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The Economy-wide Greenhouse Gas Impacts of the Biofuels Boom (or Bust)

by

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Abstract

Several studies in the recent past have offered a contrasting and wide range of perspectives on economic and environmental implications of biofuels. In this study we develop a comprehensive and consistent framework for analyzing the global economic interactions and the direct and indirect impacts of biofuels production on greenhouse gas (GHG) emissions. We utilize a global Computable General Equilibrium (CGE) model which consists of interaction of energy commodities with explicit biofuels and their by-product sectors, land endowment classified by agro-ecological zones, and emission of four major GHGs - carbon dioxide, methane, nitrous oxide, fluorinated gases from agricultural and economic activities, including emissions associated with biofuel feedstock, crop conversion to fuel, and land cover conversion through change in ecosystem carbon stock. This study also pays special attention to pasture-crop and Conservative Reserve Program land due to their potential sectoral competition for land. In this paper, we examine the proposed policies for biofuels expansion in the US, EU and Brazil, as well as alternative potential trajectories of larger and smaller growth, including a collapse of the traditional biofuels market. The impact on GHG emissions are decomposed and associated with the individual drivers behind the biofuels boom, including: changes in subsidies, rising oil prices, and other major policy drivers.

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Introduction

Biofuels have drawn lot of attention across the world in the recent years due to concerns of oil dependence and interest in reducing green house gas (GHGs) emissions. Passing of biofuel friendly legislation in several countries has resulted in an exponential growth in global biofuels production. For instance, the "Energy Independence and Security Act (EISA) of 2007" in the U.S., mandates a 'renewable fuels standard (RFS)' to use 36 billion gallons of renewable fuels per year by 2022. This includes a cap on corn starch-derived ethanol at 15 billion gallons and a 3 billion gallons increment of advanced biofuels every year starting 2015 until 2022 (Yacobucci and Schnepf, 2007). The European Union Biofuels Directive requires that member states realize a 10% share of biofuels on the liquid fuels market by 2020 (European Commission, 2008). Brazil, with its geographic comparative advantage to grow sugarcane, has massive potential to produce ethanol.

The global consequences of massive expansion of biofuels are extremely complex, resulting in economic responses across sectors and regions, with direct and indirect effects on land-use and greenhouse gas (GHG) emissions. Previous studies have found that greater use of biofuels and other liquid and gaseous fuels for transport could reduce greenhouse gases, improve vehicle performance, protect ecosystems, and enhance rural economic development by providing employment opportunities (Dufey, 2006; EFRAC, 2006; Kojima *et al*., 2007; Urbanchuck, 2007). To date, the impact of biofuels on global GHG emissions has largely been explored using Life Cycle Analysis (LCA) – a form of engineering analysis with limited economic content. Hill *et al*. (2006) by using LCA approach found that the corn-ethanol yields 25% more energy and reduces 12% of GHGs, and soybean-biodiesel yields 93% more energy and reduces 41% of

GHGs relative to fossil fuels. However, recently, results from economic models have been combined with LCA in order to permit assessment of more complex aspects of the problem, including international land use change (e.g., (Fargione *et al*., 2008; Searchinger *et al*., 2008).

While these studies offer a variety of perspectives on biofuel impacts, a comprehensive consistent framework of global economic interactions and associated emissions is still lacking. In this paper we depart entirely from LCA – instead computing the GHG emissions impacts of biofuels entirely within an economic model. Since our model is global in scope, and covers all economic activities, this permits us to capture the direct and indirect impacts of biofuels on emissions in a more comprehensive and consistent fashion.

Modeling Framework

In order to model the global, economy-wide activity of biofuels, we utilize a global Computable General Equilibrium (CGE) model offered by Birur *et al*. (2007) which is the extension of GTAP-E model (Burniaux and Truong (2002) and McDougall and Golub (2009)). Birur *et al*. (2007) have allowed for substitution of biofuels to petroleum products in the consumption demand structure and at the same time as complementary petroleum and biofuel composite goods in the firms' production structure implying the blending demand for biofuels. They incorporate three types of biofuels, including grain-based ethanol (mainly corn in the US), sugarcane-based ethanol, and vegetable oil based biodiesel (Taheripour *et al.*, 2007). Furthermore, Birur *et al*. (2007) incorporate disaggregated land endowments broken into 18 Agro-Ecological Zones as offered by Lee *et al*. (2008) in order to yield a more accurate representation of sectoral competition for land. As given by Hertel *et al.* (2008), we adopt a nested constant elasticity of transformation (CET) function which allocates land in two tiers: In the first stage, the land-owner makes optimal allocation of a given parcel of land under crops, pasture or commercial forest, while the choice of crops is made in the second stage (six categories of crops – refer to Table 1 for sectoral aggregation). Given that any increase in biofuel production would necessitate an increase in the supply of feedstock, which has to come from diversion of feedstock from other uses, increased yields and/or expansion of land area under that feedstock crop. Also, there is a possibility of keeping cropland idle or taking up pasture-crop in the second stage of land-allocating decision making. In addition to the earlier work, we pay special attention to the potential for cropland pasture and Conservation Reserve Program land to meet the increased demand for cropland.

Production of biofuels also yields co-products, which form another source of revenue for the biofuel plants. For example, one bushel of corn (56 lbs) can produce about 2.70 gallons of ethanol and 17 lbs of distillers dried grains with solubles (DDGS) as a co-product. Sales of DDGS as a livestock feed generate roughly 16% of total ethanol revenues in the U.S. and displace corn and other feedstuffs (Tiffany and Eidman, 2003). Similarly biodiesel produced from one bushel of soybeans (60 lbs) yields 1.47 gallons of biodiesel and 48 lbs of oil-meal and that of rapeseed generates 3.41 gallons of biodiesel and 39 lbs of meal. Taheripour *et al*. (2008) show that ignoring the by-products of biofuels leads researchers to significantly overstate the impact of biofuel production. Therefore, we follow their approach in incorporating DDGS and vegetable oil cake (soybean meal in the U.S. and rapeseed cake in EU) and then augment feed demand in the livestock sector by allowing for substitution between biofuel by-products and other animal feed.

Analyzing the GHG implications of biofuels is rather complex, as biofuels production stimulates economy-wide changes in sources and sinks of GHGs such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Fluorinated-gases (HFCs, PFCs, and SF_6) due to related agricultural activities. In the GTAP-E model, Burniaux and Truong (2002) have incorporated CO_2 emission data (Lee, 2007) by linking the emissions to the combustion of fossil fuels in the model. We inherit this model structure and supplement it with data on GHG emissions associated with biofuel feedstock, crop conversion to fuel, and land cover conversion - direct and indirect. The *direct* land use change refers to change induced by specific biofuel activity in a given region and the repercussions of a region's biofuel activity in another region is referred as *indirect* land use change (Kim *et al*., 2009). Recently, the indirect land use change (ILUC) has raised serious concerns among the biofuel policy makers as the magnitude of ILUC determines if a particular type of biofuel is net GHG emitter or not.

Incorporating GHGs Emissions in the Database

One of the major driving forces for targeting greater use of biofuels is their potential for GHGs savings. However, studies by Fargione *et al*. (2008) and Searchinger *et al*. (2008) indicate that U.S. corn-ethanol is a net emitter of GHGs when indirect land-use emissions are accounted. Levels of carbon dioxide and other GHGs such as methane, nitrous oxide, F-gases in the atmosphere have risen steeply since the industrial revolution. Emissions (anthropogenic *sources*) of CO_2 have increased mainly because of economic activities such as use of fossil fuels, deforestation, etc. It has been argued that biofuels will emit lesser CO_2 compared to fossil fuels and also growing feedstocks could be *sink* of CO_2. As Dufey (2007) reports, the reduction in CO_2 emissions vary by the type of feedstock – wood biofuel being extremely promising to the lowest from corn-ethanol. However, agricultural activities also result in emission of N_2O (produced by nitrification and de-nitrification in soils) and CH_4 (produced by anaerobic decomposition of organic matter), which are heavier (relative to molecular weight of CO_2) and has longer average global warming potential. Crutzen *et al.* (2007) show that biofuel crops can result in enhanced global warming when CO_2 equivalent of N_2O is accounted. This explains the complexity in analyzing biofuel implications on GHGs emissions.

The GTAP-E model developed by Burniaux and Truong (2002) and revised by McDougal and Golub (2008) facilitates evaluation of CO_2 emission under different policy instruments. The CO_2 emission data is read from the database and it is linked to the levels of economic activities defined in the model. In order to utilize this module for biofuels study requires computing CO_2 emission resulting from use of biofuels. Lee (2002) utilizes energy volume data to compute Giga- grams of CO_2 emitted by consuming different fossil fuels in thousand tonnes of oil equivalent (toe). In a similar fashion, for calculating emissions from biofuels, we use the guidelines laid out by US-EPA (2004).

$$CO_{2_i} = Fuel_i.FD_i.C_i.FO_i.\frac{CO_{2_{m.w}}}{C_{m.w}} \quad (1)$$

Where, $Fuel_i$ is the volume of fuel type i combusted, FD_i is the density of fuel type i (mass/volume), C_i is the carbon content fraction of fuel type i (mass C/volume), FO_i refers to fraction oxidized of fuel type i and $CO_{2_{m.w}}$ and $C_{m.w}$ refers to molecular weight of carbon. The emission factor used for ethanol is 5.5 kg CO_2/gal and that of biodiesel is 9.29 kg CO_2/gal. In the GTAP-E model, the emissions are assumed to be in proportion to the use of fuels and this come from consumption of energy commodity by *firms*, *government*, and *private households* each by *domestic* and *imported* use. The biofuels database used in this study corresponds to 2001 during which most of the biofuels was used as additive and hence we assume that 75% of the ethanol is used by firms and the remainder by households, where as all the biodiesel is consumed by the household. The resulting emissions from biofuels are estimated accordingly.

Linking Biofuels and GHGs Emissions Models

For analyzing the overall impacts on non-CO_2 greenhouse gas emissions in agriculture and across the economy, we build on the works of Hertel *et al*. (2008). They identify three types of non-CO_2 emissions using a database prepared by Rose and Lee (2008), based on information available from the US-EPA. Emissions are handled in three distinct ways. Some are associated with primary inputs (e.g., livestock capital), some are tied to intermediate input use (e.g., fertilizers), and others are associated with outputs (e.g., agricultural residues). They introduce three tier land supply function, the three non-CO_2 GHGs (N_2O, CH_4, F-gas) and mitigation responses. They link methane emissions from paddy-rice cultivation and the emissions change in proportion to the paddy-rice acreage response. Emission of nitrous oxide has been linked with the use of fertilizers in crop production. This is important for this study since biofuels expansion can result in *intensification* as well which can result in greater use of fertilizers and consequent increase in GHG emissions. The emissions associated with burning of agricultural crop residues, stationary and mobile combustion are tied with the output of a given commodity. They further link the emissions from enteric fermentation, manure management in non-ruminants with livestock capital and that of ruminants are linked with their output. The emissions of GHGs vary in proportion to changes in the level of the underlying economic driver.

Emissions associated with land conversion to crops are also incorporated into the model. For this, we base our analysis on estimates from Searchinger *et al*. (2008) for ecosystem carbon stocks and losses resulting from land cover conversion. Within this modeling framework, we can measure global, general equilibrium impact on GHG emissions owing to biofuels expansion in the US, EU, Brazil, and potentially elsewhere.

In this study we use aggregated database to focus on the sectors and regions that are relevant to biofuels policy analysis. We aggregate the database into 31 economic sectors which basically includes all the land-based emitting sectors (crops, forestry, and pasture), biofuels, energy commodities and other sectors (Table 1). The global regions are aggregated into 19 depending on whether they are major producers and consumers of energy (Table 2).

Policy Analysis

We begin by focusing on the historical period: 2001-2006 which was a period of rapid growth in biofuel production in the US and the EU. The drivers behind biofuels expansion over this period have been examined in considerable detail in Birur *et al*. (2007). In this paper, we examine the impact of this rapid expansion in biofuels production on GHG emissions globally with 2006 baseline. Thus, these estimates include the changes in emissions in the biofuel-focused countries (Brazil, EU and US) as well as the international changes induced by changes in international energy markets, trade flows and world prices. As discussed earlier, with the passing of Energy Independence and Security Act of 2007, U.S. mandates to produce 15 bgy of corn-ethanol, and 2.5 bgy of advanced biofuels, by 2015. Similarly EU biofuel directive requires its member states to meet a target for 10% share for biofuels in transportation liquids, by 2020. With the growing interest in biofuels world-wide, Brazil is aiming to double its current biofuel usage by 2015 and also export to the world market. The targets for the three regions are listed in Table 3 based on energy content of the fuels. Following the baseline-2006, a 2015 scenario will be implemented where we increase the share of biofuels in U.S., EU, and Brazil.

In addition, these changes in GHG emissions are decomposed and associated with the individual drivers behind the biofuels boom, including: changes in subsidies, rising oil prices, and other drivers (e.g., the ban in MTBEs as gasoline additives).

We then look into the future at alternative biofuel growth scenarios. We consider proposed policies for biofuels expansion in the US, EU and Brazil for year 2015, as well as alternative potential trajectories of larger and smaller growth, including a collapse of the traditional biofuels market. With these experiments, we examine the implications for GHG emissions across the world as petroleum is displaced in liquid fuels production, crop production intensifies, crop land expands, intermediate input and output markets respond, and consumption changes.

The policy analysis focuses on examining the key issue whether biofuels production reduce green house gas emissions.

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Figure 1. Modification of Production Structure in the GTAP-E-Biofuels Model

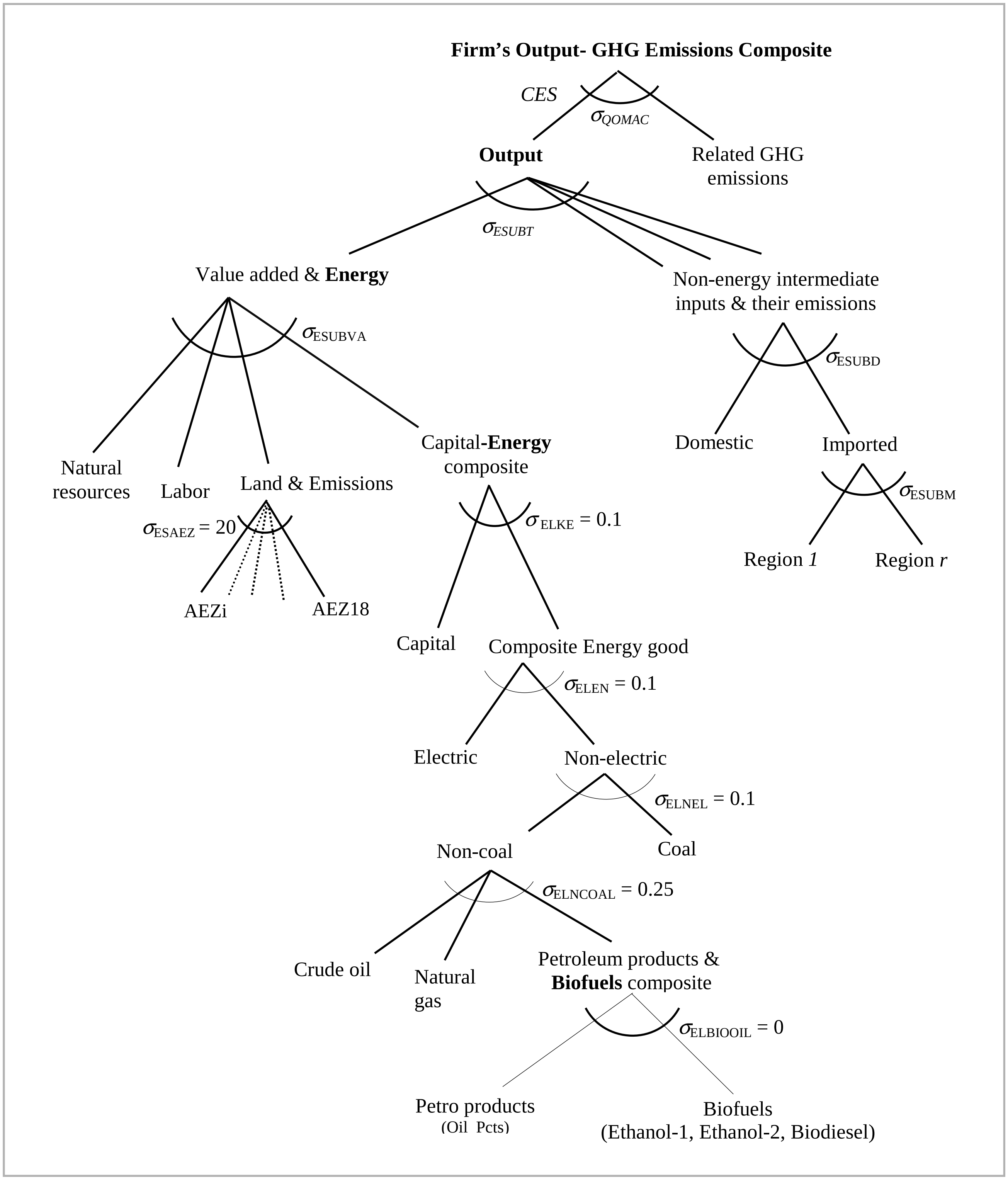

Table 1. Aggregation of GTAP Sectors in the Model

No.	Industries	Commodities	Description of Sectors	Corresponding GTAP Sectors
1	Paddy_Rice	Paddy_Rice	paddy rice	pdr
2	Wheat	Wheat	Wheat	wht
3	CrGrains	CrGrains	Coarse Grains	gro
4	Oilseeds	Oilseeds	Oilseeds	osd
5	Sugar_Crop	Sugar_Crop	Sugracane, Sugarbeet	c_b
6	OthAgri	OthAgri	Other agriculture crops	v_f, pfb, ocr
7	Forestry	Forestry	Forestry	frs
8	Dairy_Farms	Dairy_Farms	Milk	rmk
9	Ruminant	Ruminant	cattle, sheep, goats,	ctl, wol
10	NonRuminant	NonRuminant	other Animal Products	oap
11	Proc_Dairy	Proc_Dairy	Processed dairy products	mil
12	Proc_Rum	Proc_Rum	Cattle meat	cmt
13	proc_NonRum	proc_NonRum	Other meat	omt
14	Cveg_Oil	Cveg_Oil1	Crude vegetable oil	vol1a
		VOBP	Oil meal	vol1b
15	Rveg_Oil	Rveg_Oil	Refined vegetable oil	vol2
16	Bev_Sug	Bev_Sug	Beverages, sugar	sgr, b_t
17	Proc_Rice	Proc_Rice	Processed rice	pcr
18	Proc_Food	Proc_Food	processed food products	ofdn1
19	Proc_Feed	Proc_Feed	processed feed products	ofdn2
20	OthPrimSect	OthPrimSect	fishing, other mining	fsh, omn
21	EthanolC	Ethanol1	Grain Ethanol	eth1 (ofd1)
		DDGS	Distiller's Dried Grains with Solubles	
22	Ethanol2	Ethanol2	Sugarcane based ethanol	eth2 (crp1)
23	Biodiesel	Biodiesel	Veg oil based biodiesel	biod (vol1)
24	Coal	Coal	coal	coa
25	Oil	Oil	Crude oil	oil
26	Gas	Gas	Natural gas, gas distribution	gas gdt
27	Oil_Pcts	Oil_Pcts	Petroleum & coke	p_c
28	Electricity	Electricity	Electricity	ely
29	En_Int_Ind	En_Int_Ind	Energy intensive Industries	crpn, i_s, nfm
30	Oth_Ind_Se	Oth_Ind_Se	Other industry and services	tex, wap, lea, lum, ppp, nmm, fmp, mvh, otn, ele, ome, omf, cns, trd, otp, wtp, atp, cmn, ofi, isr, obs, ros
31	NTrdServices	NTrdServices	Non-tradable services	wtr, osg, dwe

Table 2. Aggregation of GTAP Regions in the Model

No.	Regions	Description	Corresponding GTAP Regions
1	USA	United States	usa
2	EU27	European Union 27	aut bel dnk fin fra deu gbr grc irl ita lux nld prt esp swe bgr cyp cze hun mlt pol rom svk svn est lva ltu
3	BRAZIL	Brazil	bra
4	CAN	Canada	can
5	JAPAN	Japan	jpn
6	CHIHKG	China, Hong Kong	chn hkg
7	INDIA	India	ind
8	C_C_Amer	Caribbean and Central America	mex xna col per ven xap arg bra chl ury xsm xca xfa xcb
9	S_o_Amer	South and Rest of America	col per ven xap arg chl ury xsm
10	E_Asia	East Asia	kor twn xea
11	Mala_Indo	Malaysia, Indonesia	ind, mys
12	R_SE_Asia	Rest of Southeast Asia	phl sgp tha vnm xse
13	R_S_Asia	Rest of South Asia	bgd lka xsa
14	Russia	Russia	rus
15	Oth_CEE_CIS	Oth Eastern Europe & FSU	xer alb hrv xsu tur
16	Oth_Europe	Rest of Europe	che xef
17	MEAS_NAfr	Middle East & North Africa	xme mar tun xnf
18	S_S_AFR	SSA & Rest of Africa	bwa zaf xsc mwi moz tza zmb zwe xsd mdg uga xss
19	Oceania	Oceania countries	aus nzl xoc

Table 3. Biofuels Consumption in the U.S., EU, and Brazil on Energy Basis

Fuel Consumption:	*Units*	US			EU-27			Brazil		
		2001	**2006**	**2015**	**2001**	**2006**	**2015**	**2001**	**2006**	**2015**
Liquid fuels for Transport:										
Petroleum	*Quad Btu*	25.96	27.57	29.63	18.20	18.20	18.50	3.28	3.51	3.78
Total Biofuels[1]	*Quad Btu*	0.150	0.503	1.508	0.037	0.224	1.156			
Ethanol	*Quad Btu*	0.149	0.471	1.341	-	0.035	0.183	0.26	0.39	0.73
Biodiesel	*Quad Btu*	0.001	0.032	0.167	0.037	0.189	0.973	-	0.01	0.09
Share of biofuels in liquids for transport (energy basis) *%*		***0.58***	***1.83***	***5.09***	***0.20***	***1.23***	***6.25***	***7.84***	***11.11***	***19.31***