Climate Change Assessment and Agriculture in General Equilibrium Models: Alternative Modeling Strategies

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Abstract

Agricultural sectors have a vital role in understanding the economic aspects of climate change. Land as an input to the agricultural production is one of the most important links of economy and biosphere, representing a direct projection of human action on the natural environment. On the one hand, agricultural management practices and cropping patterns have a vast effect on biogeochemical cycles, freshwater availability and soil quality; on the other hand, the same factors govern the suitability and productivity of land for agricultural production. Changes in agricultural production directly determine the development of the world food situation. Agriculture also plays an important role in emitting and storing greenhouse gases. Agricultural sectors can contribute significantly to the portfolio of policy measures to combat global warming. Thus, to consistently investigate climate policy and the future pathway of economic and natural environment, a realistic representation of agricultural land-use dynamics on the global perspective is essential.

The aim of this study is to overview modeling strategies to improve the representation of the agricultural sector in general equilibrium models. Then, for an illustration, we present some preliminary results obtained from introducing a modification in land supply structure of the dynamic general equilibrium model ICES.

Keywords: CGE, agriculture, land use, climate change

JEL Classification: C68, D58, Q24, Q51, Q54

This paper has been produced within the framework of the project CIRCE - Climate Change and Impact Research: the Mediterranean Environment, contract N. 036961, funded by the European Commission within the Sixth Framework Programme

Acknowledgements: We wish to thank Ramiro Parado for programming assistance and valuable comments.

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1. Introduction

Relationships between the greenhouse effect and agricultural activity are usually and firstly considered in terms of the impact of climate change on agriculture. Food production will be particularly sensitive to climate change, because crop yields depend in large part on prevailing climate conditions (temperature and rainfall patterns). Agriculture currently accounts for 24% of world output, employs 22% of the global population, and occupies 40% of the land area. 75% of the poorest people in the world (the one billion people who live on less than $1 a day) live in rural areas and rely on agriculture for their livelihood (Bruinsma 2003 ed.). Forecasts predict that agriculture in higher-latitude developed countries is likely to benefit from moderate warming (2 –3°C), however even small amounts of climate change in tropical regions will lead to declines in yield. The agricultural sector is one of the most at risk to the damaging impacts of climate change in developing countries (Stern 2006 ed.).

Agricultural emissions mainly come from a large number of small emitters (farms), over three quarters of which are in developing and transition economies. In its climate change report on Mitigation, the Intergovernmental Panel on Climate Change (IPCC, 2001) clearly assesses that the transport and the energy production sectors constitute the main anthropogenic GHG sources, and states that "agriculture contributes only about 4% of global [i.e. world-wide] carbon emissions from energy use, but over 20% of anthropogenic GHG emissions in terms of MtC-eq/yr[1], mainly from methane (55-60% of total CH_4 emissions) and nitrous oxide (65-80% of total N_2O emissions) as well as carbon from land clearing". The IPCC (2007) report states that “the largest growth in global GHG emissions between 1970 and 2004 has come from the energy supply sector (an increase of 145%). The growth in direct emissions in this period from transport was 120%, industry 65% and land use, land use change, and forestry (LULUCF) 40%. Between 1970 and 1990 direct emissions from agriculture grew by 27%”.

Emissions from agriculture and land use occur through different processes (IPCC, 1996a, Alcamo et al., 1998): enteric fermentation and animal waste disposal and fermentation, anaerobic process when growing rice, nitrification and de-nitrification linked with fertilisation, and also land clearing, the burning of biomass, of fuel wood, of agricultural waste, and of savannah. Non-CO_2 emissions from agriculture amount to 14% of total GHG emissions. Of this, fertiliser use and livestock each account for one third of emissions. Over half of GHG emissions are from developing countries. Agriculture is also indirectly responsible for emissions from land-use change (agriculture is a key driver of deforestation), industry (in the production of fertiliser), and transport (in the

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[1] MtC-eq/yr are millions of tons of carbon equivalent GHG per year, with global warming potentials of methane, nitrous oxide and other GHG other than carbon dioxide, used as conversion coefficients for non-CO2 gases.

movement of goods). Increasing demand for agricultural products, due to rising population and incomes per head, is expected to lead to continued rises in emissions from this source. Total non-CO_2 emissions are expected to double in the period to 2050 (Stern 2006 ed.).

Nevertheless, agriculture can contribute to climate change sequestration and abatement efforts, mainly through reforestation, forest management, bio-fuels and soil carbon stocking,[2] changes in practices and land uses. In addition, farmers and herders may react to a climate policy which impose a carbon price to GHG-emitting activities, and possibly contribute to the emissions mitigation as well as to carbon sequestration. The degree of efficiency of the reactions will vary across regions of the world and across activities.

The potentials of emitting sectors for mitigation and the costs of abatement or sequestration options are currently debated. Could and should agriculture modify its present land-use patterns and agricultural practices for the explicit purpose of reducing emissions while satisfying demand? This study overviews modelling approaches in order to provide a comprehensive answer to this question.

The appraisal of various climate change aspects employing computable general equilibrium (CGE) “top-down” modelling has had many advantages over partial equilibrium “bottom-up” models, including: (a) greater theoretical consistency, (b) improved welfare analysis, (c) exhaustive coverage of the farm and food complex, and (d) integrated treatment of agriculture and non-agriculture liberalization. Research on GHG abatement or sequestration options in agriculture employing CGE models stems from a need to evaluate and compare net abatement options of all emitting sectors. However, there have also been disadvantages associated with this general equilibrium approach to modelling of agricultural trade. One of these has been the tendency to abstract from specific structural features that characterize global food and agricultural markets. Critics argue that the CGE models are overly simplistic and do not capture many important characteristics of the agricultural economy. They also argue that the CGE parameters need more solid econometric foundations.

The aim of this paper is to overview modeling strategies to improve the representation of the agricultural sector in general equilibrium models. A CGE modeler normally needs to choose between two main alternatives: whether to develop an integrated assessment model (IAM), i. e. to couple a top-down CGE model with a bottom-up agricultural land-use model or to improve the relevant functional structure inside the CGE model itself. Each possibility has its own advantages and drawbacks in the sense of data requirements, computational practices and accuracy of representation. This paper stands on the different aspects involved in each procedure and illustrates a brief comparison between the approaches. Then, for an illustration, we present some preliminary

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[2] For a review on carbon sequestration in terrestrial ecosystems, refer to http://csite.esd.ornl.gov.

results obtained from introducing a modification in land supply structure of the dynamic global general equilibrium model ICES (Inter-temporal Computable Equilibrium System).

The paper is organized as follows. Section 2 reviews modeling approaches to refine the presentation of agricultural and other land-using sectors in a CGE model. Section 3 presents the ICES model structure and explains how a baseline scenario is built. Climate change impacts are analyzed in Section 4. The last section draws some conclusions and directions for future development.

2. Overview of Existing Agriculture and Land Use Modeling Approaches

This survey focuses on CGE modeling applications related to agricultural and climate change assessment. There are several important advantages offered by the CGE approach over partial equilibrium models, even though partial equilibrium models are capable to include detailed biophysical land use characteristics, to simulate comprehensive policy proposals and to capture local or regional environmental and economic effects. This traditional agricultural economic analysis has tended to focus on commodities, and associated factor returns. In contrast, welfare in a CGE model is computed directly in terms of household utility and not by some abstract summation of producer, consumer and taxpayer surpluses. Additionally, a CGE model insures for finite resources and accounting consistency by relying on Social Accounting Matrices (SAM). It allows capturing the inter-industry linkages between agricultural and non- agricultural sectors of economy and provides economy-wide perspective of analyzes, that are particularly important when tackling cost-effective climate policy or adaptation strategies.

In the past decade, different attempts have been made to extend top-down computable general equilibrium models to allow for detailed analyzes of the agricultural sector. Two broad approaches have been used. The first approach is to advance the treatment of land within the CGE framework. The initial step in this respect is to better model the transition of land between different uses – in particular crop production, livestock and forestry. In section 2.1 we present several researches that follow this direction. An other step is to distinguish between various land classes that have different characteristics and productivities and are only suitable for some uses. A few models that take this approach, which requires a high level of detail and hence has a considerable demand for data, are discussed in section 2.2. The second approach to extend CGE models to be better capable to answer questions related to agriculture and land use is to link an economic model with a detailed sectoral model of land use. Several appropriate examples are discussed in section 2.3. We draw some conclusions on agricultural modeling for climate change in general and on discussed notions in particular in section 2.4. Table 1 lists the studies presented in following sub-sections of this review.

Table 1: CGE models covered in the review

Modeling Framework	Reference	Temporal resolution and coverage	Spatial resolution and coverage	Motivation
1. CGE Models Extended for Land-Use Analyses				
CGE for USA	Hertel and Tsigas (1988a).	Comparative static; base-year 1977	USA, 7 agricultural sectors	Analyze effects of eliminating farm and food tax preferences in 1997.
GTAP	Hertel (1997)	Comparative static; base-year 2001	Latest available version GTAP6 allows for 89 regional and 57 sectoral disaggregation, Global	Evaluate effects of agricultural policies on commodity markets and trade.
GTAPE-L	Burniaux and Lee (2003)	Comparative static; base-year 1997	5 regions; Global	Exemplify the incorporation of land/land use in GTAP; assessing GHG mitigation policies with focus on land-use impacts
GTAP-AGR	Keeney and Hertel (2005)	Comparative static; base-year 1997	23 regions, global; 5 agricultural sectors	Assess the Implications of Multilateral Changes in Agricultural Policies
G-Cubed (Agriculture)	McKibbin & Wang (1998)	Dynamic, 1-year step; 1993-2070	12 regions, Global; 4 agricultural out of 12 total sectors	Explore the impact of international and domestic stocks like trade liberalization on US agriculture
CGE for Canada	Robidoux et al. (1989)	Comparative static;	Canada	Analyze Canadian farm policies
CGE for Philippines	Abdula (2005)	static CGE model	Small open economy Philippines	Study the conflict between food and bio-fuel production
GTAP-based CGE for Poland	Ignaciuk (2006, chapter 5)	Comparative static 1997	Small open economy (Poland)	Explore the potential of biomass as a source of energy
GTAPEM	Hsin et al. (2004), Brooks and Dewbre (2006)	Comparative static; 2001-2020	7 regions, global; 8 agricultural sectors	Analyze the impact of agriculture and non-agriculture reform, with a particular focus on the effects of OECD agricultural policy on developing countries.
FARM	Darwin et al.	Comparative	Multi-scale: 8 regions	Integrate explicit land and water assessment

	(1996)	static; 1990-2090	world 0.5 lon/lat ;	into CGE, environmental focus on climate change
D-FARM	Ianchovichina *et al.* (2001), Wong et al., (2003).	Recursive dynamic 1997-2007/2020	Multi-scale: 12 world regions	Analyze resource use and technological progress in agriculture
GTAP-AEZ	Lee (2004), Hertel et al. (2006)	static	8 agricultural sectors + forestry, 3 world regions	Investigate the role of global land use in determining greenhouse gases mitigation costs
GTAP-Dyn/AEZ modified for land use analyzes	Golub et al. (2006)	Recursive dynamic 1997-2025	11 regions, global	Analyze the GHG emissions driven by land use and land-use changes at the global scale.
GTAP-Dyn and Global Timber Model	Golub et al. (2007)	Recursive dynamic 1997-2025	11 regions, global	Enhance the understanding of land-use related GHG emissions
2. Integrated Assessment Models				
GTAP-LEI/IMAGE coupling within EURURALIS	Klijn et al. (2005)	10-year steps; 2001-2030	Multi-scale: national level, sub-national level (NUTS2), grid level; Global with focus on EU15	Integrated assessment to evaluate impacts of different policies on land use in Europe
IIASA LUC China	Fischer & Sun (2001); Hubacek & Sun (2001)	quasi static; 1992-2025	Multi-scale: 8 economic regions, 5x5 km grid; National (China)	Evaluate alternative policy scenarios
GCM-GTAP	Bosello and Zhang (2005)	comparative static; 1997-2010-2030-2050	8 regions, Global; 4 agricultural out of total 17 sectors.	Estimate the economy-wide implications of climate change on agricultural sectors.
KLUM@GTAP	Ronneberger et al. (2006)	comparative static; 1997-2050	16 regions, Global; 4 agricultural out of total 17 sectors.	Assess the integrated impacts of climate change on global cropland allocation and its implication for economic development

2.1. Refined CGE models

Perhaps the simplest method of introducing land-related economic behavior in a AGE model is constraining acreage response as employed by Hertel and Tsigas (1988). They specify a transformation function which takes aggregate farm land as an input and distributes it among various uses in response to relative rental rates. Given a finite elasticity of transformation, rental rates differ across uses and acreage response may be calibrated to econometrically estimated values. The Global Trade Analysis Project (GTAP) (Hertel, 1997) follows this approach defining the land input as exogenously fixed at the regional level; it is imperfectly substitutable among different crops or land uses. This fundamental project though employs the naive assumption that land is like labour and capital inputs – homogeneous and perfectly mobile in the medium run and therefore overstates the potential for heterogeneous land to move across uses.

The Global Trade Analysis Project, Energy - Land model (GTAPE-L) (Burniaux, 2002; Burniaux & Lee, 2003) is the first attempt to extend the standard static GTAP model to track inter-sectoral land transitions and to estimate sectoral net emissions of methane, CO_2 and N_2O, due to land-use changes. On the supply side of the land market, land owners rent out land (which is a homogenous input) to uses that give the highest return, under a land transformation restriction: a Constant Elasticity of Transformation Function (CET) determines the degree of land mobility between different crops, livestock and forestry. Perfect competition on input and output markets assures that all markets, including that of land, clear.

The value added of the paper is that it tracks GHG emissions from changes in land use. To obtain land transition emission rates, a land transition matrix is derived for 1995 from the IMAGE 2.2. model (IMAGE team 2001), and so are the 1995 net carbon emissions (tons of carbon equivalents). After applying a policy shock to the model, a new land transition matrix occurs. When multiplying the land transition emission rates with the land use changes that occur after the policy shock, one can calculate the corresponding change in GHG emissions due to changes in land use.

Keeney and Hertel (2005) offer another special purpose version of the GTAP model for agriculture nicknamed GTAP-AGR. The study focuses a particular attention on the factor markets, which play a critical role in determining the incidence of producer subsidies. This includes modifying both the factor supply and derived demand equations. The authors also modify the specification of consumer demand, assuming separability of food from non-food commodities. Finally, they introduce substitution possibilities amongst feedstuffs used in the livestock sector.

The G-CUBED (Agriculture) model (McKibbin and Wang, 1998; van Tongeren and van Meijl, 1999) is an extension and a variation of the G-CUBED model developed by McKibbin and Wilcoxen (1995) to include relatively detailed agricultural sectors and a country disaggregation relevant for key U.S. agricultural markets. The original G-CUBED model combines the disaggregated, econometrically-estimated, intertemporal GE model of the U.S. economy by Jorgenson and Wilcoxen (1990) with the macroeconomic modeling approach of McKibbin and Sachs (1991). The G-CUBED (Agriculture) model focuses on impacts of international and domestic economic shocks on U.S. agriculture. Main applications have been the impact analysis of APEC trade liberalization and the Asian economic crisis. A specific feature of the model is the imposition of intertemporal budget constraints on households, governments and nations. To accommodate these constraints, forward looking behavior is incorporated in consumption and investment decisions. The model treats land as homogeneous.

The studies above exemplify foremost attempts to deal with agricultural specification in the CGE framework. Their limitation mainly manifests in the representation of land. Land is treated as homogeneous and space-less, ignoring biophysical characteristics and spatial interactions.

The next level of complexity in modeling the heterogeneous nature of agricultural land involves drawing a distinction between land types and land uses. In their AGE model for Canada, Robidoux et al. (1989) specify CES aggregator functions that combine three land types, each of which is used - to some degree - in the production of six different farm products. An interesting wrinkle in their approach is the way in which they estimate benchmark equilibrium rental rates, by land type. These are obtained by regressing total land rents in each sector on the observed quantity of each land type used in that sector. In equilibrium, the land-specific rental rate (i.e., the coefficient on acreage) must be equal across uses.

Abdula (2005) and Ignaciuk (2006, chapter 5) pursue this approach. Abdula (2005) uses a static CGE model for the Philippines and extends it with a bio-fuels sector, to study the conflict between food and bio-fuels production. Since both activities use scarce land, subsidizing biofuels may induce farmers to move away from food production towards the production of inputs for the bio-fuel industry. Land is treated as a heterogenous input as Abdula distinguishes three land types (cropland, pasture and forest, all in fixed supply), some of which are only suitable for particular uses. Ignaciuk (2006, chapter 5) introduces land that has been contaminated by heavy metals, e.g. through mining and industrial activities in the past, in a GTAP-based CGE model for the Polish economy. Contaminated land can only be used for biofuels production, hence it is excluded from producing food. The main modeling improvement in these papers is that land is explicitly treated as a heterogeneous input been unsuitable for certain crops.

It seems that the most extended version of global computable general equilibrium model developed for analyses of agriculture until now is GTAPEM (e. g. Hsin et al., 2004; Brooks and Dewbre, 2006)- a specially tailored version of GTAP that inherits some of the features of GTAP-

AGR and fully utilizes the domestic support data (PSE) available at the OECD. The important value added of GTAPEM to GTAP-AGR is distinguishing land in the production structure of the agricultural sector into miscellaneous agricultural land, rice and the group field crops and pastures. For these land types, three different elasticities of transformation are defined, reflecting that certain transformations are more inert than others. Additional modifications include factor substitution between purchased farm input intermediates, and between the aggregate intermediates and farm-owned inputs. GTAPEM is being further developed to align the representation of policy more closely with the way support measures are classified for the OECD's PSE.

2.2. Modeling agro-ecological zones (AEZs)

The approach of Robidoux et al., as well as of Abdula, Ignaciuk and even GTAPEM deals with land type variations, but not with regional or climatic differences. However, the capacity of a given acre of land to produce a particular farm product varies with a soil type, location in the watershed, and climatic conditions. Models designed to assess the effects of climate change, must therefore disaggregate land endowments still further.

The Future Agricultural Resources Model (FARM) was developed in the mid 1990s to evaluate impacts of global climate change on the world's agricultural system (Darwin et al., 1995; Darwin et al., 1996). The authors disaggregate land classes into six types characterized by length of the growing season. These land classes are employed differentially across farming and forestry sectors, according to observed patterns of production. In addition, the authors explicitly identify water as an input into the production function of each crop. The authors then turn to the results of the global climate simulation models in order to assess the impact of alternative climate change scenarios on the temperature and precipitation by region. This causes a shift in each region's land endowment across land classes and therefore causes patterns of agricultural production to change. Darwin et al., are then able to assess the consequences of climate change for patterns of trade, consumption and welfare.

While FARM was originally a static model, a dynamic version denoted D-FARM is available now too. It enriches the original model with asset ownership and investment theory to create a recursive dynamic model based on estimates of annual growth rates of regional GDP, gross domestic investment, population, skilled and unskilled labor. D-FARM has a time horizon that goes until the year 2007 (Ianchovichina et al., 2001) or even 2020 (Wong et al., 2003) aggregated to twelve world regions.

Another possibility to account for heterogeneity of land is to severalize land according to Agro-Ecological Zones (AEZ) (see e.g. Lee, 2004). In this case there are different land inputs which are imperfectly substitutable in the production function within, but not across, climatic zones.

Accordingly the reaction of the economic system to prices and quantity is exposed to one more rigidity.

In the first version of GTAP-AEZ (Lee, 2004) it is assumed that each of the land-using sectors in a specific AEZ has its unique production function. For example, the wheat sector located in AEZ 1 has a different production function from the wheat sector located in AEZ 6, which allows to identify differences in the productivity of land of different climatic characteristics. All six wheat sectors in various AEZs though produce the same homogenous output. For this approach it is necessary to have information on cost shares, respective input shares, in the AEZs, which are not yet provided in the GTAP-AEZ data-base.

In the extended version of GTAP-AEZ (Hertel et al., 2006b) it is assumed instead, that there is a single, national production function for each (agricultural) commodity: rather than having for the same crop a different production function for each AEZ, various AEZs are now inputs to the national production function for this crop characterized by a sufficiently high elasticity of substitution. Generally, the model facilitates the study of the role of non-CO_2 GHG reductions and land use change in national and international climate policy and assess the implications of different climate policy strategies on land-use decisions.

The GTAP-AEZ project (see e.g. Lee et al. 2005b) develops an integrated land-use data base including data on land use and land cover, forest carbon stock, and both CO_2 and non-CO_2 emissions that can be used together with the GTAP data-base. GTAP-AEZ is based on the static GTAP model and has been used for analysis of carbon taxation using three world regions only: USA, China and the rest of the world (Hertel et al. 2006a). The results show that forest carbon sequestration is the dominant mean for global GHG emissions reduction in the land using sectors.

Golub et al. (2006) move one step further and expand the GTAP-Dyn (Ianchovichina and McDougall, 2001) dynamic general equilibrium model of the global economy to investigate long-run land-use changes at the global scale. They modify both the supply and the demand of land. Consumer demand is translated into derived demands for land through a set of sectoral production functions that differentiate the demand for land by AEZ. On the supply side, land mobility across uses is addressed via sequence of successively more sophisticated models of land supply, beginning with a model in which land is perfectly mobile and undifferentiated, and ending with one in which land mobility across uses is governed by a nested Constant Elasticity of Transformation function which also accounts for the heterogeneity of land within AEZs. In the final modification landowners solve a sequential revenue maximization exercise in which land is first allocated between forestry and agriculture, then between grazing and crops, and finally, amongst competing crops. Although this ultimate version offers the most sensible representation of land supply, the resulting baseline land rental changes in forestry and grazing seem (to authors) unrealistically high.

To resolve this problem the subsequent study by Golub et al. (2007) iterate between GTAP-Dyn and Global Timber Model of Sohngen and Mendelson (2006) to determine forestry input-augmenting productivity growth of forestry processing sectors in GTAP-Dyn. Using the rate of unmanaged forest access predicted by the Global Timber Model, Golub et al. introduce the possibility of conversion of unmanaged forest-land to land used in production when demand for cropland and pasture is high, and land rents are high enough to cover costs of access to unmanaged land.

2.3. Integrated Assessment

Finally, an alternative methodology interlinks between top-down general equilibrium model, which consistently address demand, supply and trade via price mechanisms, and the bottom-up model enabled in capturing the spatial determination of land use and in quantifying supply side constraints based on land resources. That is, instead of modeling the economics of land use as an integrated part of the top-down model, as was done by the models presented in previous sub-sections, a detailed bottom-up land allocation model is linked to a standard top-down CGE model. These coupling frameworks, starting from prices, predict how land is allocated among competing uses. Land uses are not always limited to different cultivation types, but may include also urban development. In this way the additional feedback from land/crop prices to land allocation is added. Generally the process should be iterated until a reasonable convergence can be found.

Within the EURURALIS project the IMAGE model is coupled to GTAPEM (Hsin et al., 2004). Crop yields and a feed conversion factor, determined by IMAGE are exchanged with production of food and animal products and a management factor (describing the management induced yield changes) as calculated by GTAPEM (van Meijl et al., 2006). The advantage of coupling the two comprehensive models lies in detailed and exhaustive process representation. Moreover, this is one of the few approaches, where a feedback between economy and vegetation is at least partly realized. However, the land allocation tool of the coupled framework is still based on empirically estimated rules according to land potential, largely ignoring economic motivations of allocation decisions.

The IIASA LUC model for China (Fischer & Sun, 2001; Hubacek & Sun, 2001) aims at a similar degree of integration, proposing a combination of an AEZ assessment, an input-output analysis and a CGE. The depth of the integration in this approach is remarkable - but it may also hamper its implementation which is still pending. The resulting CGE would not only exchange exogenous parameters with an environmental model, but actually synthesize economic and geographic thinking within its theoretical foundation. Future land-use scenarios have been developed by using an extended input-output (I-O) model and spatially explicit measures of land productivity and land availability. An enhanced AEZ assessment model is utilized to provide these measures. By means of empirical estimation the agro-environmental characterization of a spatially explicit production function can be gained from the produced scenarios. This function as well as the projected I-O tables are proposed as the basis of a not yet developed CGE model.

Bosello and Zhang (2005) offer another integrated assessment exercise to evaluate climate change impact on agriculture. They couple a global circulation model GCM containing a crop-growth model, with a global CGE model based on GTAP-E. The climatic scenario is endogenously produced by the economic model, which is benchmarked to reproduce a hypothetical world economic system in 2010, 2030 and 2050. Their results confirm both the limited impact of climate change on agricultural sectors, largely determined by the smoothing effect of economic adaptation, but also the relative higher penalization of the developing world. The authors admit that this exercise suffers from some major limitations such as: simplifications and generalizations of both climatic conditions and crop responses in addition to a narrow number of observations.

Alternatively, KLUM@GTAP (Ronneberger et al., 2006) is a coupling experiment in which the static global GTAP-based CGE model is linked to the land use model KLUM (Ronneberger et al., 2005). KLUM is a land allocation model, in which, for each hectare of land, a representative farmer maximizes her expected profits. Risk-aversion ensures that she prefers multi-product land uses over monoculture. The biophysical aspects of land are included indirectly, as area specific yields differ for each unit of land. In the coupling experiment, yield changes due to climate change in 2050 (as reported by Tan and Shibasaki, 2003) are applied to KLUM, which calculates corresponding changes in land uses. These in turn are fed into GTAP-based model (which has been scaled up to represent the economy in 2050) to obtain management induced yield and price changes (through changes in input combinations), which consequently are fed back into KLUM.

Although the experiment shows that the results of the coupled and uncoupled simulations can differ by several hundred percents, it also shows that linking the models comes with serious difficulties. In this case, one of the problems was that GTAP has its land data in value terms with its price normalized to unity, while KLUM database uses quantity format. This makes land data incomparable between the models. To overcome this limitation, a key parameter in GTAP (the elasticity of substitution between land, capital and labour) had to be tripled, to make the model less sensitive to the input that comes from the KLUM model. Without this intervention, the results of the two models would not converge, and hence coupling of the two models would not give meaningful results.

2.4. Major achievements, deficits and potentials

The reviewed literature demonstrates two major approaches to overcome limitations of CGE models in accounting for land supply constraints, reflecting the impact of demand on actual land-use change processes and representing other than price related behaviors. Introducing heterogeneity in available land, as was outlined in sections 2.1 and 2.2, increases the credibility of CGE analyzes regarding changes in agricultural production. The second technique presented in section 2.3, links a CGE to a land use model and aims to benefit from the strength of both notions, although it may come at a cost due to technical problems with establishing the link.

Even though the quintessential aspects in modeling agriculture for climate change analyzes are global-type approach; dynamic and long term horizon; accounting for multi GHG emissions; implementing land heterogeneity; esteeming water issues; and considering trade-off between different land uses and forest types, the surveyed (representative) studies are still not sufficient to provide an all-inclusive analytical framework, albeit GTAP-Dyn/AEZ and D-FARM models do contain many. Both models have a detailed and heterogeneous representation of land, based on length of growth periods. An important advantage of the current version of GTAP-Dyn/AEZ is its multi-gas and dynamic approach, while the advantages of D-FARM are the inclusion of water, the fact that it is a dynamic model, and a more detailed regional dissaggregation. However, both models (thus far) only have a single forest type, while the issue of carbon sequestration through forestry is best studied with a dynamic model, using data on several forest types, with each forest type divided into several age classes. In addition, neither GTAP-Dyn/AEZ nor D-FARM contains a biofuels sector. Here, both models face some scope for improvement. Finally, both models currently only have a limited regional disaggregation. GTAP-Dyn/AEZ currently only has three regions, while D-FARM contains not more than 12 regions. Moreover, even though D-FARM improves the representation of environmental impacts on the economy, still the location of changes and reverse effects on the environment are not simulated. Additional disadvantage common to CGE models is due to a non-linear treatment of land in the production functions, for which land cannot be measured in physical units of area, but instead is quantified in the value added to the production. This complicates the interpretation of the resulting changes in land allocation. The final weakness of the most developed CGEs for agricultural and climate change analysis (GTAPEM and GTAP-Dyn/AEZ) is an absence of empirical evidences for the land transformation structure and arbitrary set of the transformation elasticities, which may have a crucial effect on the outcomes of the models.

Current integrated land-use modeling approaches provide evidence that some of the intrinsic deficits of partial and general equilibrium approaches can be overcome to a certain extent. The coupling of IMAGE and GTAP-LEI (EURURALIS), as well as linking between KLUM and GTAP, aim to improve on the weakness of economic demand module within IMAGE / KLUM respectively, and to advance the representation of land supply in the corresponding GTAP version.

On the other hand, despite certain achievements, the full potential of integrating CGE and partial equilibrium models seems not to be fully explored, yet. For the coupling of different modeling approaches as in the EURURALIS and KLUM@GTAP frameworks, the advantages of process detail stands against the risk of inconsistencies and redundancies. EURURALIS lack endogenous approaches to determine whether food demand will be satisfied rather by expansion of agricultural area than by the intensification. Beyond a more detailed representation of agricultural management, including the feedback with soil and water is also needed. Irreversibly degraded soil or the exhaustion of freshwater resources are major constraints on future land use, that have not yet been tackled sufficiently by any land-use or CGE model.

To summarize, regardless of accomplishments and individual strengths of the selected modeling approaches, core problems of global agricultural and land-use modeling have not yet been resolved. Up to date, the main advantage of the integrated assessment (coupling) approach is the ability to benefit from from the strength of partial equilibrium, which represents in detail agriculture and land use aspects, in the economy-wide comprehensive framework of the CGE model. Yet coupling approach tackles major difficulties in the sense of data incomparability, computational limitations and sophisticated programming. In addition, establishing the link may demand theoretically or empirically inconsistent compromises. On contrary, internal extension of a CGE involves in introducing new structural relations and corresponding parameters, which ideally should have an empirical evidence. Recalibrating the model might follow. This method is certainly more feasible, but, in spite of the reviewed recent development, still incomparable with IAM for accuracy of mirroring the decision making of agricultural and other land-using units.

Our research in progress aims to contribute to the effort of agricultural modeling for climate change assessment. First, we attempt to overcome the deficit of empirical foundation for land transformation function between different uses. For this purpose we use the output of regional land use model VALUE (Kan et al., 2007) and estimate the most suitable functional structure and the accompanying elasticities of substitution. According to the obtained results we modify the land supply equation in ICES (Inter-temporal Computable Equilibrium System) (Eboli et al., 2008). We proceed with creating baseline projection of world economic development without climate change. Assessment of climate change impacts on regional economic growth in the world follows.

3. The Methodology

3.1. ICES: The Point of Departure

In order to assess the systemic general equilibrium effects of climate change on agriculture and land use, we employ a dynamic multi-regional CGE model of the world economy called ICES. ICES is derived from a static CGE model named GTAP-EF (Roson, 2003; Bigano et al., 2006)[3]. The latter is a modified version of the GTAP-E model (Burniaux and Troung, 2002), which in turn is an extension of the basic GTAP model (Hertel, 1997).

ICES is a recursive model, generating a sequence of static equilibria under myopic expectations, linked by capital and international debt accumulation. Although its regional and industrial disaggregation may vary, the results presented here refer to 8 macro-regions and 17 industries, listed in Table 2.

Table 2: ICES Sectoral and Regional Disaggregation

<table>
<tr><th colspan="4"><i>Sectors</i></th></tr>
<tr><th><i>Land-Using Industries</i></th><th><i>Other Food Industries</i></th><th><i>Heavy Industries</i></th><th><i>Light Industries</i></th></tr>
<tr><td>Rice</td><td>Forestry</td><td>Coal</td><td>Energy intensive industries</td></tr>
<tr><td>Wheat</td><td>Fishing</td><td>Oil</td><td>Water</td></tr>
<tr><td>Cereal Crops</td><td></td><td>Gas</td><td>Other industries</td></tr>
<tr><td>Vegetables & Fruits</td><td></td><td>Oil Products</td><td>Market Services</td></tr>
<tr><td>Animals (livestock)</td><td></td><td>Electricity</td><td>Non-Market Services</td></tr>
<tr><th colspan="4"><i>Regions</i></th></tr>
<tr><th><i>Code</i></th><th colspan="3"><i>Description</i></th></tr>
<tr><td>USA</td><td colspan="3">United States</td></tr>
<tr><td>EU</td><td colspan="3">European Union-15</td></tr>
<tr><td>EEFSU</td><td colspan="3">Eastern Europe and Former Soviet Union</td></tr>
<tr><td>JPN</td><td colspan="3">Japan</td></tr>
<tr><td>RoA1</td><td colspan="3">Other Annex 1 countries</td></tr>
<tr><td>EEx</td><td colspan="3">Net Energy Exporters</td></tr>
<tr><td>ChInd</td><td colspan="3">China & India</td></tr>
<tr><td>ROW</td><td colspan="3">Rest of the World</td></tr>
</table>

Growth is driven by exogenous changes in labour, land and natural resources from 2001 (calibration year of GTAP6 database) onward. In addition, endogenous dynamics is applied for capital (for detail description of the model see Eboli et al., 2008).

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[3] Detailed information on the model can be found at the ICES web site: http://www.feem-web.it/ices.

3.2. Modification

ICES follows the standard assumption of GTAP-based models on equal transform-ability of land among different uses. We modify the structure of land allocation in the model to better capture the role of heterogeneous land endowments. Where possible we support these new behavioral relationships with land-use model -based estimates of both the mean and standard deviation of behavioral parameters. Currently, the heterogeneity of agricultural land is modeled using a structure similar to that found in the OECD (2001) Policy Evaluation Model (PEM). In the future analyses we intend to evaluate the most applicable nested structure of land transformation between uses. This is a necessary requirement if we are to analyze climate change impacts on agriculture that may affect farmer’s land allocation decisions.

The revised model (which we will refer to as ICES-L) covers several types of land more or less suited to various crops and livestock. The crops include wheat, cereal crops, rice and vegetables and fruits. The transformability of land between different uses is an empirical question. The parameters to be used in the ICES-L model will be derived from the VALUE (Vegetative Agricultural Land Use Economic) model (Kan et al., 2007). The output of this regional land allocation model, which accounts also for water application and water salinity, will be analyzed to evaluate the elasticity of land transformation among agricultural uses following Shumway and Powell (1984) approach. Figure 1 mirrors the difference in land allocation tree in ICES and in ICES-L.

Figure 1: land allocation tree in ICES and ICES-L

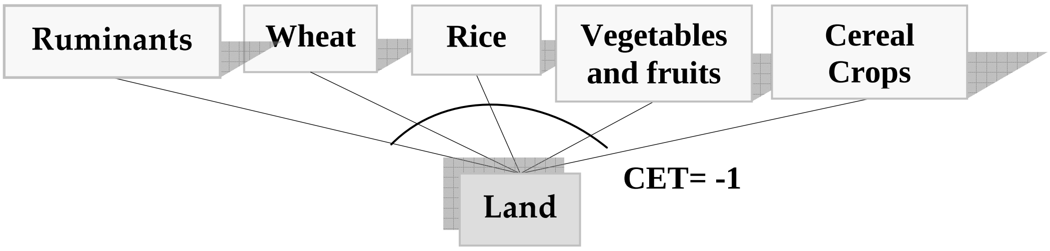


Figure 1a: ICES Land Structure

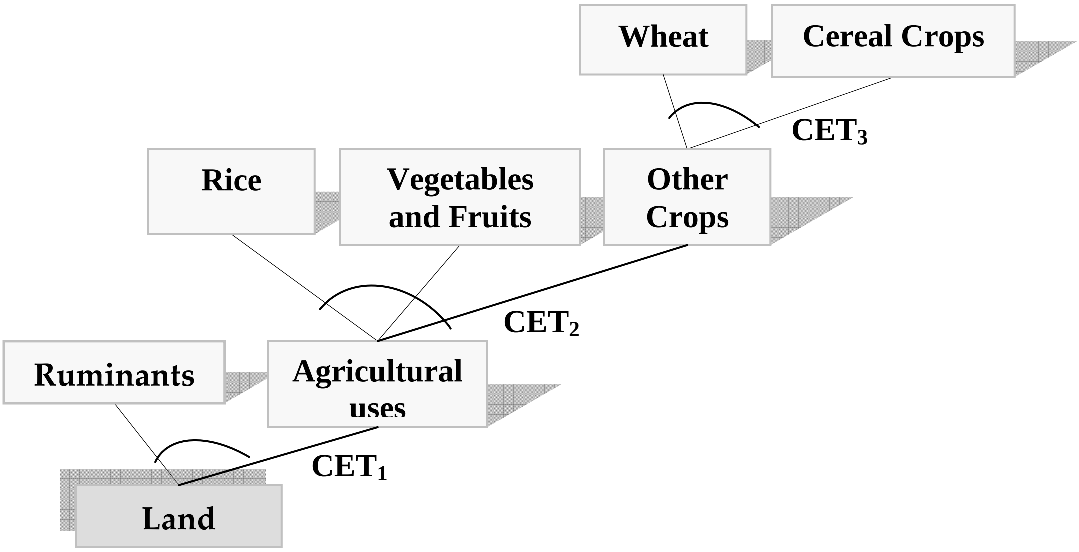


Figure 1b: ICES-L Land Structure

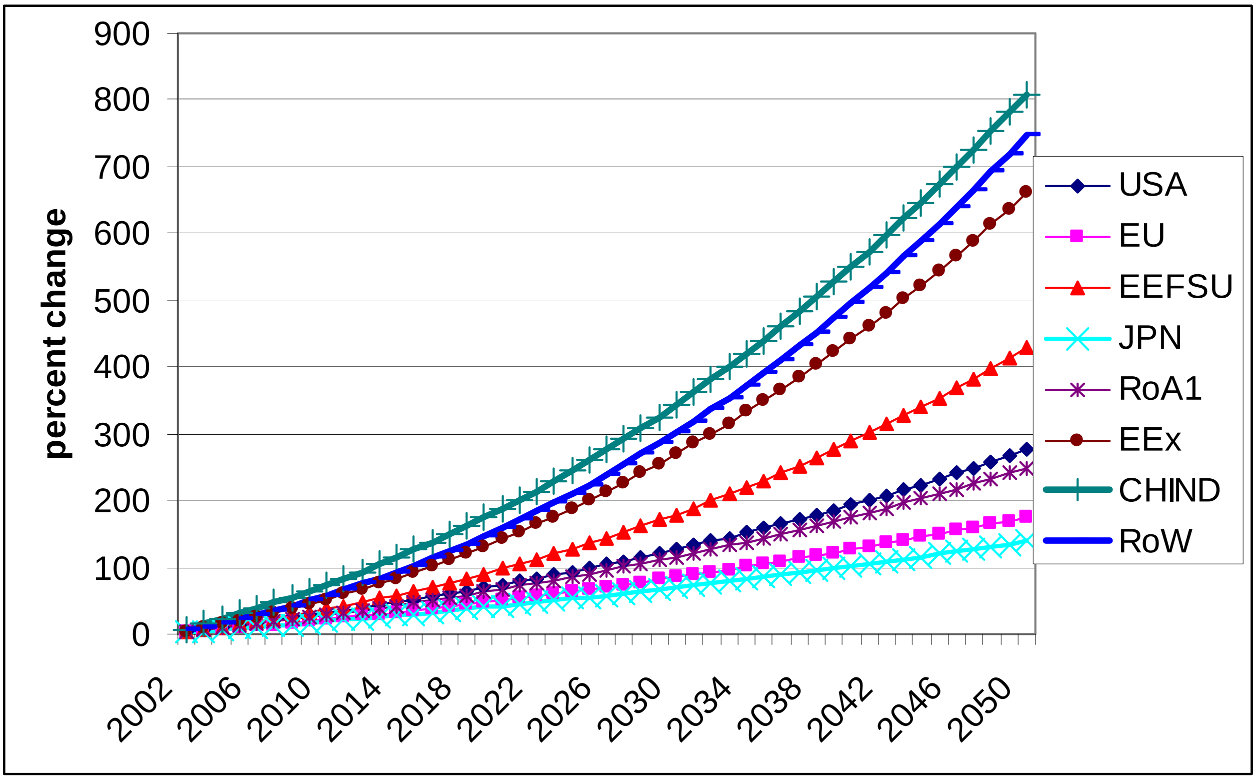
ICES-L introduces a nested structure to better reflect the transformation possibilities across uses. Here, land owners first decide on whether the land will be in ruminant livestock production or agriculture to maximize the total returns from land. The transformation is governed by the elasticity of transformation CET$_1$. Then, based on composite return to land in rice and vegetables & fruits, relative to other crops (namely, wheat and cereal crops) the land owner decides on the allocation between these two broad types of activities. Here the elasticity of transformation is CET$_2$. Finally, the transformation of land within the upper nest, between wheat and cereal crops, is modelled with an elasticity CET$_3$. In this way the degree of substitutability of types of land can be varied between the nests. It captures to some extent agronomic features. At each stage in the decision making process, the CET parameter increases, reflecting the greater sensitivity to relative returns amongst crops. This means that it is relatively easier to change the allocation of land within the Wheat and Cereal Crops group, while it is more difficult to move land out of this group into a lower nest, such as into Vegetables & Fruits and Rice. Transformation possibilities of land between livestock production and agriculture are even more rigid.

3.3. Climate Change Impacts on Agriculture

We run the model at yearly time steps from 2001 to 2050. In each period, the model solves for a general equilibrium state, in which capital and debt stocks are "inherited" from the previous period, and exogenous dynamics is introduced through changes in primary resources and population. In addition, impacts are simulated by "spreading" the climate change effects over the whole interval 2001-2050. For example, changes in crop productivity are related to changes in temperatures and precipitation. As temperatures progressively rise over time, wider variations are imposed to the model productivity parameters.

In this way, the model generate two sets of results: a baseline growth path for the world economy, in which climate change impacts are ignored (Figure 2), and a counterfactual scenario, in which climate change impacts are simulated. The latter scenario differs from the basic one, not only because of the climate shocks, but also because exogenous and endogenous dynamics interact, and climate change ultimately affect capital and foreign debt accumulation.

Figure 2: Baseline Projection of Real Regional GDP Growth Path



Agricultural impact estimates are based on Tol (2002) who extrapolated changes in specific yields for some scenarios of climate change and temperature increase. Climate change impact on agriculture is modeled through a linear change in land productivity corresponding to temperature increase of 1.5ºC in the year 2050 comparing to 1990. Table 3 depicts the exogenous shocks introduced in the model to simulate the climate change impacts on agriculture.

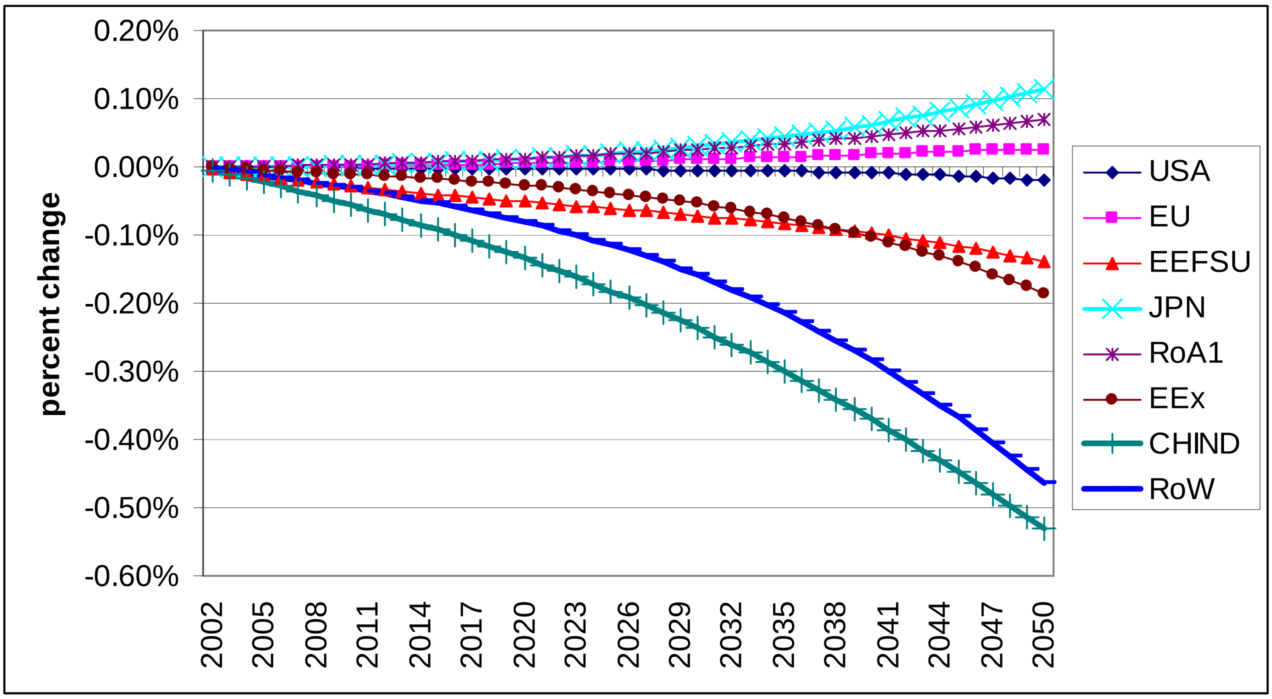
Table 3: 2001-2050 Percentage change in parameters' variation due to climate change impact on land productivity

			Land Productivity		
Regions\Sectors	**Wheat**	**Rice**	**Cereal Crops**	**Vegetables & Fruits**	**Animals**
USA	-5.655%	-6.177%	-8.168%	-6.667%	-6.667%
EU	-5.195%	-5.047%	-7.035%	-5.759%	-5.759%
EEFSU	-5.909%	-7.266%	-9.505%	-7.560%	-7.560%
JPN	-5.649%	-5.532%	-7.448%	-6.230%	-6.230%
RoA1	1.945%	-0.032%	-1.926%	-0.004%	-0.004%
EEx	-1.948%	-2.677%	-4.937%	-3.187%	-3.187%
CHIND	-2.024%	-3.121%	-4.956%	-3.367%	-3.367%
RoW	-6.728%	-7.033%	-8.714%	-7.492%	-7.492%

4. Results

Figure 3 presents differences in GDP in the period 2001-2050, obtained by simulating a progressive change in land productivity, as reported in Table 3 above. Land productivity is generally reduced. This hits more severely some agriculture-based, relatively poorer economies: ChInd; EEFSU; EEx and RoW. Other regions are not affected (USA) or even get benefits (JPN, RoA1 and EU), primarily because of positive changes in the terms of trade.

Figure 3: % Change in Regional Real GDP Due to Climate Change Impact on Land Productivity



Using a dynamic model allows us to investigate the increasing influence of climate change on the global economic growth in general and on secrotal (agricultural) production specifically. This influence is twofold: on one hand, the magnitude of physical and economic impacts will rise over time and, on the other hand, endogenous growth dynamics is affected by changes in income levels, savings, actual and expected returns on capital. We concentrate on the

The impact of a changing climate on the sectoral output and land allocation are shown in Figures 4 and 5 respectively. We observe increases in the area share and price for cereal crops production in nearly all countries and regions; production instead is decreasing in USA, EU, China&India and Rest of the World. Obviously the losses in land productivity are counteracted by an increase of the area share, increasing the prices. Also for several other regions and land using industries, such as livestock in USA and EU yield losses are compensated by area gains and prices rise. For vegetables & fruits and rice this pattern is not observable: land allocation and output move in parallel paths. The cropland changes of wheat and cereal crops as well as rice and vegetables & fruits reveal the expected scheme: they are of opposed signs in nearly all countries. This can be interpreted as direct competition for land between these crops which is driven from the land supply modification. The nested land allocation structure makes relative land allocation changes for crops in the same nest sensitive to small perturbations: according to minor price changes either one or the other is preferred in production.

Figure 4: Climate Change Impact on Industrial Output

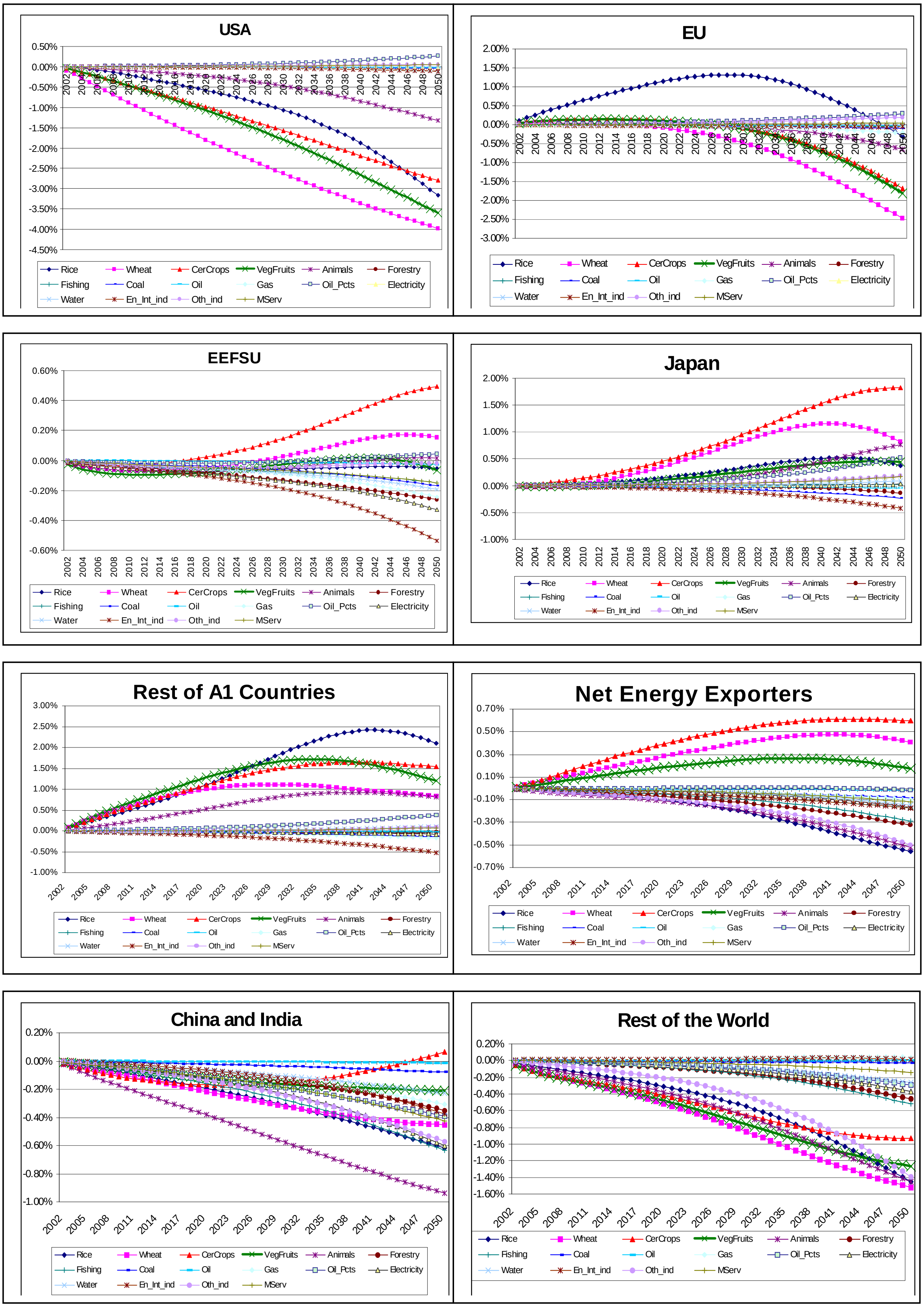
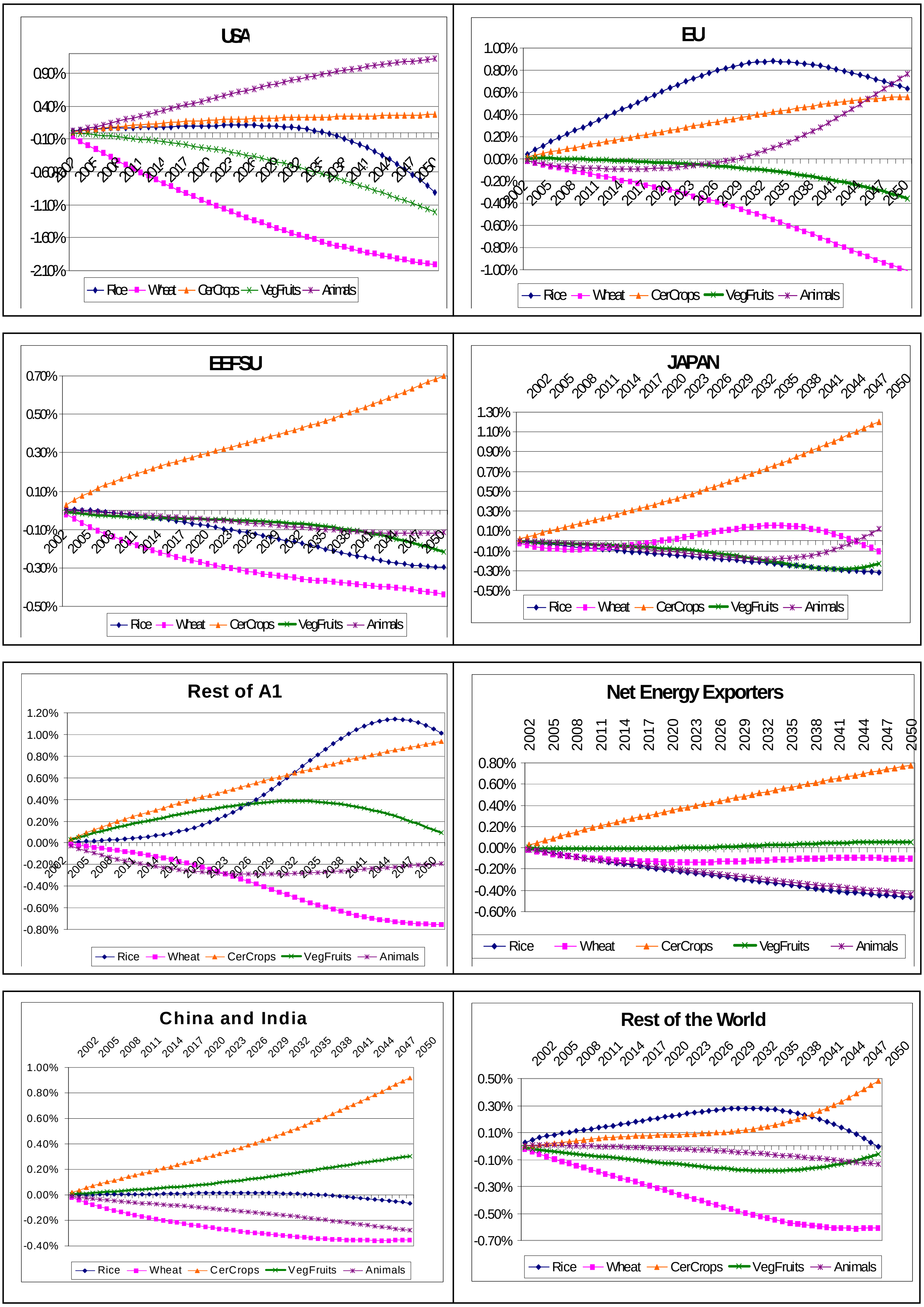


Figure 5: Climate Change Impact on Land Allocation



5. Conclusions and Directions for Future Work

In this paper we offered a survey of the various approaches used to describe, model and measure the complex relationships between climate change, agriculture and land-use. Two major strategies were outlined: internal model extension and soft-link coupling of CGE and partial equilibrium land-use model. The main message that can be grasped from the relevant literature is that climatic, agricultural and economic information need to be consistently melted in order to provide a reliable and sound impact assessment analysis in this field. This is witnessed by the constant effort to expand the comprehensiveness of the investigation. But despite the achievements and individual strengths of the selected modeling approaches, core problems of global land-use modeling have not yet been resolved.

Our study in progress relies on previous efforts and attempts to provide an elaborated framework to fully cover the related aspects. The first step is refining the dynamic global CGE model to allow for land heterogeneity. Preliminary results reflect the significance of structural features specific to agriculture for consistent analyses of climate change impacts on land use, future crop patterns and economic development.

Further model developments will focus on improving the representation of agricultural features and obtaining econometrically estimated structural parameters. Other methodological challenges are still ahead. For comprehensive analyses of climate change impacts it is important to include water demand and supply and distinguish farm land by its access to water.

Beyond, the inclusion of feedbacks between society and environment are needed and call for further efforts in integrated land-use modeling. For a new generation of integrated large-scale land-use models, a transparent structure is needed which clearly employs the discussed advantages of both general and partial equilibrium modeling concepts within one consistent framework and avoids redundancies.

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