with the change from natural vegetation to re-growth after timber extraction:
In this prototype version of GTAPE-L, these emissions are associated with the permanent use of forest land (i.e. the diagonal of the forestry sector in the land transition matrix).

Table 5 shows the net emission matrices corresponding to the land transition matrices. Table 6 shows the corresponding net emission rates. Status change of agricultural land to natural vegetation—which involves afforestation and reforestation—sequesters an average of 20.8 tons of Ceq per km^2 in the US, and 103.5 tons of Ceq per km^2 in the EU. These net emission rate estimates are preliminary and subject to the way of interpretation for the results from the IMAGE 2.2 model. Note that we do not account for net emissions from land that permanently remains same status (for instance, sinks into permanent forests), except for emissions from timber extraction.

4. Illustrative simulations with GTAPE-L

We use this prototype GTAPE-L model to simulate impact of a 30 per cent reduction of all GHG emissions in the US and the EU. For both regions, this targets is achieved in three different ways: (1) by reducing emissions of carbon dioxide, methane and nitrous oxide from all sources, without considering land use changes and associated emissions; and (2) by reducing all three GHG emissions from all sources, including land use changes[12]. The total abatement (in million tons of Ceq.) is the same in the three scenarios and so is the environmental benefit.

Potential cost savings and gas contribution

Marginal abatement costs

Figure 6 reports the marginal abatement costs (MACs) in the US and the EU under the two scenarios as described above. The marginal abatement costs are further reduced by taking into account the sequestration potential from land use changes. While this potential seems negligible in the US (only -3%), it is substantial in the EU (-30%). We explain the differences between the US and the EU as follows.

Figures 7(a) and 7(b) respectively show the contribution of the three GHG emissions—CO_2, CH_4, and N_2O and sinks to the total abatement in the US and the EU. In both regions, carbon dioxide accounts for most of the total abatement, even when the non-CO_2 gases and sinks are considered. Methane and nitrous oxide emissions are reduced by some small amount—20 million tons of Ceq in the US, and 10 million tons of Ceq. in the EU—when only carbon dioxide emissions are cut. This reflects complementary relationship between gases, especially in the coal mining and natural gas sectors.

The major difference between the US and the EU relates to the role of carbon sequestration through land use changes. In the US, only 8.5 million tons of Ceq. are sequestered at a marginal

[12] In this later scenario, net emissions from land that does not change status (i.e. emissions from timber extraction) are not involved.

abatement cost of 85 USD per ton of Ceq. This is much below the range of the mitigation response functions estimated by Gillig, McCarl and Sands (2002)—for the US, around 100 million tons of Ceq. can be sequestered at a marginal abatement cost of about 50 USD per ton of Ceq. In the EU, 56 million tons of Ceq. are sequestered at a marginal abatement cost of 144 USD per ton of Ceq. Although this might also be considered as a under-estimation, it is striking that such an amount suffices to cut the abatement cost in the EU by a third. The imputed degree of land mobility is central to the magnitude of the cost saving originating from sinks. This will be developed further below.

Macro-economic costs

As a CGE model, GTAPE-L is able to provide quantitative measurements for macro-economic costs based on a consistent accounting of producer and consumer surplus losses. Table 7 reports the percentage changes of per capita household utility in these three scenarios of simulation. Although GHG mitigation policies usually imply large energy price rises and energy output decreases, aggregate costs at economy-wide scale is relatively modest. In the scenario that takes into account carbon sequestration, a 30 per cent reduction of emissions would reduce household utility by less than 1 per cent (0.24 per cent in the US, 0.89 per cent in the EU). The cost reductions due to inclusion of non-CO_2 gases and carbon sequestration respectively are comparable with the marginal cost reductions as discussed previously.

Impact on prices and outputs

Table 8 reports the impact on sector outputs and prices. As expected, carbon dioxide abatement mostly hurts the energy sectors. Coal mining output cuts almost by half; natural gas production drops by about 30 per cent; and petroleum product output[13] drops by 10 to 20 per cent. Extending the GHG coverage to CH_4 and N_2O (excluding emissions from land uses), we find that the burden of GHG mitigation shifts partially onto the agriculture sector. Rice output falls by 20 to 30 per cent, reflecting taxes on methane emissions. Crops output drops by 3 to 4 per cent as nitrous oxide emissions are taxed. Livestock output drops by about 1 per cent due to taxes on methane emissions. The impact on agriculture due to incorporation of sinks from land use changes is twofold. On one hand, agriculture benefits from the overall reduction of the marginal abatement cost—at least in the EU—resulting from the shift towards sequestration. On the other hand, more agricultural land is diverted into forestry sector results in an increase of cropland prices (a +37.1 per cent compared with a –2.0 per cent in the scenario without sequestration in the EU; a –2.9 per cent compared with a –7.5 per cent in the US)[14]. In the EU—where the impact of sequestration is higher—the first effect dominates and agricultural output falls less than in the scenario without sequestration. In the US—where sequestration has almost no impact—the opposite outcome occurs with agricultural output falling more.

[13] With a higher carbon content, the output of petroleum products should normally falls more than natural gas. This is more than offset by the existence of higher taxes on petroleum products – especially in Europe – than for natural gas. Since a carbon tax is an excise tax, its impact on consumer prices is reduced the higher the level of the existing taxation.

[14] Agricultural land price increases result from the increased demand for agricultural land for reforestation/afforestation as well as the capitalization into the agricultural land rent of the subsidies associated with the corresponding sequestration.

Impact on land use allocation

Table 9 shows percentage changes of the land value-added generated in the crops, livestock, forestry and other (urban, residential and recreational) sectors from the third simulation—i.e., considering land use change associated carbon sequestration. Inheriting the nature of conventional CGE models, GTAPE-L considers "efficiency units" (e.g., evaluated in 1995 USD), instead of physical units (e.g., measured in km^2 or hectares). This prevents us from figuring out the effect of a given sequestration program on land area (in km^2 or hectare). In the US, the land value-added in forestry would increase by 15.7 per cent and the land value-added in the crops sector would be reduced by 1.2 per cent under a carbon tax of 85 USD per ton of Ceq. Changes are dramatic in the EU. Land value-added of the forestry sector increases by 38.7 per cent. The crops sector has a 7 per cent reduction in land value. Although simply illustrative, the results indicate that any sequestration program—if intended be influential in cutting marginal abatement costs—will induce dramatic impact on land reallocation and thus rural landscape.

5. An alternative: omitting track of sources of land supply in GTAPE-L

We make an alternative version of the prototype GTAPE-L model, in which sources of land supply are not identified. This is similar to the approach used by the MIT Joint Program on the Science and Policy of Global Change in their EPPA model (Babiker *et. al.*, 2001). In this alternative version, we sum up the sources of land supply of the land transition matrix so that only sectoral total land values are presented. We apply the growth of sectoral land as calculated from Table 4—a -2.4%[15] for the US crops sector, and a +3.6%[16] for the US forestry sector; a -3.8%[17] for the EU crops sector, and a +2.8%[18] for the EU forestry sector. Also, we aggregate the source dimension of the land use change associated net emissions. As a result, we do not distinguish the carbon sequestration due to afforestation/reforestation (i.e., cropland changed to be forest land).

By aggregating the land supply sources, we are not able to recognize differences in pair-wise net emission intensities associated with inter-sectoral land transition. Based on the land transition and associated net emissions matrices as presented previously, we sum up the net carbon emissions due to land transition from the crop sector to the forestry sector, and from harvested timberland to re-growth (forestry to forestry). That is, we sum across the rows of the net emissions matrices in Table 5, and come up with a single value for net carbon emissions due to inflow of land to the forestry sector. The US has a 2.5 million tons of Ceq. carbon emissions from land inflow to forestry[19], while the EU has a 1.3 million tons of Ceq. carbon sequestration[20]. Comparing with the original net emission rate matrices (see Table 6), the row aggregation here omits the presentation (and thus obscures inter-regional and inter-sectoral comparison) of the afforestation/reforestation carbon sequestration potential. The net emission

[15] -2.4 = 100*(3797322 - 3888768)/3888768.
[16] +3.6 = 100*(2646192 - 2554746)/2554746.
[17] -3.8 = 100*(1267324 - 1317546)/1317546.
[18] +2.8 = 100*(1820838 - 1770616)/1770616.
[19] 2.5 = -1.9 + 4.4.
[20] -1.3 = -5.2 + 3.9.

rate for land transition to the forestry sector in the US is 27.34[21] ton of Ceq. per km^2. For the EU, it is -25.89[22] ton of Ceq. per km^2.

We run the simulation with the third scenario of the three, i.e., a 30% reduction of CO_2, CH_4, and N_2O, including emissions from land use changes. For the US, the per capita household utility of such a GHG mitigation plan reduces by 0.26%, comparing with the 0.24% reduction of results from the original GTAPE-L (with recognition of land supply sources). For the EU, the per capita household utility reduces by 0.83%, comparing with the 0.89% reduction of results from the original GTAPE-L.

Comparing for output and price changes, the crops and forestry sectors show significant differences. Table 9 lists the sectoral output and price changes from both version of GTAPE-L. For the US, the forestry sector output falls 1.2%, relative to the positive 1.3% in the original GTAPE-L results. This is mainly due to the sequestration potential of afforestation/reforestation is omitted, while the net emissions of permanent forest outnumber the forestry carbon sequestration. For the EU, the forestry sector produces more output (3.8% against 2.5% in the original GTAPE-L) as it is mis-credited more for carbon sequestration potential due to the aggregation of land transition associated net emissions. For the EU crops sector, its output reduces less than in the original GTAPE-L. This is because the carbon sequestration potential of land transition from cropland to forestry is obscured. Thus the cropland price does not increase as much as in the original GTAPE-L.

The alternative approach produces results showing that without considering the inter-sectoral transitions of land, and recognition of associated emission/sequestration potentials, the model tends to over-estimate the marginal abatement cost. This approach is not sufficient to address how the LULUCF activities help reduce GHG emissions and abatement costs.

6. Concluding remarks and research agenda

This paper introduces the GTAPE-L model—a prototype model which attempts to incorporate land use transitions into the GTAP-E model to facilitate integrated assessment (IA) for climate change policies. The land use transition matrix and associated net emissions are derived from the IMAGE 2.2 model. To demonstrate how the inclusion of land use change contributes to the reduction of marginal abatement costs, we run illustrative simulations of a 30% reduction in greenhouse gas emissions of the US and the European Union (EU) under the two sets of scenarios: with and without counting in changes in net emissions due to land use changes (or transitions). The results indicate that the marginal abatement costs can be significantly reduced via land use transitions—a 3% reduction for the US, and a 30% for the EU. Such substantial difference between the US and the EU could be explained by the relatively higher carbon emission intensity in agricultural production of the US and possible under-estimation of carbon sequestration potential as indicated in the net emissions matrix corresponding to land use changes.

Based on GTAPE-L, we make an alternative version, which obscures the inter-sectoral land transitions and associated carbon emissions. Comparing the results of the same simulation by the two versions of GTAPE-L, we find that neglecting the sources of land supply and thus net carbon emission/sequestration will lead to mis-measurement of economic costs and sectoral

[21] $27.34 = 10^6*2.5/(2646192 - 2554746)$.
[22] $-25.89 = 10^6*(-1.3)/(1820838 - 1770616)$.

responses. For the US, the economic cost of GHG abatement is relatively higher due to the positive net emission rate associated with land use change. For the EU, the economic cost of GHG abatement is relatively lower due to the negative net emission rate (i.e., sequestration) associated with land use change.

The methodological approach in GTAPE-L model takes consistent account of the main inter-sectoral spill-over effects due to carbon sequestration, particularly those arising from land use reallocation. However, the prototype GTAPE-L model does not allow to assess magnitude of cost-saving from sequestration as the results seem to be sensitive to relevant parameter values, e.g., net emission rates and degree of land mobility. The current version of GTAPE-L is simple and preliminary. Thus far, it aims merely at illustrating the potential merits of the approach to help identify the data that will be needed. It needs a sustained effort over the longer term on the huge data collection task of land use changes and on the modelling aspect as well. Ultimately, these improvements should lead to building an integrated GTAP database to facilitate economic assessments of policies climate change.

The following issues are included in our research agenda for the development of GTAPE-L and its data base.

1. Improving the calculation of the land transition matrices: we are in the process of collaborating with the team lead by Roy Darwin at the Economic Research Service (ERS) of the US Department of Agriculture (USDA). We hope to integrate the land data of the USDA/ERS FARM model to generate better estimates for the land transition matrices—specifically, with more disaggregated categories of land use.
2. Collecting non-CO_2 emission rates for the major GHG sources and corresponding marginal abatement costs (MACs).
3. Improving the estimates of the net emission rates from land uses and land use changes either by using the information from the FARM data base or by relying on carbon-cycle models.
4. Establishing MACs that incorporate the response of the land management practices to increasing carbon prices.
5. Reviewing the literature to collect information about the specification of the production function in agriculture and estimates of key substitution elasticities[23]. An appropriate representation of the farmer behavior is critical in assessing the impact of non-CO_2 GHG abatements and the economy's response to large-scale carbon sequestration programs.
6. Introducing emission changes from adaptation of land management practices explicitly: i.e. by disaggregating the net emission rates associated with diagonal land uses (land that does not change status) into sinks and emissions that can be reduced by adopting alternative land management practices.
7. Introducing dynamics of land stocks and carbon sequestration.
8. Introducing the concept of Agro-ecological zoning (AEZ) to GTAPE-L: this is to address the fact that land use changes tend to occur within the same agro-ecological zone, where the temperature and moisture support a certain period of growing season.

[23] See Burniaux and Truong (2002) for a similar approach.

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Appendix: Tables and Figures

Table 1. Sectoral aggregation of GTAPE-L

GTAPE-L sectors			GTAP version 5 sectors		
No.		Description	No.	Code	Description
1	Rice	Rice	1	pdr	paddy rice
2	Crops	Primary agriculture and fishing	2	wht	wheat
			3	gro	cereal grains nec
			4	v_f	vegetables, fruit, nuts
			5	osd	oil seeds
			6	c_b	sugar cane, sugar beet
			7	pfb	plant-based fibers
			8	ocr	crops nec
			14	fsh	fishing
3	Livestock	Livestock products	9	ctl	bovine cattle, sheep and goats
			10	oap	animal products nec
			11	rmk	raw milk
			12	wol	wool, silk-worm cocoons
4	Forestry	Forestry	13	for	forestry
5	Coal	Coal Mining	15	col	coal
6	Oil	Crude oil	16	oil	oil
7	Gas	Natural gas extraction	17	gas	gas
			44	gdt	gas manufacture, distribution
8	Oil_Pcts	Refined oil products	32	p_c	petroleum, coal products
9	Electricity	Electricity	43	ely	electricity
10	Oth_ind_ser	Other industries and services	18	omn	minerals nec
			19	cmt	bovine cattle, sheep and goat
			20	omt	meat products
			21	vol	vegetable oils and fats
			22	mil	dairy products
			23	pcr	processed rice
			24	sgr	sugar
			25	ofd	food products nec
			26	b_t	beverages and tobacco products
			27	tex	textiles
			28	wap	wearing apparel
			29	lea	leather products
			30	lum	wood products
			31	ppp	paper products, publishing
			33	crp	chemical, rubber, plastic prod
			34	nmm	mineral products nec
			35	i_s	ferrous metals
			36	nfm	metals nec
			37	fmp	metal products
			38	mvh	motor vehicles and parts
			39	otn	transport equipment nec
			40	ele	electronic equipment
			41	ome	machinery and equipment nec
			42	omf	manufactures nec
			45	wtr	water
			46	cns	construction
			47	trd	trade
			48	otp	transport nec
			49	wtp	water transport
			50	atp	air transport
			51	cmn	communication
			52	ofi	financial services nec
			53	isr	insurance
			54	obs	business services nec
			55	ros	recreational and other service
			56	osg	public admin. and defence, edu
			57	dwe	ownership of dwellings

Table 2. Region aggregation of GTAPE-L

GTAPE-L sectors			GTAP version 5 sectors		
No.		Description	No.	Code	Description
1	USA	United States	19	USA	United States
2	EU	European Union	31	AUT	Austria
			32	BEL	Belgium
			33	DNK	Denmark
			34	FIN	Finland
			35	FRA	France
			36	DEU	Germany
			37	GBR	United Kingdom
			38	GRC	Greece
			39	IRL	Ireland
			40	ITA	Italy
			41	LUX	Luxembourg
			42	NLD	Netherlands
			43	PRT	Portugal
			44	ESP	Spain
			45	SWE	Sweden
3	RoA1	Oth. Annex 1 countrie	1	AUS	Australia
			2	NZL	New Zealand
			5	JPN	Japan
			18	CAN	Canada
			46	CHE	Switzerland
			47	XEF	rest of EFTA
			48	HUN	Hungary
			49	POL	Poland
			50	XCE	rest of Central European Assoc
			51	XSU	former Soviet Union
4	CHIND	China and India	3	CHN	China
			15	IND	India
5	RoW	Rest of the World	4	HKG	Hong Kong
			6	KOR	Korea, Republic of
			7	TWN	Taiwan
			8	IDN	Indonesia
			9	MYS	Malaysia
			10	PHL	Philippines
			11	SGP	Singapore
			12	THA	Thailand
			13	VNM	Viet Nam
			14	BGD	Bangladesh
			16	LKA	Sri Lanka
			17	XSA	rest of South Asia
			20	MEX	Mexico
			21	XCM	Central America and Caribbean
			22	COL	Colombia
			23	PER	Peru
			24	VEN	Venezuela
			25	XAP	rest of Andean Pact
			26	ARG	Argentina
			27	BRA	Brazil
			28	CHL	Chile
			29	URY	Uruguay
			30	XSM	rest of South America
			52	TUR	Turkey
			53	XME	rest of Middle East
			54	MAR	Morocco
			55	XNF	rest of North Africa
			56	BWA	Botswana
			57	XSC	rest of SACU
			58	MWI	Malawi
			59	MOZ	Mozambique
			60	TZA	Tanzania, United Republic of
			61	ZMB	Zambia
			62	ZWE	Zimbabwe
			63	XSF	rest of southern Africa
			64	UGA	Uganda
			65	XSS	rest of sub-Saharan Africa
			66	XRW	rest of world

Table 3. Values of the substitution elasticities for various non-CO_2 emission sources

Sources	Values of the CES substitution elasticities
methane emissions from livestock production	0.062
methane emissions from rice cultivation	0.08
methane emissions from coal mining	0.2
methane emissions from natural gas systems	0.12
nitrous oxide emissions from crops	0

Notes : the same elasticity values are used in all regions of the model.
all substitution elasticities related to land uses are equal to zero.

Table 4. Land transitions in 1995 (km^2 per year)

United States

	Crops	Livestock	Forestry	Others	Total
Crops	3797322		91446		3888768
Livestock		285817			285817
Forestry			2554746		2554746
Others				2372221	2372221
Total	3797322	285817	2646192	2372221	

European Union

	Crops	Livestock	Forestry	Others	Total
Crops	1267324		50222		1317546
Livestock		165669			165669
Forestry			1770616		1770616
Others				345626	345626
Total	1267324	165669	1820838	345626	

Table 5. Emissions from land uses in 1995 (million tons of Ceq per year)

United States

	Crops	Livestock	Forestry	Others	Total
Crops			-1.9		-1.9
Livestock					0.0
Forestry			4.4		4.4
Others					0.0
Total	0.0	0.0	2.5	0.0	2.5

European Union

	Crops	Livestock	Forestry	Others	Total
Crops			-5.2		-5.2
Livestock					0.0
Forestry			3.9		3.9
Others					0.0
Total	0.0	0.0	-1.3	0.0	-1.3

Table 6. Emission rates in 1995 (tons of Ceq per km^2/year)

United States

	Crops	Livestock	Forestry	Others
Crops	0.0	0.0	-20.8	0.0
Livestock	0.0	0.0	0.0	0.0
Forestry	0.0	0.0	1.7	0.0
Others	0.0	0.0	0.0	0.0

European Union

	Crops	Livestock	Forestry	Others
Crops	0.0	0.0	-103.5	0.0
Livestock	0.0	0.0	0.0	0.0
Forestry	0.0	0.0	2.2	0.0
Others	0.0	0.0	0.0	0.0

Table 7. Macro-economic costs of a 30 per cent reduction of all GHG emissions under various alternative scenarios (percentage changes of household utility per capita)

	US	EU
All three gases but emissions from land use changes excl.	-0.24	-1.31
All three gases incl. Emissions from land use changes	-0.24	-0.89
Cost reduction (%)	***-4%***	***-32%***

Table 8. Output and price changes under various scenarios of a 30 per cent abatement of total emissions in the US and the EU (in percentage change)

	All three gases, excl. land emissions		**All three gases, incl. land emissions**	
	US	EU	US	EU
Output changes				
Rice	-23.3	-33.3	-22.6	-19.7
Crops	-4.1	-3.1	-4.4	-3.0
Livestock	-1.3	-1.2	-1.3	-0.8
Forestry	-0.4	0.0	1.3	2.5
Coal	-39.5	-55.7	-38.6	-48.7
Oil	-5.6	-4.2	-5.0	-3.8
Gas	-28.1	-35.9	-27.4	-28.1
Oil_Pcts	-18.7	-10.7	-18.3	-7.3
Electricity	-5.9	-10.1	-5.8	-8.1
Chemicals	-2.8	-3.6	-2.9	-2.4
Oth_ind_ser	-0.3	-0.5	-0.2	-0.3
Price changes(1)				
crops land	-7.5	-2.0	-2.9	37.1
crops output	6.2	6.1	6.4	5.9
forestry output	1.0	0.0	-1.6	-4.0

(1) equilibrium market prices, excluding carbon taxes/subsidies.

Table 9. Output and price changes due to a 30% abatement of GHG in the US and EU: comparing the original and the alternative GTAPE-L results

	All three gases, incl. land emissions (original GTAPE-L)		All three gases, incl. land emissions (alternative GTAPE-L)	
	US	EU	US	EU
Output changes:				
Rice	-22.6	-19.7	-23.0	-17.4
Crops	-4.4	-3.0	-4.2	-1.5
Livestock	-1.3	-0.8	-1.3	-0.1
Forestry	1.3	2.5	0.8	3.8
Coal	-38.6	-48.7	-38.7	-45.8
Oil	-5.0	-3.8	-5.0	-3.7
Gas	-27.4	-28.1	-27.6	-27.9
Oil_Pcts	-18.3	-7.3	-18.4	-6.9
Electricity	-5.8	-8.1	-5.8	-8.0
Chemicals	-2.9	-2.4	-2.9	-2.4
Oth_ind_ser	-0.2	-0.3	-0.2	-0.3
Price changes:				
Cropland	-2.9	37.1	-2.7	10.0
Crops output	6.4	5.9	6.1	3.5
Forestry output	-1.6	-4.0	-2.3	-5.2

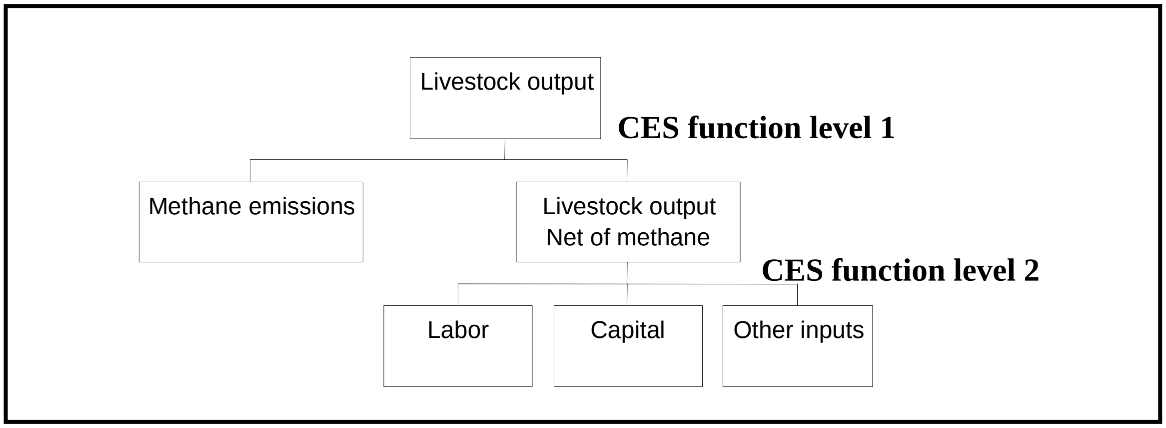

Figure 1. Incorporating GHGs into the production function

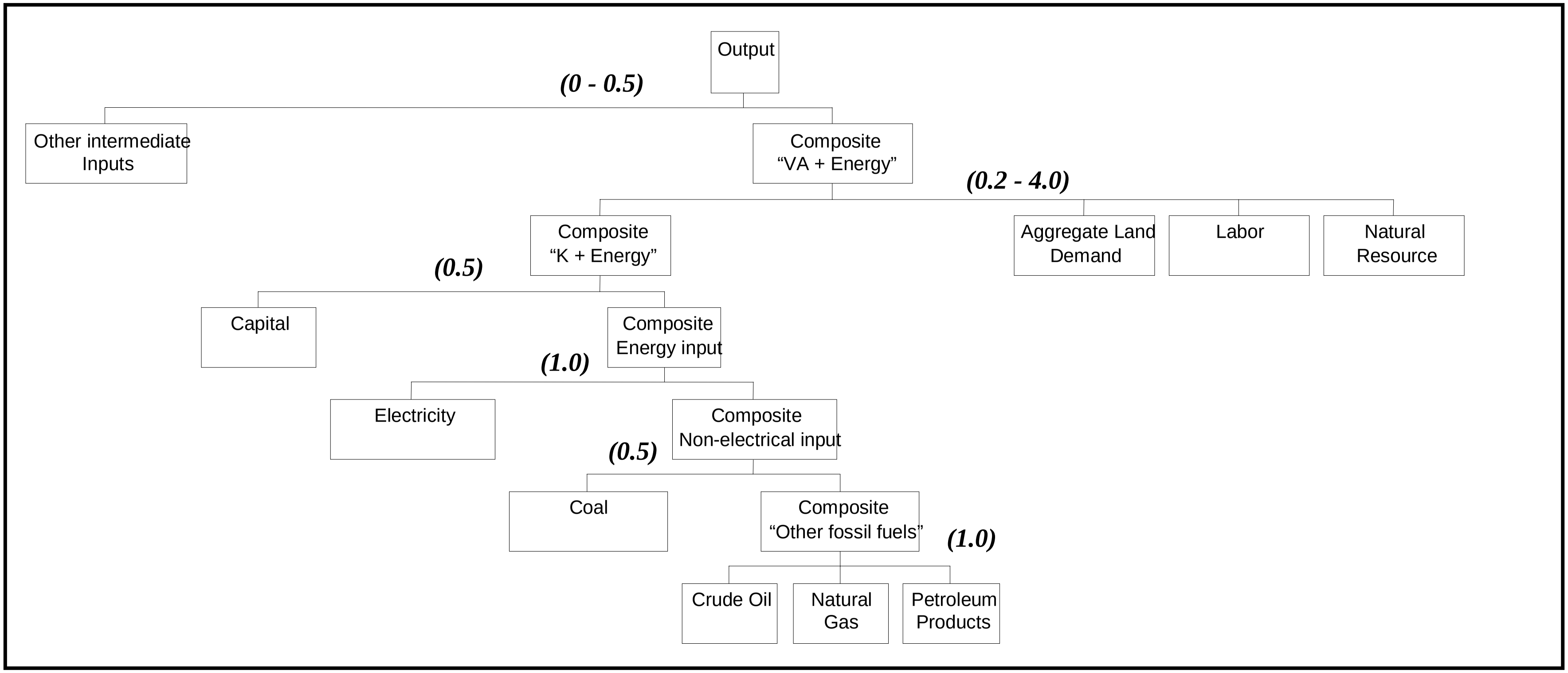

Figure 2. Tree-structured production function in GTAPE-L

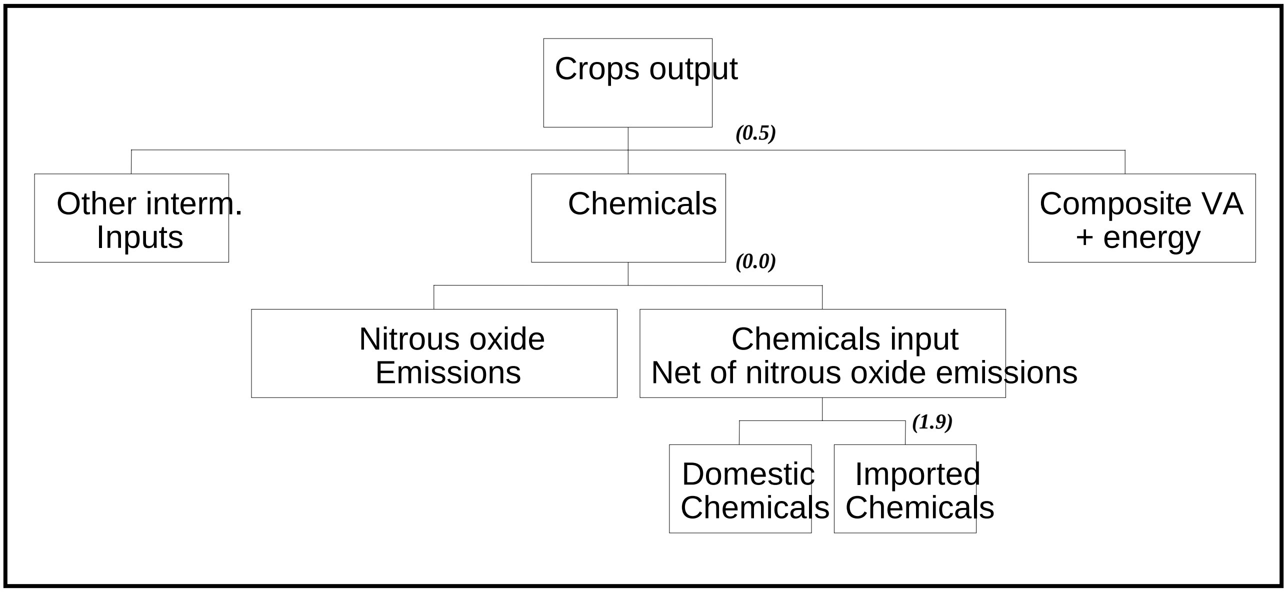

Figure 3. nesting of nitrous oxide emissions in GTAPE-L

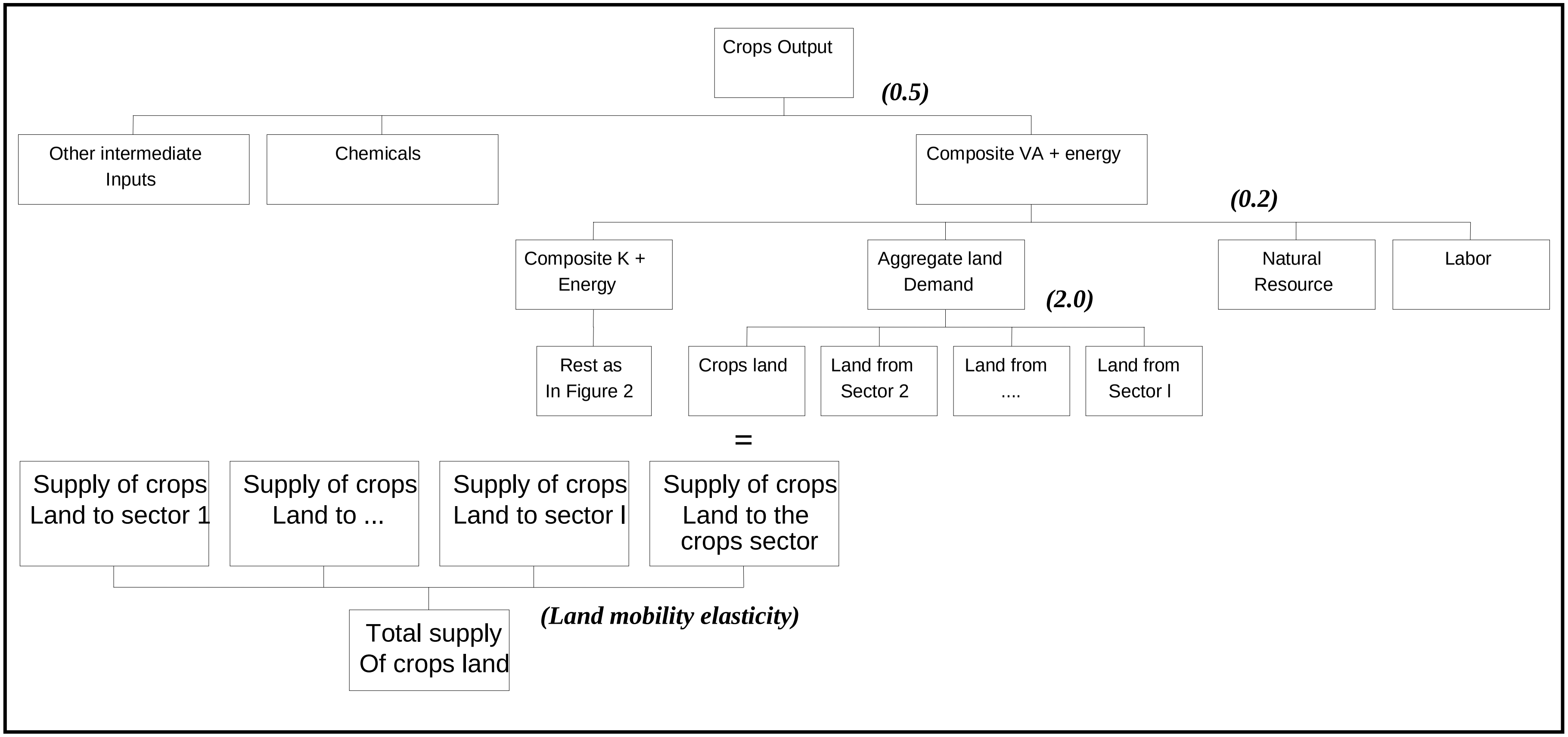

Figure 4. **Structure of the land market in GTAPE-L**

Sectors that are using land

Sectors from which land originates	sector 1	...	sector j	...	sector n	initial land allocation
sector 1	$\text{lnd}_{1.1}$	...	$\text{lnd}_{1.j}$	...	$\text{lnd}_{1.n}$	$\sum_j \text{lnd}_{1.j}$
...	...		...			...
sector i	$\text{lnd}_{i.1}$	...	$\text{lnd}_{i.j}$	...	$\text{lnd}_{i.n}$	$\sum_j \text{lnd}_{i.j}$
...	...		...			...
sector n	$\text{lnd}_{n.1}$	...	$\text{lnd}_{n.j}$	...	$\text{lnd}_{n.n}$	$\sum_j \text{lnd}_{n.j}$
final land allocation	$\sum_i \text{lnd}_{i.1}$	...	$\sum_i \text{lnd}_{i.j}$	...	$\sum_i \text{lnd}_{i.n}$	$\sum_i \sum_j \text{lnd}_{i.j}$

Figure 5. A land transition matrix

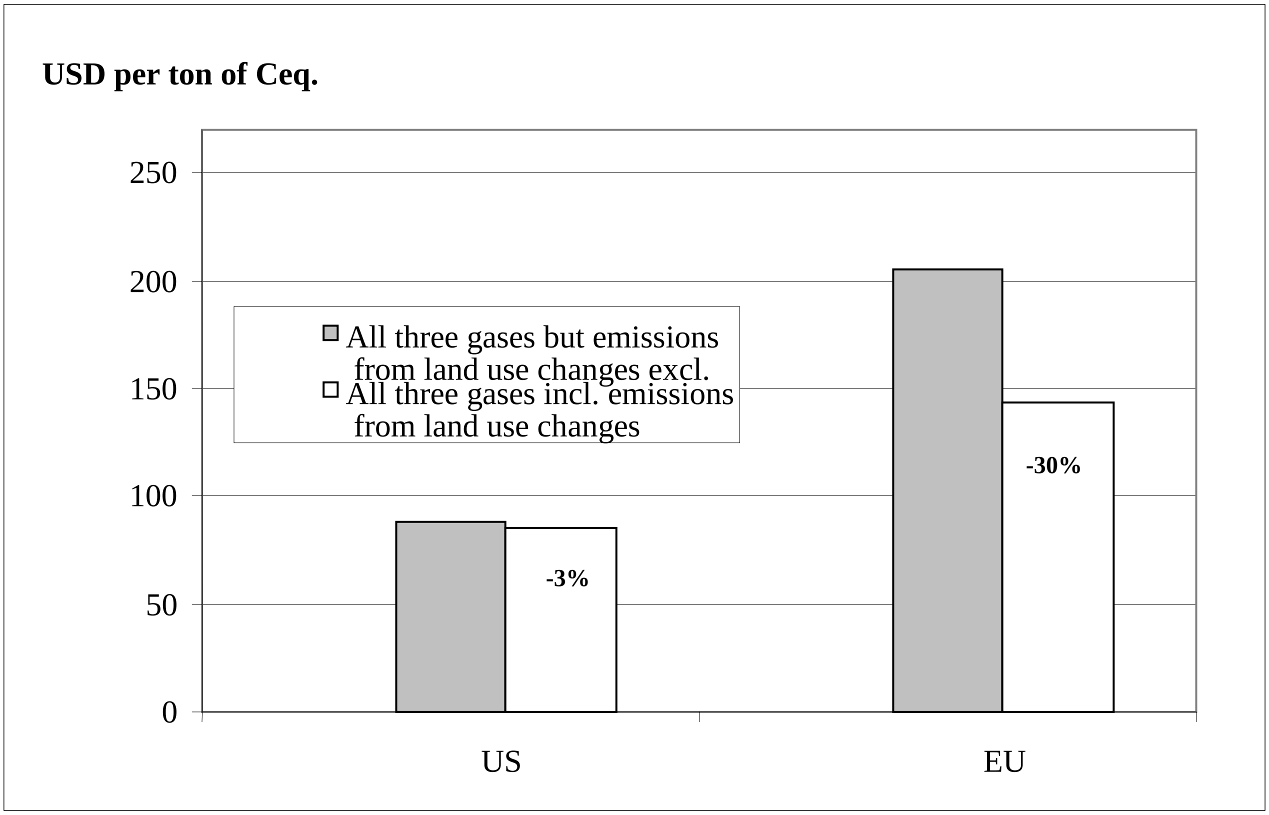

Figure 6. Marginal abatement costs of a 30 per cent reduction of GHG emissions under alternative scenarios

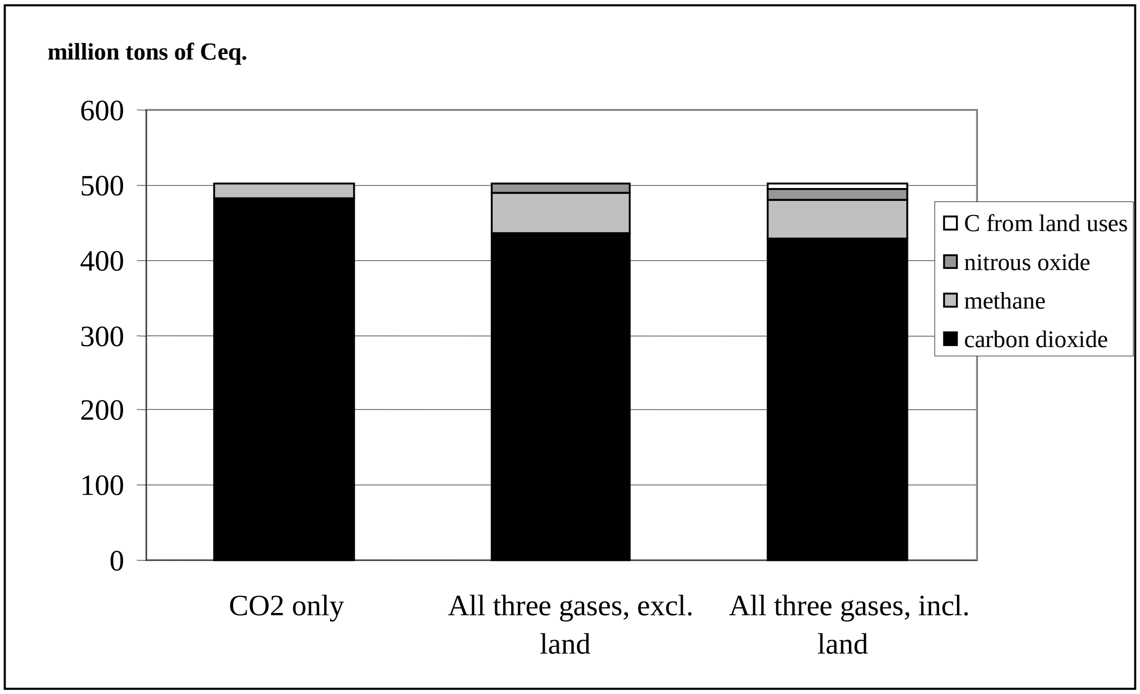

Figure 7(a) Contribution of GHGs and sinks to a 30 per cent reduction of emissions in the US

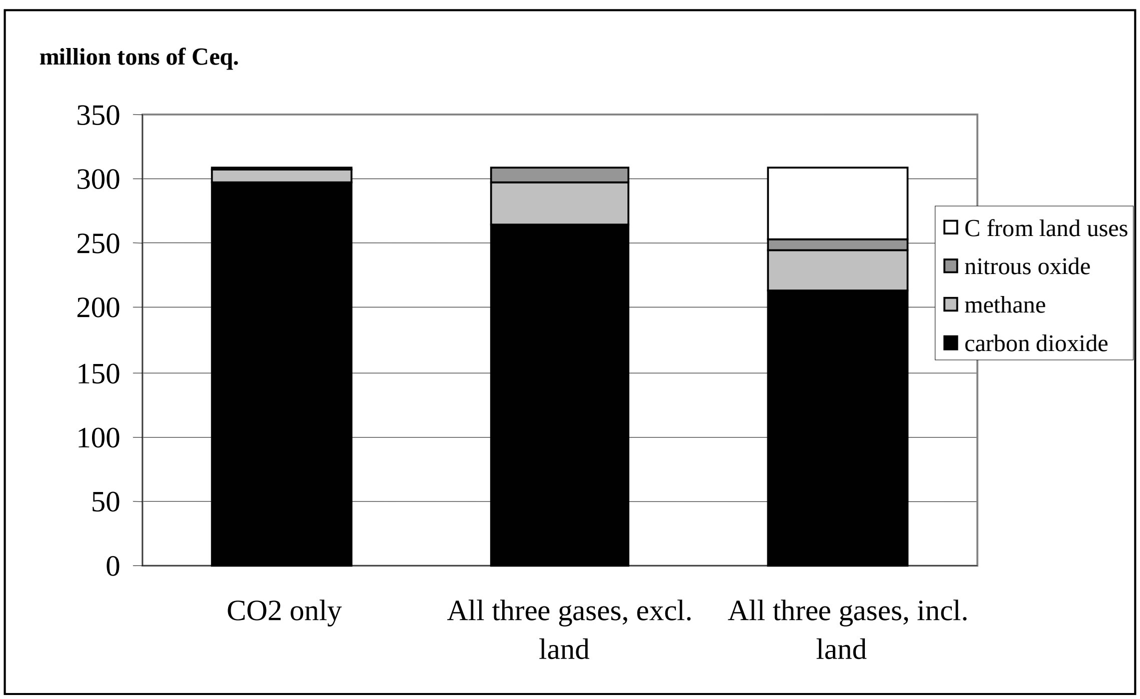

Figure 7(b) Contribution of GHGs and sinks to a 30 per cent reduction of emissions in the EU