Annotated example of a GHG calculation using the EU Renewable Energy Directive methodology

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Annotated example of a GHG calculation using actual values

1 Background

The purpose of this paper is to provide insight into how economic operators and other interested bodies can execute the life cycle calculation of greenhouse gas emissions (GHG) from biofuels. This example calculation shows how the methodology as laid down in the Renewable Energy Directive (RED) and also further addressed by the Commission in the recent Communication[1], works in practice.

Reference is made to the overview of standard values for often used parameters, which is available through the Commission's transparency platform.

The annotated example represents a typical biofuel production chain. It should be noted that the annotated example does not intend to reproduce the default or typical values as presented in the RED, but solely to show how to execute a GHG calculation using actual values.

2 Structure of report

A brief explanation of the methodology is described in the next section, where it is shown what consecutive calculation steps need to be taken. It does not reproduce what's already written in the RED or Communication, but functions as a guidance to our annotated examples. In Section 4 we describe the annotated example and in Section 5 we present the annexes per chain where all the input values, parameters and output emissions are given.

3 General GHG methodology

The GHG emissions are calculated using the formula outlined in the RED[2]. The system boundary takes account any emissions associated with the cultivation of the biomass, processing and transport and distribution. Emissions resulting from land-use change are also included. Finally, emission savings from the adoption of improved agricultural

[1] http://ec.europa.eu/energy/renewables/biofuels/sustainability_criteria_en.htm

[2] Annex V, Section C - Methodology

practices, use of carbon capture and storage or the generation of excess electricity if the process uses cogeneration are also included.

The GHG calculation formula is detailed below:
$E = e_{ec} + e_l + {}_{ep} + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$

where

E = total emissions from the use of the fuel;
e_{ec} = emissions from the extraction or cultivation of raw materials;
e_l = annualised emissions from carbon stock changes caused by land-use change;
e_p = emissions from processing;
e_{td} = emissions from transport and distribution;
e_u = emissions from the fuel in use;
e_{sca} = emission saving from soil carbon accumulation via improved agricultural management;
e_{ccs} = emission saving from carbon capture and geological storage;
e_{ccr} = emission saving from carbon capture and replacement; and
e_{ee} = emission saving from excess electricity from cogeneration.

Note: Emissions from the manufacture of machinery and equipment are not to be taken into account.

Emissions are calculated by multiplying "input data" by pre-determined emission factors, also known as "standard values" (see Annex 5.4 for further details).

Where the biofuel production process produces co-products, GHG emissions are allocated to the biofuel and co-product on an "energy content" basis.

4 Annotated example

4.1 Wheat to ethanol using a natural gas fired boiler

The calculation methodology for wheat to ethanol using a natural gas fired boiler will be illustrated in this paper. In this example, it is assumed that there has been no land-use change (e_l), that no improved agricultural management methods are used (e_{sca}), that CCS technology is not employed at the biofuel plant (e_{ccs}, e_{ccr}) and that no excess electricity is produced (e_{ee}).

Consequently, the calculation formula becomes:

$E = e_{ec} + e_p + e_{td} + e_u$

4.1.1 Calculation of GHG emissions per phase

a. Cultivation

The following categories are included in the calculation of GHG emissions in relation to the cultivation of the biomass feedstock.

- Agro-chemicals (i.e. fertilisers and pesticides)
- Seeding material (i.e. wheat seed)
- Field N_2O emissions (i.e. emissions associated with the use of N-fertiliser and crop residues being left in the field)
- Fossil fuel use (i.e. diesel usage for farm machinery)

Agro-chemicals

Any GHG emissions associated with the application of agro-chemicals used in the cultivation of the wheat need to be calculated. These could include: N, P and K fertilisers, as well as CaO (i.e. lime); and pesticides (i.e. herbicides, fungicides and pesticides).

The same calculation method is to be used for all agro-chemical inputs, and is described below.

- **Step 1:** Establish the "input" application rate of the agro-chemical used in the cultivation of wheat. Units: kg nutrient[3]/ha
- **Step 2:** Look up the relevant "emission coefficient" for each agro-chemical using the "standard values" (see Annex 5.4). Units: kg CO_2eq/kg nutrient
- **Step 3**: Calculate the GHG emissions (i.e. input rate x emission coefficient). Units: kg CO_2eq/ha
- **Step 4:** Convert units to kg CO_2eq/MJ ethanol (see below for explanation of how to do this)

This process is repeated for each agro-chemical input that is used in the cultivation of the wheat.

Seeding material

The GHG emissions associated with the production and distribution of wheat seed needs to be taken into consideration.

[3] Note that the unit for pesticide application is kg active substance/ha.

- **Step 1:** Establish the "input" rate of seed. Units: kg seed/ha
- **Step 2:** Look up the relevant "emission coefficient" for wheat seed (see Annex 5.4). Units: kg CO_2eq/kg seed
- **Step 3:** Calculate the GHG emissions (i.e. seed input x emission coefficient). Units: kg CO_2eq/ha
- **Step 4:** Convert units to kg CO_2eq/MJ ethanol (see below for explanation of how to do this).

Field N_2O emissions

As advised in the Communication[4], it is possible to use either an IPCC Tier 1, 2 or 3 approach to calculate field N_2O emissions. In this example, a Tier 1 approach will be used. It is assumed that no crop residues (i.e. straw) are left on the field.

- **Step 1:** Calculate the total N_2O-N emissions[5] relating to fertiliser application[6]. These include both direct and indirect emissions (i.e. volatilization of N as NH_3 and leaching to groundwater). Units: N_2O-N/kg N input
- **Step 2:** Convert N_2O-N emissions to N_2O using a conversion factor or 44/28. Units: kg N_2O/kg N input
- **Step 3:** Convert N_2O emissions to CO_2eq by multiplying by 296. Units: kg CO_2eq/kg N input
- **Step 4:** Calculate the N_2O emissions/ha by multiplying by the fertiliser input rate. Units: kg CO_2eq/ha

Fossil fuel use

Any fossil fuel (i.e. diesel) usage on the farm needs to be taken into account. This is likely to include any fuel used in the preparation of the land, seed planting, application of agro-chemicals and harvesting of the wheat.

- **Step 1:** Establish the total "fossil fuel usage" for all on-farm activities releted to the cultivation wheat. Units: MJ diesel/ha
- **Step 2:** Look up the "emission coefficient" for the fossil fuel (see Annex 5.4). Units: kg CO_2eq/MJ diesel
- **Step 3:** Calculate the GHG emissions (i.e. fossil fuel usage x emission coefficient). Units: kg CO_2eq/ha
- **Step 4:** Convert units to kg CO_2eq/MJ ethanol (see below for explanation of how to do this)

[4] Refer to Annex II: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:160:0008:0016:EN:PDF

[5] Refer to IPCC (2006) Chapter 11, N_20 emissions from managed soils, and CO_2 emissions from lime and urea application. Refer to: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

[6] Emissions from both synthetic and organic fertilisers (i.e. manure) should be considered.

Handling and storage of wheat grain

Any electricity usage on the farm associated with handling and storage of the wheat grain needs to be taken into account (e.g. electricity used in drying the wheat grain to the desired moisture content).

- **Step 1:** Establish the total "electricity usage" related to any hauling and storage on the farm. Units: MJ electricity/ton wheat
- **Step 2:** Look up the "emission coefficient" for grid electricity (see Annex 5.4) – selecting Low Voltage (LV). Units: kg CO_2eq/MJ electricity
- **Step 3:** Calculate the GHG emissions (i.e. electricity usage x emission coefficient). Units: kg CO_2eq/ton wheat
- **Step 4:** Adjust for any biomass losses. Units: kg CO_2eq/ton wheat
- **Step 5:** Convert units to kg CO_2eq/MJ ethanol (see below for explanation of how to do this)

b. Biomass transport

In this example the wheat is transported by road from the farm to the biofuel production facility.

- **Step 1:** Calculate the "round trip distance" travelled from farm to the biofuel production facility (i.e. include both outward and return journeys). Units: km
- **Step 2:** Look up the "transport efficiency" for the relevant transport type (see Annex 5.4). In this example, "Truck for dry product (Diesel)" should be used. Units: MJ/ton.km
- **Step 3:** Look up the relevant "fuel emission factor" – for example diesel (see Annex 5.4). Units: kg CO_2eq/MJ diesel
- **Step 4:** Calculate the "transport emission coefficient" by multiplying the "transport efficiency" and "fuel emission factor". Units: kg CO_2eq/t.km
- **Step 5:** Calculate the GHG emissions (i.e. distance x transport emission coefficient). Units: kg CO_2eq/ton wheat
- **Step 6:** Adjust for any biomass losses. Units: kg CO_2eq/ton wheat
- **Step 7:** Convert units to kg CO_2eq/MJ ethanol (see below for explanation of how to do this).

c. Processing

In this example, the biofuel plant process type is a steam boiler run on natural gas (NG). The GHG emissions associated with the NG usage can be calculated as follows:

- **Step 1:** Calculate the total "natural gas usage" for the biofuel plant on a per ton ethanol basis. In this example, average yearly data is used. Units: GJ NG/ton ethanol
- **Step 2:** Look up the "emission coefficient" for natural gas (see Annex 5.4). Units: kg CO_2eq/MJ NG
- **Step 3:** Calculate the GHG emissions (i.e. natural gas usage x emission coefficient). Units: kg CO_2eq/ton ethanol

- **Step 4:** Convert units to kg CO_2eq/MJ ethanol (see below for explanation of how to do this).

The plant also has an electricity requirement, the GHG emissions of which are calculated as follows:

- **Step 1:** Calculate the total "electricity usage" for the biofuel plant on a per ton ethanol basis. In this example, average yearly data is used. Units: GJ NG/ton ethanol
- **Step 2:** Look up the "emission coefficient" for grid electricity (see Annex 5.4) – selecting Medium Voltage (MV). Units: kg CO_2eq/MJ electricity
- **Step 3:** Calculate the GHG emissions (i.e. electricity usage x emission coefficient). Units: kg CO_2eq/ton ethanol
- **Step 4:** Convert units to kg CO_2eq/MJ ethanol (see section 4.1.2 for explanation of how to do this).

d. Biofuel transport and distribution

In this example, the ethanol biofuel is transported by road from the biofuel production facility to the fuel depot and onwards to the filling station.

- **Step 1:** Calculate the total "round trip distance" travelled from the biofuel production facility to the depot and filling station (i.e. include both outward and return journeys). Units: km
- **Step 2:** Look up the "transport efficiency" for the relevant transport type (see Annex 5.4). In this example, "Truck for liquids (Diesel)" should be used. Units: MJ/t.km
- **Step 3:** Look up the relevant "fuel emission factor" – i.e. for diesel (see section 5.4). Units: kg CO_2eq/MJ diesel
- **Step 4:** Calculate the "transport emission coefficient" by multiplying the "transport efficiency" and "fuel emission factor". Units: kg CO_2eq/t.km
- **Step 5:** Calculate the GHG emissions (i.e. total distance x transport emission coefficient). Units: kg CO_2eq/ton ethanol
- **Step 6:** Convert units to kg CO_2eq/MJ ethanol (see below for explanation of how to do this)

e. Ethanol depot and Filling station

Any electricity usage at the bioethanol depot and filling station need to be included. Standard values can be used.

- **Step 1:** Look up the electricity usage at the depot and filling station (see Annex 5.4). Units: MJ elec/MJ ethanol
- **Step 2:** Look up the "emission coefficient" for grid electricity (see Annex 5.4) – selecting Low Voltage (LV). Units: kg CO_2eq/MJ elec
- **Step 3:** Calculate the GHG emissions (i.e. electricity usage x emission coefficient). Units: kg CO_2eq/MJ ethanol

4.1.2 Unit conversion

The calculated GHG emission outputs from the above phases (and input parameters) are in different units, as summarised in Table 1 below.

Table 1: Summary of calculated GHG emision units per input parameter

Phase	Units
Agro-chemicals	kg CO_2eq/ha
Seeding material	kg CO_2eq (for all)/ha
N_2O field emissions	kg CO_2eq/ha
Fossil fuel usage	kg CO_2eq/ha
Electricity usage	kg CO_2eq/ton wheat
Biomass Transport	kg CO_2eq/ton wheat
Processing	kg CO_2eq/ton ethanol
Bioethanol Transport and Distribution	kg CO_2eq/ton ethanol
Ethanol depot and Filling station	kg CO_2eq/MJ ethanol

The above units need to be converted into kg CO_2eq/MJ ethanol. Several parameters are needed for this conversion. These are indicated in Table 2 below.

Table 2: Parameters required for unit conversion

Phase	Units
Wheat yield	ton wheat/ha
Wheat moisture content (mc)	%
Wheat LHV	MJ/kg wheat
Ethanol LHV	MJ/kg ethanol
Ethanol yield	ton ethanol/ton wheat
DDGS LHV	MJ/kg DDGS
DDGS yield	ton DDGS/ton ethanol
Wheat yield	ton wheat/ha
Wheat moisture content	%
Wheat LHV	MJ/kg wheat
Ethanol LHV	MJ/kg ethanol

The conversion step is dependant on the phase step. For example, for Agro-chemicals the following approach can be used.

- **Step 1:** Convert kg CO_2eq/ha to kg CO_2/MJ wheat
  = kg CO_2eq/ha x 1/ (kg wheat/ha x (100 - mc)% x MJ wheat/kg)
- **Step 2:** Account for any losses (e.g. transport of wheat)
  = kg CO_2eq/MJ wheat x MJ wheat/MJ wheat
- **Step 3:** Convert kg CO_2eq/MJ wheat to kg CO_2eq/MJ ethanol
  = kg CO_2/MJ wheat x (wheat:ethanol yield x (1 – wheat mc %) x wheat LHV) / ethanol LHV
- **Step 4:** Account for any losses (e.g. transport of biofuel)
  = kg CO_2eq/MJ wheat x MJ ethanol/MJ ethanol

4.1.3 Allocation of emissions

Co-product emissions are allocated on the basis of their energy content. In the case of wheat to ethanol production, DDGS is produced as a co-product. The GHG emissions of ethanol production up-to-and-including the conversion phase therefore need to be allocated to both wheat and DDGS.

The calculation method used to determine the allocation share of GHG emissions for ethanol is as follows:

- **Step 1:** Calculate the "DDGS yield" as a ratio of ton DDGS produced per ton ethanol. Units: ton DDGS/ton ethanol
- **Step 2:** Look up the "Lower Heating Values (LHV[7])" for ethanol and DDGS (see Annex 5.4). Units: MJ/kg ethanol, MJ/kg DDGS
- **Step 3:** Calculate the allocation by energy content: Divide ethanol LHV by sum of (DDGS yield x DDGS LHV) + ethanol LHV

4.1.4 Final calculation of emissions savings

The calculate the emissions savings, the total calculated GHG emissions in the production of the ethanol need to be referenced against the gasoline comparitor, using the following formula.

$SAVING = (E_F – E_B)/E_F$

where

E_B = total emissions from the ethanol; and
E_F = total emissions from the gasoline comparator: **83.8 g CO_2eq/MJ**

[7] The Communication states that the LHV should be that of the entire (co)-product, and not only the dry fraction of it. Refer to Annex II: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:160:0008:0016:EN:PDF

5 Annexes (with values)

5.1 Input values

Table 3: Cultivation parameter inputs

Parameter	Input	Units
Wheat feedstock characteristics		
Wheat yield	6.5	ton wheat/ha
Moisture content	13.5	%
Agro-chemicals		
N - Fertiliser	100	kg/ha
K_2O - Fertiliser	15	Kg/ha
P_2O_5 - Fertiliser	20	kg/ha
Pesticides	2.5	kg/ha
Seeding material	125	kg/ha
Field N_2O emissions		
N - Fertiliser	100	kg/ha
Fuel and energy usage		
Diesel	3,500	MJ diesel/ha
Electricity (hauling & storage)	5	MJ electricity/ton wheat

Table 4: Transport parameter inputs

Parameter	Input	Units
Distance – Transport of wheat to biofuel plant	55	km
Distance – Transport of bioethanol from biofuel plant to bioethanol depot	100	km
Distance – Transport of bioethanol from bioethanol depot to filling station	100	km

Table 5: Conversion parameter inputs

Parameter	Input	Units
Natural gas demand	9,000	MJ natural gas/ton ethanol
Electricity demand	1,300	MJ electricity/ton ethanol

5.2 Allocation parameters

Table 6: Allocation parameters for ethanol and DDGS co-product

Parameter	Input	Units
Ethanol yield	0.335	ton ethanol/ton wheat
DDGS yield	1.10	ton DDGS/ton ethanol

5.3 Output values with selected example calculations

Table 7: Cultvation output values

Parameter	Output	Units
Agro-chemicals		
N - Fertiliser	588.06 (= 100 x 5.8806)	$kgCO_2$/ha
K_2O - Fertiliser	8.64	$kgCO_2$/ha
P_2O_5 - Fertiliser	20.21	$kgCO_2$/ha
Pesticides	27.43	$kgCO_2$/ha
Seeding material	34.49	$kgCO_2$/ha
Field emissions		
Field N_2O emissions - direct	Direct: 0.01	KgN_2O-N/kgN
Field N_2O emissions - indirect	Indirect: (0.01 x 0.1) + (0.0075 x 0.3) = 0.00325	KgN_2O-N/kgN
Field N_2O emissions - total	616.31 (= 0.01325 x 44/28 x 296 x 100)	$kgCO_2$/ha
Fuel and energy usage		
Diesel	383.42	$kgCO_2$/ha
Electricity (hauling & storage)	4.20	$kgCO_2$/ha/ton wheat

Table 8: Transport output values

Parameter	Output	Units
Transport of wheat to biofuel plant	4.51 (= 55 x 0.936 x 0.08764)	$kgCO_2$/ton wheat
Transport of bioethanol from biofuel plant to bioethanol depot	8.83	$kgCO_2$/ton ethanol
Transport of bioethanol from bioethanol depot to filling station	8.83	$kgCO_2$/ton ethanol

Table 9: Processing output values

Parameter	Output	Units
Natural gas demand	608.28 (= 9,000 x 0.067587)	$kgCO_2$/ton ethanol
Electricity demand	165.95	$kgCO_2$/ton ethanol

Table 10: Ethanol depot and Filling station output values

Parameter	Output	Units
Depot	0.11 (= 0.00084 x 0.129)	$kgCO_2$/MJ ethanol
Filling station	0.44	$kgCO_2$/MJ ethanol

Table 11: Allocation output

Parameter	Output	Units
Energy content of ethanol to DDGS co-product	60.4% (= 26.8/(26.8 + (16 x 1.10))	N/A

Table 12: **Final results (including allocation)**

Phase	Output	Units
Cultivation	19.97	gCO_2/MJ ethanol
Biomass transport	0.34	gCO_2/MJ ethanol
Processing	17.43	gCO_2/MJ ethanol
Biofuel transport	0.66	gCO_2/MJ ethanol
Ethanol depot and Filling Station	0.55	gCO_2/MJ ethanol
Total	**38.95**	gCO_2/MJ ethanol
Saving	**54%**	

5.4 Standard values (for often used parameters)

Standard values are available at:
http://www.biograce.net/content/ghgcalculationtools/standardvalues

Standard values for electricity usage at the depot and filling stations can be found at:
http://www.biograce.net/content/ghgcalculationtools/excelghgcalculations