Use of General Equilibrium Models in Evaluating Biofuels Policies

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I. Introduction

Biofuels as an alternative for fossil fuels were in the center of attention during the recent years. Environmental effects of fossil fuels, energy security concerns, and high energy prices were the main motivations for biofuel supporting policies around the world. In addition to the United States, Brazil, and EU, as the main producers of biofuels, have had different policies aimed at supporting biofuels. Other countries such as China and India also setting ambitious targets for their biofuel industries (Koizumi and Ohga, 2007). Analyzing different aspects of direct and indirect effects of biofuels and the wide range of results from different methods and models, using different data and assumptions heated up the discussions about possible consequences of biofuel policies. Conflicting effects of direct benefits from using biofuel and indirect undesirable effects such as GHG emissions from indirect land use change, food security impacts and other socio-economic complications of biofuels are among the main reasons for these uncertainties and difficulties in evaluating biofuel impacts. Many of these indirect and intricate effects of biofuels resulted from complex ties among energy, food, agriculture, and other parts of the economy. Considering these facts, biofuel policy analysis is enabled by an economy wide and international prospective to incorporate various links and effects of biofuel sectors. Computable general equilibrium (CGE) models, because of their economy wide nature, integrate diverse effects of biofuels on different sectors of the economy are an appropriate tool for this study. Another approach for modeling biofuels are partial equilibrium (PE) models, and while it is not intended in this paper to discuss these models in detail, we need to mention them in some sections to get a better understanding of CGE models properties with this comparison. PE models used in biofuel studies generally are detailed models of agricultural sector covering livestock and forestry production in most cases. Some PE models also include a component for biophysical characteristics of the area to provide the researcher with a more realistic modeling ground. But all these fine details in PE models are achieved at a cost, losing the interactions among different sectors of the economy across various geographical regions that is a vital element in biofuel studies. On the other hand, CGE models by having a worldwide scope, accounting for trade, and considering different ties and possible interconnections across economy sectors provide a solid ground for modeling biofuel impacts. One disadvantage of CGE models is their treatment of land, which has been accomplished in several different ways. Improving land modeling within the CGE model such as GTAP-AEZ model (Lee, 2005) and linking a CGE model with a detailed land use model tried in KLUM@GTAP project (Ronneberger, et al., 2006) are two different approaches to handling land use analysis within the GE structure. Others have introduced a land supply structure in their analysis as in LEITAP and EPPA models (Babiker, et al., 2001, Banse and Grethe, 2008).

GTAP and other CGE models have been used in four key areas to assess the impacts of biofuels and their related policy effects:

- Induced land use changes (ILUC) and its associated greenhouse gas (GHG) emissions caused by increases in biofuels production – this refers to land conversion from pasture and forest to cropland to provide the additional crop production needed for biofuels. When pasture and forest are converted to cropland, there is a release of GHG emissions that are commonly referred to as induced land use change emissions.
- Impacts of biofuels production on crop and food production and prices – this refers to the famous food-fuel debate. The main question is the extent to which biofuels have caused significant increases in commodity and food prices.
- Economic and welfare effects of biofuels – since most biofuel industries have come into being as a result of government interventions and would not have existed in a market economy, the questions is to what extent have biofuel policies reduced economic welfare (ignoring any environmental benefits achieved by biofuels).
- Other extensions of the biofuels research such as their effects on livestock sector – the main first generation biofuels (corn ethanol and oilseed biodiesel) have co-products (distillers dried grains with solubles (DDGS) and oilseed meals), there

has been considerable interest in the interactions between biofuel production and livestock sector impacts.

To perform a dependable study and answer related questions, a suitable model is one part of the problem in a real-world situation like biofuel impacts. The other equally important part is access to high quality data as a base for running the model. The global trade analysis project (GTAP), provides a periodically updated global database of social accounting matrices that is used by almost all global CGE models (Kretschmer and Peterson, 2010).

In the remainder of the paper we describe various attempt to understand different aspects of a growing biofuel industry, demonstrate the evolution of CGE models and different techniques and methods used in implementing CGE models in the biofuel area. The topic with the most significance and controversy is induced land use change that we look into it in the second section of this paper. ILUC occurs due to the market mediated responses which in turn stems from an increasing demand for feedstock as the main input for biofuel industry. In section three we will discuss different attempts to explain the interactions between the biofuel industry and food markets and possible competition between food production and feedstock production and its effects on food prices. The fourth section of the paper is allocated to a review of different approaches to quantifying the economic and welfare impacts of biofuels. There are a wide range of studies utilizing CGE models to simulate diverse welfare and distributional effects of biofuel policies. The effect of biofuels on the livestock sector is the main topic for section five. We will conclude the paper and sum up the main points on biofuel impacts in the sixth section and point out the main required improvements in CGE modeling.

II. Land Use Change

Direct and Indirect land use changes resulting from increasing biofuel production is one of the most important and controversial subjects among different biofuel impacts. Considering its crucial role to emission changes and economic and welfare assessments, land use change has received a fair amount of attention from researchers in the area.

Direct land use change refers to changing current land use to produce biofuel crops. Indirect land use, on the other hand, refers to changes in land use and displacements of land types anywhere in the world to meet the increased demand for the biofuel crop. When the analysis is done with computable general equilibrium (CGE) models such as GTAP, the term used more today is induced land use change, which includes both direct and indirect. CGE models generally do not distinguish between direct and indirect land use changes.

While there are many different models used for various aspects of land use change, many of the models can be classified into two main categories – constrained optimization and market equilibrium (Wise, et al., 2014). Examples of the constrained optimization models are FASOM (Beach and McCarl, 2010), POLYSYS (Langholtz, et al., 2016, Ray, et al., 1998), and GLOBIOM (Havlík, et al., 2011) . The constrained optimization approach maximizes some economic objective (often consumer plus producer surplus) subject to a set of constraints. There are standard resource constrains, but also what are called flexibility (or inflexibility) constraints, which help calibrate the model baseline, but also can limit changes when shocks are applied.

Market equilibrium models can be divided into two main categories – general equilibrium and partial equilibrium. Examples of general equilibrium models that have been used for land use change analysis include GTAP-BIO (Golub and Hertel, 2012, Hertel, et al., 2010), MIRAGE (Decreux and Valin, 2007, Laborde, 2011), EPPA (Babiker, et al., 2001, Paltsev, et al., 2005), and LEITAP (Banse and Grethe, 2008, Edwards, et al., 2010). Examples of partial equilibrium models in this category are FAPRI (Devadoss, et al., 1993, Fabiosa, et al., 2010) and GCAM (Calvin, et al., 2014, Wise, et al., 2014). The partial equilibrium models commonly are more focused on the agricultural and related sectors of direct interest, whereas the general equilibrium models are more comprehensive and include some representation of all economic sectors in the economy, and often are global in scope. In fact, the four listed above all use the GTAP global database.

The nature of induced land use change requires a global view for being able to tackle the questions because of the fundamental role of international trade. That is important because price changes resulting from biofuel production in an economy may lead to induced land use change anywhere in the world. The global scope of the problem makes CGE models an appropriate tool for its assessment. Induced land use change can manifest in changes at the intensive or extensive margins. Intensive margin changes refer to things like double cropping that lead to greater use of existing cropland. To the extent the change is on the extensive margin, there can be conversion of pasture and/or forest to cropland to meet the added demand. These land conversions are what are called induced land use change, and they cause release of carbon emissions in above ground biomass and soil carbon. It is these emissions that are estimated to obtain the GHG emissions from induced land use change.

Emission effects of land use change from increases in biofuel production is one of the most debated topics in the field of biofuel impacts. Fargione and Searchinger are two pioneers in this area. Their research challenged the conventional wisdom that an increase in share of biofuels would result in a decrease in greenhouse gas emissions compared to fossil fuels. Fargione, et al results showed that converting native ecosystems to cropland for biofuel production would result in a drastic increase in GHG emissions for decades or even centuries compared to fossil fuel emissions. On the contrary, biofuels produced from perennial grown, degraded lands and wastes are able to decrease the GHG emissions (Fargione, et al., 2008). Searchinger's study on using US cropland for producing biofuels showed similar results, and they argued that use of US cropland for biofuels production would double greenhouse gas emissions through emissions from land use changes (Searchinger, et al., 2008). Many later studies find reduced amounts of net emission amounts from biofuels due to market mediated responses. (Hertel, et al., 2010) and (Beckman, et al., 2011) tried to address this problem. Hertel, et al used GTAP-BIO to estimate effects of US maize ethanol on global land use and greenhouse gas emissions. Considering by-product use and accounting for market mediated responses their results suggest 27 grams per MJ per year over 30 years of ethanol production. Hertel's estimation is about one fourth of 100 grams per MJ per year ethanol production that is reported by Searchinger. Subsequently GTAP-BIO was used by Beckman, et al. to simulate change in GHG emissions due to biofuel mandates. Their study accounts for all categories of market mediated feedbacks, consisting of direct and price-change-induced feedback effects of these mandates in both mandate and nonmandate regions and to all segments of agriculture, forestry, and fossil fuel. Tyner, et al also utilize GTAP-BIO-ADV with several improvements from GTAP model to improve corn ethanol analysis. Their model contained GTAP-E and GTAP-AEZ for energy-greenhouse gas emissions and land use calculations respectively. Improving the model, updating baseline data and accounting for growth in demand and yield, their estimation of GHG emissions due to land use changes concluded that emissions from US corn ethanol are only 13.6% of Searchinger, et al results. They also reported 24 percent of estimated land use to happen inside the US and the remaining 76 percent will be in other parts of the world (Tyner, et al., 2010). Darlington, et al used GTAP to compare its results on land use change GHG gas emissions due to EU biofuel policies and to compare then with the results from IFPRI2011 report (Laborde, 2011). Their results suggests that emissions are much less than IFPR2011 estimates from MIRAGE-Biof Model. Two primary reasons of this decrease compared to IFPRI2011 are because less land is required for the same policies, and a smaller share of that land comes from deforestation in the Darlington results. Assuming higher yield on converted lands, better representation of biodiesel industry, adding a new category of cropland-pasture for some regions and improved data and methods in the new GTAP model compared to the MIRAGE version used in IFPR2011 are the main reasons of those differences in results (Darlington, et al., 2013). Later in 2014, Escobar, et al studied EU's anti-dumping and first generation biofuel cap policies that are intended to decrease import of biodiesel and decrease GHG gas emissions from land use changes. Their finding from modeling those policies in GTAP-BIO suggests that in spite of anti-dumping policies, biodiesel imports will increase because of its rapidly increasing demand (Escobar, et al., 2014).

There are large differences between land use change impacts from first and second generation biofuels, with second-generation biofuels having far less land use changes than first-generation biofuels. Taheripour and Tyner developed a new version of GTAP-BIO to account for second generation biofuels as well as first generation. Their results for second-generation biofuels show that increase in cellulosic biofuel generation primarily come with conversion of cropland-pasture to dedicated crops and also a moderate deforestation. They also utilize their results to emphasize the importance of inclusion or exclusion of cropland-pasture and the significant role of change in soil carbon sequestration due to changes in land cover vegetation (Taheripour and Tyner, 2012). Furthermore, they improved GTAP model by calibrating the land transformation parameters to global regions and differentiating between costs of converting pasture and forest to cropland that were considered the same in previous versions of the model. Implementing these changes, they report a decrease in total land conversion, cropland expansion and also in the share of forests in cropland expansions (Taheripour and Tyner, 2013). Their results highlight the impacts of different ways for treating land conversions from natural areas to agricultural use is an important factor in general equilibrium models. (Gurgel, et al., 2007) also look into the role of different land conversion approaches by comparing results from two different methods. Using the EPPA model and GTAP data they parametrize a second-generation cellulosic biofuel production process and model associated land conversion in two different ways. In the first method, they use land supply elasticity based on observed land supply responses. In the second approach, they only use direct cost of land conversion. Results show significantly different amounts of each land type conversion but insignificant changes in total biofuel production. (Taheripour, et al., 2012) In another study showed a reduction in required land for ethanol production by estimating disaggregated by the country and agroecological zone values for extensive margin (productivity of new over existing croplands). All CGE models use different elasticity factors to model the interaction between different parts of the system due to changes in prices and quantities. One of the most important factors in assessment of emission and land use changes due to biofuels is yield elasticities. Models report differing results, and difference in yield elasticities could be one of the main reasons of these discrepancies. (Keeney and Hertel, 2009) studied effects of yield responses along with bilateral trade specifications on predictions of global land use changes. They tried to show the complexity inherent in large scale models used for indirect land use change studies by pointing out the importance of different assumptions on supply and bilateral trades responses for understanding the GHG emissions from indirect land use changes. Their results show that differing treatments of yield responses will lead to significantly different results in the US coarse grains land expansion and consequently different land conversions in the rest of the world. Moreover, they indicated a similarly strong impact on indirect land use change and associated emissions from different treatments of the acreage allocation and bilateral trade patterns in international commodity markets. Gohin investigates this issue further by comparing results of FAPRI and GTAP-BIO on modeling US corn ethanol estimates. He suggests that sensitivity to crop yield elasticity is not comparable between these two models because the ex-ante production and land elasticities are not comparable in those models. He suggests using comparable share of crop yield elasticities in production elasticities instead, and this approach leads to a more similar dramatic reduction in land use change and GHG emissions (Gohin, 2014). Gohin's results should be interpreted with caution since those results build on the crucial assumption that historical price-induced yield improvements are also attainable in the future. The global change assessment model or GCAM is another tool that is widely used for land use and climate change studies. (Wise, et al., 2014) used it to compare land use change results from different scenarios for agricultural productivity. Their results stress the importance of agricultural productivity. In their high productivity growth scenario, results indicate lower prices, higher crop production in developing countries and lower terrestrial carbon emission due to forest preservation. On the contrary, no productivity growth scenario shows higher prices for crops, more production increase in developed nations and higher terrestrial carbon emissions as a result of deforestation.

Another important subject in the field of biofuel and land use changes is introduction of new technologies. Taheripour and Tyner investigate such a situation by introducing a new, recently adopted technology into GTAP-BIO and compare the results. They introduced a new technology that involves biodiesel production from corn oil that is extracted from ethanol producer's residue. This corn oil extraction was enabled by a new technology. They showed that land use changes and GHG emissions would decrease due to increase in the amount of biofuel generated from a fixed amount of crop. They are also raised a question about how to allocate extra produced energy. Should it be credited to corn ethanol, to soy biodiesel or be shared between them, or should it be considered a new biofuel with zero land use impact (Taheripour and Tyner, 2014).

The wide range of land use change emission estimations presented by different studies and different models is an issue in assessing biofuel impacts and policy design. Plevin, et al studied this problem by linking GTAP-BIO-ADV and agro-ecological zone emission factor model (AEZ-EF). Based on their results they concluded the economic model is the main source of uncertainty that is expected because of its statistical and abstracted nature compared to carbon accounting that is based on physical science and behavior of a more stationary system (Plevin, et al., 2015).

(Schmitz, et al, 2014) used a multi model approach to compare results from different models to present a better image of how biofuels promote land use change in different regions. Four partial equilibrium models used in this study are MAgPIE, GLOBIOM, CGAM and IMPACT (Rosegrant et al., 2012). Six general equilibrium models were included, all based on the GTAP database. The AIM, FARM (Sands et al., 2013, 2014), and GTEM (Pant, 2007) models determine land use based on agro-ecological zones (AEZs; FAO, 1996). ENVISAGE (van der Mensbrugghe, 2013) and MAGNET model land use at the national level. EPPA is coupled with TEM (Felzer et al., 2004) to model land use change. While all these models approach land use change from an economic prospective, there are significant differences in their methods. For spatial dimensions and data sources, all CGE models adopt a more aggregate level of resolution compared to PE models. MAGNET, GTEM, ENVISAGE and EPPA all use a regional crop allocation, but EPPA uses TEM in addition to the same regional crop allocation in order to get a finer land use prediction based on climate, soil and economic date. FARM and AIM use GTAP AEZ data, and since most economic data are accessible at the country level, assume a single production function for each country and allow substitution of land types from different AEZs within a country. ENVISAGE, FARM, GTEM and MAGNET work based on a constant elasticity transformation function (CET) to transform a limited endowment of land across different uses, assuming land heterogeneity. AIM uses a logit function for the same purpose. All these five models nest the land allocation function. EPPA on the other hand, allows land conversion between categories if farmers are able to pay the conversion costs explicitly. Comparing to CET method EPPA’s approach allows longer-term analysis in which some land use demands may change drastically in contrast to the share preserving nature of the CET method. New land supply also is handled differently across models. MAGNET and ENVISAGE use a land supply function based on land rent. EPPA relies on historical land supply responses. CGE models account for all markets and sectors, but have less resolution to absorb spatial heterogeneity and also utilize fewer land types compared to PE models. Differences in yield improvement assumptions and elasticity of substitution between different inputs are another source of result discrepancy across models. For example, AIM and MAGNET assume little substitution possibility between land and capital-labor, while it is considered far more possible in ENVISAGE, GTEM and FARM. Schmitz results show that the main discrepancy between model results comes from different assumptions about land conversion costs, potential croplands and productivity responses.

III. Food-Fuel Tradeoffs

Policies focused on increasing biofuel share in total energy consumption have different goals and motivations. Reducing carbon emissions, energy independence, energy security and answering the increasing demand for energy are the main reasons for promoting biofuels as one of the main energy sources that can help us in achieving those goals. As for other policies, there are different intended and unintended consequences associated with these efforts. The link between agricultural and energy markets and the new bonds between these two markets that emerge with the increase in biofuel production is one of the most discussed side effects of bioenergy production (Tyner, 2010). Food price spikes in 2007-2008, which occurred as biofuel production was increasing rapidly, brought the food-fuel issue to the fore. Concerns about food price effects of an increase in biofuel production were raised by (Elobeid and Tokgoz, 2006, von Lampe, 2006). Both studies used partial equilibrium models (Aglink, Cosimo and OECD world sugar model) and used exogenous shifters for biofuel demand to investigate the interactions between agricultural and energy markets. (Banse, et al., 2007) for the first time used a computable general equilibrium model to account for direct and indirect effects of first generation biofuels on the agricultural markets. Using the LEITAP model, they demonstrated that with mandatory blending policies, biofuel could have a strong impact on global agriculture markets. Declining trends of agricultural product prices would slow down or even reverse. On the other hand, in absence of mandatory blending, subsidies or other incentives, there would be little effect on agriculture markets from the biofuel industry because production levels would be much lower absent incentives.

(Birur, et al., 2009) explored the future of biofuels and their effects on agricultural markets. They securitize the origins of US biofuel boom and predict a slowing of this rapid increase in US ethanol production. Their conclusion is based on the fact that current ethanol production fulfilled the demand as an octane and oxygen additive, and any further expansion in demand means direct competition with fossil fuels on an energy basis. Despite this fact, they report a doubling share for corn ethanol from the US corn production and a tripling biodiesel share for EU oilseed from 2006 to 2010. These developments would alter different markets. Their results suggest an improvement in the US petroleum products trade balance by about $6 billion that is largely offset by a drop in its agricultural trade balance. A larger deterioration in agricultural trade balance of EU will be compensated by an increase in manufactures and services exports. (Reilly and Paltsev, 2009) tried to predict the future of biofuel and food markets relationship for a longer period. They use EPPA model to simulate the effects of increased biofuel production on conventional agricultural markets by 2050 and 2100. They introduce two different technologies into EPPA that use biomass to generate electricity and produce liquid fuel. They also use two different scenarios for existence or nonexistence of climate policy. Their results show a necessity for substantial land conversion to biofuel crops. Based on their findings, the United States is able to produce enough biofuel from domestic resources by 2100 to supply 55% of its liquid fuel requirements, but at the cost of changing from a net exporter of agricultural products to a large net importer (From $20 billion exports to $80 billion imports). This study illustrates the large size of energy demands and possible significant effects of a biofuel industry on agricultural markets and land use.

Biofuels production increase, changes the type and strength of the bonds between energy and conventional agricultural markets by linking energy and food commodity markets in some new ways. These additional relationships between different markets increase the importance of CGE models in studying the cause and effects of different issues in the economy as a whole and more specifically in the affected energy and agriculture sectors. (Beckman, et al., 2011, Hertel and Beckman, 2011) tried to shed light on the new structures for these markets by modeling their interactions in using the GTAP model. Their results indicate that agricultural price variation is driven in large part by energy price volatility in the presence of large-scale biofuel production. However, the nature of some of the biofuel market conditions under policy supports can attenuate the price variability. The RFS places a required minimum on biofuel production regardless of energy prices. The blend wall can limit the maximum amount of ethanol regardless of energy prices. Thus, under these conditions, the market fossil energy prices cannot be transmitted to agricultural commodity markets as effectively. Similar investigations carried out by (Diffenbaugh, et al., 2012) emphasize the joint effects of climate change and biofuels on food prices. They used GTAP-BIO-AEZ in conjunction with a statistical model for simulating response of US corn yields to climate conditions. They report lower sensitivity for US corn price to energy policies and food-fuel market integrating than to anticipated near-term climate changes. Results also show a 50% enhancement in US corn price volatility sensitivity to climate change in presence of a biofuel mandate. They also argue that despite significant effects of closer integration of energy and agricultural markets on US corn price volatility, there will be little impact on food prices.

Having less detailed regional land data is one of the main shortcomings of CGE models compared to higher resolution PE models in the land use area. (Britz and Hertel, 2011) try to address this issue by coupling the GTAP model as a well-known CGE model with the CAPRI model of EU agricultural production and resource use. This combination of models helps to improve the prediction of change in global land use and trade due to an increase in EU bio-energy policies. While CAPRI offers a more accurate supply response for EU regions, GTAP results are crucial to answer the questions about the share of domestic oilseed production as a feedstock for biodiesel production - how much of it should be imported from non-EU regions. These results, attainable from the CGE model, are crucial since greenhouse gas emissions are determined by the global distribution of cropland conversion.

Due to links among different markets and direct and indirect interactions among different parts of the economy, any change in a sector will affect other sectors in different ways. (Smeets and Tabeau, 2015) look into the interaction of biofuel and food markets from a different prospective. Their approach is to investigate changes in food security as a result of using agricultural residue for bioenergy production. Using MAGNET, they implement a conceptual framework for analyzing effects of using residues on profitability of agriculture and forestry sectors. Results suggest a main commodity crop price decrease and an increase in production and consumption of the crops. This result occurs because of the increase in profitability of agriculture owing to the new market for the residues. They conclude that using agricultural residue will improve food security and alleviate some of adverse effects of using crops for energy production on food markets.

(Lotze-Campen, et al., 2014, Searchinger, et al., 2015) both used results from different general and partial equilibrium models to offer a better understanding of interactions between biofuel and food markets. Lotze-Campen, et al compared results of two general equilibrium models, AIM and MAGNET in addition to three partial equilibrium models, GLOBIOM, MAgPIE and GCAM. Detailed inter-model comparison of results for impacts of a high demand for a second-generation biofuel on food prices show a modest price increase. AIM and MAGNET show higher average price responses compared to the PE models used in the study, due to a more limited trade implementation. While allocation of biomass production differs between models, most of them show land supply elasticity beyond existing croplands or some tradeoffs with livestock and feed production. Land use change and new land expansion results show that MAGNET and AIM expand most of biomass production into currently unmanaged lands. PE models that show a larger rule for forestry products and forestry residue or relying on endogenous yield increases. They also compare a very ambitious emission reduction scenario with a worst case scenario for climate change and report a significantly larger price increase in climate impacts scenario (25% average increase across models) compared to a mitigating scenario (5% average increase across models). (Searchinger, et al., 2015) pick another approach and by using results from GTAP (Board, 2014, Edwards, et al., 2010), FAPRI-CARD (Transportation and Quality, 2006) and MIRAGE (Laborde, 2011) argue that all biofuel policies' gains in the area of emission reduction are at the cost of decreasing food resources and food consumption reductions. Considering this, they emphasize the importance of having a broad view on direct and indirect consequences of biofuel policies.

IV. Economic and welfare impacts of biofuels

The biofuel industry has grown rapidly during the past decades, and its considerable size makes it a new influential sector in the economy. There is new competition for resources between biofuel sector and agriculture, forestry, livestock and other parts of the economy that did not exist before. There is competition in the energy market as a result of the increased biofuel share in this market. There are also a wide range of subsidies and mandates, and each has different implications for the economy. Considering all of these effects, biofuel policies have important consequences that may affect the economy and make different groups of people better or worse off. CGE models are a crucial tool to study these effects, due to the inherent links across the different sectors of the economy. CGE models have this unique role because these economy wide effects can only be captured by a model that accounts for all different sectors and interconnections, potential substitutions, possible rebound effects, and other economy functions.

(Timilsina, et al., 2012) studied effects of biofuel mandates on different parts of the economy and the economy-wide impacts. Utilizing the GTAP database through the World Bank's ENVISAGE model, they focus on analyzing different consequences of a large biofuel expansion on different sections of the world economy, assuming all currently announced targets for future biofuel production will be achieved. They also include an ambitious scenario by doubling the planned goals. They report a modest price increase in food supply at the global level in both scenarios, but significant food supply effects in some developing countries. Agricultural commodity price increase is the largest for agricultural products that are used as feedstock for energy extraction such as sugarcane, corn and oilseeds. With respect to economy-wide impacts, biofuel expansion leads to a global GDP decrease. This aggregated GDP decline compared to baseline is expected since a large portion of biofuel targets are achieved by different mandates and interventions that have different efficiency loss consequences in the resource allocation procedure. GDP changes are not uniform; there are countries with increased GDP such as Brazil, Argentina and Thailand, but United States, China and India see a reduction in their GDP compared to baseline.

(Cororaton and Timilsina, 2012) in their study of biofuel expansion effects on poverty and income distribution used a CGE Model in conjunction with a Global Income Distribution Dynamics, GIDD Model, to simulate biofuel policy worldwide effects on income distribution and poverty. Their GIDD model results, based on ENVISAGE model output suggest an increase in the number of people living in poverty in both biofuel expansion scenarios compared to the baseline scenario, but this result is different for various countries. In East Asia poverty head count will increase largely driven by China. On the other hand in South America there is a reduction in poverty mainly influenced by Brazil results. Biofuel policies have distribution effects too. The overall GINI coefficients decrease in both biofuel scenarios compared to the baseline, although these reductions are small, they represent a more equal income distribution as a result of biofuel policies. These changes are expected since an increase in rural residents' income due to increase in agricultural product prices is anticipated. Although we have the opposing effect of increase in poverty among non-farmer low-incomes, the net effect is positive, and biofuel policies lead to a more equal distribution of income.

There are different parameters that affect distribution changes due to biofuel mandates. Keeney results show that these changes are not uniform across different geographical regions and various wealth levels. (Keeney, 2009) investigate impacts of biofuel mandates on US farm household wealth and report based on their GTAP bio results using a statistical model. This statistical model helps them to provide insight into distributional effects of biofuel policies. Their results show a positive role for initial wealth in distribution of the earnings and also differences between various geographical regions with the highest benefits received by Heartland and Northern Crescent farmers.

(Al-Riffai, 2010, Al-Riffai, et al., 2010) Used MIRAGE in two different studies to investigate different aspects of EU and Unites States biofuel policies. They have extended the Global Trade Analysis Project (GTAP) database to identify ethanol, biodiesel, additional feedstock and vegetable oil sectors, fertilizers and transport fuel sectors separately. Their results show a very limited food price increase due to EU biofuel policies. Biofuel policies also account for no significant income impacts in EU, but a modest decline in oil exporters and sub-Saharan Africa as a result of decreased oil and increased food prices, so global real income effect is negative on average. Employment effects vary across sectors and regions, but employment increases in feedstock related agricultural sectors and declines in employment in non-biofuel related sections. There are also a global increase in agricultural value added through almost all of the regions and sectors as a result of biofuel mandates. (Satyakti, et al., 2012) On the other hand, based on their EU biofuel mandates simulation results from GTAP-BIO, report a welfare increase as a result of a spillover for developing countries and welfare reduction for EU.

De Gorter and Just used a variety of methods and models in a set of studies to investigate economic and welfare effects of biofuels with a focus on comparing effects of different policies. They used a PE model of the U.S corn market in (De Gorter and Just, 2009) to estimate the welfare effects of a biofuel tax credit. Their findings demonstrate a direct welfare gain for corn farmers and a small welfare improvement for gasoline consumers resulting from a reduction in gasoline prices due to increased biofuel production. Later, (De Gorter and Just, 2010), they used a stylized model of the United States gasoline and ethanol market to assess welfare results for different biofuel policies. Based on their results, they argue that a mandate is far superior to consumption subsidies on biofuels.

(Taheripour and Tyner, 2014) Investigate the shortcomings of partial equilibrium analyses of biofuel policy impacts by calling attention to the limited scope of those models, that are typically limited to the agricultural and energy sectors. They argue that partial equilibrium model results could be misleading by not accounting for interactions among various economy sectors and possible rebound effects. They also raise concerns about omitting tax and subsidies and not considering interactions between these two and other distortionary policies in both partial and general equilibrium studies. Using GTAP-BIO-ADV for their study, they show that biofuel price impacts on coarse grains could be more than previously estimated. This underestimation is a result of decrease in agricultural subsidies due to allocating some of their resource to biofuel subsidies that will exacerbate the coarse grains price increase. They also report a possible rebound effect owing to a global decrease in gasoline price. They also report a welfare reduction impact for the US biofuel mandates because of efficiency losses associated with distortionary mandates.

Biofuel and agricultural sectors are closely related, and any change in one will affect another, so we can gain a better understanding of various policy effects if we look at the combined effects of those policies. (von Lampe, et al., 2014) Investigate economic consequences of OECD fertilizer and biofuel support policies using a CGE model, MAGNET. They argue that combined biofuel and fertilizer support policies have little effect on prices since lower agricultural demands due to abolishing biofuel support policies will cancel out by increased production costs because of no fertilizer support. Agricultural income decreased in case of eliminating biofuel and fertilizer policies by about 1% average globally, mostly from biofuel mandates. More generally their results show that biofuel support policies have a far greater impact on agricultural incomes compared to fertilizer subsidy policy, $0.9 global farm income increase for each dollar spent on biofuel support policies, compared to $0.05 for each dollar spent on fertilizer subsidies.

V. Impacts of biofuel on livestock sector

There are various ways that biofuel policies can affect the livestock sector, but there are two predominantly important paths that livestock can be affected from biofuel policies. The first one is changes in traditional feed markets and pastureland due to changes in agricultural product prices and land use changes due to the growing biofuel sector. The second way that biofuel industries could affect livestock sector is through biofuel byproducts such as DDGS and oilseed meals that can be used as animal feed in the livestock sector. These two main forces might move in opposite directions since land use changes and agricultural product price increase are limiting and cost increasing for livestock production. On the other hand, using biofuel byproducts as input for livestock can be cost decreasing.

(Taheripour, et al., 2010) studied different aspects of ties between livestock and biofuel, using GTAP-BIO. Their results show considerable price increase in pastureland and also price increase in crops used as animal feed. On the other hand, price of biofuel byproducts such as DDGS and oilseed meals that are used, as animal feed will decrease compared to crops or even in absolute terms in biofuel producing regions. Decrease in biofuel byproducts price as an alternative feed option compensate the price increasing effects of biofuel industries in the US and EU and improve the situation of livestock producers in these two regions, but has an adverse effect on livestock industries in other parts of the world that have no or limited access to the biofuel byproducts. Their results also show that 23% of estimated reduction in food demand due to biofuel policies is related to livestock and processed livestock products. In case of animal feed composite, they report a decrease in the cost share of coarse grains and increase the cost share of DDGS and oilseed meals. DDGS production boom will benefit ruminant meats industry the most. It also improves the situation for dairy farms and nonruminant industry, but with smaller magnitudes. In the EU, Reduced prices for oilseed meal will increase its share in feed rations of all EU livestock industries. They also look into several restricted situations with additional constrains to better understand the nature of effects. Their results show significantly higher food prices and more land conversion from forests and pasturelands to new cropland in case of assuming no byproducts for biofuels. Comparing results from this scenario and full effect experience, we can see about 50% land conservation from use of byproducts. (Birur, et al., 2009) also report similar results with reduced livestock output, using GTAP-BIO and ignoring byproducts role in the livestock industry. Altogether, we can conclude that while biofuel mandates have important implications for the livestock industry, the fact that biofuel coproducts become available attenuates the impact of other livestock feedstuffs.

There are different, sometimes contradictory studies on this subject. (Gohin, 2008) reported a reduction in input costs of livestock industry due to decreased price of protein-rich byproducts from biofuel industry. He also estimated a slight increase in animal/meat production using a CGE approach. These results are different with a partial equilibrium study by (Elobeid, et al., 2006) that predict a decrease in livestock product demand and a smaller livestock sector due to both reduced domestic demand and decreased exports. These differences can be justified by pointing out to the better representation of existing links between various markets such as labor markets in the CGE model. Results from a study by (Al-Riffai, et al., 2010) using MIRAGE, another CGE model, also predict a positive effect from biofuel mandates on livestock producers based on a reduction in byproduct prices. All these studies highlight the importance of biofuel byproducts to mitigate crop price increase as an input for livestock sector and show that considering these byproducts, livestock industry will not significantly affected by biofuel mandates.

VI. Conclusions

Biofuels as a growing sector of the economy have different effects on the environment, related sectors of the economy and also on the economy as a whole. Considering trade as an intrinsic element in this effects, we can argue on the inevitability of employing CGE models as the main tool to simulate interactions between economy sectors at a global level. GTAP, both as a well-known CGE model, and as a provider of required data in an international scale to other global CGE models has an important role in biofuel policy analysis. In this paper, we investigated different CGE approaches to model diverse aspects of biofuels. Table 1 provides a condensed summary of some of the major studies that are reported in this paper.

There are extensive studies on ILUC triggered by biofuels and related GHG emissions. ILUC is a multi-region, multi-sector subject by nature and global scope of CGE models are an essential character in ILUC analysis. Early studies reported very high levels of ILUC and enormous amounts of associated GHG emissions to the extent that biofuel GHG emissions exceed all GHG emission saving from substituting fossil fuels. This result caused biofuels to seem inefficient and unattractive. However, improved methods and enhanced models such as improved versions of GTAP-BIO with accounting for all market mediated responses, improved methods for treating land use, better representation of yield improvements and accounting for second generation biofuels, decrease the ILUC estimations and report much lower converted land and GHG emissions due to biofuel policies. Accounting for all markets and economy sectors in conjunction with a global scope, let GTAP and other CGE models produce dependable results in the area of land use change and associated GHG gas emissions.

GTAP also plays an important role in studies aimed at answering the food-fuel debate. Due to the importance of considering various interactions among different markets, especially energy and agriculture markets, CGE models are well suited for this assessment. While there isn't a collective agreement between different studies on effects of biofuel polices on food markets, most of studies show small effects on price and supply of food due to biofuel policies. Comparing effects of biofuel policies with climate changes also show a much higher impact from climate changes on food prices compared to biofuel induced food price increases.

Economy and welfare effects of biofuels is another topic for using CGE models to answer questions on these subjects. CGE models are a good choice for these analyses because of presence of different rebound effects and distributional and income effects in this area. Various studies using the GTAP model or GTAP database through other CGE models reveals a welfare and growth loss due to biofuel polices that is expected due to distortional nature of these policies. Results on distributional effects are not unanimous but we can predict a positive distribution effect for rural areas due to increased agricultural incomes, and deteriorated situation for urban area low-incomes.

With respect to biofuel and livestock sector interactions, different studies by GTAP and MIRAGE, both based on GTAP database put emphasis on the importance of including biofuel by-products in the analysis. Byproducts can be a low-cost alternative feed substituted for traditional crop feed and thereby alleviate the impacts of biofuels and soften the effects of biofuel policies and mandates on the livestock industry. In absence of by-products these impacts will be much larger due to increased price of traditional feed and conversion of pastureland.

Results from various studies and different CGE models show that there are two main issues in the CGE approach to biofuel modeling that need to be addressed. While the AEZ approach to land supply and conversion used in the GTAP model is quite advanced, land use treatment strategies in CGE models still need a lot of improvement and validation. Second, issues arise from different assumptions and coefficients used in modeling frameworks that need more extensive validation processes. Overall, considering multi-sectoral links of the biofuel industry, GTAP and other CGE models utilizing the GTAP database are primary tools for many assessments and simulations of biofuel impacts and will have an important role in future studies and policy evaluations as they have in the past.

Table 1. Condensed summary of some key CGE analyses

	Studies used CGE models to investigate biofuel policy effects		
	Study	**Area**	**Contribution**
GTAP	(Birur, et al., 2009)	Induced Land Use Change	Comparing different approaches to land supply
	(Keeney, 2009)	Economics and welfare impacts	Spatial wealth effects of biofuel polices
	(Keeney and Hertel, 2009)	Induced Land Use Change	Sensitivity of land use studies to yield responses along with bilateral trade assumptions
	(Tyner, et al., 2010)	Induced Land Use Change	Accounting for growth in demand and yield
	Hertel, et al., 2010	Induced Land Use Change	Accounting for market mediated responses
	(Britz and Hertel, 2011)	Food-Fuel Tradeoffs	Linking GTAP with CAPRI
	(Hertel and Beckman, 2011)	Food-Fuel Tradeoffs	Relationship between commodity price volatility and energy prices
	(Beckman, et al., 2011)	Induced Land Use Change	accounting for by-product use and market mediated responses
	(Diffenbaugh, et al., 2012)	Food-Fuel Tradeoffs	Accounting for climate condition
	(Golub and Hertel, 2012	Induced Land Use Change	Improving GTAP model by accounting for more parameters
	(Satyakti, et al., 2012	Economics and welfare impacts	Spillover and welfare effects
	(Taheripour and Tyner, 2012)	Induced Land Use Change	Adding second generation biofuels
	(Taheripour, et al., 2012)	Impacts on livestock	Biofuel byproducts and effects on livestock
	(Taheripour and Tyner, 2013	Induced Land Use Change	Calibrating land transformation parameters to global regions
	(Darlington, et al., 2013).	Induced Land Use Change	Comparing GTAP and Mirage-Biof
	(Escobar, et al., 2014).	Induced Land Use Change	Studying EU anti-dumping and first generation biofuel cap policies
	(Board, 2014)	Food-Fuel Tradeoffs	Pointing out food price increase due to biofuel policies
	(Taheripour and Tyner, 2014).	Economics and welfare impacts	Tax/Subsidy importance and rebound effects
	(Taheripour and Tyner, 2014)	Induced Land Use Change	Introducing new biofuel technology and studying its effects
	(Plevin, et al., 2015).	Induced Land Use Change	Studying sources of uncertainty in emission estimates
	(Taheripour, et al., 2015).	Induced Land Use Change	Effects of a GMO ban
EPPA	(Paltsev, et al., 2005),	Induced Land Use Change	Improving model
	(Reilly and Paltsev, 2009)	Food-Fuel Tradeoffs	Long term effects of biofuel on food market
MIRAGE	(Al-Riffai, 2010)	Economics and welfare / livestock impacts	Improving model by providing a more detailed database
	(Al-Riffai, et al., 2010)	Economics and welfare / livestock impacts	Improving model by providing a more detailed database
LEITAP	(Banse and Grethe, 2008)	Economics and welfare impacts	Discussing results from a CGE and a PE Model
	(Banse, et al., 2007)	Food-Fuel Tradeoffs	Using CGE model to study biofuel effects on ag. Market
ENVISAGE	(Cororaton and Timilsina, 2012)	Economics and welfare impacts	Effects of biofuel mandates on the whole economy (GDP, ..)
	(Timilsina, et al., 2012)	Economics and welfare impacts	Effects of biofuel mandates on poverty and income distribution
AIM	Lotze-Campen, et al., 2014,	Induced Land Use Change	Comparing results from AIM, MAGNET and PE Models
MAGNET	Lotze-Campen, et al., 2014,	Induced Land Use Change	Comparing results from AIM, MAGNET and PE Models
	(Smeets and Tabeau, 2015)	Food-Fuel Tradeoffs	Effects of using agricultural residue on food security
	(von Lampe, et al., 2014)	Economics and welfare impacts	Effects of fertilizer and biofuel support policy on agricultural income

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