Comparison of Biofuel Life Cycle Assessment Tools

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Brazilian Bioethanol Science and Technology Laboratory (CTBE)
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Task 39 – Commercializing Liquid Biofuels
International Energy Agency (IEA)

February, 2017

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Presentation

This report includes the results of phase 1 of the study entitled “Comparison of Biofuel Life Cycle Assessment Tools” prepared by the CTBE team for the Task 39 group (Commercializing Liquid Biofuels) which is part of the Bioenergy division of the International Energy Agency (IEA).

Phase 1 comprises the period from March 2016 to January 2017 and was developed in collaboration with Helena Chum (Task 38) and Ethan Warner from the National Renewable Energy Laboratory (NREL).

Introduction and objective

Governmental agencies and initiatives from the transportation sector have defined targets to reduce global greenhouse gas (GHG) emissions in face of the concern about climate change. The use of alternative fuels for transportation, particularly bio-based, is considered the main approach to reach these targets given their potential to reduce life cycle GHG emissions compared to petroleum-based fuels. In order to quantify these reductions and determine the compliance with the indicated targets, a number of calculation models have been developed and utilized to measure GHG and other impacts originated from fuel pathways. Some were specifically designed according to regulatory schemes, whereas others were adopted and/or modified from existing tools. These models utilize, to a greater or lesser extent, the orientations given by the Life Cycle Assessment (LCA) methodology defined by ISO documents (ISO 14040, 2006; ISO 14044, 2006) considering all the stages of production, transportation, distribution, and use of fuels.

Despite the need for consistent GHG emissions calculations to provide reliable lifecycle impacts assessment results, significant variations have been observed across models in values obtained, especially for biofuels. The different assumptions, input data, treatment of co-products, and calculation structure, characteristic of the LCA approach utilized within the models have major influence on the results, eventually leading to significant variability in impact values for the same biofuel pathway assessed. The motivation of this study is that the application of different models, specifically for the calculation of GHG emissions jeopardize the optimal use of LCA in the policy context and discredits the compliance with the reduction targets established.

Three regulatory models which are currently operational and publicly available (namely GHGenius, GREET, and BioGrace), and an assessment platform designed for the assessment of sugarcane ethanol (Virtual Sugarcane Biorefinery or VSB) were utilized to calculate the GHG emissions associated with ethanol produced from sugarcane, corn, and wheat. GHGenius was developed by $S\&T^2$ Consultants (2013) as an expanded version of Delucchi's Lifecycle Emissions Model (Delucchi, 2003); the Greenhouse gases, Regulated Emissions and Energy in Transportation (GREET) model was developed in 1996 by the Argonne National Laboratory (ANL) sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) (ANL, 2016); the BioGrace model was developed aimed to harmonize the default values used in European calculations of biofuel GHG emissions for use in the EU Renewable Energy Directive (RED) and Fuel Quality Directive (FQD) (Neeft, 2013); and the VSB tool was developed by the Brazilian Bioethanol Science and Technology Laboratory (CTBE) focusing on the sustainability assessment of sugarcane biorefinery configurations in Brazil (Bonomi et al., 2016). (*See* ***Table 1*** *of the supplementary material for general information about the models*). The aim of this study was to provide an overview of the tools, and to identify and track the main reasons for the results obtained by each model, depicting the main differences and commonalities in methodological structures, calculation procedures, and assumptions made for the biofuels. As an additional outcome, this analysis provided recommendations for the development of improved, harmonized and more appropriated calculation of GHG emissions impacts.

Main results

Differences in GHG impacts across the models can be visualized in **Figure 1**. GHGenius presented the most discrepant value for sugarcane ethanol, due to the impacts associated with the agricultural stage (farming), in which diesel, limestone and nitrogen emissions are the most relevant inputs. For corn and wheat ethanol, BioGrace presented the lowest impacts, mainly due to the default allocation method (energy) which led to a 50% partitioning of the total. Additional causes of the differences observed in those cases are related to the amount of inputs considered in the agricultural and industrial stages. (*See **Figures 2, 3** and **4,** and **Tables 2**, **3** and **4** of the supplementary material for detailed breakdown of the impacts and inventories of the agricultural and industrial stages for the different models*).

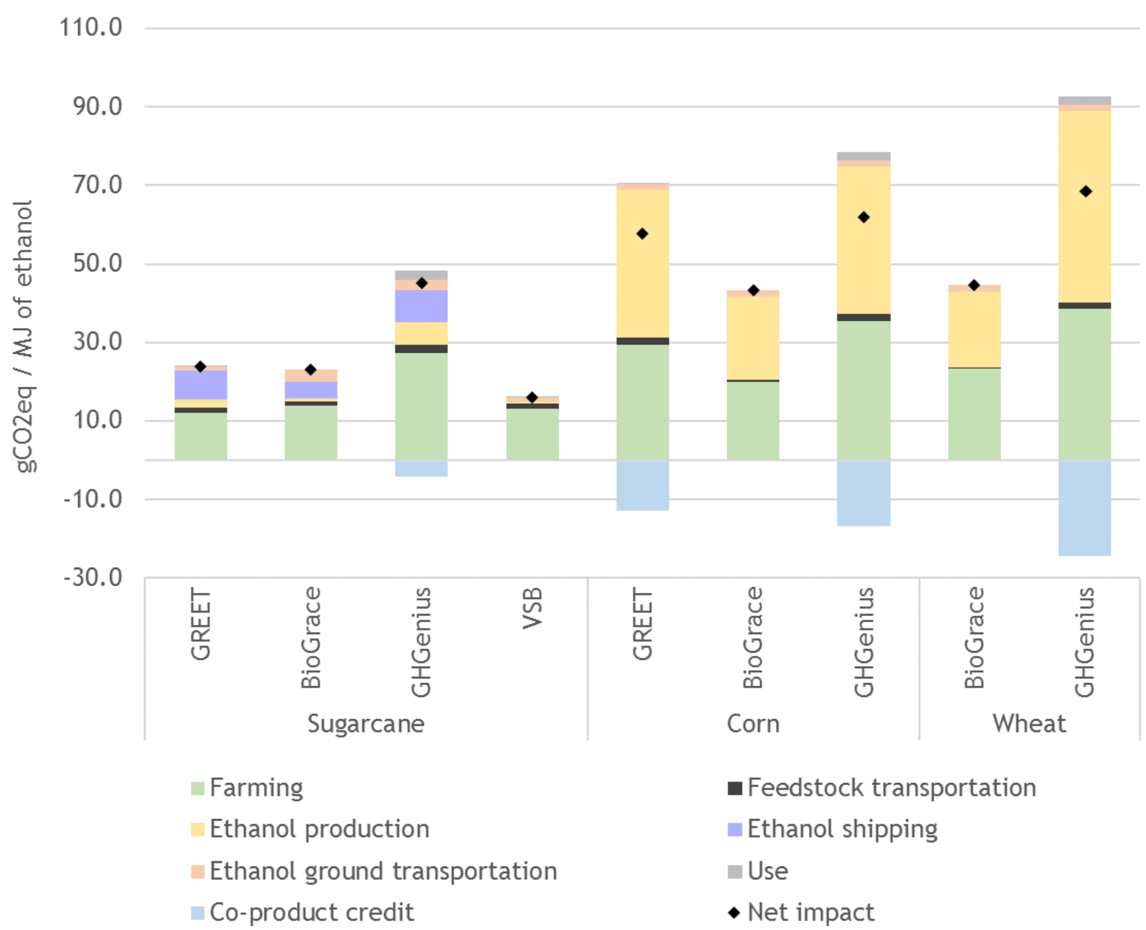

Figure 1. Greenhouse gases emissions impacts of ethanol produced from sugarcane, corn and wheat in gCO_2eq per MJ of ethanol calculated with GREET, BioGrace, GHGenius and VSB models.

General causes of differences observed across GHG models

Variations in the life cycle datasets and inventories led to differences in the GHG models examined. These variations are usually related to the data source (references utilized as default) and the level of details (scope and items considered). For instance, the GREET model was developed in the US by the ANL is very much aligned with the production of ethanol in the US, and therefore, utilizes comprehensive and updated data for corn as agricultural feedstock, whereas the inventory for Brazilian sugarcane ethanol is over-simplified and outdated for some important inputs. *(See **Tables 2**, **3** and **4** of the supplementary material for details about the inventories for the agricultural and industrial stages for the different models).*

Coupled with the variations observed in the inventories, the upstream life cycle data had huge influence in the results obtained. Main relevant items in terms of GHG impacts include fertilizers, diesel, and natural gas accounting for their manufacture and use. The impacts can significantly vary across models: as much as 30% for diesel production and combustion with 116.4 gCO_2eq MJ^{-1} for GHGenius and 81.6 gCO_2eq MJ^{-1} for the VSB (based on the Ecoinvent database v2.2), and 43% for the production of nitrogen fertilizer with 5.88 gCO_2eq kg^{-1} for BioGrace (based on the Joint Research Centre-EUCAR-CONCAWE (JEC) database v4.a) and 3.35 gCO_2eq kg^{-1} for the VSB. (*See **Table 5** of the supplementary material for upstream lifecycle data of selected inputs).*

The contribution of N_2O to net GHG emissions is an additional important variable, magnified by the high global warming potential that can be as much as 298 times greater than that of CO_2 depending on the IPCC GWP method chosen (*See **Table 1** of the supplementary material for details about the GWP method utilized by each model).* These emissions come from nitrogen fertilizer application and organic matter decomposition (Stehfest and Bouwman, 2006); and depend on soil type, climate, crop, tillage method, and fertilizer and agricultural residues application rates. Although considered GHG models utilize the IPCC 2006 method (Klein et al., 2006) as basis to account for the N_2O field emissions, small differences in the assumptions led to significant variability in the results obtained by each model. For instance, for direct N_2O emissions associated with the use of N-fertilizer, BioGrace and the VSB utilize the default IPPC values for the direct N_2O emissions (equivalent to 1.00%), whereas the others consider differentiated values for the crops (GHGenius considers 1.00% for wheat and 1.25% for corn and sugarcane; whereas GREET considers 0.895% for Brazilian sugarcane and 0.900% for corn). *(See **Table 6** of the supplementary material for details about the direct and indirect N_2O emissions factors utilized by each model).*

The choice of the allocation procedure is one of the most controversial topics in LCA. The issue arises when a system produces more than one valuable output. The concern is automatically associated with biofuels production systems, since by- and co-products are often produced along with the fuel of interest. The models investigated in this study take different approaches: the VSB considers economic allocation as default; BioGrace uses energy for partitioning as recommended by the EU RED, although JEC (2011) suggests substitution as the most appropriate approach; GHGenius utilizes the substitution method as standard, whereas GREET uses mixed approaches depending of the biofuel pathway. For example, impacts from sugarcane ethanol and surplus electricity produced in Brazil are allocated according to energy as default, whereas the impacts of corn ethanol in the US are partitioned with the co-products using the substitution method. It is important to mention that some models give flexibility for the user to choose among different approaches *(See **Table 7** of the supplementary material for details about the allocation methods).*

Specific causes of differences observed across GHG models

The impacts associated with straw burning during the manual harvesting of sugarcane are a sensitive issue with relevant contribution to GHG emissions impacts. All models give a certain flexibility for the user to choose a certain percentage of manual harvesting. However, changing the default values can be tricky and complex as models are not designed for non-expert users. Default values (as they are presented in the models) were maintained for this comparative assessment. GREET assumes a time series for straw burning with values ranging from 95% of manual harvesting in 1995 to 14% in 2015. The value for 2015 (which is used in this study) is close to the 18.4% value considered within the VSB tool. BioGrace, on the other hand, considers that 100% of the straw is burned in the field, whereas GHGenius assumes no burning as default. *(See **Figure 2** of the supplementary material for a visualization of the effect of straw burning on the impacts).*

Impacts of the overseas transportation of ethanol from sugarcane are particularly high in GREET, BioGrace and GHGenius, since these models assume that the fuel is produced in Brazil and then shipped to the US and Europe for distribution and use. This is not the case for corn and wheat ethanol as they are assumed to be produced and used domestically.

The amount of limestone considered by GHGenius for sugarcane production is very discrepant if compared to the other models. The value was calculated based on the average of three studies: Seabra et al. (2011) with 450 kg CaO ha^{-1}, Macedo et al. (2004) with 366 kg CaO ha^{-1} and Macedo et al. (2008) with 1,900 kgCaO ha^{-1}, resulting in 11.7 kg per tonne of sugarcane, against a value of around 5 kg per tonne of sugarcane assumed for the other models. *(See **Table 2** of the supplementary material for details about the amount of limestone considered).* Additionally, **emissions associated with the manufacture and use of limestone assumed by GHGenius present a much higher value than those from the other models** *(See **Table 5** of the supplementary material for the emissions of limestone).*

Harmonization

A harmonization procedure was performed with the objective of achieving similar results using the different models. A schematic representation in **Figure 2** shows step-by-step modifications to depict the influence of a selected parameter and/or approach in the calculation mechanisms for corn and sugarcane ethanol. For sugarcane ethanol, the VSB model was utilized as basis of comparison, whereas GREET was chosen for corn ethanol (*aligned with the study performed by Helena Chum's group from the National Renewable*

Energy Laboratory (NREL) for the IEA Bioenergy Task 38). The harmonization procedure included: (1) allocation method (VSB utilizes economic allocation for sugarcane ethanol, whereas GREET uses substitution for corn ethanol); (2) removal of the ethanol shipping parameters (for sugarcane ethanol only), with feedstock and ethanol logistics, and vehicle use equal to those from the basis model; (3) nitrogen, limestone (for both ethanol cases) and straw burning emissions (for sugarcane ethanol only) equal to those from the basis model; (4) energy used in the agricultural operations equal to those from the basis model; (5) emissions from the ethanol production stage (industrial conversion) equal to those from the basis model.

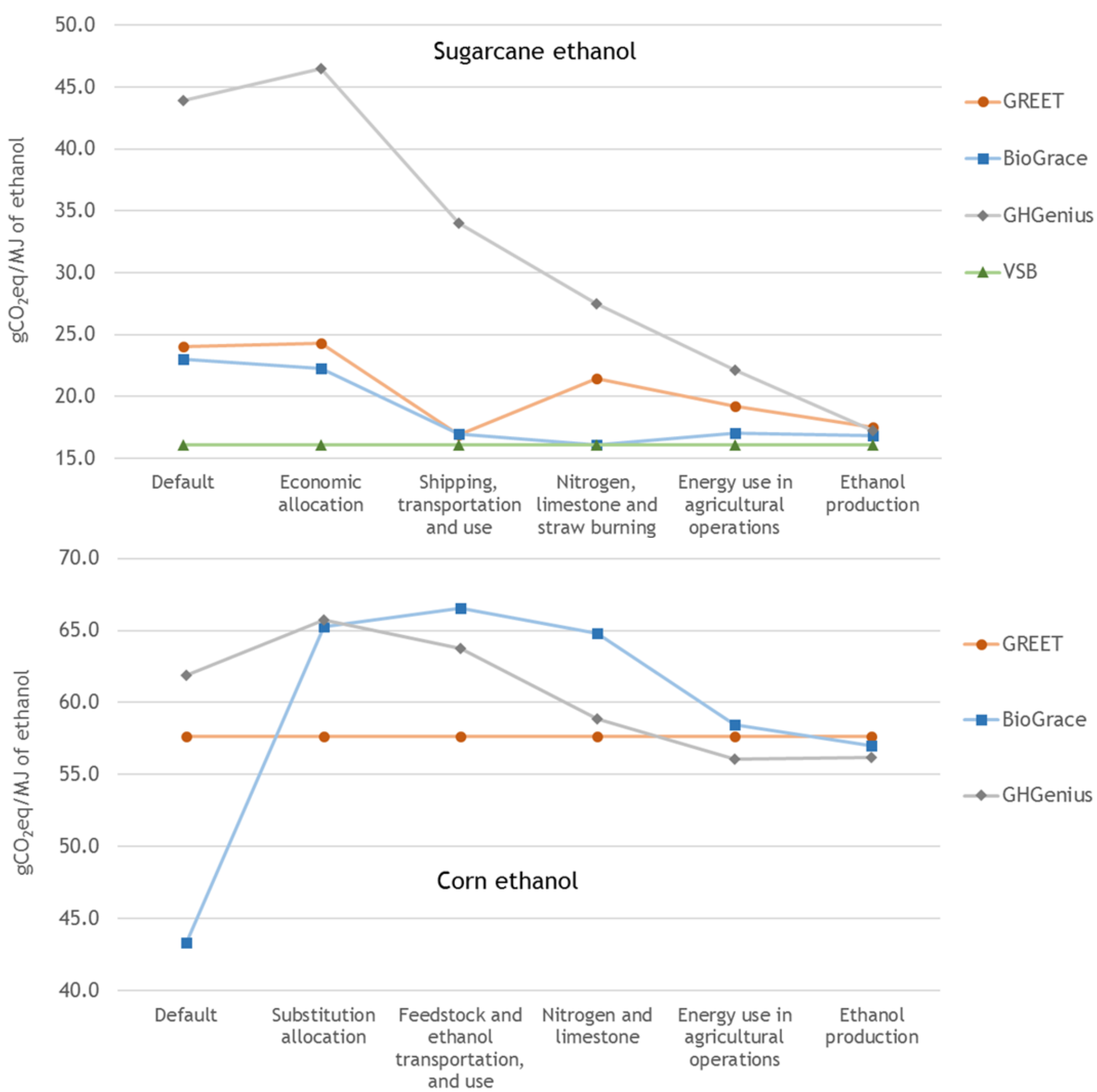

Figure 2. Schematic representation of step-by-step modifications in parameters to reach similar results for sugarcane and corn ethanol.

Recommendations

Recommendations presented in this report have the purpose of minimizing the differences observed across models and providing consistency for the GHG emissions calculations. **Life cycle inventories should be constantly updated**: data on biomass productivity, agricultural practices and industrial technologies are constantly modified and improved which can lead to substantial variability in the results. As an example of this disparity, for sugarcane ethanol agricultural inventory BioGrace utilizes Macedo et al. (2004), which contains data from the year 2002, while VSB uses average values from 2015 utilizing various official public references. **Allocation methods should be clearly indicated and flexibility should be provided** to allow the user to choose from a set of defined approaches within the models in order to obtain consistent and comparable results. **GHG models should be adapted to a non-expert audience**: GHGenius and GREET models are particularly complex to be modified although providing a certain flexibility; it is also challenging to visualize a breakdown of results per stage, as models do not have a standardized scheme of presenting the impacts. Specifically, for sugarcane ethanol production in Brazil, **calculations should consider the amount of surplus electricity generated as co-product**, characteristic of the current production system and disregarded by BioGrace.

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Supplementary Material

Table 1. Main characteristics of the GHG models

	BioGrace	GHGenius	GREET	VSB
Developed for regulatory purpose	Yes	No	No	No
Type of LCA	Attributional	Attributional	Attributional	Attributional
Upstream life cycle data[a]	JRC database	Internal	Internal	Ecoinvent
IPCC GWP-100yr method[b]	2001		2007	2007
Land use change (LUC)[c]	C stocks	None	CCLUB	None
Gasoline baseline ($gCO_2eq\ MJ^{-1}$)	83.8	95.0	90.2	87.5
Ethanol emissions ($gCO_2eq\ MJ^{-1}$)[d]				
Sugarcane	24.0	43.3	25.3	16.0
Corn	43.6	64.2	67.8	-
Wheat	69.9	71.0	-	-

[a]The European life cycle database (ELCD 3.2) utilized by BioGrace can be found at: http://eplca.jrc.ec.europa.eu/ELCD3/; the VSB utilizes the Ecoinvent database v2.2;
[b]IPCC Global warming potential methods: 2001: CH_4 23 gCO_2eq and N_2O 296 gCO_2eq - 2007: CH_4 25 gCO_2eq and N_2O 198 gCO_2eq - 2013: CH_4 30 gCO_2eq and N_2O 265 gCO_2eq; for BioGrace the EU RED indicates the use of the 2001 IPCC GWP method as default, however JEC recommends the use of the 2007 IPCC GWP method;
[c]BioGrace offers the possibility of the calculation of direct land use change through carbon stocks (actual land use (CS_A) and reference land use (CS_R)) for which guidelines as published in the Commission Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC can be found at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:151:0019:0041:EN:PDF; the GREET model holds a separate model for direct and indirect land use change estimation entitled CCLUB (Carbon Calculation for Land Use Change from Biofuels) that can be used for corn, miscanthus, and switchgrass ethanol;
[d]Land use change (LUC) not included, considering lower heating values (LHV) and default allocation methods

Table 2. Main agricultural and industrial inputs for sugarcane ethanol production

	BioGrace[a]	GHGenius[b]	GREET[c]	VSB[d]
Inputs per tonne of sugarcane				
N fertilizer (kg)	0.91	1.08	0.80	1.23
P_2O_5 fertilizer (kg)	0.41	0.58	0.30	0.14
K_2O fertilizer (kg)	1.08	1.47	1.00	1.31
Limestone (kg)	5.34	11.65[e]	5.20	5.00
Pesticides, herbicides, insecticides (g)	29.1	5.1	47.5	16.7
Seedlings (kg)	29.1	30.3	-	44.1
Diesel (machinery operation) (L)	0.8	2.9	1.1	1.9
Inputs per L of ethanol				
Sulfuric acid (g)	16.06	7.40	-	4.94
Lime (g)	17.97	11.00	10.85	7.48
Cyclohexane (g)	1.06	-	-	0.71
Phosphoric acid (g)	-	-	-	2.70
Inorganic chemicals (g)	-	-	-	0.044
Zeolites (g)	-	-	-	0.047

[a]Based on Macedo et al. (2004); a factor of +40% is applied to industrial inputs for BioGrace to encourage voluntary contribution from the private sector;
[b]Based on average values from three studies (Macedo et al., 2004; Macedo et al., 2008 and Seabra et al., 2011), except for diesel use;
[c]Seabra et al. (2011) apud Wang et al. (2012);
[d]Based on experts' recommendations and literature;
[e]The amount of limestone considered within GHGenius is an average value calculated based on Seabra et al. (2011) with 450 kg CaO ha^{-1}, Macedo et al. (2004) with 366 kg CaO ha^{-1} and Macedo et al. (2008) with 1,900 kgCaO ha^{-1}, resulting in a much larger value than those assumed for the other models.

Table 3. Main agricultural and industrial inputs for corn ethanol production

	BioGrace[a]	GHGenius	GREET[b]
Inputs per tonne of corn			
N fertilizer (kg)	13.3	17.2	16.7
N in animal manure (kg)	-	1.9	-
P_2O_5 fertilizer (kg)	8.9	5.0	5.7
K_2O fertilizer (kg)	6.6	6.9	6.0
Limestone (kg)	412.0	-	45.3
Pesticides, herbicides, insecticides (g)	618.0	312.3	277.8
Seeds (kg)	-	2.32	-
Diesel (machinery operation) (L)	26.3	4.8	4.2
Natural gas (L)	-	8,706	2.1
LPG (L)	-	4.8	1.7
Electricity (MJ)	-	-	17.4
Inputs per L of ethanol			
Electricity (MJ)	-8.0	0.9	0.7
Natural gas (MJ)	27.1	7.9	6.1
Coal (MJ)	-	1.8	0.53
Alpha-amylase (g)	-	-	0.657
Glucoamylase (g)	-	-	1.41
Ammonia (g)	-	21.6	4.67
Enzymes (g)	-	5.0	-
Sodium hydroxide (g)	-	5.8	5.85
Sulfuric acid (g)	-	10.9	4.67
Calcium oxide (g)	-	-	2.8
Yeast (g)	-	3.5	0.71

[a]A factor of +40% is applied to industrial inputs for BioGrace to encourage voluntary contribution from the private sector; Electricity coproduced with required steam is accounted as a credit to the product system.
[b]GREET considers three types of corn mills existent in the US for the production of ethanol: dry mill without corn oil extraction (17.72%); dry mill with corn oil extraction (70.88%); and wet mill (11.40%).

Table 4. Main agricultural and industrial inputs for wheat ethanol production

	BioGrace[a]	GHGenius
Inputs per tonne of wheat		
N fertilizer (kg)	21.0	18.0
P_2O_5 fertilizer (kg)	4.2	10.3
K_2O fertilizer (kg)	3.1	0.83
Sulphur fertilizer (kg)	-	0.22
Pesticides, herbicides, insecticides (g)	448.3	316.1
Seeds (kg)	23.0	43.8
Diesel (machinery operation) (L)	19.8	8.5
Inputs per L of ethanol		
Electricity (MJ)	-5.6	10.8
Natural gas (MJ)	20.2	13.4
Ammonia (g)	-	13.9
Enzymes (g)	-	5.5
Sodium hydroxide (g)	-	1.6
Sulfuric acid (g)	-	4.9
Yeast (g)	-	4.0

[a]A factor of +40% is applied to industrial inputs for BioGrace to encourage voluntary contribution from the private sector. Industrial inputs considering a configuration with steam production from a natural gas CHP system.

Table 5. Upstream lifecycle data for selected inputs

Input	BioGrace[a]	GHGenius[b]	GREET[b]	VSB[c]
kg CO_2eq per kg of nutrient (manufacture)				
Nitrogen (N)	5.88	3.51	4.48	3.35
Phosphate (P_2O_5)	1.01	0.73	1.51	2.16
Potassium (K_2O)	0.58	0.47	0.66	0.55
g CO2eq per kg of input (manufacture + use)				
Limestone (CaO)	129.5	790.0	236.0	131.6
g CO_2eq per MJ of fuel (production + combustion)				
Diesel	87.6	116.4	90.2	81.6
Coal	111.3	103.7	96.0	-
Natural gas	67.6	83.1	66.7	-

[a]The European life cycle database (ELCD 3.2) from the Joint Research Centre (JRC) can be found at: http://eplca.jrc.ec.europa.eu/ELCD3/;
[b]Internal calculation;
[c]Ecoinvent database v2.2.

Table 6. Emissions factors for direct and indirect N_2O emission from fertilizers and agricultural residues

Emission factors[a]	BioGrace	GHGenius	GREET	VSB
Direct N_2O emissions[b]	1.00%			
Sugarcane	-	1.25%	0.895%	1.00%
Corn	-	1.25%	0.900%	-
Wheat	-	1.00%	-	-
Indirect N_2O emissions[c]				
Volatilization of N as NH_3	10%	10%	10%	30%
N in NH_3 converted to N_2O	1.00%	1.00%	1.00%	1.00%
Runoff/leaching as nitrate	30%	30%	30%	5%
Nitrate converted to N_2O	0.75%	0.75%	0.75%	0.75%
Total N_2O emitted	1.325%			
Sugarcane		1.575%	1.220%	1.460%
Corn		1.575%	1.225%	-
Wheat		1.325%	-	-

[a]GHG models utilize as basis default Tier 1 emission factors published by IPCC, which estimates emissions from several sources (Klein et al., 2006): volatilization of N as NH_3, at a rate of 10% of total N in the case of synthetic N application (ranging from 3% to 30%) or 20% of total N in the case of manure application; direct soil emissions of N_2O, at 1% in case of synthetic N and 2% in case of manure; runoff and leaching to groundwater as nitrate at a rate of 30% of total N applied (ranging from 10% to 80%) with 0.75% of it converted to N_2O; default resulting effect is that 1.325% of N in synthetic fertilizer is emitted as N in N_2O;
[b]BioGrace and the VSB utilize the default IPPC values for the direct N_2O emissions, whereas GHGenius and GREET consider differentiated values for the crops;
[c]BioGrace, GHGenius, and GREET models utilize the default IPPC values for the indirect N_2O emissions, whereas the VSB considers specificities of the soil used for sugarcane production in Brazil with a higher value for volatilization of N as NH_3 (30%) and lower for runoff/leaching as nitrate (5%), according to agronomical recommendations from CTBE.

Table 7. Methods and parameters for dealing with co-products in the different models

	BioGrace	GHGenius	GREET	VSB
Default method for dealing with co-products	Energy allocation[a]	Substitution[b]	Substitution[c] Energy[d]	Economic allocation[e]
Partitioning/credit				
Sugarcane				
Ethanol	100%	100%	95.0%	96.5%
Electricity	-	-4.3 $gCO_2eq\ MJ^{-1}$	5.0%	3.5%
Sugar	-	-	-	
Corn				
Ethanol	54.6%	100%	100%	-
DDGS[h]	45.4%	-16.7 gCO2eq MJ^{-1}	-12.8 $gCO_2eq\ MJ^{-1}$	-
Wheat				
Ethanol	59.5%	100%	-	-
DDGS[f]	40.5%	-24.5 $gCO_2eq\ MJ^{-1}$	-	-

[a]Energy content of ethanol (LHV) = 26.8 MJ kg^{-1}; energy content of dry DDGS = 16.0 MJ kg^{-1};
[b]Substitution method in GHGenius considers a credit equivalent to surplus electricity produced (10.7 kWh tonne of $sugarcane^{-1}$) for sugarcane; credit equivalent to the DDGS produced (0.29 kg DDGS kg $corn^{-1}$ and 0.38 kg DDGS kg $wheat^{-1}$) displacing 0.78 kg corn kg $DDGS^{-1}$ and 0.31 kg soybean meal kg $DDGS^{-1}$ for corn and 0.45 kg wheat kg $DDGS^{-1}$ and 0.55 kg soybean meal kg $DDGS^{-1}$ for wheat; in addition to avoided CH_4 emissions (3.74 g CH_4 kg $DDGS^{-1}$ equivalent to 2.8 gCO_2eq MJ^{-1} of corn ethanol and 4.0 gCO_2eq MJ of wheat $ethanol^{-1}$);
[c]Substitution method in the GREET model is utilized for corn and wheat co-products; whereas energy allocation is applied to surplus electricity generated in sugarcane ethanol production; surplus electricity of 75.0 kWh tonne of $sugarcane^{-1}$ in 2015 is considered for sugarcane ethanol production; three types of mills are considered for the production of corn ethanol in the US: dry mills with and without corn oil extraction representing 70.9% and 17.7%, respectively, and wet mills representing 11.4% of total mills; besides ethanol, dry mills produce DDGS that displace 78.12% corn, 30.72% soybean meal and 2.27% urea; whereas wet mills produce corn gluten meal (CGM) displacing 152.90% corn and 2.33% urea, corn gluten feed (CGF) displacing 100% corn and 1.52% urea, and corn oil displacing 100% soy oil;
[d]Energy content of ethanol (LHV) = 21.3 MJ L^{-1};
[e]Ethanol price = 1.56 R$ L^{-1} (0.49 US$ L^{-1}); electricity price = 182.5 R$ MWh^{-1} (57.03 US$ MWh^{-1}), assuming US$ 1.00 = R$ 3.20;
[f]Distiller's dried grains with solubles.

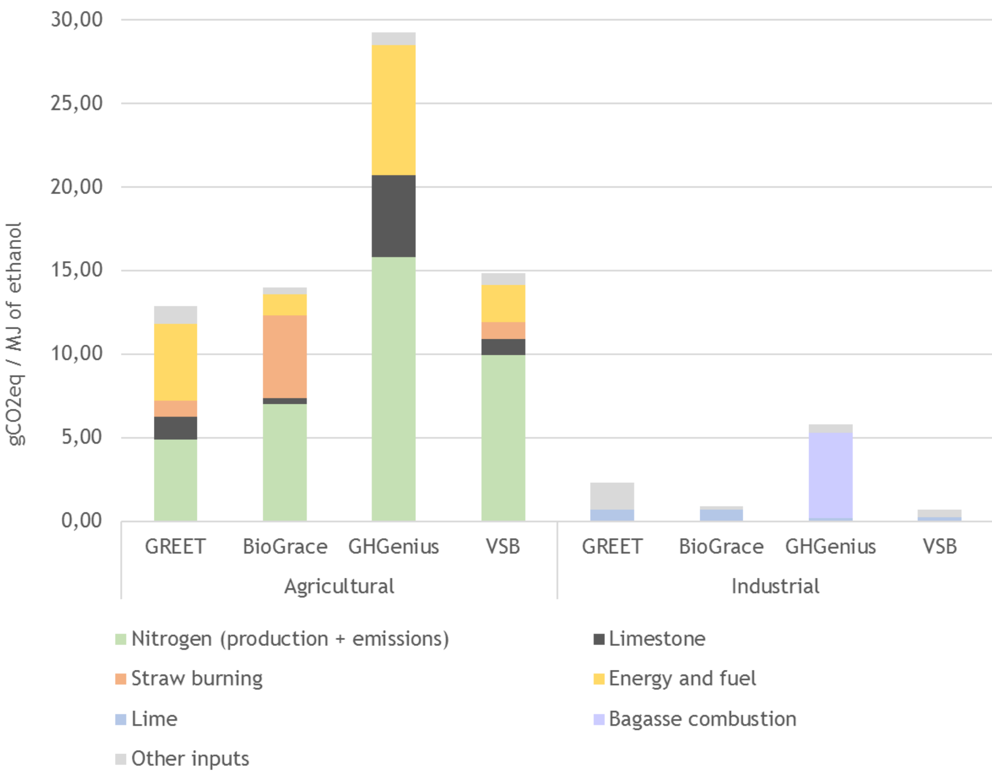

Figure 2. Breakdown for unallocated GHG emissions impacts of the agricultural and industrial stages of sugarcane ethanol production (ethanol transportation, distribution and use not included).

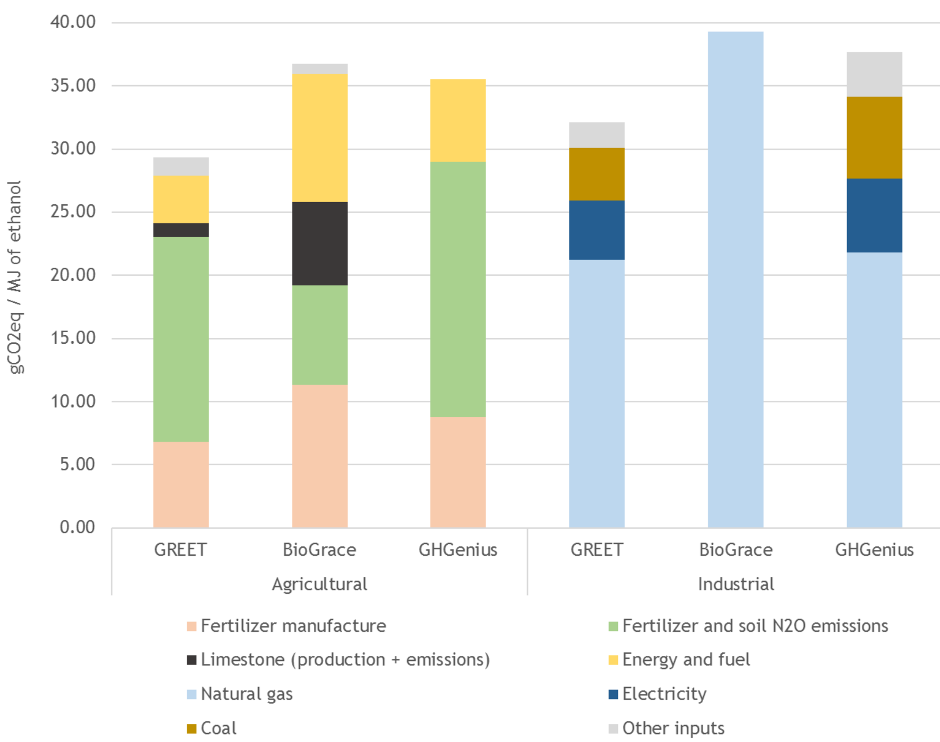

Figure 3. Breakdown for unallocated GHG emissions impacts of the agricultural and industrial stages of corn ethanol production (ethanol transportation, distribution and use not included).

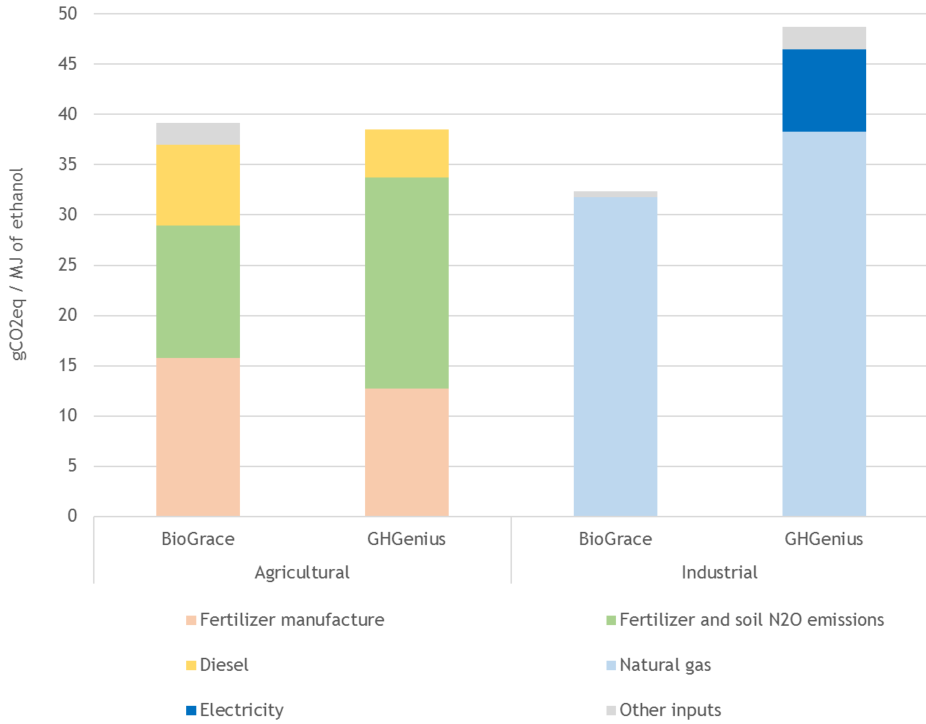

Figure 4. Breakdown for unallocated GHG emissions impacts of the agricultural and industrial stages of wheat ethanol production (ethanol transportation, distribution and use not included).

Inconsistencies in the GHG models

GHGenius

Subject1: straw burning impact
Location: spreadsheet 'Fertilizer'
Formula: SUM(Fertilizer!I160:I173)*'Energy Use'!P62*'Alt Fuel Prod'!AD28*1000+ 'Equip Emis Factors'!CU27*(**Fertilizer!I115**-1)*(1-Fertilizer!I145)*Fertilizer!I119*'Alt Fuel Prod'!AD25/('Fuel Char'!B120/1000).
Inconsistency: the term 'Equip Emis Factors'!CU27*(**Fertilizer!I115**-1)*(1-Fertilizer!I145)*Fertilizer!I119*'Alt Fuel Prod'!AD25' refers to CO_2eq emissions per kg of dry straw burned; the term 'Fertilizer!I115' refers to the 'ratio of above ground residue of crop or product harvested'; considering that the ratio is always lower than 1.0, the term 'Fertilizer!I115-1' results in a negative value, which reduces the total impact in case of increased burning.

Subject2: limestone emissions
Location: spreadsheet "Equip Emis Factors'
Formula: AE183
Inconsistency: the impact value (790 g CO_2eq kg^{-1}) is too high if compared to the values used by the other models; no distinction between production and use emissions is presented; apparently, this issue has already been identified in the past but not solved.

Subject3: transportation distance by rail and shipping for sugarcane ethanol
Location: spreadsheet "Input"
Formula: X92 and X94
Inconsistency: sugarcane ethanol transported by rail is set at 12,558 km, whereas the value for international water is set at 400; in the calculation formulas, however, the values are correctly applied.

GREET

In addition to the excel-based model GREET, ANL provides a graphic interface called GREET.net 2016 for download in its website, which does not necessarily contain the same data as used in the excel-based one. Some inconsistencies were found in this novel tool:

Subject1: straw burning
Location: ethanol production from sugarcane
Inconsistency: the 'amount of sugarcane straw' produced is set at 18.9 kg per tonne of sugarcane and 'sugarcane straw field burning' is set as 100% as default; the excel-based model, however, sets the amount of sugarcane straw produced at 140 kg per tonne of sugarcane and the burning at 14.0% for 2015.

Subject2: electricity co-generation
Location: ethanol production from sugarcane
Inconsistency: no net electricity is considered to be generated in the production of ethanol from sugarcane in the GREET.net 2016 model; the excel-based model, however, sets the amount of net electricity produced at 75 kWh per tonne of sugarcane for 2015.

BioGrace

Subject1: straw burning
Location: spreadsheet 'N2O emissions IPCC'
Formula: C47
Inconsistency: 'share of trash burned' is set at 100% as default by citing Macedo et al. (2004) as reference; however, Macedo et al. (2004) utilized data from 2002 considering average values for Brazil of 65% manual harvesting and 80% burning.