A Global General Equilibrium Analysis of the Interactions between Biofuel Mandates and Greenhouse Gas Mitigation Policy

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Abstract. Using a global general equilibrium model, we simulate a reference scenario and three policy scenarios with a focus on capturing net carbon dioxide (CO_2) emissions from fossil fuels and land use change. The three policy scenarios are (1) global mandates for first-generation biofuels; (2) a price of US$ 15 per ton CO_2 imposed on Annex I countries; and (3) biofuel mandates combined with the Annex I country CO_2 price. The general-equilibrium modeling framework is comparative-static with 18 world regions, representing biofuel policies anticipated for year 2015. For the scenarios with a price on CO_2 emissions, the price is imposed on fossil fuel emissions only. However, we calculate changes in CO_2 emissions from both the energy system and land use change. Land use change emissions are annualized over 30 years for comparison with fossil fuel emissions. In the scenario with biofuel mandates only, CO_2 emissions from fossil fuels decline but are partly offset by annualized emissions from land use change. Global emissions decline by 3,060 Mt CO_2 in the scenario with only a CO_2 price. The decline in global emissions is 3,185 Mt CO_2 for the scenario with both biofuel mandates and a CO_2 price.

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In the last decade, global biofuel production has grown rapidly as a result of oil price increases and government policies promoting the development of biofuels. The policies have been motivated by multiple goals – including reducing net greenhouse gas (GHG) emissions, as well as increasing energy security and promoting rural development. Recently, the GHG implications of biofuels have come under intensive scrutiny, particularly the direct and indirect effects on land conversion to produce feedstocks for the first-generation biofuels that are currently commercially viable.

Global biofuels production currently represent about 3 percent of total transportation fuels, with the vast majority of production concentrated in the U.S., Brazil, and the European Union (EU). The primary sources are maize-feedstock ethanol in the U.S., sugarcane-feedstock ethanol in Brazil, and oil seed-feedstock biodiesel in the EU; second-generation technologies, which make ethanol from biomass feedstocks, are at the demonstration stage, and have not yet achieved cost-effectiveness for commercial scale production.

The U.S., Brazil, and the EU all have mandatory production/consumption biofuel requirements currently in place, as well as other policies designed to promote production. In addition, numerous other countries have articulated ambitions to increase their production and some have established legal mandates for production/consumption blending targets. Past research on the economic and GHG implications of biofuel mandates has focused on U.S. and/or EU mandates. In this paper, we explore the impact of a broader range of global mandates over the medium-term on global agricultural production, land use change, and greenhouse gas emissions (GHG). We focus solely on first-generation biofuels, i.e., ethanol from maize, wheat, barley, sorghum, sugar cane or molasses; and biodiesel produced from oil-bearing crops such as oilseeds and palm oil. We also consider the impact of combining incentive-based greenhouse gas mitigation policies with the global biofuel mandates. Though currently implemented only in the EU, such GHG mitigation policies are currently being considered by many countries.

One challenge in modeling GHG impacts of biofuel production is capturing the increased competition for land use, and the resulting implications for the economics of agricultural production. To accomplish this, we employ a CGE model of global economic patterns of production, consumption and trade that includes an explicit representation of heterogeneous land productivity. With this framework, we are able to take into account differences in land and other factor productivity and in competitive advantage for agricultural trade across regions.

Background and Literature review

Global biofuel production has increased rapidly in the last decade (Table 1). Though production is currently concentrated almost completely in the U.S., Brazil, and EU, numerous other countries have ambitions to increase their production and have articulated production or consumption blending targets or mandates (Table 2). Countries with significant potential include China, India, Canada, several Latin American energy exporters (including Argentina and Colombia), several Asian energy exporters (including Indonesia, Vietnam and Malaysia), as well as Thailand and the Philippines. If these countries increase biofuel production, the increased competition for land for food, feed and fuel is likely to have significant impacts on global food and agricultural systems.

Several studies have examined the greenhouse gas implications of biofuels. Life-cycle analysis is a common tool and examples include Fargione et al. (2008), Searchinger et al. (2008), and the U.S. Environmental Protection Agency (2009). These analyses estimate net greenhouse gas emissions, including carbon dioxide (CO_2) emissions from land use change, for given amounts of biofuel production.

The conventional wisdom has been that substituting ethanol for gasoline will reduce GHG emissions modestly with maize feedstock, and substantially with sugarcane or second-generation cellulosic feedstocks, and that substituting biodiesel for diesel fuel will reduce GHG emissions modestly with oil seed feedstocks, more with waste vegetable oil, and substantially with palm oil.[1]

Searchinger et al. (2008) challenged the conventional wisdom, arguing that with a complete accounting for GHG emissions, direct and indirect land use change (LUC) emissions greatly exceed combustion-related emission reductions for many crop-based feedstocks. Direct land-use change refers to the conversion of land from forestry or pasture to produce additional feedstocks; indirect land-use change refers to land conversion – perhaps in other countries - to produce crops displaced by additional feedstock production.

Life-cycle analysis has the advantage of providing great detail on relevant technologies, but can miss economic interactions through land competition and international trade. An alternative approach is to embed biofuels within a global computable general equilibrium (CGE) model. General equilibrium models have the advantage of capturing important economic interactions, but it can be challenging to introduce the level of technological detail found in life-cycle analysis.

Keeney and Hertel (2009) use the GTAP-BIO general equilibrium model to simulate the impact of U.S. biofuel policies on global land use. Sorda, Banse, and Kemfert (2009) provide a survey of biofuel policies across countries, a survey of modeling approaches, and an application of the LEITAP general equilibrium model to food production and land allocation in Germany. Hertel et al. (2009) illustrate the sensitivity of LUC projections to various assumptions, particularly the price-elasticity of crop yields, substitutability of ethanol co-products as animal feed, and intensity of livestock production. These CGE models introduce land use through agro-ecological zones (AEZs), where forests, agricultural crops, and livestock compete for land. Model results include changes in land use, agricultural production, and international trade in response to biofuel policies. However, only the Hertel et al. (2009) paper reported carbon dioxide emissions from land use change; and this was only for a ‘U.S.’ only scenario. Other studies of biofuel policies and the global agricultural economy include Banse et al. (2008) and Valin et al. (2009).

Besides biofuel mandates, another important policy driver is a greenhouse gas mitigation policy that establishes a price on emissions of carbon dioxide equivalent (CO2-eq). Reilly and Paltsev (2009) use the EPPA computable general equilibrium model to simulate the response of land use and biofuel production to a very stringent greenhouse gas mitigation policy in the U.S.

Forests present a challenge to economic modelers because of the lag between planting and harvest dates. Sohngen, Golub, and Hertel (2009) discuss the role of forestry in carbon sequestration and options for representing forests in a CGE model.

Wise et al. (2009) also simulate the role of biofuels under alternative greenhouse gas mitigation policies, with a global price on greenhouse gas emissions set to stabilize concentrations of carbon dioxide. This study uses a partial-equilibrium model that includes calculations of CO_2 emissions from land use change and a forward market for forest products. If CO_2 emissions from land use change are priced the same as other greenhouse gas emissions, the pattern of global land use is very different than in a policy that does not value land use emissions. Global forestland expands if land-use emissions are valued, but contracts if land-use emissions are not valued.

The contribution of our paper is to examine the interaction of biofuel policies with GHG mitigation policies, using a global general equilibrium model that allows us to take into account global feedback effects. We examine three policy scenarios: (1) global mandates for first-generation biofuels; (2) a price of US$ 15 per ton CO_2 imposed on Annex I countries; and (3) biofuel mandates combined with the CO_2 price in Annex I countries.

Methodology

CGE Model

The impacts of biofuel mandates are far-reaching, affecting all sectors of the regulated economies and beyond through trade, which creates market feedback effects. To capture the resulting feedback effects across production sectors and countries, we use a global Computable General Equilibrium (CGE) model, GTAP-BIO (Taheripour et al., 2007), which incorporates biofuels and biofuel co-products into the GTAP-E model (Beckman, Hertel, Tyner, 2009). GTAP-BIO has been used to analyze the global economic and environmental implications of biofuels in Hertel et al. (2008), Taheripour et al. (2008), and Hertel et al. (2009). The 18 regional aggregations used in this study, including separate regions for US, EU27, Brazil, China, Canada, and India, allow us to capture the variation in future mandates as well as in coverage by carbon mitigation incentive policies across countries and regions. (See Appendix A for the full listing of regions.)

In the GTAP-BIO model, the three biofuel commodities (biodiesel, coarse-grains ethanol, and sugar-cane ethanol) are specified as substitutes for oil products in the production and consumer sectors. (Gasoline, diesel or blended road fuels make up between half to two-thirds of the oil products commodity in most regions, with the remainder other types of fuel such as heating oil.) The production sector purchases some of the ethanol or biodiesel to blend with oil products, and the blended product is offered to consumers as part of the 'oil products' commodity. The consumption sector purchases some biofuels directly as a substitute for the gasoline or diesel road-fuel component of oil products, in addition to purchasing the blended products. The ethanol co-product, distillers dried grains with solubles (DDGs), is included as a separate commodity that functions as a feed substitute for livestock. The GHG accounting in the model captures CO_2 emissions from energy use by the energy sector (i.e., by the coal, oil, natural gas, and petroleum products sectors), and CO_2 emissions (or sequestration) from land use changes (LUC) in the agricultural and forestry sectors. Capturing non-CO_2 GHG emissions is beyond the scope of this analysis.

Because of the challenges in modeling direct and induced land-use change from increased production of biofuel feedstocks, we discuss in some detail the GTAP-BIO approach. To capture heterogeneous land quality, Hertel et al. (2008) integrated a detailed land-use module (GTAP-AEZ) within GTAP-BIO. Land use is disaggregated into 18 agro-ecological zones (AEZs) that share common climate, precipitation and moisture conditions. Alternative agriculture and forestry land uses then compete for lands with heterogeneous quality. Land use competition is modeled in the AEZ module with a nested constant-elasticity-of-transformation (CET) function. By imposing homothetic separability on the revenue function, the land allocation decision can be split into two sequential stages. In the first stage, the land-owner decides on land cover, i.e. whether a given parcel of land will be in crops, forestry or pasture. In the second stage, crop land is allocated across different uses. The econometric analysis of land use change by Lubowski et al. (2006) provides the parameters for the second stage.

GTAP is a comparative static model, forecasting changes from one equilibrium to another. To estimate the CO_2 implications from the forecast land-use changes, Hertel et al. (2009) developed an emission factor for each pair of land-cover transitions (i.e., forestland to/from cropland; pastureland to/from cropland; and forestland to/from pastureland). In order to be able to compare the change in CO_2 associated with a one-time land use change against the future stream of annual flows of reduced fossil fuels emissions enabled by the land use change, a time horizon and a discount rate must be chosen. Following Searchinger et al. (2008), Hertel et al. (2009) chose a 30-year time horizon with zero discount rate. Consequently the emission/sequestration factors are designed to account for the change in above- and below-ground carbon stocks over a 30-year period following a land use change. To compare net CO_2 impacts from LUC and from fossil fuel emissions, we annualize the estimated LUC emissions using the 30-year time horizon and zero discount rate.

GTAP-BIO is constructed with version 6 of the GTAP database, which has a 2001 base year. Since global biofuel production has only recently become more prevalent, we employ an historical updating simulation to shift the base year to 2007. In the simulation, we apply shocks to the structure of the bio-economy, including the price of petroleum, the ethanol additive requirement in the U.S., and U.S. and EU biofuels policies (subsidies), as well as to demand and supply factors, including population, factor endowments and technology productivity parameters. Benchmarking predictions against actual data on price and quantity changes in the agriculture sector indicates the simulation tracks actual outcomes reasonably well. (For more details on the procedure and the performance testing, see Beckman, 2008, pp. 143-146.) Further, to reflect the expanding global potential for production in U.S., EU, Brazil as well as other countries, we update the new 2007 database with 2007 levels of production, consumption, and trade amounts for three biofuel commodities: ethanol from coarse grain feedstock[2], ethanol from sugar feedstock, and biodiesel from oilseed feedstock.[3]

Policy Scenarios

To highlight the economic and GHG implications of mandated future global biofuel production, independently and in conjunction with GHG mitigation policies, we developed three scenarios. Scenarios A and C implement medium-term official biofuel production/consumption mandates for 8 countries/regions, including the U.S., EU, and Brazil. [4] (It does not include non-legislative, aspirational "goals".) See table 1 for the regional numerical mandates. For the U.S., the target is set at the maximum quantity mandated for conventional biofuels, which is to be attained in 2015 (and carried through 2022). For other countries, the mandates are specified as a share of transportation fuel usage; therefore, the shocks are modeled as consumption shares of road transportation fuels (with some specific to gasoline or diesel, others for total road fuels.) For regions with different mandate levels across countries, we calculated a weighted average.

For the GHG mitigation policy, Scenario B and C implement a US$15 price per metric ton of CO_2 emissions. Following the spirit of current policy in the EU and legislative proposals elsewhere in the globe, the incentive is levied only on fossil fuel sources. Following the spirit of the Kyoto Protocol, we implement the price only for developed countries (as defined by Annex I of the Kyoto Protocol.) The price level is based on U.S. EPA and U.S. EIA estimates of the allowance prices as of 2015 with implementation of current U.S. legislative proposals.[5]

Results

Table 3 reports the main results – changes in CO_2 emissions – for the three policy scenarios. We focus on the direction and relative magnitudes of the changes to compare results. A positive (negative) number in table 3 represents an increase (decrease) in the annual rate of emissions from the 2007 baseline to the policy scenario. For land use change, a reduction in CO_2 emissions represents an increase in the sequestration of carbon. The first three columns report LUC emissions, relative to the 2007 baseline land use. The fourth column reports annualized LUC emissions, which we compare against the annual fossil fuel emissions (column 5).

In Scenario A, as global biofuel production increases by about 17 B gallons from the baseline level of 20B gallons, the model projects LUC CO_2 emissions will increase and that fossil fuel CO_2 emissions will decrease. Based on the 30-year averaging method we employ to annualize emissions from one-time land-use changes, the net global effect is a reduction in annualized global CO_2 emissions. To analyze the variation in patterns across different policy treatments, we distinguish four sub-groups of regions, based on whether or not they have a biofuel mandate, and whether or not they have carbon incentives in the appropriate scenarios. The pattern observed for both groups of biofuel mandate countries (neither of which face a carbon price in this scenario) is driving the world pattern: mandate countries consistently generate higher LUC emissions and lower fossil fuel emissions. (The single exception is the Latin American energy exporters region, for which LUC emissions slightly decrease in as a result of land shifting from pastureland into forestry as well as into crop land.)

In contrast, the spillover effects projected for (both sets of) non-mandate countries are reversed; however, they are of much smaller magnitude in aggregate than for mandate countries and several regions diverge from the aggregate pattern. In aggregate, fossil fuel emissions increase in the set of regions without biofuel mandates because the reduction in mandate-region demand for oil products lowers global oil prices; absent a biofuel mandate, consumption of fossil fuel-based products increases. This reversal of the regulated-country pattern is often referred to as “leakage” from the policy gains in regulated countries.

Induced price changes in the agricultural and forestry sectors have more complex feedback effects. Prices are higher for crops – particularly for feedstock crops, but also for other crops, forestry, and livestock, which is a stimulus for increasing production. At the same, higher crop prices translate to higher costs for livestock, which is a damper on demand in that sector. Whereas regions with biofuel mandates consistently have higher emissions from land use change out of *both* forest and pasture into crop land, regions without mandates consistently have higher LUC emissions from net conversion only out of pastureland -- they are sequestering additional carbon by expanding net land in forests. In other words, the LUC spillover effects in nonmandate countries moderate global CO_2 emissions from forestry, but augment global emissions from pasture – on net, LUC emissions from this group of countries fall, for a moderating global effect. The variations across nonmandate regions in whether their LUC emissions are higher or lower follow from the relative shares of net land use change into forest vs. cropland from pasture, which will be influenced by regional variations in productivity by land-use and in market opportunities.

In Scenario B, the model projects that fossil fuel CO_2 emissions will decrease substantially, compared to the marginal reduction for implementing global biofuel mandates in Scenario A. The greater mitigation observed in Scenario B than Scenario A is consistent with expectations, given that a carbon-incentive levied on fossil fuel CO_2 emissions in developed countries has a direct incentive effect by increasing the cost of fossil fuel emissions – and covers a much larger share of the global economy than the global biofuel mandates. Again the pattern observed in the countries receiving the policy treatment is driving the world pattern: Annex I countries with carbon incentives consistently produce lower fossil fuel emissions. (The aggregate LUC effects are very small compared to the fossil fuel impacts in this scenario and compared to the LUC effects in Scenario A.) And again the spillover effects in countries without incentives again work in the opposite direction, creating “leakage”: this time, it is the reduction in Annex I region demand for oil products that lowers global oil prices, which in turn induces higher consumption of fossil fuel-based products and higher related emissions in non-Annex I countries.

In Scenario C, the model projects fossil fuel CO_2 emissions will decrease substantially, slightly more than the simple sum of the effects from the two policies independently.

However, the synergistic effect further reducing fossil fuels emissions is completely driven by the U.S. response – for every other region, the net effect is less than the sum of the two policies. For land use, the synergistic effect is to further increase LUC emissions. Decomposing the responses for countries with and without mandates, we see that LUC emissions in mandate countries have increased by more than the simple sum of the two policy effects with the addition of a carbon price in Scenario C (relative to Scenario A) – most notably in the three countries subject to both policies, U.S., EU, and Canada. At the same time, the spillover effect whereby LUC emissions decrease in nonmandate countries is also augmented. The net effect is virtually a wash. However, an interesting outcome is that the composition of total LUC emissions changes: the share from deforestation drops from over 60% to around 50%, as emissions from pasture land conversion commensurately increase.

To better understand the patterns of LUC emissions, it is helpful to look at the underlying market impacts. For the three scenarios, table 4 reports changes (relative to the 2007 baseline) in outputs for biofuels and oil products, crop sectors, livestock and forestry. It is apparent that the mandates are projected to generate very large increases in production in many of the regions, particularly for biodiesel, which raises questions of their feasibility in the 5-7 year time frame.

As global biofuel production increases in Scenario A, global production of feedstock crops (coarse grains, sugar cane, oil seeds) increases, and global production of other grains (paddy rice and wheat), forestry and livestock decreases. The global patterns reflect the direction of the effects in countries with mandates. For some commodities, the spillover effects in the rest of the world augment mandate-country impacts, whereas for others, spillover effects moderate them.

The increase in demand for feedstock crops is sufficiently large to generate large price increases in many regions, inducing additional production in non-mandate countries to supplement additional mandate-country production. Livestock decreases in all countries – those with and without mandates - due to the higher costs of feed and land. The scale of land use requirements to grow coarse grains displaced from feed to biofuels is moderated by the decline in the livestock sector, as well as by substitution of the biofuel byproduct, DDGs, for coarse grains in livestock feed.

In contrast, some of the production of other grains and of forestry products that is displaced from mandate regions to accommodate feedstock production is shifted to non-mandate regions, which consistently increase production of both relative to the baseline. As noted earlier, the expansion of forestry in non-mandate regions, which occurs particularly in AEZs where feedstock crops cannot be grown or are at a competitive trade disadvantage, reduces the net CO_2 emissions from deforestation in the global GHG accounting relative to the levels for mandate countries only.

In Scenario B, for Annex I regions, production of oil products consistently decreases, and production of biofuels and their feedstocks increases marginally. Production of forest products generally declines, with the dominating exception of the Eastern Europe/Former Soviet Union region; the direction of changes in livestock production levels varies across regions. Non-Annex I regions evidence essentially the reverse patterns: production of oil products consistently increases, and production of biofuels and their feedstocks increases to a smaller extent than in Scenario A or declines marginally. Production of forest products generally increases, and production of livestock generally declines. In Scenario C, the changes in production levels tend to approximate the combined effects of the two policies implemented singly.

Conclusion

In this paper, we explore the medium-run effects (5-7 years) of two sets of related policies: an expanded set of production/consumption mandates for first-generation biofuels (beyond US, EU and Brazil) and economic incentives for reducing CO_2 emissions from fossil fuels. We consider each by itself and then jointly, focusing on regional outcomes for agricultural production, land use change, and GHG emissions on the global scale. Our simulations project that current global biofuel mandates will yield a small reduction in global CO_2 emissions in the medium term (due in part to our assumption of the 30-year time horizon for land-use changes). Our simulations further project that fossil-fuel carbon emission incentives in developed countries yield a substantially greater reduction in global CO_2 emissions, compared to the currently legislated global biofuel mandates. The cumulative effect on reducing CO_2 emissions of implementing the two policies jointly is slightly greater than the sum of the mitigation effects of the policies implemented singly.

The global CGE framework we employ, which includes an explicit representation of heterogeneous land productivity, allows us analyze the market-mediated feedback effects in land use change, as well as in fossil fuel use, in countries not subject to the policies. In regions subject to a carbon price or biofuel mandate, production of fossil-fuel based products declines, along with the related CO_2 emissions. But leakage in fossil fuel emission reduction occurs in regions not covered by the biofuel mandate or a carbon price. The model captures the lower global oil price that results from the policy-induced reduction in global demand for oil, and the extent to which unregulated regions increase their consumption of oil-related product as a result.

The model also captures the spillover effects in land use change induced by biofuel mandates. In regions subject to a biofuel mandate, both the livestock and forestry sectors shrink, as forest and pasture land on net are converted to crop land – releasing CO_2 emissions. But in regions not subject to a biofuel mandate, CO_2 emissions from land use change fall, again providing a countervailing effect. Due to the increased competition for land, prices of all agricultural products increase, but the increase in crop prices results in higher livestock costs as well – leaving it at a greater disadvantage. On net pasture is converted to crop land, which releases CO_2 emissions, but also to forest land, which sequesters carbon. If these feedback effects in the uncovered regions are not included, for example in the life-cycle accounting approach, the net global increase in LUC emissions will be overstated.

The results in this paper should be interpreted as suggestive for several reasons. Previous studies on the economics of biofuels have shown that the economic impacts are sensitive to a number of factors about which there is much uncertainty, particularly energy prices, the degree of substitutability between DDGs and coarse grains for livestock feed, the rate of technological change in agricultural production and in biofuel production, and changes in the structure of demand for agricultural products as populations and income levels rise in the developing world. Further the GHG accounting only includes CO_2 from land use change and from fossil fuel emissions; also, the comparisons of levels of CO_2 emissions from fossil fuels and land use change are sensitive to the particular approach to annualization. Important next steps in the modeling would be to include non-CO_2 GHG emissions from agriculture. An important extension of the policy scenarios would be to consider carbon incentives on LUC emissions as well as fossil fuel emissions. A comprehensive greenhouse gas policy would place a value, or CO_2 price, on all emissions of greenhouse gases, whether they originate with fossil fuel combustion or with land conversion.

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Table 1. Ethanol and Biodiesel Production, Consumption and Imports, 2001, 2007, and Medium-term Mandates (5-7 years)

	Ethanol				Biodiesel			Total
	Production		Net Imprt	Mandate	Production		Mandate	Production
	(Mgal)		(Mgal)	(biofuel %)	(Mgal)		(biofuel %)	(Mgal)
Region	**2001**	**2007**	**2007**	**Med. run**	**2001**	**2007**	**Med. run**	**2007**
United States	2,154	6,871	355	15B gal[a]	34	510	1B ga[a]	7,381
Canada[b]	74	160	131	5	0	24	2	184
EU 27	252	951	386	5.75[c]	256	1,666	5.75[c]	2,617
Brazil	3,039	5,957	-933		0	106	5	6,063
India	469	647	-2	10	0	3	5	650
Latin Am Energy Exporters	67	142	2	2[c]	3	117	2[c]	259
S. Asia Energy Exporters	43	50	-12	2	0	75	1	125
Rest of Asia	93	264	-39	8	0	57	3	321
Japan	0	29	124		0	0		29
E. Europ., FSU Energy Exporters	247	232	-20		0	0		232
Rest of Europe	158	185	10		0	18		203
Oceania	46	53	-4		0	30		83
China	806	991	-34		2	30		1,021
Rest of Latin Am	160	216	-60		34	34		250
Middle East	106	34	6		0	0		34
Sub-Sahara Afr Energy Exporters	35	61	48		0	0		61
Rest of Africa	91	107	-46		0	0		107
Rest of High Income Asia	61	48	79		0	24		72

Source: F. O. Licht, compiled by William Coyle, ERS.

Notes:

a. Unlike other countries, the US mandates is defined in terms of quantities of production. We use the maximum current quantity mandate for conventional biofuels, to be attained in 2015 (and carried through 2022).

b. This is the federal mandate, some of the provinces have mandates that are more stringent.

c. These mandates are specified on the combined total of biodiesel and ethanol, not on the individual products.

d. Mgal = million U.S. gallons

Table 2. Biofuel medium-term blending targets and other developments, selected countries	
Regions/ Countries:	**Medium-term blending targets and other developments**
U. S.	Conventional fuel standard increases through 2015 (to 15 B gal ethanol and 1 B gal biodiesel, carried through 2022), with an additional 5.5 B gal in advanced biofuels in 2015. [EISA, 2007]
Canada	5 percent ethanol content in gasoline by 2010, 2 percent biodiesel in diesel by 2012. [Federal standards.]
EU27	5.75% biofuel share of transportation fuel in 2010, 10% share in 2020. [Renewable Energy Directive, 2008]
Brazil	Ethanol use (anhydrous blend and pure hydrous ethanol) now accounts for about 50 percent of fuel use by private vehicles (excluding trucks). Mandatory 25 percent mix of anhydrous ethanol in gasoline as of 2007 (but no hydrous ethanol mandate); 5% percent blend of biodiesel with diesel as of 2010.
Japan	3% non-mandatory ethanol blend. Proposed 5% biodiesel blend. 2011 production goal, 0.0125 mi. gal. [no target]
China	Goal of 15% share of transportation fuels, 2020. [no target]
India	10% ethanol content in gasoline, 2008; 5% biodiesel blend, 2012. Proposed 20% biofuel content by 2017.
Latin American energy exporters	
Argentina	5% biofuel blend, 2010. [Biofuels Act, 2006]
Colombia	20% ethanol blend, 2012. 10% biodiesel mix by 2009.
Mexico	Developing 6% blend ethanol for sale in 3 largest cities; will begin testing biodiesel blends of 0.5-1.0 % between 2008 and 2010. [no target]
South Asia energy exporters	
Indonesia	3% ethanol blend of gasoline, 2.5% biodiesel blend, 2010.
Malaysia	5% biodiesel blend used in public vehicles now; plans to extend mandate to all diesel-consuming vehicles and industry in the near future are on hold. [no target]
Vietnam	1% share of country's petroleum demand, 2015.
Rest of Asia	
Philippines	5% ethanol share in gasoline, 2011, and 2% biodiesel blend in diesel products, 2008 [Biofuels Act (2007)].
Thailand	15% ethanol share target and 5% biodiesel (from palm oil) share target, 2011.

Sources: Compilation from F.O. Licht by Wiliam Coyle, ERS, personal communication, 2009.
Notes: Petroleum barrel" is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 liters); about 7.2 barrels oil are equivalent to one tonne of oil (metric) = 42-45 GJ.

Table 3. Change in CO2 Emissions for Three Policy Scenarios, by Region.

Scenario A: Global biofuel mandates only.
units = million tons CO2 emissions

	1	2	3	4	5	6
Region	**LUC from Forest**	**LUC from Pasture**	**Total LUC**	**LUC* - annualized**	**Fossil fuels**	**Net Annual Emissions**
With biofuel mandates:						
US	18.4	42.6	61.0	2.0	-41.5	-39.4
Canada	258.2	36.1	294.3	9.8	-2.4	7.4
EU 27	234.2	49.3	283.4	9.4	-0.7	8.8
Subtotal	***510.7***	***128.0***	***638.7***	***21.3***	***-44.6***	***-23.3***
Brazil	10.0	25.6	35.6	1.2	-0.6	0.5
India	203.5	21.3	224.8	7.5	-7.2	0.3
LAm EEX	-25.3	20.4	-4.9	-0.2	-4.9	-5.1
SASIA EEX	212.4	2.9	215.3	7.2	-2.7	4.4
RoASIA	120.9	12.5	133.4	4.4	-10.1	-5.6
Subtotal	***521.4***	***82.8***	***604.2***	***20.1***	***-25.6***	***-5.5***
Without biofuel mandates:						
Japan	4.7	0.1	4.8	0.2	0.8	1.0
EE FSU EEX	-80.2	87.3	7.1	0.2	-1.9	-1.6
R of Eur	1.0	15.8	16.8	0.6	0.3	0.9
Oceania	-4.0	12.0	8.0	0.3	0.3	0.6
Subtotal	***-78.4***	***115.1***	***36.7***	***1.2***	***-0.4***	***0.8***
China	-184.8	52.4	-132.3	-4.4	2.3	-2.1
Ro LAC	-63.2	17.9	-45.3	-1.5	-0.3	-1.8
Middle East	-0.5	2.9	2.4	0.1	0.9	1.0
SSA EEX	-23.8	25.4	1.7	0.1	0.5	0.6
Rof Afr	-1.2	3.8	2.6	0.1	0.1	0.2
RoHiIncAsia	-0.1	0.0	-0.1	0.0	0.6	0.6
Subtotal	***-273.5***	***102.4***	***-171.1***	***-5.7***	***4.1***	***-1.6***
All Mandate	***1,032.1***	***210.8***	***1,242.9***	***41.4***	***-70.2***	***-28.7***
All No-mandate	***-351.9***	***217.5***	***-134.4***	***-4.5***	***3.7***	***-0.8***
Total	**680.2**	**428.3**	**1,108.5**	**37.0**	**-66.5**	**-29.5**

* Annualized LUC emssions (col. 4) are a 30-year average of total LUC emissions.

Annex I country/region (has carbon price in scenarios B and C.)

Table 3, cont'd.

Scenario B: Carbon price only.
units = million tons CO2 emissions

	1	2	3	4	5	6
Region	**LUC from Forest**	**LUC from Pasture**	**Total LUC**	**LUC* - annualized**	**Fossil fuels**	**Net Annual Emissions**
With biofuel mandates:						
US	32.3	-0.6	31.6	1.1	-1,251.6	-1,250.5
Canada	20.2	-4.8	15.5	0.5	-69.8	-69.3
EU 27	11.7	-0.8	10.9	0.4	-639.8	-639.4
Subtotal	***64.2***	***-6.2***	***58.0***	***1.9***	***-1,961.1***	***-1,959.2***
Brazil	-31.3	3.1	-28.3	-0.9	1.3	0.3
India	-13.0	-2.0	-15.0	-0.5	-1.0	-1.5
LAm EEX	-8.0	1.0	-7.0	-0.2	2.5	2.3
SASIA EEX	-9.3	0.1	-9.2	-0.3	2.5	2.2
RoASIA	-7.1	-0.5	-7.6	-0.3	2.7	2.4
Subtotal	***-68.7***	***1.6***	***-67.1***	***-2.2***	***8.0***	***5.8***
Without biofuel mandates:						
Japan	0.5	0.0	0.5	0.0	-145.0	-145.0
EE FSU EEX	-141.5	61.1	-80.4	-2.7	-784.8	-787.5
R of Eur	3.3	-1.4	1.9	0.1	-68.4	-68.3
Oceania	17.5	-4.7	12.8	0.4	-122.0	-121.6
Subtotal	***-120.2***	***54.9***	***-65.2***	***-2.2***	***-1,120.2***	***-1,122.4***
China	23.1	-5.9	17.3	0.6	8.5	9.0
Ro LAC	3.0	-0.9	2.1	0.1	-1.2	-1.2
Middle East	-0.2	-0.8	-0.9	0.0	4.2	4.2
SSA EEX	-36.6	3.4	-33.2	-1.1	0.8	-0.3
Rof Afr	-0.7	-0.4	-1.1	0.0	1.2	1.2
RoHiIncAsia	0.0	0.0	0.0	0.0	2.6	2.6
Subtotal	***-11.3***	***-4.5***	***-15.9***	***-0.5***	***16.0***	***15.5***
All C-price	***-55.9***	***48.7***	***-7.2***	***-0.2***	***-3,081.3***	***-3,081.6***
All No-C-price	***-80.0***	***-2.9***	***-82.9***	***-2.8***	***24.0***	***21.3***
Total	**-136.0**	**45.8**	**-90.2**	**-3.0**	**-3,057.3**	**-3,060.3**

* Annualized LUC emssions (col. 4) are a 30-year average of total LUC emissions.

Annex I country/region (has carbon price in scenarios B and C.)

Table 3, cont'd.

Scenario C: Global biofuel mandates and carbon price.
units = million tons CO2 emissions

	1	2	3	4	5	6
Region	**LUC from Forest**	**LUC from Pasture**	**Total LUC**	**LUC* - annualized**	**Fossil fuels**	**Net Annual Emissions**
With biofuel mandates:						
US	197.9	71.3	269.3	9.0	-1,480.5	-1,471.5
Canada	271.6	37.2	308.8	10.3	-68.7	-58.4
EU 27	260.2	54.4	314.6	10.5	-619.9	-609.4
Subtotal	***729.7***	***162.9***	***892.6***	***29.8***	***-2,169.1***	***-2,139.4***
Brazil	-13.4	29.5	16.1	0.5	2.5	3.0
India	187.3	19.8	207.1	6.9	0.3	7.2
LAm EEX	-50.0	29.7	-20.3	-0.7	0.5	-0.1
SASIA EEX	197.1	3.6	200.7	6.7	2.8	9.5
RoASIA	113.4	11.7	125.1	4.2	-4.6	-0.4
Subtotal	***434.5***	***94.2***	***528.8***	***17.6***	***1.5***	***19.2***
Without biofuel mandates:						
Japan	6.7	0.1	6.8	0.2	-141.4	-141.2
EE FSU EEX	-235.8	158.2	-77.6	-2.6	-772.6	-775.2
R of Eur	6.8	17.2	24.0	0.8	-65.6	-64.8
Oceania	3.5	13.3	16.8	0.6	-120.6	-120.0
Subtotal	***-218.8***	***188.8***	***-29.9***	***-1.0***	***-1,100.2***	***-1,101.2***
China	-193.4	57.2	-136.2	-4.5	21.5	17.0
Ro LAC	-70.6	20.8	-49.8	-1.7	0.1	-1.5
Middle East	-0.6	2.5	1.9	0.1	11.7	11.8
SSA EEX	-99.7	43.5	-56.2	-1.9	2.7	0.8
Rof Afr	1.8	4.2	6.0	0.2	2.3	2.5
RoHiIncAsia	0.0	0.0	0.0	0.0	5.5	5.5
Subtotal	***-362.4***	***128.1***	***-234.2***	***-7.8***	***43.8***	***36.0***
All Mandates	***1,164.2***	***257.1***	***1,421.4***	***47.4***	***-2,167.6***	***-2,120.2***
All Non-mandate	***-581.2***	***317.0***	***-264.2***	***-8.8***	***-1,056.4***	***-1,065.2***
All C-price	***510.9***	***351.7***	***862.7***	***28.8***	***-3,269.3***	***-3,240.6***
All No-C price	***72.1***	***222.4***	***294.5***	***9.8***	***45.4***	***55.2***
Total	**583.1**	**574.1**	**1,157.2**	**38.6**	**-3,224.0**	**-3,185.4**

* Annualized LUC emssions (col. 4) are a 30-year average of total LUC emissions.

Annex I country/region (has carbon price in scenarios B and C.)

Table 4
Percent Changes in Agricultural, Biofuels, and Oil Products Sector Output

Scenario A: Global biofuel mandates only *(percent change)*

Sectors:	Coars Grains	Other Grains	Oil seeds	Sugar cane	Live-stock	For-estry	Oil Prdct	Crsgrn Ethanol	Sugarcn Ethanol	Bio-diesel
With biofuel mandates:										
USA	4.5	-1.3	5.1	-0.3	-0.2	-0.4	-5.7	107.0	*	100.0
CAN	5.8	-2.1	8.2	-0.3	-0.8	-0.5	3.5	134.1	*	1548.7
EU27	0.5	-3.8	17.2	-1.0	-0.5	-1.4	0.8	135.1	-0.4	106.5
BRAZIL	-1.9	-2.7	13.9	-3.7	-0.5	-0.6	0.5	*	-5.1	1157.4
INDIA	-0.6	-0.2	2.3	3.2	-0.5	-0.3	-0.5	*	106.0	*
LAEEX	0.1	-0.1	5.3	15.7	-0.2	-0.2	4.9	310.4	356.5	129.6
SASIAEEX	-1.3	-1.4	9.8	29.8	-0.5	-0.3	0.3	2.2	761.4	208.3
RoASIA	-2.8	-1.1	3.8	31.1	-0.8	-0.5	-1.0	73.3	472.3	823.7
Without biofuel mandates:										
JAPAN	2.9	0.6	4.4	0.0	0.1	0.0	0.2	97.0	0.0	*
EEFSUEX	0.2	0.3	7.4	0.1	0.0	0.3	0.9	1.1	*	0.4
RoE	0.3	0.7	5.2	0.3	-0.2	0.2	0.7	23.4	*	-2.0
Oceania	0.0	0.2	8.0	0.4	0.2	0.1	0.7	*	0.0	-2.5
CHIHKG	0.2	0.2	2.5	0.5	-0.1	0.4	0.2	0.0	*	-0.7
RoLAC	0.2	0.5	6.3	0.0	-0.1	0.1	4.3	54.1	-2.1	-1.5
MEASTNAEX	-2.8	1.1	4.1	0.0	-0.1	0.1	1.6	136.5	0.2	0.4
SSAEX	-0.1	0.8	5.1	0.3	-0.2	0.0	2.8	93.7	2.2	0.9
RoAFR	-0.8	1.0	6.7	0.1	0.1	0.0	0.2	1.1	-0.4	0.4
RoHIA	-2.7	0.3	4.1	0.5	-0.3	0.4	1.3	0.7	1.1	-0.9

* indicates that production levels were negligible in 2007.

Annex I country/region (has carbon price in scenarios B and C.)

Table 4 cont'd.
Scenario B: Carbon price only *(percent change)*

Sectors:	Coars Grains	Other Grains	Oil seeds	Sugar cane	Live-stock	For-estry	Oil Prdct	Crsgrn Ethanol	Sugarcn Ethanol	Bio-diesel
With biofuel mandates:										
USA	0.5	-0.8	0.0	0.0	-0.1	-0.1	-3.7	5.5	*	3.0
CAN	0.4	-0.4	-0.1	0.1	0.2	-0.1	-2.3	5.0	*	10.5
EU27	-0.1	-0.4	1.2	0.1	-0.2	-0.1	-0.6	3.8	1.6	7.9
BRAZIL	0.0	0.1	0.5	-1.1	-0.2	0.2	0.6	*	-1.8	-1.0
INDIA	-0.1	0.0	0.0	0.0	0.1	0.0	1.5	*	0.7	*
LAEEX	0.1	-0.1	0.1	0.0	0.0	0.0	1.2	-0.8	-1.1	-3.3
SASIAEEX	-0.1	0.0	-0.2	0.0	-0.1	0.0	1.6	0.0	0.3	-3.9
RoASIA	-0.3	0.0	0.0	0.0	0.1	0.0	2.1	-0.3	0.7	-2.1
Without biofuel mandates:										
JAPAN	-0.2	0.0	0.0	0.1	-0.1	-0.1	-0.7	-9.1	1.0	*
EEFSUEX	-0.4	0.2	0.9	-0.8	-0.6	0.2	-2.5	1.8	*	-1.6
RoE	-0.1	-0.3	0.1	0.0	0.1	-0.1	-0.4	2.6	*	8.6
Oceania	0.1	-0.1	0.2	0.6	0.4	-0.2	-3.1	*	2.1	12.7
CHIHKG	0.0	0.0	0.0	0.0	0.0	-0.1	0.7	-0.1	*	-0.4
RoLAC	0.1	0.0	0.1	-0.3	0.0	0.0	1.3	-2.0	-7.1	-3.5
MEASTNAEX	-0.3	0.0	0.1	-0.1	-0.1	0.1	1.2	-10.7	-1.1	0.0
SSAEX	-0.1	0.0	0.2	0.0	-0.2	0.0	3.3	-35.4	2.1	0.1
RoAFR	0.0	-0.1	0.2	-0.2	0.1	0.1	0.3	0.2	-0.5	0.0
RoHIA	-0.2	0.0	0.0	0.7	0.0	-0.1	2.4	-0.3	1.8	-1.7

* indicates that production levels were negligible in 2007.

Annex I country/region (has carbon price in scenarios B and C.)

Table 4 cont'd.

Scenario C: Global biofuel mandates and carbon price *(percent change)*

Sectors:	Coars Grains	Other Grains	Oil seeds	Sugar cane	Live-stock	For-estry	Oil Prdct	Crsgrn Ethanol	Sugarcn Ethanol	Bio-diesel
With biofuel mandates:										
USA	9.0	-4.9	2.7	-1.2	-0.7	-1.1	-14.8	108.0	*	100.0
CAN	4.7	-2.4	9.2	-0.1	-0.5	-0.5	-2.0	62.0	*	1504.5
EU27	1.5	-4.1	17.4	-1.1	-0.7	-1.7	0.4	129.4	-0.7	106.1
BRAZIL	-0.6	-2.4	15.1	-5.8	-0.5	-0.4	0.2	*	-8.4	1165.3
INDIA	-1.5	-0.2	2.5	3.3	-0.4	-0.2	0.7	*	109.0	*
LAEEX	1.7	-0.4	6.0	15.7	-0.3	-0.2	2.3	318.2	361.1	132.0
SASIAEEX	-1.1	-1.5	10.4	30.6	-0.6	-0.2	1.8	2.6	776.6	213.7
RoASIA	-2.9	-1.1	4.4	31.8	-0.5	-0.4	0.6	74.6	481.0	837.7
Without biofuel mandates:										
JAPAN	6.9	0.7	5.2	0.0	0.1	-0.1	-0.6	88.4	-0.1	*
EEFSUEX	-0.1	0.6	9.0	-0.6	-0.5	0.6	-3.0	-1.1	*	-1.2
RoE	1.1	0.6	5.7	0.4	-0.1	0.1	1.2	25.4	*	-1.0
Oceania	1.9	0.1	9.0	0.5	0.4	0.0	-2.3	*	-1.3	-1.5
CHIHKG	0.3	0.2	3.6	0.5	-0.1	0.4	0.0	-0.9	*	-2.2
RoLAC	2.1	0.6	7.0	-0.4	-0.1	0.1	3.3	60.4	-12.5	-8.0
MEASTNAEX	-1.3	1.5	4.9	-0.4	-0.1	0.2	1.9	132.4	-2.5	0.0
SSAEX	-0.3	1.2	6.2	0.3	-0.9	0.0	5.6	36.6	3.8	1.3
RoAFR	0.6	0.9	7.3	-0.4	0.4	-0.1	-1.0	0.7	-2.5	0.4
RoHIA	-0.7	0.4	5.0	0.7	-0.2	0.4	2.4	-0.8	1.6	-4.7

* indicates that production levels were negligible in 2007.

Annex I country/region (has carbon price in scenarios B and C.)

Appendix A.

Regions and their members, with biofuel and carbon price policy status.	
Region	**Corresponding Countries in GTAP**
Regions with medium-run biofuel mandates:	
USA #	United States
CAN#	Canada
EU27#	Austria; Belgium; Bulgaria; United Kingdom; Cyprus; Czech Republic; Germany; Denmark; Spain; Estonia; Finland; France; Greece; Hungary; Ireland; Italy; Lithuania; Luxembourg; Latvia; Malta; Netherlands; Poland; Portugual; Romania; Slovakia; Slovenia; Sweden
BRAZIL	Brazil
CHIHKG	China and Hong Kong
INDIA	India
LAEEX	Argentinal; Columbia; Mexico; Venezuela
SASIAEEX	Indonesia; Malaysia; Vietnam; Rest of Southeast Asia
RoASIA	Bangladesh; Sri Lanka; Philippines; Singapore; Thailand; Rest of East Asia; Rest of South Asia
Regions without medium-run biofuel mandates:	
JAPAN#	Japan
EEFSUEX#	Russia; Rest of EFTA; Rest of Former Soviet Union*
RoE#	Albania; Switzerland; Croatia; Turkey; Rest of Europe*
Oceania#	Australia; New Zealand; Rest of Oceania*
RoLAC	Chile; Peru; Uruguay; Rest of Andean Pact; Central America; Rest of the Caribbean; Rest of Free Trade Area of the Americas; Rest of North America; Rest of South America
MEASTNAEX	Botswana; Tunisia; Rest of Middle East; Rest of North Africa
SSAEX	Madagascar; Mozambique; Malawi; Tanzania; Uganda; Rest of South African Customs Union; Rest of Southern African Development Community; Rest of Sub-Saharan Africa; Zimbabwe
RoAFR	Morocco; South Africa; Zambia
RoHIA	Korea; Taiwan

Notes:

# Indicates the region is assigned a carbon price for fossil fuel emissions in the relevant scenarios, based on inclusion in Annex I of the Kyoto Protocol.

* Indicates that some of the smaller countries are not part of Annex I of the Kyoto Protocol.

Endnotes

[1] Life-cycle GHG emission accounting for transportation fuels takes into account various stages of the product life-cycle, including: feedstock production (farm production or petroleum recovery from wells), feedstock processing, fuel transportation and blending, and vehicle operation (combustion). For biofuels, the final stage - combustion - is in concept carbon-neutral. Biological feedstocks are recycling carbon already in the global carbon cycle: their combustion is releasing the CO_2 absorbed by the crop feedstocks from the atmosphere. In contrast petroleum feedstocks are introducing new carbon into the carbon cycle (i.e., carbon previously sequestered in the earth.) Otherwise, estimated GHG emissions from production, processing and transportation vary across products, feedstocks, and a variety of technology and input choices at each stage (Fehrenbach 2006).

[2] Biofuel production occurs using other feedstocks (e.g., wheat, cassava); however, coarse-grain ethanol, sugar-based ethanol, and biodiesel from oil seeds are by far the most prevalent. For simplicity, we retain the original GTAP-BIO product categories.

[3] Note that some of the ethanol produced in 2007 was for non-fuel use. However, we use total ethanol production, on the grounds that countries will likely need to reallocate ethanol production to transportation fuels since the biofuel mandates represent such a large increase in the amount of biofuels used for transportation.

[4] For Brazil, we include only the biodiesel mandate, because the ethanol mandate is only for the blended product.

[5] The estimated allowance prices were US$12.64 (EPA) and US$20.96 (EIA) in 2005$