Biofuels and their By-Products: Global Economic and Environmental Implications

By:

Farzad Taheripour, Thomas W. Hertel, Wallace E. Tyner,
Jayson F. Beckman, and Dileep K. Birur

Corresponding Author
Farzad Taheripour
Department of Agricultural Economics
Purdue University
403 West State St.
West Lafayette, IN 47907-2056
765-494-4321
Fax 765-494-9176
E-mail: tfarzad@purdue.edu

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Department of Agricultural Economics
Purdue University
West Lafayette, Indiana

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Abstract

The biofuel industry has been rapidly growing around the world in recent years. Several papers have used general equilibrium models and addressed the economy-wide and environmental consequences of producing biofuels at a large scale. They mainly argue that since biofuels are mostly produced from agricultural sources, their effects are largely felt in agricultural markets with major land use and environmental consequences. In this paper, we argue that virtually all of these studies have overstated the impact of liquid biofuels on agricultural markets due to the fact that they have ignored the role of by-products resulting from the production of biofuels.

Feed by-products of the biofuel industry, such as Dried Distillers Grains with Solubles (DDGS) and biodiesel by-products (BDBP) such as soy and rapeseed meals, can be used in the livestock industry as substitutes for grains and oilseed meals used in this industry. Hence, their presence mitigates the price impacts of biofuel production on the livestock and food industries. The importance of incorporating by-products of biofuel production in economic models is well recognized by some partial equilibrium analyses of biofuel production. However, to date, this issue has not been tackled by those conducting CGE analysis of biofuels programs. Accordingly, this paper explicitly introduces DDGS and BDBP, the major by-products of grain based ethanol and biodiesel production processes, into a worldwide CGE model and analyzes the economic and environmental impacts of regional and international mandate policies designed to stimulate bioenergy production and use.

We first explicitly introduce by-products of biofuel production into the GTAP-BIO database, originally developed by Taheripour et al. (2007). Then we explicitly bring in DDGS

and BDBP into the Energy-Environmental version of the Global Trade Analysis Project (GTAP-E) model, originally developed by Burniaux and Truong (2002), and recently modified by McDougall and Golub (2007) and Birur, Hertel, and Tyner (2008). The structure of the GTAP-E model is redesigned to handle the production and consumption of biofuels and their by-products, in particular DDGS, across the world.

Unlike many CGE models which are characterized by single product sectors, here grain based ethanol and DDGS jointly are produced by an industry, named EthanolC. The biodiesel industry also produces two products of biodiesel and BDBP jointly. This paper divides the world economy into 22 commodities, 20 industries, and 18 regions and then examines global impacts of the US Energy Independence and Security Act of 2007 and the European Union mandates for promoting biofuel production in the presence of by-products.

We show that models with and without by-products demonstrate different portraits from the economic impacts of international biofuel mandates for the world economy in 2015. While both models demonstrate significant changes in the agricultural production pattern across the world, the model with by-products shows smaller changes in the production of cereal grains and larger changes for oilseeds products in the US and EU, and the reverse for Brazil. For example, the US production of cereal grains increases by 10.8% and 16.4% with and without by-products, respectively. The difference between these two numbers corresponds to 646 million bushels of corn. In the presence of by-products, prices change less due to the mandate policies. For example, the model with no by-products predicts that the price of cereal grains grows 22.7% in the US during the time period of 2006 to 2015. The corresponding number for the model with by-products is 14%. The model with no by-products predicts that the price of oilseeds increases by 62.5% in the EU during 2006-2015. In the presence of by-products, this price grows 56.4%.

Finally, we show that incorporating DDGS into the model significantly changes the land use consequences of the biofuel mandate polices.

Introduction

The biofuel industry has been rapidly growing around the world in recent years. Biofuels are produced in conjunction with other by-products such as Condense Distillers Solubles CDS, Dried Distillers Grains with Solubles (DDGS), Wet Distillers Grains with Solubles (WDGS), and soy and rapeseed meals (BDBP)[1]. The rapid growth of the biofuel industry has led to the massive production of these by-products as well. For example, the US DDGS production has increased from about 4.5 million metric tons in 2001 to 11.25 million metric tons in 2006. These by-products represent an important component of the biofuel industry revenues. For example one bushel of corn used in a typical dry milling ethanol plant generates roughly about 2.7 gallons of ethanol and 18 pounds of DDGS. Correspondingly, producing one gallon of biodiesel from soybean/rapeseed generates 32/10.3 pounds soy/rapeseed meal. According to our calculation about 16 percent of a corn based dry milling ethanol plant's revenue comes from DDGS sales. Corresponding shares for typical rapeseed and soybean based biodiesel producers are about 23% and 53%, respectively. These by-products are mainly used as a protein source and are strong complements to coarse grains in the animal feed rations. Furthermore, their prices are highly correlated with the prices of grains and oilseeds.

An important outcome of the multiple product aspect of the biofuel industry is that when biofuel production is encouraged, for example due to government subsidies or positive oil price shocks, the production of these by-products also increases, and, as a result, their prices fall relative to other feed ingredients. This encourages livestock producers to use more biofuel by-products in their production processes. On the other hand, reduction in the prices of by-products

[1] Soy meal and Rapeseed meal are by products of producing biodiesel from soybean and rapeseed, respectively. In this paper, we refer to these by-products as BDBP.

diminishes the growth rate of biofuel industry. Hence, from this prospective biofuel by-products function as both a shock absorber and a price adjuster.

Another important aspect of the biofuel by-products is that they help mitigate environmental consequences of the biofuel industry. For example, DDGS substitutes for both corn and soybean meal in livestock rations but mainly for corn. This ultimately reduces the land use consequences of the biofuel production and eases the demand for chemical inputs, such as fertilizers and pesticides, in crop production.

The importance of incorporating by-products of biofuel production in economic models is well recognized by some partial equilibrium analyses of biofuel production. For example, Tokgoz et al. (2007) have incorporated DDGS as a substitute for corn into the agricultural model of the Center for Agricultural and Rural Development (CARD) of the Iowa State University and show that the inclusion of DDGS in the model significantly changes the results. Two recent papers by Tyner and Taheripour (2008) and Babcock (2008) have also incorporated by-products of biofuels into their partial equilibrium models to evaluate the economic impacts of biofuel production. By-products from grain milling have previously been incorporated into a computational general equilibrium (CGE) framework by Rendleman and Hertel (1993) who show that, by ignoring this factor, the benefits to corn producers from the sugar program are greatly overstated. However, to date, this issue has not been tackled by those conducting CGE analysis of biofuels programs. Several papers have used CGE models and addressed the economy-wide and environmental consequences of producing biofuels at a large scale (recent examples are: Reilly and Paltsev 2007; Dixon, Osborne, and Rimmer 2007; Banse et al. 2007, and Birur et al. 2007). These papers mainly argue that since biofuels are mostly produced from agricultural sources, their effects are largely felt in agricultural markets with major land use and environmental consequences. In this paper, we argue that virtually all of these studies have overstated the impact of liquid biofuels on agricultural markets due to the fact that they have ignored the role of by-products resulting from the production of biofuels.

In this paper we introduce DDGS and BDBP, the main by-products of producing ethanol from food grains and biodiesel from oilseeds into a global CGE model which was originally developed by Burniaux and Truong (2002), and has been recently modified and updated by McDougall and Golub (2007) and Birur, Hertel, and Tyner (2008) to introduce biofuels into the GTAP-E model. To accomplish this task we use and extend the GTAP_BIOB database which has been generated by Taheripour et al. (2007) and has explicitly incorporated biofuels production into the GTAP database. Unlike many CGE models which are characterized by single product sectors, here the grain based ethanol sector (named EthanolC) produces jointly a major output (Ethanol1) and a by-product (DDGS). The biodiesel industry (named Biofuel) also produces jointly a major output (Biodieself) and a by-product (BDBP). We have also introduced biofuel by-products into the production functions of the livestock industries where they serve as substitutes for animal feeds. Finally, the model incorporates disaggregated Agro-ecological Zones (AEZs) (Lee *et al*., 2005) for each of the land using sectors to examine impacts of biofuel production on global land use changes.

This paper divides the world into 20 sectors/industries, 22 commodities[2], and 18 regions comprising the major biofuel producers (including US, Canada, EU, and Brazil) as well as non-biofuel producers. It analyzes impacts of implementation of biofuel promotion policies on key economic variables such as land use, production, prices and trade of a wide range of commodities, emphasizing on the food and agricultural commodities. In particular, this paper

[2] In the standard GTAP framework number of sectors and commodities are the same, but in this work number of commodities is larger than the number of sectors due to the presence of biofuel by-products.

examines global impacts of the US Energy Independence and Security Act of 2007[3] and the European Union mandates[4] for promoting biofuel production.

The paper depicts the future of the global economy with and without having by-products of biofuels and shows that introducing by-products of biofuel significantly mitigates the impact of the biofuel mandates on agricultural markets. It shows that models with and without DDGS demonstrate different portraits from the economic impacts of international biofuel mandates for the world economy in 2015. Finally, it shows that studies that ignore biofuel by-products may be misleading in their estimates of economic and environmental consequences of biofuel mandates.

Data

Taheripour et al. (2007) have explicitly introduced three biofuel commodities[5] into the GTAP database. They provided three databases under three different sets of assumptions. We extend their third and fourth databases, recognized as GTAP_BIOB, by explicitly separating out DDGS and BDBP as by-products of the corn ethanol and of biodiesel industries. We have developed codes which split sales of corn ethanol industry between two distinct commodities of ethanol and DDGS and sales of biodiesel industry between biodiesel fuel and BDBP. These codes generate a database which unlike the standard GTAP databases carries out the presence of multiple products. The generated database includes 60 industries, 62 commodities, and 87 regions. For this paper we used an aggregated version of the database comprising 22 commodities, 20 industries, and 18 regions. Appendix A maps the list of industries, commodities, (Table A1) and regions (Table A2) used in this paper.

[3] Available on line at: http://thomas.loc.gov/cgi-bin/bdquery/z?d110:h.r.00006:
[4] Reflected in a report by the Commission of European Communities (2003).
[5] Including ethanol from food grains, ethanol from sugarcane, and biodiesel from oilseeds.

GTAP-BYP Model

The model used in this paper, GTAP-BYP, is a modified version of the GTAP_E model, originally developed by Burniaux and Truong (2002) to incorporate energy into the GTAP framework, and recently modified by McDougall and Golub (2007) and Birur, Hertel, and Tyner (2008) to introduce biofuels into the model. The GTAP_BYP model incorporates the possibility of producing multiple products (in this paper DDGS and BDBP as byproducts of grain based ethanol and biodiesel industries) into the standard GTAP framework which originally is designed for an economy without byproducts.[6] These involve modifications, both on the supply side (joint products produced from a single sector) and on the demand side to appropriately characterize the use of these by-products.

To introduce by-products into the supply side of the model we revised the zero profit condition of the original model. The original GTAP model and its extensions, including GTAP-E, assume each sector only produces one commodity. These models determine the endogenous output level for each and every sector, qo_j, according to the following zero profit condition[7]:

$$(1)\quad ps_j = \sum_i \theta_i pf_{ij} \ .$$

Here ps_j, θ_i, and pf_{ij} represent the price of output in sector *j*, the share of input *i* in total costs of producing commodity *j*, and the price of input *i* paid by sector *j*, respectively. The derived demand for inputs in these sectors, qf_{ij}, are determined from the following type of equation (this is for the one-level CES case):

[6] We have introduced several new equations and made several changes in the GTAP-BIO model code to accomplish this task. This section explains new equations and components which are added into the model. Interested readers may obtain the TAB file from the authors upon request.

[7] Exogenous variables are intentionally dropped from the equations presented in this section.

$$(2)\quad qf_{ij} = qo_j + \sigma_j (ps_j - pf_{ij}).$$

Where σ_j represents the elasticity of substitution among inputs in the production function for sector *j*.

To introduce multiple products into the model we revise the above equations for the grain ethanol and biodiesel industries which they each produce by-products of DDGS and BDBP. Here we first define new variables, which are indices of the activity levels in the grain based ethanol and biodiesel industries, qz_i for *j = EthanolC* and *Biodiesel*. The model endogenously determines these variables according to the following zero profit conditions for the grain ethanol and biofuel industries:

$$(3)\quad pz_j = \sum_i \theta_i pf_{ij} \qquad for \quad j = EthanolC, Biodiesel.$$

Here pz_j is a composite output price index for industry *j*, comprising both prices of the main and by-products according to the following equations:

$$(4)\quad pz_j = \sum \Omega_{kj} . ps_{kj} \qquad \begin{array}{l} for \quad j = EthanolC \quad and \quad k = ethnaol1, DDGS, \\ for \quad j = Biodiesel \quad and \quad k = biodieself, BDBP. \end{array}$$

In these equations, Ω_{kj} is the share of the *kth* product in total revenues of sector *j*. The model endogenously determines production of the main and by-products according to the following equations:

$$(5)\quad qo_{kj} = qz_j + \sigma_j^T (pz_j - ps_{kj}) \qquad \begin{array}{l} for \quad j = EthanolC \quad and \quad k = ethnaol1, DDGS, \\ for \quad j = Biodiesel \quad and \quad k = biodieself, BDBP. \end{array}$$

Here $\sigma_j^T \le 0$ represents the constant elasticity of transformation between "the main and by-products in industry *j*. In the case of pure by-products, its value is zero in each industry and the main and by-products are always produced in a constant proportion, regardless of relative prices. However, if there is some scope for enhancing the supply of the by-product at the expense of the main product, then this value would be strictly negative. In our model, we set this value equal to -0.005 in both industries.

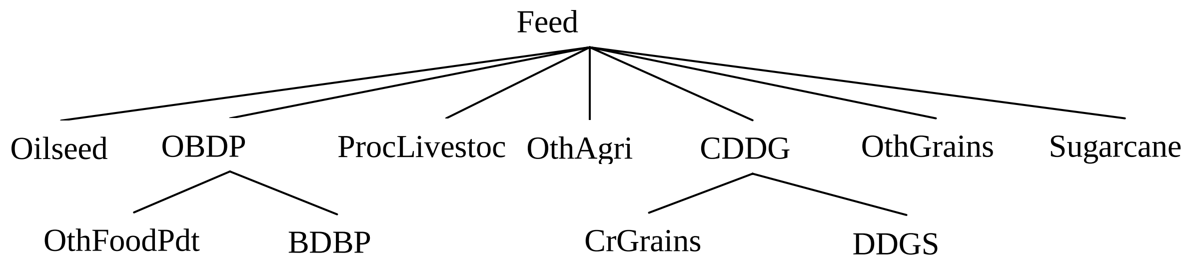
Finally, we modify the derived demand functions for inputs into the grain based ethanol and biodiesel industries by replacing the indices of outputs with the indices of sectoral activity levels:

(6) $qf_{ij} = qz_j + \sigma_j (pz_j - pf_{ij})$.

With these modifications in hand, we can now deal with the supply side of the multiproduct problem posed by the grain based ethanol and biodiesel by-products.

We now turn to the demand side for the by-products. The uses of DDGS and BDBP in the livestock industry have significantly increased in the US, EU, and many other countries in recent years due to the sharp increase in the grain and oilseed prices. For example, consumption of DDGS in the US has increased from 3.7 million metric tons to 10 million metric tons from 2001 to 2006. This reflects the important fact that DDGS and corn are good substitutes in the livestock industry. Table 1 also shows that DDGS and corn prices are highly correlated and their correlation has likely increased in recent years.

Soy and rapeseed meals have also been a major component of animal feeds. To implement the possibility of substitution between by-products and other animal feedstuffs into the demand side of the model we assume producers, in particular the livestock industry, use DDGS in their production process as a substitute for cereal grains (mainly corn). We also consider BDBP as a substitute for feedstuffs produced by the food industry (OthFoodPdt). Given these assumptions and following Keeney and Hertel (2005) for the general approach to introducing feedstuff substitution in livestock production within the GTAP framework, we have introduced the following nested demand structure in the livestock sectors of the model:



At the lower level of this figure, the model combines DDGS and CrGarins to generate a new composite input named CDDG. At this level the model also substitutes BDBP with OthFoodPdt to generate another composite input named OBDP. At the higher level the model combines CDDG and OBDP with other feedstuffs used in the livestock industry to generate a composite input, named Feed, for this industry. Since the elasticities of transformation between the main and by-products are very small in the ethanol and biodiesel industries, the magnitudes of the elasticities of substitution between Crgarins and DDGS and between OthFoodPdt and BDBP are crucial for this model. They offer the opportunity for linking the prices of DDGS and corn, and the prices of BDBP and other food products.

In the past, DDGS and corn prices have followed increasing paths, but the corn price has increased faster than the DDGS price, and as the result the price of DDGS relative to corn has dropped (see Figure 1). This has provided a strong incentive for livestock producers to use more DDGS in their production process and has also enhanced exports of DDGS from the US.

Of course, as with any feedstuff, there are limits to the amount of DDGS that can be fed to livestock. However, Cooper (2005) and Dhuyvetter (2005) have reported two estimates: 42

million tons and 52 million tons, respectively, of the potential demand for DDGS within the US. These numbers are significantly larger than the current production of DDGS within the US – suggesting that the maximum ration may not be an issue in the near future. In addition, the potential market overseas is even further from satiation, and US exports of DDGS have increased from 0.8 million metric tons to 1.25 million metric tons during the time period of 2001-2006.

We do not have a lot of direct evidence upon which to base our choice of elasticity of substitution between DDGS and Crgrains. However, in our historical simulations, we find that a very large value is required in order to replicate the US price path of DDGS over the 2001-2006 period when ethanol production – and hence the availability of DDGS -- was rising sharply, yet DDGS prices were also rising. Accordingly, we used a value of 30 for the elasticity of substitution between GrGrains and DDGS in this paper. The elasticity of substitution between BDBP and OthFoodPdt used in the livestock industry is high too, since the food industry also produces oilseed meal. For example, edible rapeseed oil production also generates rapeseed meal. Hence, we applied a value of 125 for the elasticity of substitution between OthFoodPdt and BDBP to replicate the price path of rapeseed meal in the EU. Finally, following Keeney and Hertel (2005) we used 0.9 for the elasticity of substitution at the higher level of the feed demand nest.

Alternative Scenarios

The goal of this paper is to highlight the importance of incorporating biofuel by-products in the economic and environmental analysis of biofuel production at a global scale. To accomplish this goal we build our scenarios based on the recent work done by Hertel et al. (2008). They have provided a baseline which depicts the world economy with biofuel production in 2006 without incorporating biofuel by-products in their model. Then they have used the baseline to study the implications of US and EU biofuel mandate policies for the world economy. Their prospective simulation replicates the biofuel economy in 2015. In this paper we first replicate their baseline using our database which has DDGS and BDBP in it, and then we replicate their prospective simulation in the presence of these by-products. Since our baseline is just a replication of Hertel et al. (2008) we do not report their results in this paper.

Simulation Results

Here we compare the results from the two prospective scenarios which depict the world economy in 2015 in the presence of the US and EU biofuel mandate policies, with and without biofuel by-products present in the analysis. In this comparison we highlight the implications of having by-products for several key economic variables and land uses changes under the following topics.

Production

Table 2 compares percentage changes in the outputs of non-energy commodities during the time period of 2006 to 2015 for three major biofuel producers (i.e. US, EU and Brazil). The model with by-products reveals that production of DDGS and BDBP grow by 173.2% and 172.5% in the US, respectively (Table2). Corresponding numbers for EU are 432.9% and 429.4%. These regions mainly produce ethanol from grains and biodiesel from oilseeds and as the result their DDGS and BDBP outputs grow rapidly with the biofuel mandate policies. For example, the US production of DDGS grows from 12.5 million metric tons in 2006 to 34 million metric tons in 2015. A major portion of this by-product will be used within the US and the rest will be exported to other regions[8]. On the other hand the EU production of BDBP grows from about 6.1 million metric tons in 2006 to 32.5 million metric tons in 2015. The EU production of BDBP will be

[8] About 12.4% of the US DDGS outputs have been exported to other countries as Canada, EU members, Mexico, and African and Asian countries.

mainly used within this region. This huge production of DDGS and BDBP significantly affect the production pattern of agricultural commodities within these regions and the rest of the world.

The models with and without by-products suggest different production patterns for these three major biofuels producers. The models with and without by-products predict 10.8% and 16.4% growth rates for the US production of CrGarins, respectively. The difference between these two numbers corresponds to 646 million bushels of corn which can be used to produce about 1.7 billion gallons of ethanol. This is really a big number to ignore and disregard in the economic analyses of biofuel production. The model with no by-products predicts a 2.5% growth rate for the production of CrGrains in EU, but the model with DDGS predicts a negative growth rate of 3.7% for this commodity in this region. In the presence of by-products, EU uses its own DDGS and BDBP and imports some by-products to from the US[9] to support its own livestock industry. As a result, it does not need to allocate more land to meet the demand for grains used in its livestock industry. Instead, it allocates additional land to produce more oilseeds to support its biodiesel production. As indicated in table 2, the model with biofuel by-products predicts higher growth rates for oilseeds outputs in both US and EU and a lower growth rate in Brazil.

Both the models predict small reductions in the livestock outputs in the US, EU, and Brazil, but the model with by-products reveals lower reduction for the US and higher reductions for the EU and Brazil. There are very small changes in outputs of the food industry.

Trade

Introducing by-products into the model alters the trade effects of the US-EU mandate policies as well. For example, as shown in table 3, the model with no by-products estimates that the US

[9] Note that currently, EU imports considerable amount of DDGS from the US. For example it has imported about 0.32 million metric tons of DDGS from the US in 2006.

exports of CrGrains to EU, Brazil, and LAEEX (a major importer of DDGS) will be sharply dropped by -4.8%, -25.5%, and -12.7%, respectively. The corresponding figures for the model with by-Products are -2.6%, -3.8%, and -0.7%. The models with and without by-products predict that the US exports of oilseeds to EU will grow by 105.7% and 14.7%. They also predict completely different patterns for the US exports of oilseeds to Brazil and LAEEX. While the model with no by-products predicts negative growth rates for US exports of oilseeds to these regions, the alternative model demonstrates positive growth rate.

Prices

We now compare the price consequences of introducing by-products into the model. Table 4 compares percentage changes in the prices of non-energy commodities for the two prospective simulations. The model with no by-products demonstrates that the price of CrGrains increases sharply in the US, EU, and Brazil by 22.7%, 23.0%, and 11.9%, respectively. The model with by-products presents considerably lower growth rates of 14%, 15.9%, and 9.6% in these countries, respectively. The price of DDGS grows in these countries by 8.9%, and 9%, 5.9%, respectively. The US and EU biofuel mandate policies has no major impact on the price of BDBP in US, EU, and Brazil. For other commodities, prices grow at slightly lower rates in the presence of by-products compared to the case with no by-product.

Land use and land cover

Introducing by-products in the model also considerably changed the land use consequences of biofuel production within the US and EU. This change can be observed in other regions as well. To examine the scale of this change, we compare land use changes due to introducing by-products into the model for US and EU as the main producers of DDGS and BDBP, Brazil as the major producer of ethanol from sugarcane, and LAEEX as major importer of DDGS from US.

Table 4 shows that the demand for corn land grows by 9.8% with no by-products and 6.3% with by-products in the US. Unlike the demand for corn land, the demand for land to produce other grains decreases by 10.0% with no by-products and 7.1% with by-products in this country. The model with no by-products shows a small increase (1.6%) in the demand for land to produce oilseeds, but the model with by-products reveals a major boom (4.1%) in the demand for land under this category in the US. The model without byproducts predicts a major reduction (-5.7%) in the demand for land to produce sugarcane. The corresponding number for the model with by-product is -4.1%.

Both the models show that the demand for corn land goes down in the EU, but the size of the reduction is larger in the presence of by-products. The models with and without by-products demonstrate relatively similar growth rates for other land use categories in the EU. In this region, the demand for land to produce oilseeds grows very fast due to sharp increase in the production of biodiesel in this region. Both the cases, predict approximately similar land use changes in Brazil. The international biofuel mandate policies raise the demand for land to produce oilseeds (by 14.5% and 16.0% for cases with and without by-products, respectively) and sugarcane (by 4.2% and 3.8% accordingly) in this county. The demand for land to produce grains goes down in Brazil.

We now consider land use implication of international mandate policies for a major DDGS importer, LAEEX. As shown in table 5, the model with no by-product predicts that the need for land to produce cereal grains grows 1.8% in this region. This number falls to 0.3% when we by-products into the model. Both the models predict a major change in land used for oilseeds (10% and 11.3% with and without by-products, respectively).

The US-EU biofuel mandate policies also affect the non-agricultural land cover across the world. Table 6 shows the consequences of the US-EU mandate policies for the forest and pasture land in the selected regions. The models with and without by-products estimate negative growth rates for the forest and pasture areas within the selected regions. Their estimates are relatively close for the forest areas, but for the pasture land they provide considerably different figures. The model with no by-products estimates growth rates of -4.9%, -9.7%, -6.3%, and -1.9% for US, EU, Brazil, and LAEEX, respectively. The corresponding figures for the model with by-products are -1.5%, -3.9%, -3.1%, and -0.06%.

The figures presented in this section show that incorporating by-products into the model significantly alters the land use and land cover implications of the US-EU biofuel mandate policies for US, EU, Brazil, and LAEEX. This change can be observed in other regions as well. Figures 2 to 4 compare the changes in areas under CrGrains, Other Grains, and Oilseeds for both the models with and without by-products for all regions.

Conclusions

This paper uses a general equilibrium framework and reveals the importance of incorporating biofuel by-products into the economic analysis of policies which are designed to encourage production of biofuels. It shows that incorporating biofuel by-products in such analyses considerably alters the results in systematic ways in the face of 2015 international biofuel mandates. While both models demonstrate significant changes in the agricultural production pattern across the world, the model with by-products shows smaller changes in the production of cereal grains and larger changes for oilseeds products in the US and EU, and the reverse is true for Brazil. In the presence of by-products, mandate-driven price changes are dampened. Finally, it shows that studies that ignore by-products may be misleading in their estimates of land use and land cover changes due to biofuel mandates.

Table 1. DDGS and corn price correlation coefficients for different time periods

Duration	**Correlation Coefficient**	
	Price Levels	First Differences
1983-2006	0.71	0.70
1983-2000	0.71	0.68
2001-2006	0.73	0.79

Table 2. Percentage changes in the outputs of non-energy commodities during 2006-2015

Agricultural Commodities	**Without By-Products**			**With By-Products**		
	US	**EU**	**Brazil**	**US**	**EU**	**Brazil**
CrGrains	16.4	2.5	-0.3	10.8	-3.7	-2.8
OthGrains	-7.5	-12.2	-8.7	-5.0	-12.2	-8.5
Oilseeds	6.8	51.9	21.1	8.6	53.1	19.0
Sugarcane	-1.8	-3.7	8.2	-0.9	-3.3	8.4
Livestock	-1.2	-1.7	-1.3	-0.7	-2.1	-2.1
Forestry	-1.2	-5.3	-2.7	-0.7	-5.0	-2.7
OthFoodPdts	-0.3	-1.3	-2.1	0.0	-1.9	-2.0
ProcLivestoc	-0.7	-1.2	-2.2	-0.5	-1.4	-2.9
OthAgri	-1.5	-4.5	-3.8	-0.9	-4.1	-3.7
OthPrimSect	0.0	-0.1	-0.8	-0.1	-0.1	-0.7
En_Int_Ind	-0.1	0.5	-1.1	-0.1	0.6	-0.9
Oth_Ind_Se	-0.1	0.0	-0.2	-0.1	0.0	-0.1
DDGS	-	-	-	173.2	432.9	0.4
BDBP	-	-	-	172.5	429.4	-4.2

Table 3. Percentage changes in the quantities of US exports of grains and oilseeds to the selected regains during 2006-2015

Commodity	Without By-Products			With By-Products		
	EU	Brazil	LAEEX	EU	Brazil	LAEEX
CrGrains	-4.8	-25.5	-12.7	-2.6	-3.8	-0.7
OthGrains	32.0	-9.3	-8.7	-3.4	1.7	2.1
Oilseeds	105.7	-4.1	-11.3	14.7	0.3	2.3

Table 4. Percentage Changes in the supply prices of non-energy commodities (2006-2015)

Agricultural Commodities	Without By-Products			With By-Products		
	US	EU	Brazil	US	EU	Brazil
CrGrains	22.7	23.0	11.9	14.0	15.9	9.6
OthGrains	7.7	13.7	8.8	6.0	11.5	7.8
Oilseeds	18.2	62.5	20.8	14.5	56.4	18.3
Sugarcane	12.6	16.2	18.6	9.4	14.0	17.5
Livestock	3.6	4.6	4.0	3.1	6.0	5.6
Forestry	9.0	20.9	17.7	7.0	19.2	16.3
OthFoodPdts	0.5	1.9	4.0	0.4	1.7	3.5
ProcLivestoc	1.0	1.3	2.4	0.9	1.8	3.2
OthAgri	4.3	8.3	8.0	3.0	7.1	7.2
OthPrimSect	-0.7	-1.0	-0.2	-0.5	-0.9	-0.3
En_Int_Ind	-0.7	-1.0	0.0	-0.5	-0.9	-0.1
Oth_Ind_Se	-0.6	-0.9	0.3	-0.5	-0.8	0.2
DDGS	-	-	-	8.9	9.0	5.9
BDBP	-	-	-	-0.4	0.2	3.5

Table 5. Land use changes due to international biofuel mandate policies (2006-2015 %)

Type of land	Without By-Products				With By-Products			
	CrGrains	OthGrains	Oilseeds	Sugarcane	CrGrains	OthGrains	Oilseeds	Sugarcane
US	9.8	-10.0	1.6	-5.7	6.3	-7.1	4.1	-4.1
EU	-2.3	-15.1	40.1	-7.4	-7.2	-14.8	41.9	-6.7
Brazil	-3.2	-10.9	16.0	3.8	-5.2	-10.5	14.5	4.2
LAEEX	1.8	-0.2	11.3	-2.3	0.3	0.0	10.0	-1.9

Table 6. Land cover changes due to international biofuel mandate policies (2006-2015 %)

Type of land cover	Without By-Products		With By-Products	
	Forest	Pasture	Forest	Pasture
US	-3.1	-4.9	-2.3	-1.5
EU	-8.3	-9.7	-7.9	-3.9
Brazil	-5.1	-6.3	-5.0	-3.1
LAEEX	-1.4	-1.9	-1.2	-0.6

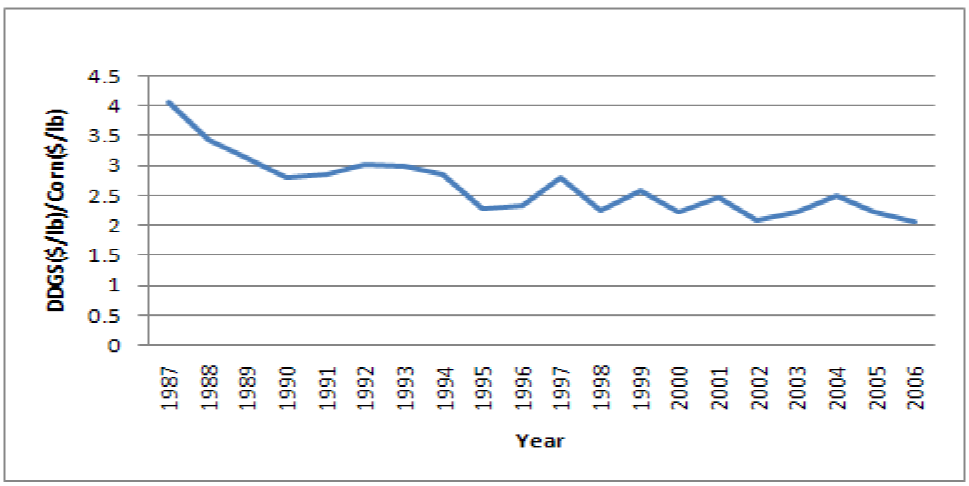
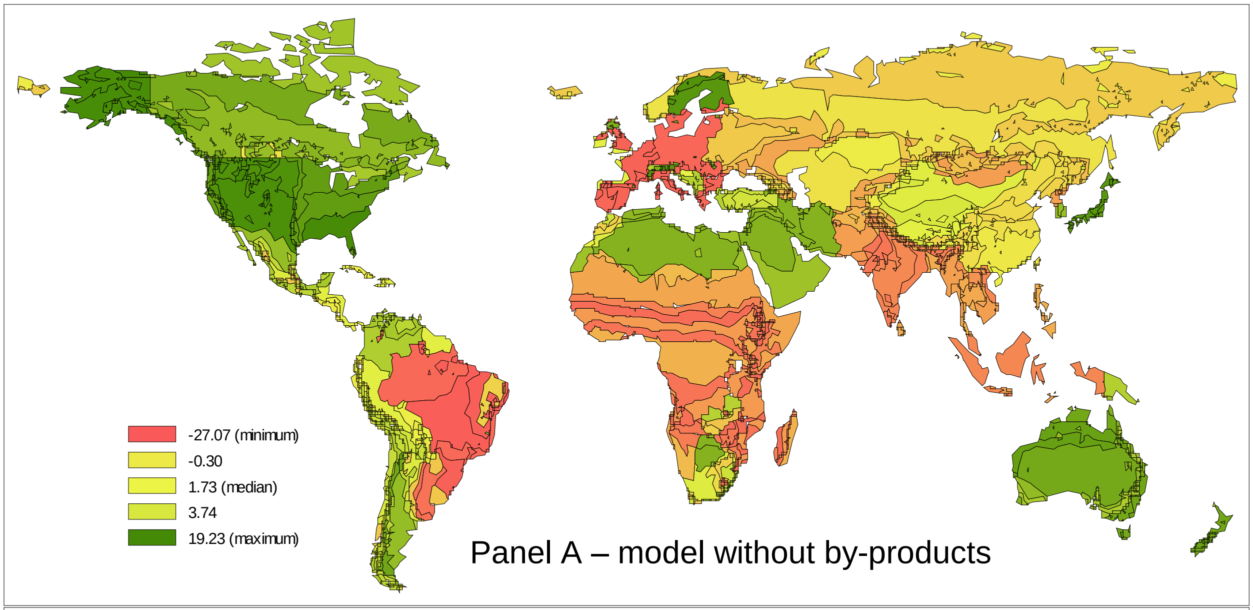
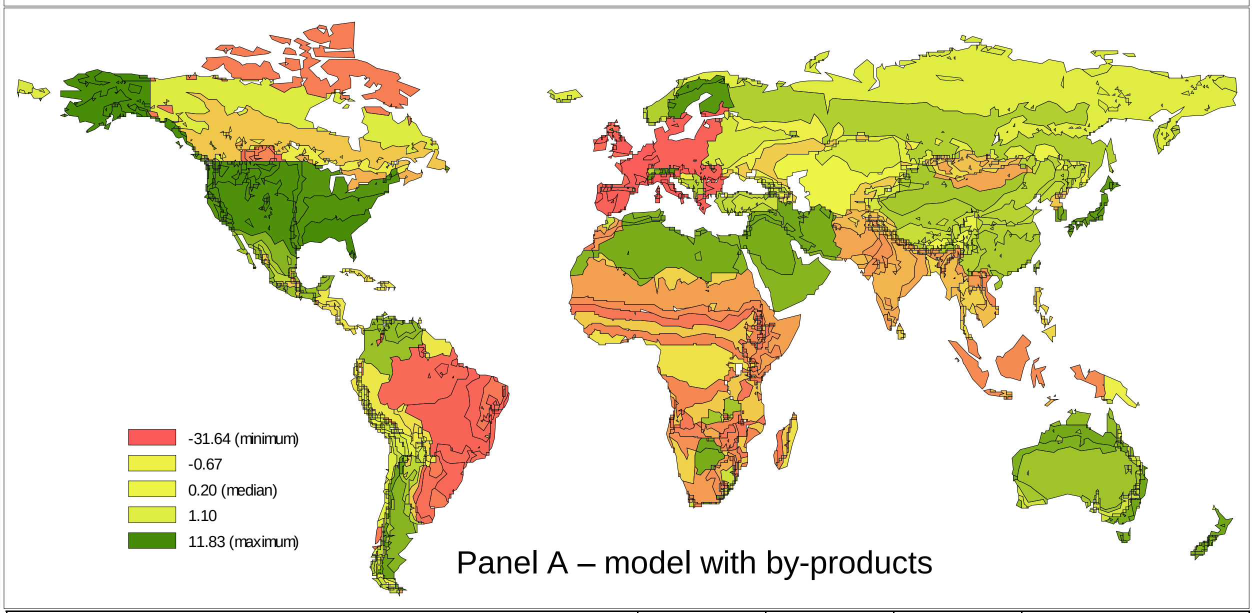


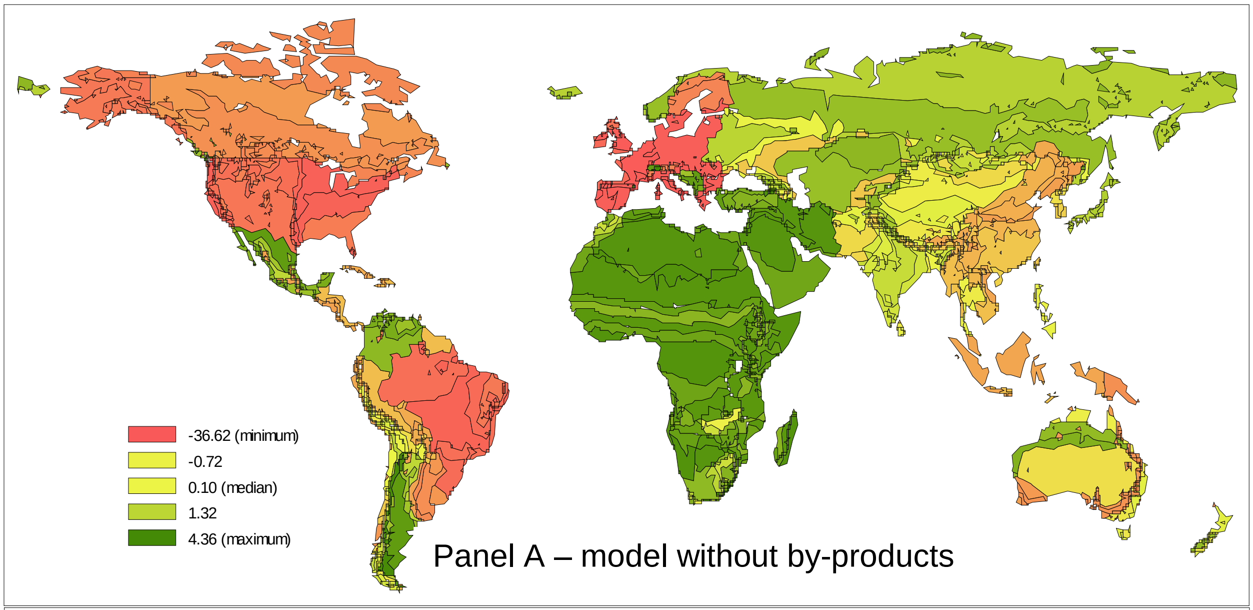
Figure 1. The Relative Price of DDGS and Corn (1987-2006)

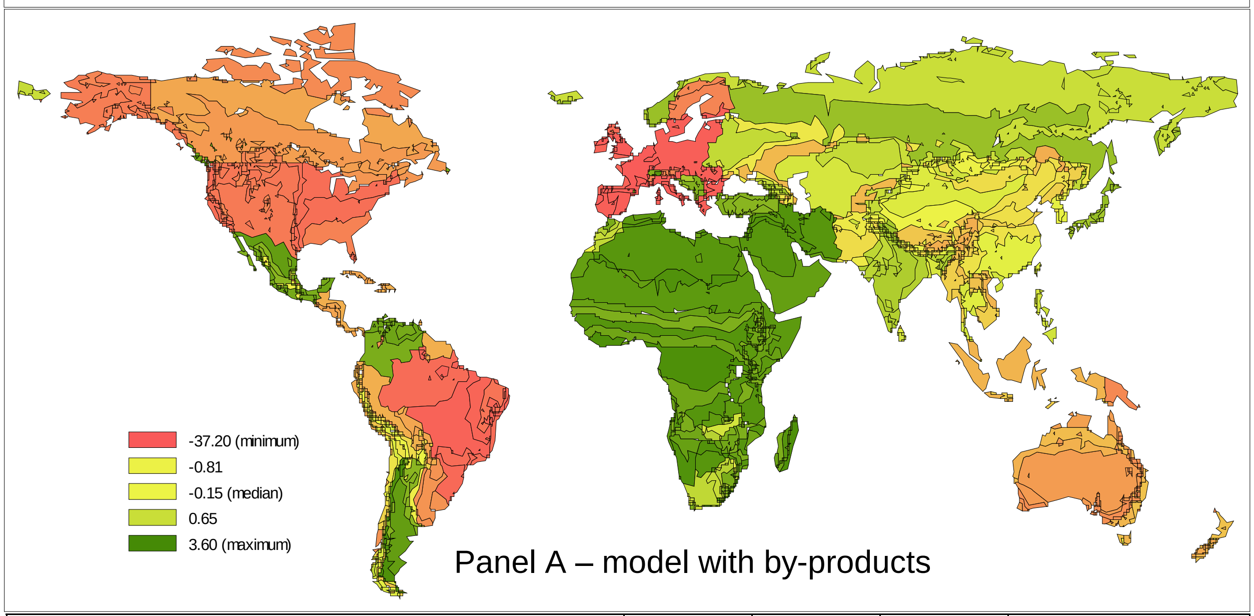




% Change for Selected Regions	US	UE	Brazil	LAEEX
Without By-Products	9.8	-2.3	-3.2	1.8
With By-Products	6.3	-7.2	-5.2	0.3

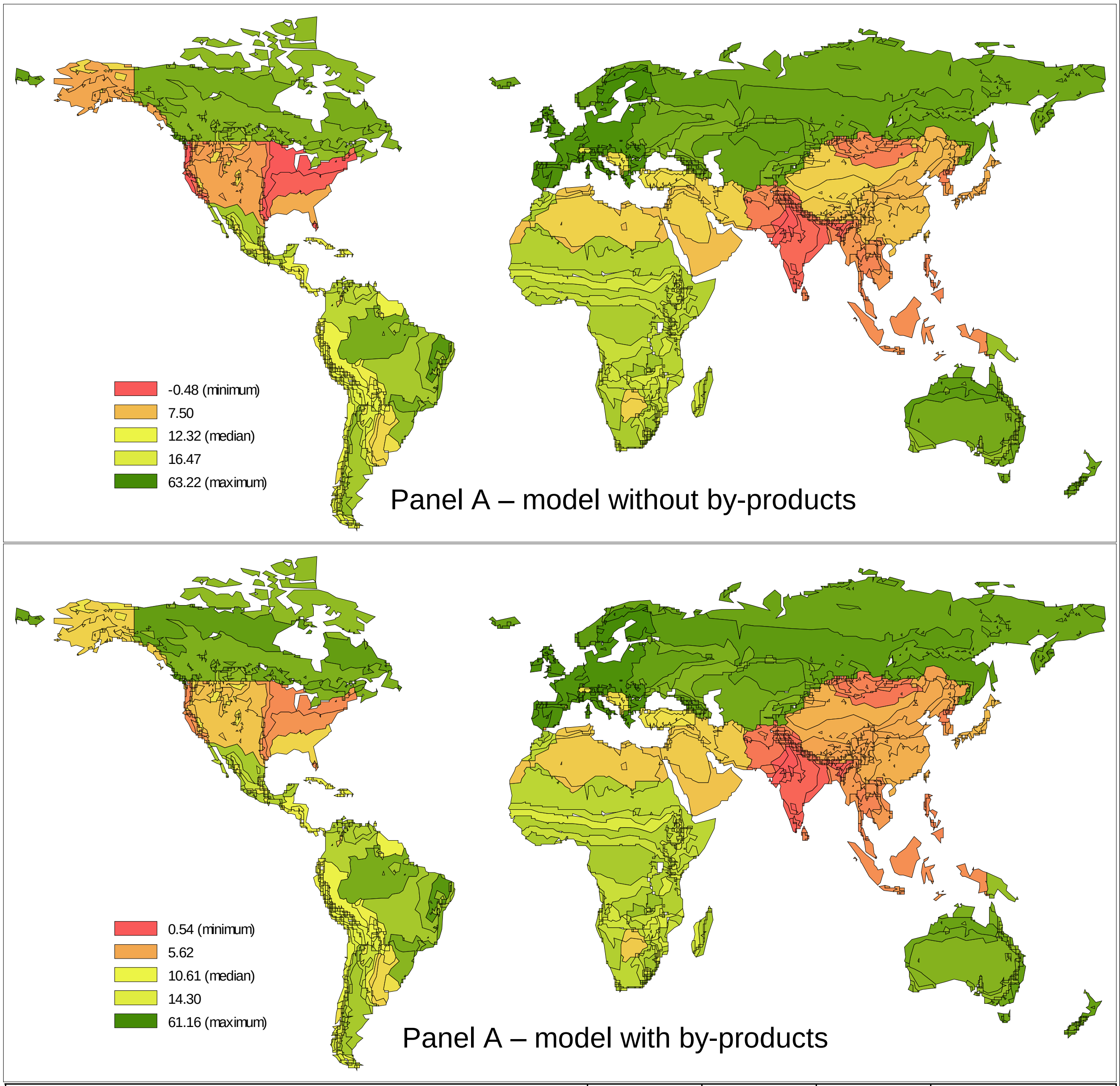
Figure 2. Change in Land Area under Coarse Grains across AEZs (2006-2015)





% Change for Selected Regions	US	UE	Brazil	LAEEX
Without By-Products	-10.0	-15.1	-10.9	-0.2
With By-Products	-7.1	-14.8	-10.5	0.0

Figure 3. Change in Land Area under Other Grains across AEZs (2006-2015)



% Change for selected regions	US	UE	Brazil	LAEEX
Without By-Products	1.6	40.1	16.0	11.3
With By-Products	4.1	41.9	14.5	10.0

Figure 4. Change in Land Area under Oilseeds across AEZs (2006-2015)

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Appendix A

Table A1. List of industries, commodities, and their corresponding from GTAP notation

Industry name	**Commodity name**	**Description**	**Corresponding Name in the GTAP_BIOB**
CrGrains	CrGrains	Cereal grains	Gro
OthGrains	OthGrains	Other Grains	pdr, wht
Oilseeds	Oilseeds	Oil seeds	Osd
Sugarcane	Sugarcane	Sugar cane and sugar beet	c-b
Livestock	Livestock	Livestock	ctl, oap, rmk, wol
Forestry	Forestry	Forestry	Frs
Ethanol2	Ethanol2	Ethanol produced from sugarcane	eth2
Biodiesel	Biodiesel	Biodiesel produced from oilseeds	Biod
OthFoodPdts	OthFoodPdts	Other Food Products	ofdn, voln
ProcLivestoc	ProcLivestoc	Meat and Dairy products	cmt, mil, omt
OthAgri	OthAgri	Other agriculture goods	b_t, ocr, pcr, pfb, sgr, v_f
OthPrimSect	OthPrimSect	Other Primary products	fsh, omn
Coal	Coal	Coal	Coa
Oil	Oil	Crude Oil	Oil
Gas	Gas	Natural gas	gas, gdt
Oil_Pcts	Oil_Pcts	Petroleum and coal products	p-c
Electricity	Electricity	Electricity	Ely
En_Int_Ind	En_Int_Ind	Energy intensive Industries	crpn, i_s, nfm
Oth_Ind_Se	Oth_Ind_Se	Other industry and services	crpn, i_s, nfm, atp, cmn, cns, dwe, ele, fmp, isr, lea, lum, mvh, nmm, obs, ofi, ome, omf, osg, otn, otp, ppp, ros, tex, trd, wap, wtp, wtr
EthanolC	Ethanol1	Ethanol produced from grains	eth1
	DDGS	Dried Distillers Grains with Solubles	-
Biodiesel	Biodieself	Biodiesel fuel	biod
	BDBP	Oilseeds meal	bdbp

Table A2. Regions and their members

Region	Description	Corresponding Countries in GTAP
USA	United States	usa
CAN	Canada	can
EU27	European Union 27	aut, bel, bgr, cyp, cze, deu, dnk, esp, est, fin, fra, gbr, grc, hun, irl, ita, ltu, lux, lva, mlt, nld, pol, prt, rom, svk, svn, swe
BRAZIL	Brazil	bra
JAPAN	Japan	jpn
CHIHKG	China and Hong Kong	chn, hkg
INDIA	India	ind
LAEEX	Latin American Energy Exporters	arg, col, mex, ven
RoLAC	Rest of LatinAmerica and Caribbean	chl, per, ury, xap, xca, xcb, xfa, xna, xsm
EEFSUEX	EE and FSU Energy Exp	rus, xef, xsu
RoE	Rest of Europe	alb, che, hrv, tur, xer
MEASTNAEX	Middle Eastern N Africa E Exp	bwa, tun, xme, xnf
SSAEX	Sub Saharan Energy Exporters	mdg, moz, mwi, tza, uga, xsc, xsd, xss, zwe
RoAFR	Rest of North Africa and SSA	mar, zaf, zmb
SASIAEEX	South Asian Energy Exporters	idn, mys, vnm, xse
RoHIA	Rest of High Income Asia	kor, twn
RoASIA	Rest of South East and South Asia	bgd, lka, phl, sgp, tha, xea, xsa
Oceania	Oceania countries	aus, nzl, xoc