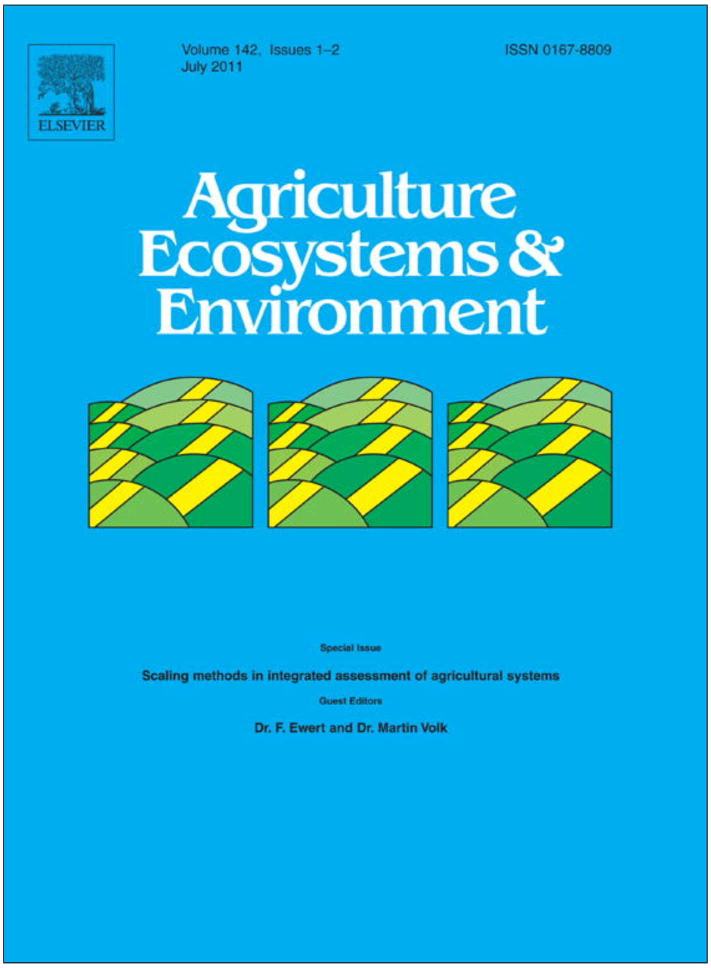
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Impacts of EU biofuels directives on global markets and EU environmental quality: An integrated PE, global CGE analysis

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ABSTRACT

As policy makers become increasingly aware of the impact of their decisions on the global economy, as well as the impact of developments in the global economy on regional and national resource use, the demand for cross-scale analysis of economic and environmental policies has become a high priority. This paper contributes to this literature by developing a new methodology to link two widely used policy models in order to provide an integrated assessment of the environmental impacts of EU biofuels mandates. By combining the CAPRI model of EU agricultural production and resource use with the GTAP model of global trade and land use, we are able to estimate both the global impacts of EU biofuels policies as well as the detailed, regional changes in land use and nutrient surplus.

The applicability of this combined modeling approach extends well beyond biofuels. It could offer important insights into the global impacts of EU agricultural policy reforms, as well as analysis of the EU-regional impacts of global agreements on trade policy or climate change mitigation. In short, the methodology developed in this paper holds great promise for future, cross-scale analysis of global issues bearing on agriculture, land use and the environment.

1. Introduction

Both the EU and the US have implemented biofuel mandates with the aim of reducing their dependency on fossil fuels while simultaneously abating Green House Gas (GHG) emissions. These policies provoke simultaneous adjustments of agricultural production and demand patterns around the globe which, in turn affect global externalities such as GHG emissions, as well as regional and even local externalities such as increased nutrient loads in ground and surface waters. Integrated impact assessment, which is now compulsory for any larger EU legislative project, will require consistent evaluation of the economic, social and environmental effects of proposed legislation. Such analyses will typically build on the application of a combined set of tools, each operating on different spatial scales.

Nowhere is this more evident than in the current debate over biofuel mandates. Recent studies (Searchinger et al., 2008; Fargione et al., 2008) have questioned the value of such mandates for reducing global warming due to the important role of indirect Land Use Change (iLUC) in increasing GHG emissions. The basic idea is that, with a relatively unchanged global demand for food, the diversion of agricultural products into the energy economy will induce cropland conversion, as new land is brought into production in order to satisfy existing global food demands. If these converted lands are high in carbon content such as tropical forests or peat bogs, then the net impact of the biofuels program on GHG emissions may be adverse. Indeed, in the case of corn ethanol produced in the US, Searchinger et al. (2008) suggest that GHG emissions could even double, when compared to the continued use of petroleum products. While their analytical framework is relatively simple, the papers by Searchinger et al. (2008) and Fargione et al. (2008) make a compelling case for considering iLUC in any assessment of the environmental impacts of biofuel mandates.

As a consequence of these discussions, and the increasing concern with global warming, some of the recent biofuel mandates have included provisions restricting the renewable fuel standards to biofuels which meet minimum GHG reduction standards, inclusive of iLUC effects. Indeed, in April of 2009, the California Air Resources Board approved their new Low Carbon Fuel Standard, which explicitly accounts for iLUC in determining the total GHG emissions associated with each feedstock. However, the Board explicitly called for additional expert input on this subject. The 2007 US Renewable Fuels Standard requires that corn ethanol contribute to at least a 20% reduction in GHG emissions, relative to petroleum products, inclusive of emissions associated with iLUC.

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The requirements for other biofuels are even more stringent. However, considerable debate has arisen about the accuracy of the models upon which the iLUC estimates are based. In the EU, the Commission has opted to leave iLUC out of the calculations for their renewable fuels standard, pending improvement in the underlying science. All of this has generated a great demand for improved analyses of iLUC and biofuels.

Existing studies of iLUC and biofuels have included both partial equilibrium (OECD, 2008; Tokgoz et al., 2007) and general equilibrium analyses (Hertel et al., 2010; Banse et al., 2007). Each of these approaches has its strengths and limitations. The partial equilibrium studies, only taking agricultural markets into account, typically offer greater commodity detail, while the general equilibrium studies are better at capturing factor market impacts (e.g., land, labor and capital) as well as linkages between the farm and non-farm sectors—in particular the energy sectors which are critical for determining the demand for biofuels products. This suggests significant benefits from developing a methodology which combines the two approaches into a unified framework. In the present paper, we develop a methodology for linking partial with general equilibrium models in order to capitalize on the strengths of each. We demonstrate the value of this combined approach by presenting an analysis of the impacts which EU biofuels programs have on global land use and GHG emissions. We find that the combined model does indeed improve the resulting estimate of global GHG impacts, in addition to facilitating analysis of the impacts on local environmental quality within the EU.

2. Methods

2.1. Overview

Biofuel mandates provoke simultaneous adjustments in the markets for both fossil fuels and raw agricultural products, and the ensuing effects will depend *inter alia* on the interplay with policy instruments in both these markets. For example, subsidizing biofuel processing or the production of biofuel feedstocks will reduce transport fuel prices and thus stimulate energy demand, whereas obligatory blending could increase fuel prices and depress demand. The effects on the overall economy thus depend on the method for the implementation of the biofuel policy, which is why CGE (Computable General Equilibrium) models have been used to analyze this issue. The CGE model which we build upon in this paper is GTAP (Hertel, 1997). In particular, we utilize the biofuels version of that model (Hertel et al., 2010), augmented with land use by Agro-Ecological Zones (AEZs: Lee et al., 2009) and by-products (Taheripour et al., in press). This model has been widely used to establish the links between energy policies and global land use. However, its capability to model detailed agricultural impacts in the EU is limited—both due to commodity and regional aggregation (the GTAP model only includes national production functions—albeit augmented by sub-national data on the distribution of production by AEZ).

In contrast to CGE models, agricultural partial equilibrium (PE) models profit from their specialized nature by offering more detail regarding spatial and commodity disaggregation, as well as improved treatment of domestic agricultural policies. Their supply response is also typically judged more robust as their results have been validated over the years through their repeated use in commodity-specific applications. Such validation is also benefited by the fact that the PE models are typically expressed in physical quantities. This also makes it easier to link them to environmental indicators. Therefore, we enrich the global economic analysis of biofuels by integrating the European supply module of the CAPRI model (Britz, 2008) into the analysis. The full CAPRI model also comprises a large-scale global trade model for agricultural products with a product differentiation, a rather detailed disaggregation of the world into individual countries or country-blocks, and a highly detailed description of EU trade policies. However, given the analysis at hand, the necessity to simulate energy markets and to include global iLUC, the benefits of adding these market module features outweigh the costs in terms of complexity and potential conflicts with the GTAP framework. This contrasts with other applications, having a different focus, where both the supply and market models of CAPRI are linked sequentially to a GTAP version with only one primary agricultural sector.

By linking the CAPRI and GTAP models, we offer an improved analysis of the impact of EU biofuels mandates – both on international markets and land use – as well as on EU environmental outcomes. We do so by modifying the GTAP model in order to include a parsimonious summary of the regional supply models of CAPRI, which is then applied to capture global land use effects and the interplay of agricultural and energy markets and biofuel policies. By taking the resulting equilibrium price changes and applying them to the supply models of CAPRI we are also able to elicit highly disaggregated changes in farming practice and their impacts within the EU. These regional results can then additionally be spatially disaggregated to a 1 km × 1 km resolution (see Britz et al., in this same special issue) to provide input into bio-physical modeling at an appropriate scale (Leip et al., 2008), or feed into a Life Cycle Assessment of energy use of EU agriculture (Kränzlein, 2008). On the other hand, global impacts of EU policies such as on poverty in developing countries (Hertel et al., 2009a) can be analyzed with post-simulation analysis of GTAP results.

Of course, the underlying methodology which we develop is also applicable in other cases which necessitate linkage of different economic models in a consistent way across regional, national and global scales. Other possible examples provide an integrated assessment of agricultural trade liberalization proposals, or, alternatively, an assessment of agricultural and rural development programs which seek to achieve specific environmental objectives.

2.2. Linking crop supply response

While CAPRI and GTAP have differing domains of application, they both predict endogenously changes in crop supplies. These predictions must be rendered consistent if the ensuing global GE–PE analysis is to be coherent. Otherwise, changes in non-EU supply and the resulting iLUC simulated with GTAP would not be compatible with the regional EU results simulated with CAPRI, thereby jeopardizing the resulting integrated assessment of biofuel mandates. In order to achieve mutually consistent supply behavior in GTAP and CAPRI we embed the crop production possibilities frontier (PPF): $f(Y,Z) = 0$ from CAPRI into the GTAP model. Here, Z represents the factors held fixed in defining this PPF, and Y represents the vector of crop outputs supplied by EU agriculture. The optimization problem associated with the compensated crop supplies may be stated as follows:

$$\begin{aligned} &\max_{Y_i} \sum_i P_i Y_i = crop\,re \\ &s.t. \quad f(Y,Z) = 0 \end{aligned} \qquad (1)$$

The solutions to (1) yield a revenue function: $R(P,Z)$ as their envelope, which, when partially differentiated with respect to an individual crop price, recovers the optimal crop supply, conditional on the fixed factors, i.e. $\partial R(P,Z)/\partial P_i = Y_i(P,Z)$. It thus summarizes the necessary information from (1) to simulate impacts on crop supply when the elements of P or Z change. This revenue function is the common element between the modified GTAP and CAPRI models, and allows for the bridging of differences in model structure as well as in product and spatial resolution. We first estimate $R(P,Z)$, based on a series of carefully designed simulations with CAPRI, and then this is embedded in the GTAP model. Once incorporated into GTAP, $R(P,Z)$ determines optimal supplies *conditional on Z*. The vector Z determines the overall size of the crops sector. Expansion and contraction of the crops sector (and hence Z) depends on profitability and is determined by the zero profits condition applicable to the crops sector as a whole.

For the sake of compatibility with the GTAP version employed, crop outputs in CAPRI are aggregated into six broad groupings as follows: wheat, rice, other grains, oilseeds, sugar crops, and all other crops. The focus in our subsequent analysis will be on oilseed production, as rapeseed and, to a minor extent, sunflower seed are feedstocks into the European biodiesel sector, along with imported oils and oilseeds. Before implementing (1) in CAPRI, we must also give careful thought about which factors to include in the vector Z. Here we take our guidance from the revised formulation of GTAP in which all inputs are held fixed in determining the compensated crop supply response. Accordingly, the regional programming models in CAPRI were modified with additional constraints permitting us to fix the value of intermediate inputs, labor and capital (via the quadratic cost function) and the subsidies paid to activities under the Common Agriculture Policy (the so-called pillar one payments). In addition, livestock activity levels were also fixed.

Based on a mapping of the six GTAP crops to products in CAPRI, sensitivity experiments were conducted by raising the group-wise prices of each of the six crop groups by 5% against the base year value, and the resulting regional individual crop supply changes were aggregated to EU-27 level. These EU-level production quantities were finally aggregated to the six GTAP crops using a Laspeyres index, and from there a matrix of own and cross-price elasticities of crop supply was computed with typical element: $[\partial Y_i(P,Z)/\partial P_j][P_j/Y_i]$. This matrix represents a critical input to our subsequent analysis as it incorporates the aggregated regional supply response from CAPRI into GTAP and therefore warrants some discussion before proceeding.

Table 1 reports the CAPRI-based compensated supply elasticities for the aggregate EU crops sector. Considering first the diagonal elements of Table 1, which represent the own-price elasticities of supply, we note that the most price responsive crop is wheat, followed by other grains and then oilseeds. According to the GTAP grouping, the latter include olive trees, which explains the somewhat muted price responsiveness. Sugar crops are less responsive to price due to the sales quota regime. Finally, the other crops aggregate, comprising *inter alia* perennials such as vineyards, shows very limited price responsiveness, when taken as a group. The cross-price elasticities of supply are also of considerable interest as they summarize the interaction between different commodities which are competing for a fixed resource base. First of all, note that the off-diagonal elements in this matrix are negative, suggesting that all of these crop groupings are net substitutes in supply. (There are a few exceptions involving rice, with extremely small positive numbers.) This means that, if we hold the aggregate input levels constant, an increase in one commodity price will cause a reduction in the optimal supply of other commodities.

Table 1
Compensated price elasticities for crop supply from CAPRI, aggregated to EU-27.

Supply	Price					
	Rice	Wheat	Cgrains	Oilseed	Sugar	OthCrop
Rice	0.170	−0.003	−0.110	−0.004	0.001	−0.053
Wheat	0.000	0.849	−0.554	−0.083	−0.018	−0.193
Cgrains	−0.006	−0.508	0.725	−0.141	−0.010	−0.060
Oilseed	0.000	−0.159	−0.296	0.693	−0.008	−0.229
Sugar	0.000	−0.062	−0.036	−0.015	0.409	−0.296
OthCrop	0.000	−0.028	−0.010	−0.018	−0.013	0.069

Source: Generated via sensitivity analysis using an input restricted version of the CAPRI model and implemented as a normalized quadratic revenue function in the GTAP model.

The absolute size of the own and cross-price elasticities depends on the relative importance of the crop (group), the flexibility by which the farming sector can change its supply, and the intensity of resource competition between crops. According to the estimates presented in Table 1, a 1% change in oilseed prices, which is of specific interest for our analysis focusing on changes in biodiesel demand, induces an expansion in oilseed supply by about 0.7%, but has only limited impacts on cereals, as the area occupied by oilseeds is small compared to cereals area. The effect on coarse grains (−0.14%) is almost double that for wheat (−0.08%), hinting at higher competition between oilseeds and coarse grains. This may be explained by the fact that farmers can switch easily between an oilseed/wheat rotation on the one hand and a coarse grains/wheat rotation on the other. Compared to oilseeds, changes in wheat or in other grain prices not only provoke larger relative expansions of the respective crop (group), but also strongly decrease the supply of competitors, which are mainly competing grains or oilseeds. Rice is not an important crop in the EU and exhibits relatively low supply response, and limited interaction with the other commodities. The relative low price responsiveness of sugar is clearly linked to the sales quota regime, whereas the other crop group (all remaining crops covered in CAPRI) comprises to a larger extent perennials which at least in the medium term show a much lower supply response compared to arable cropping. We will see further evidence of cross-commodity competition when we come to Section 3.

In order to integrate the CAPRI multiproduct crop supply responses summarized in Table 1 into GTAP, we replace the standard, single product representation of these six crop sectors in GTAP with the multiproduct representation summarized by $\partial R(P,Z)/\partial P_i = Y_i(P,Z)$. We utilize a normalized quadratic, compensated revenue function which is capable of providing a second-order approximation to any arbitrary revenue function: $R(P,Z)$. This flexibility permits us to calibrate the underlying parameters so as to ensure replication of the matrix of elasticities in Table 1, while also imposing the necessary symmetry and curvature conditions. The normalized quadratic functional form requires that revenue and prices are normalized by the division of one of the prices. In this case, the crop with the largest revenue share is used as the numeraire.

2.3. Simulation methodology

With the modified GTAP model in hand, we are in a position to initiate the policy simulation. An overview of the methodology is given in Fig. 1. Derivation of the compensated supply elasticities from CAPRI—via a set of EU-wide price experiments for crops is portrayed across the top of the figure. These feed into GTAP via the revenue function and thus brought to bear on the biofuels simulation. In addition to global land use changes and the associated GHG emissions, GTAP generates equilibrium price and quantity changes for all commodities, globally, including EU crops. The crop price changes are then fed back into the CAPRI model in order to elicit detailed EU impacts on land use and the environment. At the end of the paper we compare our market level findings to those obtained by running a standalone version of the GTAP-BIO model.

3. Results

3.1. Scenario description

Since our primary purpose in this paper is to illustrate the methodology for linking economic models on different scales, in this case PE and CGE models of agricultural trade and land use, we adopt

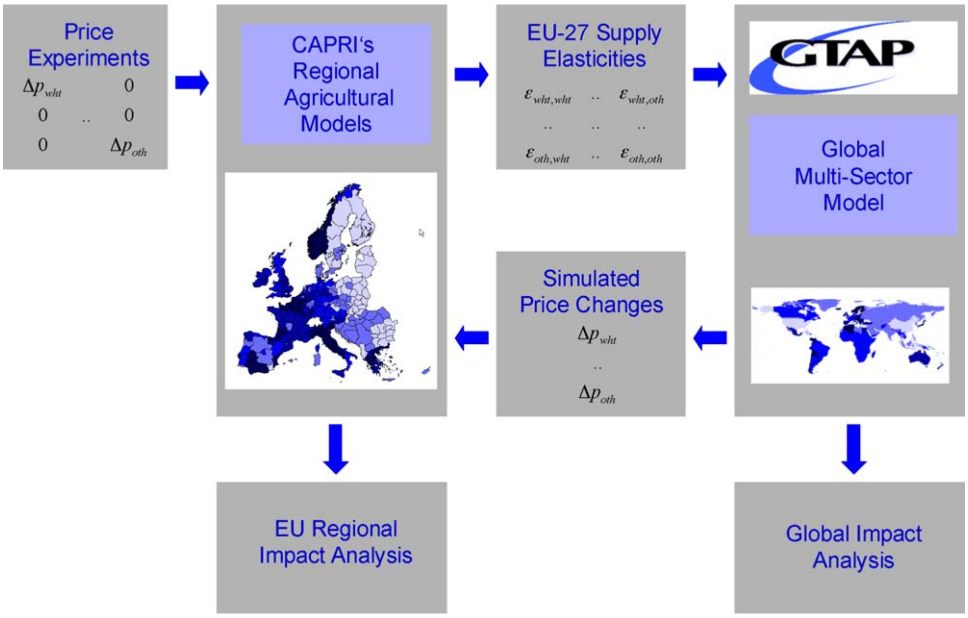


Fig. 1. Overview of simulation methodology.

a rather stylized biofuels scenario that is large enough to test the robustness of our approach, and simple enough to facilitate analysis and compact scrutiny of the results. Since the base period for the GTAP biofuels model used in this analysis is 2001, we adopt this as the starting point. While it is possible to update the starting point to a more recent year (see, for example, Hertel et al., 2010 who update the model to 2006), the global land use analysis is built upon a spatially disaggregated, global database of land use that is only available for the base period 2000 (Monfreda et al., 2008). Accordingly, it is attractive to take this as our starting point so that we are not confounding the impacts of baseline with the biofuels analysis.

In order to test the robustness of the model we seek to implement a large policy shock. This is why we choose 2015 as a focal point. By this point the EU biofuels mandate suggests that something in the neighborhood of 6.25% of liquid fuel for transport will come from biofuel (European Commission, 2007). For the sake of exploring the impact of large changes – concentrated on a single sector – we assume this all comes from biodiesel. Adding ethanol is straightforward (e.g., Hertel et al., 2010) and would enrich the policy analysis, but it would make the task of analysis more difficult as this would draw on multiple feedstock channels. Higher input costs for blending biodiesel with other fuels are assumed to be passed on to consumers, thereby raising the price of transport fuels and somewhat dampening aggregate demand.

3.2. Commodity market impacts

Fig. 2 reports the simulated change in EU crop supplies and prices. With a 48% rise in oilseed prices, oilseed supplies increase by 33%. While this equilibrium change in supply reflects the combination of own- and cross-price changes, as well as changes in the overall level of cropping inputs (Z in the revenue function), the magnitude of this increase is similar to that predicted by the own-price elasticity of oilseeds supply in Table 1 (33%/48%–0.7). This is due to the fact that oilseeds are not a dominant crop in terms of total EU production, so that cross effects with other sectors are not strong. Of course the elasticities in Table 1 are only valid locally whereas the results in Fig. 2 pertain to the case where other prices are also changing. As will be discussed below, this supply response is also considerably smaller than that predicted by the GTAP-BIO model (Hertel et al., 2010) when run in stand-along mode.

Fig. 2 also reports the impacts on other crop prices and supplies. From Table 1, we anticipate that the reduction in coarse grains supply would be roughly twice as large as that for wheat, due to the greater intensity of competition between rapeseed and barley, in particular. However, in attaining the new equilibrium, coarse grains prices rise by nearly twice as much as do wheat prices and so the differences in supply changes for these two commodity groups is similar in magnitude. As expected, sugar, rice and other crops are little affected by the biodiesel expansion.

Since the vegetable oil derived from the additional domestic production of oilseeds is not sufficient to meet the increased EU biodiesel demand, EU imports of vegetable oils and oilseeds increase dramatically—by about $US 10 billion. These imports are predicted to follow the current pattern of EU oilseed imports, modified somewhat due to supply response in the exporting regions. As such, the largest increases in imports are from Brazil and USA, the two countries with the largest share of the EU oilseeds import market currently.

3.3. Global land use impacts

The increase in oilseed production, worldwide, causes cropland returns to rise, which in turn gives rise to cropland expansion. In the land use version of GTAP (Hertel et al., 2009b), cropland

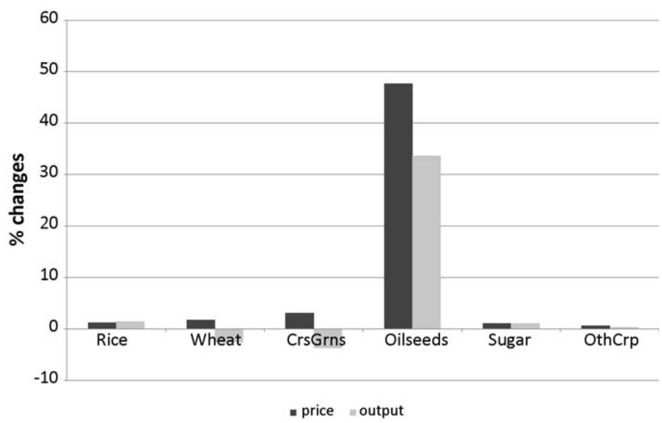


Fig. 2. Impact of biodiesel expansion on EU crop supply and prices.

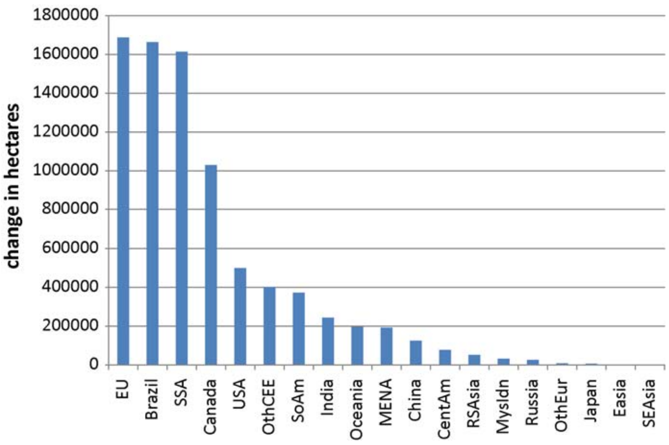


Fig. 3. Impact of biodiesel expansion on cropland cover (ha).

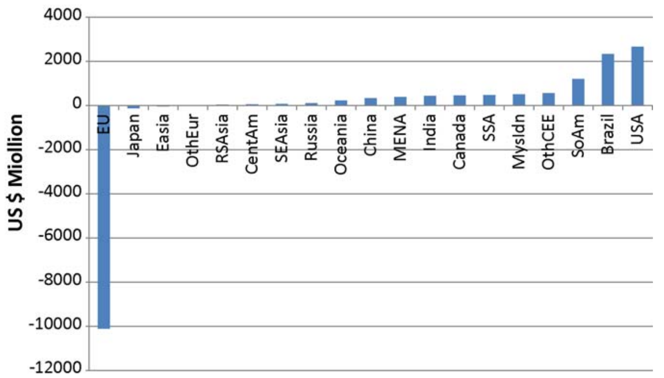


Fig. 4. Change in oilseed and oils net exports due to EU biodiesel expansion ($US million).

competes with pasture land and forest lands (the latter excludes inaccessible forests). Fig. 3 reports the cropland cover change by region in Mha. From this it can be seen that cropland expands in nearly all regions. The largest expansion is in the EU, which is hardly surprising, since the biofuels initiative is EU-based. However, the EU cropland expansion of roughly 1.7 Mha is just one-fifth of the global expansion which totals 8.2 Mha. The EU is followed closely by Brazil where cropland expands by about 1.7 Mha as well, with the largest share of this coming from pasture land. Brazil is followed by Sub-Saharan Africa (SSA), which shows 1.6 Mha expansion in cropland cover, driven largely by its close trading relationship with the EU. The size of the cropland expansion depends not only on the supply responsiveness of the different crops when EU import demand increases, but also on cropland productivity. That explains why oils and oilseeds export expansion of the US exceeds that of Brazil (see Fig. 4), but cropland expansion in Brazil is higher.

Fig. 5 maps the changes in cropland cover, globally, by AEZ, as a consequence of the EU biofuels mandates. With the exception of Russia, where forest lands increase slightly due to increased timber prices, cropland expands in every region. Globally, most of the net conversion is from pasture lands, with just 1.8 Mha of the 8.2 Mha converted Table 2 coming from forest lands. This is critically important for GHG emissions, since the emissions factors for cropland conversion vary greatly between forests and pasture as well as by region, according to the estimates obtained from Woods Hole (Searchinger et al., 2008, SOM). We estimate that global emissions rise by 1472 MMT CO_2 as a consequence cropland conversion induced by increased biodiesel production in the EU. This translates into 42.2 g/MJ of energy produced. It is interesting to compare this figure to comparable estimates (based on the GTAP model the same emission factors) of the GHG impacts of iLUC stemming from US corn ethanol expansion over the same period which is 27 g/MJ.

Fig. 6 reports the share of global GHG emissions arising in each region of the world. The first set of bars in Fig. 6 corresponds to the model results discussed thus far. Thus we see that, despite the greater area converted in Brazil, Canada shows higher GHG emissions from land cover change, due to the model's estimate that much of the net cropland conversion will be from forest lands in Canada, as opposed to Brazil, where the land is expected to come from pasture lands having a lower GHG emissions factor.

The second set of bars in Fig. 6 reports the estimated distribution of global GHG emissions estimated when the GTAP model is used alone, absent the CAPRI-based supply system. In this case, oilseeds supply is overly responsive in the EU, with production rising by 59%. As a consequence, there is more cropland conversion in the EU, a lesser increase in oilseeds and oils imports, and lower emissions in the rest of the world. The difference is particularly striking in Brazil, where GHG emissions are signifi-

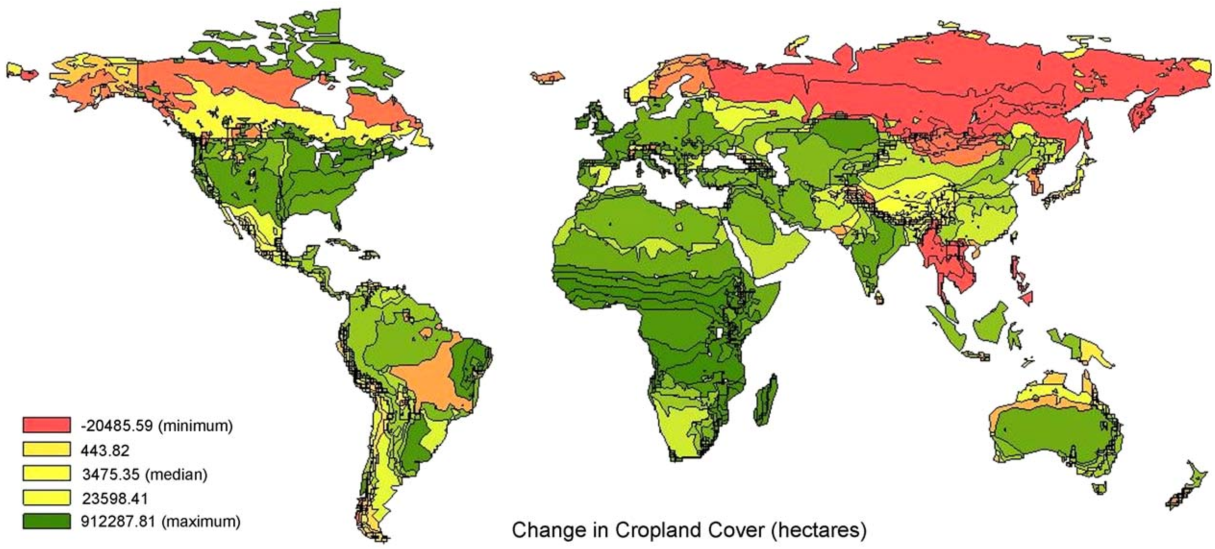


Fig. 5. Change in cropland cover, by AEZ (hectares).

Table 2
Change in cropland cover, by region.

	USA	EU-27	Brazil	Asia	Africa	RoW	World
Percent change	0.27	1.3	3.24	0.58	0.82	0.48	0.54
Million hectares	0.5	1.69	1.66	0.45	1.61	2.31	8.23

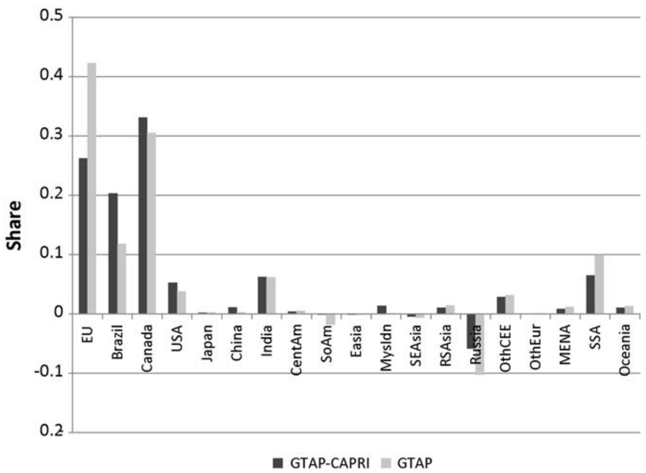


Fig. 6. Share of global increase in CO_2 emissions from cropland conversion, by region.

cantly understated in the GTAP-only model. Overall, global emissions are higher in the GTAP-only model, totalling 50.2 g/MJ, with most of this rise in emissions coming from increased conversion of pasture land to crops. We conclude that combining the two models generates significant improvements in the estimation of global GHG impacts. Of course, the other benefit from our multi-scale analysis is that we are also able to produce detailed estimates of environmental impacts with the EU region, by running the CAPRI model with the GTAP–CAPRI price changes. We turn now to a discussion of these impacts.

3.4. Detailed EU land use impacts

For the EU, the biofuels-driven expansion is mostly due to increased rapeseed areas, whereas expansions of sunflower seed and soybeans are of minor importance when measured in absolute terms. Land use cover changes depend to a large extent on the regional share of oilseeds in the base year, along with the econometrically estimated supply elasticity at the regional level. In general, we expect the supply elasticity to be larger in the regions where rapeseed is a minor crop (so that a given % increase is less disruptive of competing crops). As can be seen from Fig. 7, this results in the largest *percentage* increases (greater than 30%, see Fig. 7A) in rapeseed areas occurring in regions where initial shares in the base year are small (Fig. 7B). In Germany and France, where rapeseed area often exceeds 10% of total cropland area, the percentage increases are more modest (less than 20%).

What about the competing crops? Fig. 8 reports percentage changes in barley (Fig. 8A) and soft wheat (Fig. 8B) areas, sharper relative reductions (more than 20% decline) can be found in the regions with high rapeseed shares. The effect on barley area is somewhat more diverse than for wheat: in regions with very low oilseed shares such as in Ireland and Italy, the larger increase in coarse grain prices leads to area expansion at the regional level.

3.5. Environmental effects in the EU at the regional level

Due to the increase in EU oilseeds production, as well as higher prices which lead to an intensification of production, total crop nutrient use of nitrogen increases slightly (0.14%). Combined with slight reduction in manure (−0.5%) due to the contraction of livestock caused by higher feed prices, inorganic fertilizer applications increase by about 1.4%. The net effect is a slight increase of nitrogen surplus at the soil level of 0.5%. Gaseous losses of nitrogen are slightly decreased by −0.16% as gas losses from manure are higher than those for inorganic fertilizer. However, these modest aggregate impacts mask a more complex pattern of changes in nitrogen surplus at the regional level. Fig. 9 reports these regional changes in kg/ha. In the Netherlands, Ireland, Galicia and Scandinavia, the effect of higher feed concentrate prices leads

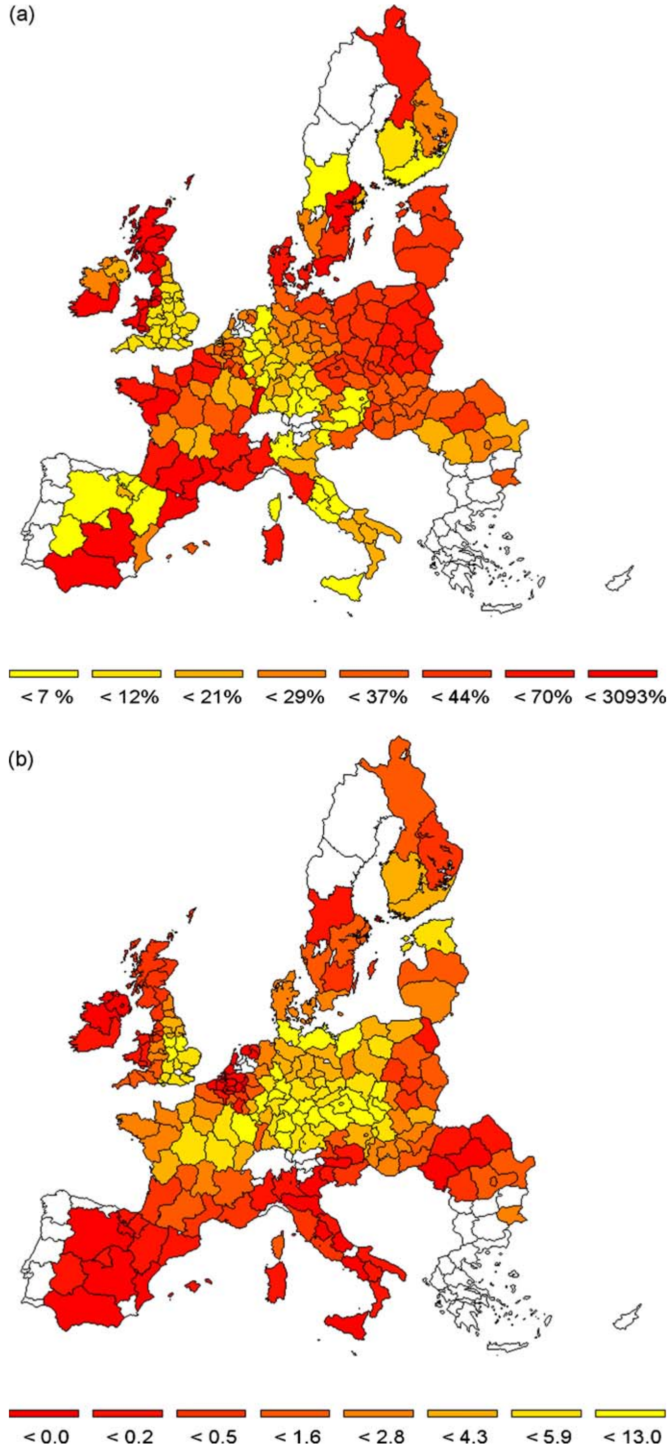
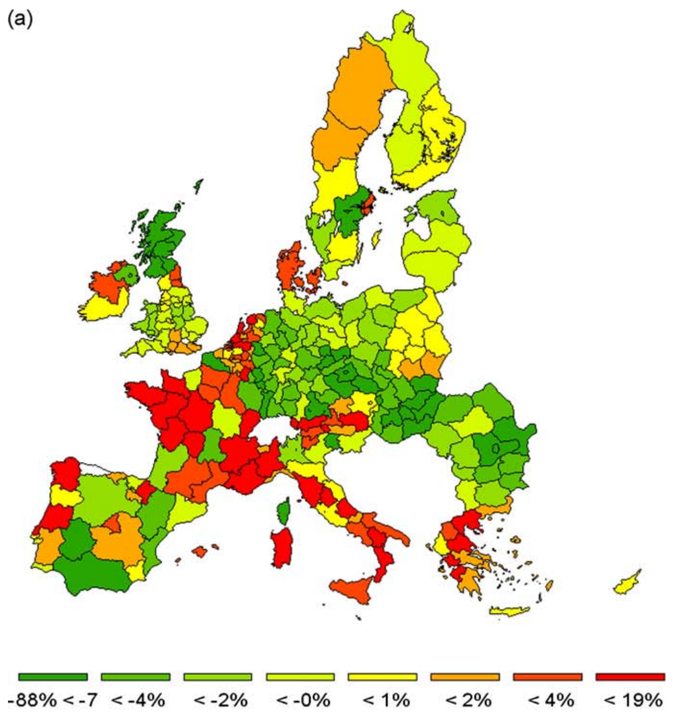


Fig. 7. (A and B) Change in rapeseed area and rapeseed share in base year crop area (%).



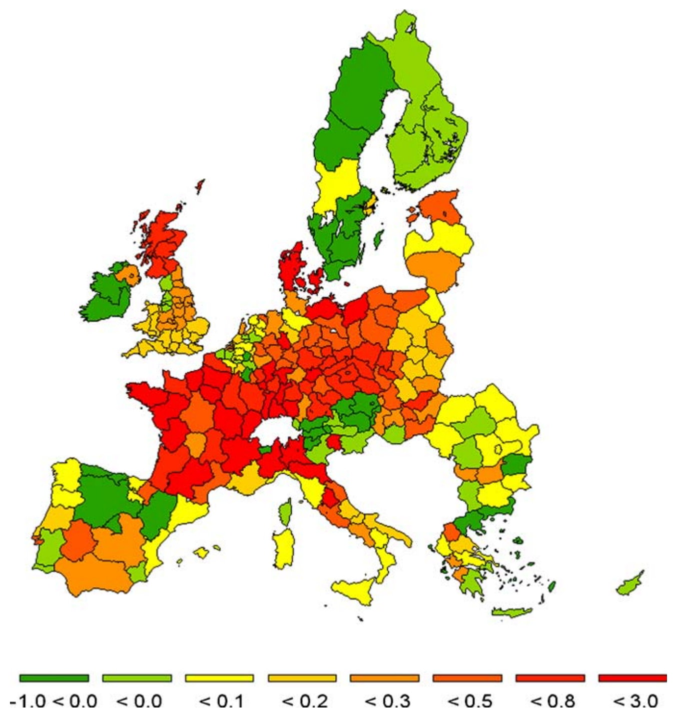


Fig. 9. Changes in nutrient surplus in kg/ha.

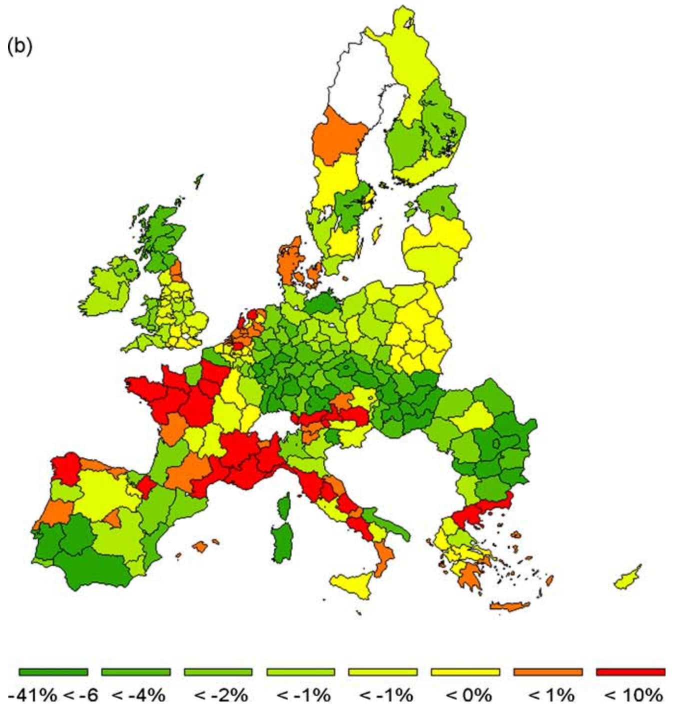


Fig. 8. (A and B) Changes in barley and soft wheat areas (%).

to a reduction of stocking densities which decreases the nutrient surplus by about 2 kg/ha. In the *Grandes Cultures* producing region, including France and Germany, higher crop yields generate an increase in nutrient surpluses of up to 2.5 kg/ha.

3.6. Uncertainties and areas for future research

As with all economic modeling exercises, the analysis presented in this paper is only as good as the data and parameters underpinning the models. Both the CAPRI and GTAP databases continue to evolve and benefit from continued policy relevant applications and research projects. If the model linkage work presented here is to be further developed, a high priority will be to reconcile the two databases. This job is made somewhat easier by the fact that we do not use the entire CAPRI model—just the supply side, and just the crops component at this point. So the key data to be reconciled include crop outputs prices, policies revenues, as well as harvested area and crop cover. Extending the model linkage to encompass the livestock sectors will be more challenging and should be delayed until full consistency for crops is obtained. Finally, any analysis of global land use change would ideally include the potential for land to be obtained from currently idle cropland or inaccessible forests. These are presently excluded from our analysis due to a lack of information about access costs and productivity of these lands. For an idea about how these lands might be incorporated into a model like GTAP, see Banse et al. (2007).

Parameters are also a key source of uncertainty in our results. Perhaps the most important parameters are those governing yield and area responsiveness to prices. Uncertainty in these parameters is explored in depth in the context of the GTAP-BIO model in a recent paper by Keeney and Hertel (2009). Comparing aggregate yield response in CAPRI to econometric estimates for the EU as a whole, and adjusting it accordingly would be beneficial. And some effort to reconcile area response in the two modeling frameworks would help in ensuring that these two margins of production response are more consistent between the two models.

As regards the modeling of biofuels, specifically biodiesel, it will be important to disaggregate the oilseeds, oils and meals sectors in greater detail, modeling their linkages to the feed, livestock and processed foods industries. Taheripour et al. (in press) show how this can be done and why it is important, particularly in the context of assessing the indirect land use impacts of biodiesel production.

4. Conclusions

As policy makers become increasingly aware of the impact of their decisions on the global economy, as well as the impact of developments in the global economy on regional and national resource use, the demand for multi-scale analysis of economic and environmental policies has become a high priority. This paper contributes to this literature by developing a new methodology to link two widely used policy models in order to provide an integrated assessment of the environmental impacts of EU biofuels mandates. By combining the CAPRI model of EU agricultural production and resource use with the GTAP model of global trade and land use, we are able to estimate both the global impacts of EU biofuels policies as well as the detailed, regional changes in land use and nutrient surplus in the EU.

The novelty in our approach involves the specification and estimation of a multiproduct crop revenue function which summarizes the key economic inter-relationships amongst EU crops sectors. The resulting own- and cross-price elasticities in turn inform the global general equilibrium analysis undertaken with the GTAP model, which seeks to predict the change in global trade and land use owing to an increase in EU biodiesel production. This cross-fertilization of modeling approaches is critical since the global distribution of cropland conversion determines the GHG emissions (the stock of above- and below-ground carbon varies greatly by region). As a consequence it is very important to know how much of the total increase in oilseed requirements can be satisfied from within the EU, how much must be imported, and where these imports will be produced. By incorporating a more detailed representation of production constraints as well as current policies in the EU, CAPRI offers a more accurate depiction of EU supply response. In particular, we find that the integrated model predicts less domestic supply response and more imports of oilseeds and oils than is the case in the standalone, GTAP-BIO model. The same goes for the cross-commodity interactions which determine the displacement of competing crops. By integrating regional models of land competition in the EU, the combined GTAP–CAPRI model offers important insights into which crops will be displaced. Finally, it also offers the opportunity to evaluate the local environmental impacts of increased biofuels production. The approach can be easily expanded to include models covering other regions of the world as long as these models are able to summarize their supply behavior as an array of compensated crop supply elasticities.

The applicability of this combined modeling approach extends well beyond biofuels. And, in light of ongoing developments in both CAPRI and GTAP, the domain of applications would seem to be expanding quite rapidly. For example, GTAP has been recently extended to deal with poverty issues (Hertel et al., 2009a). This opens the possibility of using the combined GTAP–CAPRI interface to examine the global poverty impacts of EU agricultural and biofuel policies. There are also important GTAP-related developments in the realm climate change policy (Hertel et al., 2009c). CAPRI offers the possibility of providing more refined agriculture-based GHG abatement supply schedules for the EU which could be incorporated into a global analysis based on the GTAP database and related models.

In sum, the methodology developed in this paper holds great promise for future, cross-scale analysis of global issues bearing on agriculture, land use and the environment.

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References

Banse, M., van Meijl, H., Tabeau, A., Woltjer, G., 2007. Will EU biofuel policies affect global agricultural markets? European Review of Agricultural Economics 35 (2), 117–141.
Britz, W., 2008. Automated model linkages: the example of CAPRI. Agrarwirtschaft, Jahrgang 57 (Heft 8), 363–367.
European Commission, 2007. Impact Assessment of the Renewable Energy Roadmap—March 2007. Directorate-General for Agriculture and Rural Development, European Commission AGRI G-2/WM D(2007): http://ec.europa.eu/agriculture/analysis/markets/biofuel/impact042007/text_en.pdf.
Fargione, J., Hill, J., Tillman, D., Polasky, S., Hawthorne, P., 2008. Land clearing and the biofuel carbon debt. Science 319, 1235–1238.
Hertel, T.W., Keeney, R., Ivanic, M., Winters, L.A., 2009. Why isn't the Doha development agenda more poverty friendly? Review of Development Economics 13 (4), 543–559.
Hertel, T.W., Lee, H., Rose, S., Sohngen, B., 2009. Modeling land-use related greenhouse gas sources and sinks and their mitigation potential. In: Hertel, T.W., Rose, S., Tol, R. (Eds.), Economic Analysis of Land Use in Global Climate Change Policy. Routledge Press, Abingdon (Chapter 6).
Hertel, T.W., 1997. Global Trade Analysis, Modeling and Applications. Cambridge University Press, Cambridge.
Hertel, T.W., Tyner, W.E., Birur, D.K., 2010. Global impacts of biofuels. Energy Journal 31 (1), 75–100.
Hertel, T.W., Rose, S., Tol, R. (Eds.), 2009c. Economic Analysis of Land Use in Global Climate Change Policy. Routledge Press, Abingdon.
Keeney, R., Hertel, T.W., 2009. The indirect land use impacts of United States biofuel policies: the importance of acreage, yield, and bilateral trade responses. American Journal of Agricultural Economics 91 (4), 895–909.
Kränzlein, T., 2008. Economic monitoring of fossil energy use in EU agriculture. Regional analysis of policy instruments in the light of climate-related negative external effects. Diss., Eidgenössische Technische Hochschule ETH Zürich, Nr. 17883. doi:10.3929/ethz-a-005750056.
Lee, H.L., Hertel, T.W., Rose, S., Avetsiyan, M., 2009. Economic analysis of land use in global climate change policy. In: Hertel, T.W., Rose, S., Tol, R. (Eds.), An Integrated Land Use Data Base for CGE Analysis of Climate Policy Options. Routledge Press, Abingdon (Chapter 4).
Leip, A., Marchi, G., Koeble, R., Kempen, Britz, W., Li, C., 2008. Linking an economic model for European agriculture with a mechanistic model to estimate nitrogen losses from cropland soil in Europe. Biogeosciences 5 (1), 73–94.
Monfreda, C., Ramankutty, N., Foley, J.A., 2008. Farming the planet. 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biogeochemical Cycles 22 , doi:10.1029/2007GB002947 GB1022.
OECD, 2008. Biofuel Support Policies: An Economic Assessment. OECD, ISBN-97-89r-r26404922-2.
Searchinger, T.D., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., Yu, T., 2008. Use of croplands for biofuels increase greenhouse gases through emissions from land use change. Science 319, 1238–1240.
Taheripour, F., Hertel, T.W., Tyner, W.E., Beckman, J.F., Birur, D.K., in press. Biofuels and their by-products: global economic and environmental implications. Biomass and Bioenergy.
Tokgoz, S., Elobeid A., Fabiosa J.F., Hayes D.J., Babcock B.A., Yu T., Dong F., Hart C.E. and Beghin J.C., 2007. Emerging Biofuels: Outlook of Effects on U.S. Grain, Oilseed, and Livestock Markets. Staff Report 07-SR 101, Center for Agricultural and Rural Development, Iowa State University http://www.card.iastate.edu/publications/synopsis.aspx?id=1050.