

BIOGRACE II

Harmonised Greenhouse Gas Calculations
for Electricity, Heating and Cooling from Biomass



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BioGrace II Methodological Background Document

Version 3

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1 Introduction

The EU Renewable Energy Directive (RED) lays down sustainability criteria for biofuels for transport and bioliquids used in other sectors but not for solid and gaseous biomass used for electricity, heating and cooling.

In February 2010, as required by Article 17(9) of the RED, the European Commission published a Report on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling¹ which contained a common methodology for the calculation of the GHG performance of solid and gaseous biomass used for heating/cooling and electricity production.

Differently from the method applying to biofuels and bioliquids under the RED, the GHG methodology for biomass and biogas covers also the final step of conversion of the biomass fuel into electricity, heating or cooling². The Report also contained a set of biomass and biogas default values.

In July 2014 the Commission published a new Staff Working Document on biomass sustainability (*SWD(2014) 259*)³, which contains, amongst others, an updated set of default values for the most common biomass pathways to promote regulatory convergence amongst the interested Member States. These values were calculated by the Joint Research Centre (JRC) on the basis of the most updated scientific information as described in the JRC report *EUR 27215 EN*⁴.

This document provides additional information on the methodological choices for calculating GHG performance of solid and gaseous pathways. It starts by explaining the various allocation methods applied. This is followed by sections on the EU fossil fuel comparators and the approach applied to the biogas production chain. Finally, this document offers further explanation on the methodology for calculating nitrous oxide emissions and the choice of lower heating value as a measure of energy content.

The Annex to this document includes a revised version of the harmonized GHG accounting methodology presented in the Report of the European Commission *COM(2010) 11* plus additions in the European Commission Staff Working Document *SWD(2014) 259*³. This updated methodology was used for calculating the default values as listed in *SWD(2014) 259* and in JRC report *EUR 27215 EN*⁴, and is to be used for making actual calculations.

¹ COM/2010/11, <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0011:FIN:EN:PDF>

² Annex 5 of SEC (2010)66: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010SC0065&from=EN>

³ http://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play.pdf

⁴ <https://ec.europa.eu/energy/sites/ener/files/documents/Solid%20and%20gaseous%20bioenergy%20pathways.pdf>

2 Allocation methods

How emissions are being divided between different co-products has a large impact on the final result of a life cycle analysis of a fuel or, as in this case, final energy. When making GHG calculations, the allocation method is therefore crucial to the result.

2.1 Clarifications to the use of exergy for allocation between electricity and heat

The methodology for GHG calculations of biofuels in the RED uses energy allocation based on the lower heating value of the co-products. Since energy allocation does not reflect the different values of heat and electricity, the method was not used for allocation between heat and electricity. When heat is co-produced with other energy commodities, exergy has been chosen as the basis for the allocation, instead of energy. Exergy is only used as allocation method when heat at different temperatures is produced and when heat is co-produced with electricity. Allocation between other types of products is described in section 2.3.

Different allocation methods for dividing emissions between heat, electricity and cooling were evaluated by the Commission when drawing up the new methodology for solid biomass applications. The alternatives studied were allocation based on

- energy,
- economic value, and
- exergy.

Energy allocation does not take into account the different value of different energy carriers. Energy allocation would not differentiate between 1 MJ of heat and 1 MJ of electricity even if the economic value and the capacity of performing work of the two energy carriers are not the same. Nor would energy allocation differentiate between 1 MJ of heat at 10 °C, which is unable to produce any work in any thermal cycle, and 1 MJ of heat at 1000 °C, which can be used for many purposes. This makes it difficult to distinguish between useful and useless energy when dividing emissions between electricity and heat at different temperatures. Energy allocation was therefore discarded as an allocation method when dividing emissions between electricity, heat and cooling.

The allocation method based on economic value was also discarded, mainly because of difficulties in finding relevant data. Economic allocation factors would also have had to handle both fluctuating energy prices and the various taxing and subsidising schemes of different countries in EU.

Exergy is a thermodynamic concept that describes the maximum useful work that can be done by the available energy. Thus, it considers the different value of heat and electricity. This is the main reason why the proposal from the EC ended up with exergy as the basis for allocations between energy carriers. However, the term is not commonly used due to its moderately higher complexity compared to the concept of energy with which a larger audience is accustomed. The condition for choosing exergy as the basis for allocation was that the calculation could be kept simple.

For heat the exergy value can easily be calculated using a physical formula called the Carnot efficiency (the thermodynamic quality of heat).

$$C_h = \frac{T_h - T_0}{T_h}$$

Where

- T is measured in absolute temperature (K, Kelvin),
- T_h is the temperature of the heat (K),
- T_0 is the temperature of the environment, or surroundings, set at 273 Kelvin in EU legislation (equal to 0 °C).

The formula means that the exergy of heat is dependent of the temperature of the heat; high temperatures give high values of exergy. Electricity is always given an exergy value of 1. In principle this means that heat is weighted lower than electricity, because of its lower exergy value.

The allocation factors for electricity and heat are calculated by the following formulas:

$$EC_{el} = \frac{E}{\eta_{el}} \left(\frac{C_{el} \eta_{el}}{C_{el} \eta_{el} + C_h \eta_h} \right) \quad EC_h = \frac{E}{\eta_h} \left(\frac{C_h \eta_h}{C_{el} \eta_{el} + C_h \eta_h} \right)$$

where

- EC_{el} is total greenhouse gas emissions from the electricity (per MJ).
- EC_h is total greenhouse gas emissions from the heat (per MJ).
- E is the upstream life cycle emissions for the biomass fuel (per MJ)
- η_{el} is the electrical efficiency
- η_h is the heat efficiency

For heat temperatures below 150 °C degrees a constant Carnot efficiency of 0.3546 was set (the Carnot efficiency of heat at 150 °C). The reason is to avoid very low allocation factors for the district heating.

Very low allocation factors for the district heating would give disproportionate high emissions allocated to the electricity.

Using the exergy-based allocation between heat and electricity forms an effective incentive to recover waste heat, as the more heat is usefully used, the more emissions are allocated to heat resulting in a better GHG emission saving for electricity. .

Example of the allocation method:

A CHP is fed with biomass fuel with upstream emissions of 100g CO_{2,eq}/MJ. The electric efficiency is 25 per cent and the thermal efficiency (=useful heat output divided by the total fuel input) is 50 per cent. The temperature of the delivered heat is 120°C. Since the heat temperature is below 150 °C the Carnot factor is set at 0.3546.

$$EC_{el} = \frac{E}{\eta_{el}} \left(\frac{C_{el} \cdot \eta_{el}}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h} \right) = \frac{100}{0.25} \left(\frac{1 \cdot 0.25}{1 \cdot 0.25 + 0.3546 \cdot 0.5} \right) = 234 \left[\frac{g}{MJ_{el}} \right]$$

$$EC_h = \frac{E}{\eta_h} \left(\frac{C_h \cdot \eta_h}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h} \right) = \frac{100}{0.5} \left(\frac{0.5 \cdot 0.3546}{1 \cdot 0.25 + 0.3546 \cdot 0.5} \right) = 83.0 \left[\frac{g}{MJ_{heat}} \right]$$

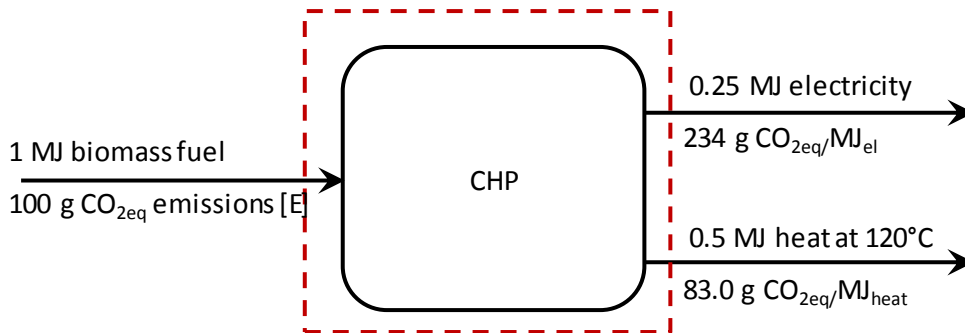


Figure 1. Allocation between electricity and heat at 120°C in a CHP.

2.2 Allocation in the case of cooling being produced

The BioGrace-II Excel tool allows calculating the emission savings from the use of waste heat to provide cooling via an absorption chiller. Even calculating a tri-generative process is possible, where electricity, heat and cooling are produced. As cooling is made from waste heat, heat production is always the first step. Depending on whether additional electricity is produced, the above described allocation step between electricity and heat may be necessary. Only in a second step, heat is further transformed into cooling based on a cooling efficiency (see *Figure 2*).

The efficiency is expressed as the seasonal coefficient of performance (SCOP). It is defined as the refrigeration effect, divided by the net heat input. The value should reflect an annual average efficiency rather than a theoretical value.

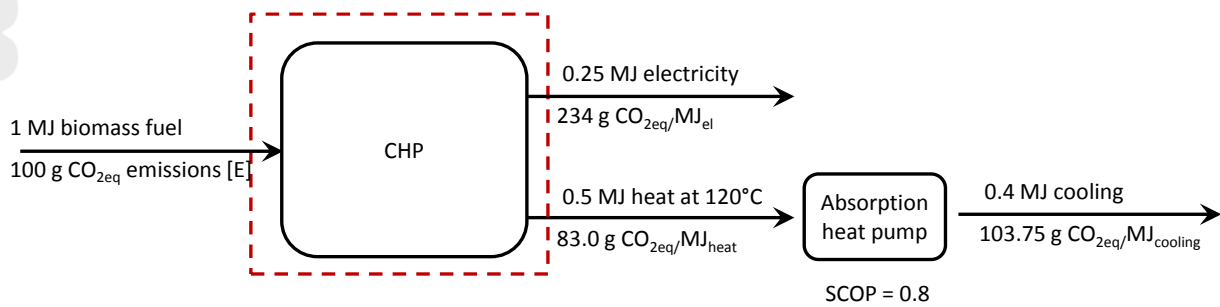


Figure 2. Allocation between electricity and heat and production of cooling from heat.

2.3 Energy allocation between other products than heat, cooling and electricity

Exergy allocation is only used between heat, cooling and electricity. For all other allocation issues, as in RED, energy allocation has been kept. This choice was made for simplicity and coherence with RED.

3 Fossil fuel comparators

In order to define the fossil fuel comparators (FFC), different alternatives for the geographical scope, the end-use technology and the replaced technologies are to be considered. Finally, four EU wide fossil fuel comparators (FFC) for different energy carriers were calculated.

Concerning the end-use technology the following three alternatives were considered:

- One single comparator irrespective of end-use (weighted average)
- One comparator for heat and electricity respectively
- One comparator for each main technology cluster; heat plants, electricity plants and CHP.

One single comparator irrespective of end-use was excluded since it does not pay attention to the different utilities of different forms of final energy, for example heat and electricity.

Also the alternative of one fossil fuel comparator for each main technology cluster i.e. one for heat plants, one for electricity plants and one for CHPs, was discarded. This alternative would imply that a fixed ratio between electricity and heat in CHPs was set. Thus, a CHP with low electricity efficiency would obtain the same FFC as a plant with higher electricity efficiency. Since electricity has higher GHG emissions, this alternative would not give the right incentives.

As a result, the alternative of one comparator for heat and electricity respectively, was chosen. In addition, one comparator for cooling and one comparator for biomethane⁵ were added.

In order to set the FFC values, considerations were needed regarding what technologies the FFCs should consist of, what conversion efficiency should be applied and what energy sources should be replaced. Should the FFC values represent conventional technologies expected to be commissioned, existing technologies or technologies that would be built in a reference scenario i.e. in the absence of energy and climate policies? A number of stakeholders have expressed the importance of stable FFCs. Due to the progressive decarbonisation of the energy sector, the GHG emissions of today, may decrease in the future. Therefore, the FFCs have been based on technologies that *would be built* in the absence of energy and climate policies.

⁵ Gas of biogenic origin upgraded to comply with the characteristics of fossil natural gas injected in the distribution grid.

According to the reasoning above, the following values for the FFC were defined⁶:

- Electricity: 186 g CO_{2,eq}/MJ
- Heat: 80 g CO_{2,eq}/MJ
- Natural gas: 72 g CO_{2,eq}/MJ
- Cooling: 47 g CO_{2,eq}/MJ

In the case of co-production, the emissions are allocated to the different energy commodities before the comparison with the FFC.

⁶ Staff Working Document SWD(2014) 259

4 Credits in biogas pathways

4.1 Avoided methane emissions from improved manure management

In the GHG methodology emission savings from improved agricultural management can be credited according to the RED. In the context of the SWD (2014) 259, the latter category also includes improved manure management for gaseous biomass applications.

When raw manure is stored or spread on the fields, greenhouse gases are released due to bacterial activity. It is mainly methane (CH_4) that is released, but also nitrous oxide (N_2O). These GHG emissions are avoided when manure is treated in an anaerobic digester.

Today, there are no incentives to cover manure storage tanks to avoid GHG emissions. Thus, it can be assumed that the emissions would happen in all reference scenarios of manure digestion. As a result, it has been decided to implement a credit of 45 g $\text{CO}_{2,\text{eq}}/\text{MJ}$ manure for improved manure management, which has been calculated as the sum of 37g of $\text{CO}_{2,\text{eq}}/\text{MJ}$ manure due to avoided methane emissions plus 8 g $\text{CO}_{2,\text{eq}}/\text{MJ}$ manure due to avoided nitrous oxide emissions. A detailed explanation of how the figures 37 g $\text{CO}_{2,\text{eq}}/\text{MJ}$ and 8 g $\text{CO}_{2,\text{eq}}/\text{MJ}$ is calculated, is given by the JRC⁷.

4.2 Digestate as fertiliser replaces synthetic fertiliser

Similar to the credits for manure management also credits for the use of digestate as fertiliser were demanded. It is argued that applying digestate lowers the demand for synthetic N-fertiliser and its emissions. Such a credit has been included indirectly in the JRC calculations. In the maize biogas/ biomethane pathways it is assumed that the digestate from the biogas plant is put back to the field. The input of mineral N fertilizer to maize crop is thus lower compared to systems where no organic fertilization is applied. The plant-available N content in the digestate is calculated taking into account N losses during digestion and the storage period.

Although this approach has been chosen by JRC to calculate the default emission factors, it has to be noted that in actual calculation no general credit can be attributed to biogas digestate. Instead, it has to be differentiated between a generic approach (as has been applied by JRC) and the reflection of reality. For calculating generic average data it can be assumed that a certain amount of digestate is applied to the field. For actual calculations, however, the actual amount of digestate and N-fertiliser used have to be

⁷ JRC Report EUR 27215 EN, page 59

taken into account at a concrete farm level. Usually this should lead to a similar indirect credit as the amount of N-fertiliser applied should consider the N-input via digestate application.

5 Mass balance approach suspended for biogas from co-digestion of substrates

The RED and also the common GHG methodology tabled in the Commission Report COM(2010) 11 applies the mass balanced approach. This approach means that physical mixing of products is allowed, but the products are kept administratively separated. However, the SWD(2014) 259 acknowledges that the mass balance approach may not apply for biogas plants that use a mixture of substrates.

The reason for suspending the mass balance approach for co-digestion plants is that the mass balance approach can create difficulties for the majority of co-digestion plants⁸. For this reason, the SWD provides a formula generating a weighted average between several default values from single-feedstock biogas that operators may use to generate default values for any arbitrary mixture of the three substrates included in the JRC report.

A weighing based on the mass of different substrates would be unfair, since different substrates produce different amounts of biogas, with different shares of methane. That is why the actual methane production is included in the weighing formula.

⁸ Staff Working Document SWD(2014) 259

6 N₂O emissions from soil – IPCC

For pathways with crop cultivation, field N₂O emissions are to be taken into account in the GHG calculation. These emissions occur during crop cultivation because of the microorganism activities in the soil. In the BioGrace-II Excel tool, two different methodologies are integrated:

- the Global Nitrous Oxide Calculator (GNOC) which has to be used for all crops that are covered by the calculator,
- for all other crops, the IPCC Tier 1 method has to be applied.

6.1 GNOC model

The IPCC Tier 1 method can be easily applied to calculate field N₂O emissions. However, it does not take into account variations in environmental conditions. Therefore, JRC developed an approach that considers different soil conditions, climate aspects and management systems and their influences on N₂O soil emissions. This approach can be applied to major crops in most regions of the world.

In that approach, the IPCC Tier 1 emission factor is replaced by Tier 2 emission factors. These factors are crop and site specific and take different environmental conditions into account. They have been developed by applying the statistical model developed by Stehfest & Bouwman, 2006⁹. The factors are applied for direct emissions from mineral fertiliser and manure application. For direct emissions from crop residues and organic soils as well as for all indirect emissions, the IPCC Tier 1 emission factors are still used. For details on the methodology refer to Edwards et al., 2012¹⁰.

This approach has been put into practice with an online calculation tool, the Global Nitrous Oxide Calculator, GNOC¹¹. Detailed instructions are available in the user manual that can be downloaded from the GNOC website.

⁹ Stehfest, E., Bouwman, L., (2006). N₂O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. *Nutrient Cycling in Agroecosystems* 74 (3), 207-228.

¹⁰ Edwards, R., Mulligan, D., Giuntoli, J., Agostini, A., Boulamanti, A., Koeble, R., Marelli, L., Moro, M., Padella, M. (2012). Assessing GHG default emissions from biofuels in EU legislation. JRC, Ispra.

¹¹ See <http://gnoc.jrc.ec.europa.eu/>

6.2 IPCC Tier 1 methodology

In its current state, the GNOC model only includes energy crops that are used for producing liquid bioenergy. Solid biomass feedstocks like eucalyptus and poplar as well as silage maize for biogas production are not included. For these crops the IPCC Tier 1 methodology is to be applied.

It covers the following emission sources:

- direct emissions from the application of mineral and organic fertiliser and from above and below ground residues,
- indirect emissions from these sources caused by volatilization and leaching / runoff.

The emission factors are taken from the IPCC 2006 document and are implemented in a separate calculation sheet in the BioGrace-II Excel tool.

The IPCC document does not contain default values for crop residues from solid biomass (eucalyptus, poplar) and silage maize. In these cases the methodology was adapted as follows:

- Solid biomass (eucalyptus, poplar): Only direct and indirect emissions from mineral and organic fertiliser application are taken into account. Residues are not taken into account. This is insofar not a problem as in the cultivation of eucalyptus and poplar there are only small amounts of residues. In general, short rotation coppice is harvested every 3-5 years and regenerate from the stools. The latter are expected to survive five rotation periods. When a plantation is rejuvenated, the stools are removed from the field.
- Silage maize (whole crop): Most data are assumed to be the same as for maize cultivation (e.g. N contents in crop and residues). However, in contrast to maize, the whole crop is harvested and it is assumed that around 1 ton dry matter (above-ground) residues per hectare remain at the field. Below-ground crop residues are calculated according to IPCC guidelines. Furthermore, it is assumed that after digestion the digestate is returned to the field. Respective N contents and emissions thereof are calculated (see JRC 2014¹² for further details).

¹² JRC Report EUR 27215 EN

7 Energy content / LHV

While making the GHG calculations, the BioGrace consortium followed the following approach on how to calculate the energy content of wet biomass, applied in the JRC Report EUR 27215 EN:

- Results are presented on an energy basis considering the LHV of the dry fraction of the biomass fuel. This means that, compared to an LHV-calculation, the latent heat of vaporisation is neglected by using Formula 1 below when converting feedstock mass (e.g. kg rapeseed or kg poplar short rotation coppice) into its energy content, or when converting an amount of MJ's (e.g. wood chips, wood pellets, vegetable oil) into kg's for calculating the transport emissions. Formula 1 shows how the energy content can be calculated using the heating value of the dry part of the biomass. Formula 1 is used consistently for feedstocks (solid biomass), intermediary products, solid biomass energy carriers and also for biofuels, biogas and bioliquids;
- For allocation to different products/co-products the LHV of the whole product, not only the dry part, is used. For this calculation the available LHV values for the products and co-products can be used, or, in case the LHV on dry basis is available, Formula 2 below can be used.

The two formulas are:

$$\text{Energy content of wet biomass} = LHV_{dry} \cdot M_{wet\ biomass} \cdot (1 - [\text{mass \% of water}]/100) \quad (1)$$

$$LHV_{wet} = LHV_{dry} \cdot (1 - [\text{mass \% of water}]/100) - 2.441 \cdot [\text{mass \% of water}/100] \quad (2)$$

In which

- “Energy content of wet biomass” is the total amount of energy (MJ) of the dry fraction of the biomass (MJ)
- $M_{wet\ biomass}$ is the mass of the wet biomass (kg wet biomass)
- LHV_{wet} is the lower heating value of the wet biomass (MJ per kg wet biomass)
- LHV_{dry} is the lower heating value of the dry biomass (MJ per kg of dry biomass)
- [mass % of water] is the water content of the wet biomass, in percent of total mass of the wet biomass
- 2,441 is the latent heat of vaporisation of water at 25°C expressed in MJ per kg water

The above mentioned approach is followed consistently for all BioGrace calculations: for solid and gaseous biomass to electricity, heat, cooling and biomethane, for bioliquids to electricity, heat and cooling and also for biofuels. In theory it would be appropriate to include the latent heat of combustion if the biomass is to be combusted, as including the latent heat of vaporisation will give an energy content that is actually available for generation of heat and electricity. However, some forms of biomass energy will not be combusted (e.g. wheat or sugar beet that will be fermented to produce ethanol, and e.g. manure or biowaste to be digested to give biogas). Therefore, Formula 1 is always used because at forehand it is not always clear whether or not a certain biomass is to be combusted (e.g. wood and straw can be combusted but can also be pretreated and then fermented into ethanol (so called lignocellulosic ethanol) and residues or co-products like crude glycerine, fatty acids, used cooking oils and waste animal fats are both combusted as well as used for digestion or biodiesel production). An additional advantage is that the energy content of the dry part of the biomass is independent of the moisture content of the biomass, so that drying the wet biomass will not result in an increase in the energy content of the biomass.

As a consequence, electrical and thermal efficiencies will also have to be calculated using the energy content of the biomass as determined by Formula 1. This is reflected in the BioGrace calculation rules on electrical and thermal efficiency.

Annex – Methodology

This Annex includes a revised version of the harmonized GHG accounting methodology presented in the Report of the European Commission *COM(2010) 11* plus additions in the European Commission Staff Working Document *SWD(2014) 259*. This updated methodology was used for calculating the default values as listed in *SWD(2014) 259* and in JRC report *EUR 27215 EN*, and is to be used for making actual calculations.

Methodology for calculating greenhouse gas performance of solid and gaseous biomass used in electricity, heating and cooling

1. Greenhouse gas emissions from the production of solid and gaseous biomass fuels, before conversion into electricity, heating and cooling, shall be calculated as:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr},$$

where

E = total emissions from the production of the fuel before energy conversion;

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, that is greenhouse gases emitted during combustion;

e_{sca} = emission savings from improved agricultural management;

e_{ccs} = emission savings from carbon capture and geological storage; and

e_{ccr} = emission savings from carbon capture and replacement.

Emissions from the manufacture of machinery and equipment shall not be taken into account.

2. Greenhouse gas emissions from the use of solid and gaseous biomass in producing electricity, heating or cooling, including the energy conversion to electricity and/ or heat or cooling produced shall be calculated as follows:

For energy installations delivering only heat:

$$EC_h = \frac{E}{\eta_h}$$

For energy installations delivering only electricity:

$$EC_{el} = \frac{E}{\eta_{el}}$$

Where:

$EC_{h,el}$ = Total greenhouse gas emissions from the final energy commodity.

E = Total greenhouse gas emissions of the bioliquid before end-conversion.

η_{el} = The electrical efficiency, defined as the annual electricity produced divided by the annual fuel input.

η_h = The heat efficiency, defined as the annual useful heat output divided by the annual fuel input.

For the electricity or mechanical energy coming from energy installations delivering useful heat together with electricity and/or mechanical energy:

$$EC_{el} = \frac{E}{\eta_{el}} \left(\frac{C_{el} \cdot \eta_{el}}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h} \right)$$

For the useful heat coming from energy installations delivering heat together with electricity and/or mechanical energy:

$$EC_h = \frac{E}{\eta_h} \left(\frac{C_h \cdot \eta_h}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h} \right)$$

Where:

C_{el} = Fraction of exergy in the electricity, and/or mechanical energy, set to 100 % ($C_{el} = 1$).

C_h = Carnot efficiency (fraction of exergy in the useful heat).

Carnot efficiency, C_h , for useful heat at different temperatures:

$$C_h = \frac{T_h - T_0}{T_h}$$

where

T_h = Temperature, measured in absolute temperature (kelvin) of the useful heat at point of delivery.

T_0 = Temperature of surroundings, set at 273 kelvin (equal to 0 °C)

For T_h , < 150 °C (423 kelvin), C_h can alternatively be defined as follows:

C_h = Carnot efficiency in heat at 150 °C (423 kelvin), which is: 0.35

For the purposes of this calculation, the following definitions shall apply:

- (a) "cogeneration" shall mean the simultaneous generation in one process of more than one useful energy commodity (electricity, heat, cooling, biomethane, mechanical energy and other energy carriers);
- (b) "useful energy commodity" shall mean an energy carrier produced in a cogeneration process to satisfy an economical justifiable demand;
- (c) "economically justifiable demand" shall mean the demand that would otherwise be satisfied at market conditions.

3. Greenhouse gas emissions from solid and gaseous biomass fuels for electricity, heating and cooling purposes, EC , shall be expressed in terms of grams of CO_2 equivalent per MJ of final energy commodity (as defined above), gCO_{2eq}/MJ .

4. Greenhouse gas emission savings from heating, cooling, electricity and biomethane being generated from biomass shall be calculated as:

$$SAVING = (EC_{F(h\&c,el,biomethane)} - EC_{B(h\&c,el,biomethane)}) / EC_{F(h\&c,el,biomethane)}, \text{ where}$$

$EC_{B(h\&c,el,biomethane)}$ = total emissions from the heat, cooling, electricity or biomethane;

$EC_{F(h\&c,el,biomethane)}$ = total emissions from the fossil fuel comparator for heating and cooling, electricity or biomethane.

5. The greenhouse gases taken into account for the purposes of point 1 shall be CO_2 , N_2O and CH_4 . For the purpose of calculating CO_2 equivalence, those gases shall be valued as follows:

CO_2 : 1

N_2O : 298

CH_4 : 25

6. Emissions from the extraction, harvesting or cultivation of raw materials, e_{ec} , shall include emissions from the extraction, harvesting or cultivation process itself; from the collection, drying, storage and transport of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of CO_2 in the cultivation of raw materials shall be excluded. Certified reductions of greenhouse gas emissions from flaring at oil production sites anywhere in the world shall be deducted. Estimates of emissions from cultivation or harvesting may be derived from the use of averages calculated for smaller geographical areas than those used in the calculation of the default values, as an alternative to using actual values.

7. Annualised emissions from carbon stock changes caused by land-use change, e_l , shall be calculated by dividing total emissions equally over 20 years. For the calculation of those emissions the following rule shall be applied:

$$e_l = (CS_R - CS_A) \times 3,664 \times 1/20 \times 1/P - e_B,$$

where

e_l = annualised greenhouse gas emissions from carbon stock change due to land-use change (measured as mass of CO₂-equivalent per unit solid and gaseous biomass energy);

CS_R = the carbon stock per unit area associated with the reference land use (measured as mass of carbon per unit area, including both soil and vegetation). The reference land use shall be the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later;

CS_A = the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation). In cases where the carbon stock accumulates over more than one year, the value attributed to CS_A shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier; and

P = the productivity of the crop (measured as solid and gaseous biomass energy per unit area per year).

e_B = bonus of 29 g CO_{2eq}/MJ solid and gaseous biomass if biomass is obtained from restored degraded land under the conditions provided for in point 8.

8. The bonus of 29 g CO_{2eq}/MJ shall be attributed if evidence is provided that the land:
 - (a) was not in use for agriculture or any other activity in January 2008; and
 - (b) falls into one of the following categories:
 - (i) severely degraded land, including such land that was formerly in agricultural use;
 - (ii) heavily contaminated land.

The bonus of 29 g CO_{2eq}/MJ shall apply for a period of up to 10 years from the date of conversion of the land to agricultural use, provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena for land falling under (i) are ensured and that soil contamination for land falling under (ii) is reduced.

9. The categories referred to in point 8(b) are defined as follows:
 - (a) "severely degraded land" means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded;
 - (b) "heavily contaminated land" means land that is unfit for the cultivation of food and feed due to soil contamination.

Such land shall include land that has been the subject of a Commission decision in accordance with the fourth subparagraph of Article 18(4) of Directive 2009/28/EC.

10. In accounting for the consumption of electricity or heat not produced within the fuel production plant, the greenhouse gas emission intensity of the production and distribution of that electricity or heat shall be assumed to be equal to the fossil fuel comparators set out in point 18. By derogation

from this rule, producers may use an average value for an individual electricity production plant for electricity produced by that plant, if that plant is not connected to the electricity grid.

11. Emissions from transport and distribution, e_{td} , shall include emissions from the transport and storage of raw and semi-finished materials and from the storage and distribution of finished materials. Emissions from transport and distribution to be taken into account under point 6 shall not be covered by this point.
12. Emissions from the fuel in use, e_{ui} , shall include emissions from CH₄ and N₂O from the combustion of solid biomass and of biogas/biomethane. Emissions of CO₂ from fuel in use shall be taken to be zero for solid and gaseous biomass.
13. Emission saving from carbon capture and storage, e_{ccs} , that have not already been accounted for in e_p , shall be limited to emissions avoided through the capture and storage of emitted CO₂ directly related to the extraction, transport, processing and distribution of fuel if stored in compliance with Directive 2009/31/EC on the geological storage of carbon dioxide.
14. Emission saving from carbon capture and replacement, e_{ccr} , shall be limited to emissions avoided through the capture of CO₂ of which the carbon originates from biomass and which is used to replace fossil-derived CO₂ used in commercial products and services.
15. Where a cogeneration unit - providing heat and/or electricity to a fuel production process for which emissions are being calculated – produces excess electricity or excess useful heat, the greenhouse gas emissions shall be divided between the electricity and the useful heat according to the temperature of the heat (which reflects the usefulness (utility) of the heat). The allocation factor, called carnot efficiency C_h , is calculated as follows for useful heat at different temperatures:

$$C_h = \frac{T_h - T_0}{T_h}$$

where

T_h = Temperature, measured in absolute temperature (kelvin) of the useful heat at point of delivery.

T_0 = Temperature of surroundings, set at 273 kelvin (equal to 0 °C)

For T_h , < 150 °C (423.15 kelvin), C_h can alternatively be defined as follows:

C_h = Carnot efficiency in heat at 150 °C (423.15 kelvin), which is: 0.35453

For the purposes of this calculation, the actual efficiencies shall be used, defined as the annual mechanical energy, electricity and heat produced respectively divided by the annual energy input.

For the purposes of this calculation, the following definitions shall apply:

- (a) "cogeneration" shall mean the simultaneous generation in one process of thermal energy and electrical or mechanical energy;
- (b) "useful" heat shall mean heat generated to satisfy an economical justifiable demand for heat;
- (c) "economically justifiable demand" shall mean demand that does not exceed the needs for heating and which would otherwise be satisfied at market conditions by energy generation processes other than cogeneration.

16. Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value in the case of co-products other than electricity).

17. For the purposes of the calculations referred to in paragraph 15 and 16, the emissions to be divided shall be $e_{ec} + e_l + e_{sca}$ + those fractions of e_p , e_{ld} , e_{ccs} and e_{ccr} that take place up to and including the process step at which a co-product is produced. If any allocation to co-products has taken place at an earlier process step in the life-cycle, the fraction of those emissions assigned in the last such process step to the intermediate fuel product shall be used for this purpose instead of the total of those emissions.

Wastes, secondary biomass and primary forest and agricultural crop residues, including tree tops and branches, straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials.

In the case of fuels produced in refineries other than the combination of processing plants with boilers or cogeneration units providing heat and/or electricity to the processing plant, the unit of analysis for the purposes of the calculation referred to in paragraph 16 shall be the refinery.

18. For biomass used for electricity production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $EC_{F(el)}$ shall be 186 gCO_{2eq}/MJ electricity.

For biomass used for useful heat production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $EC_{F(h)}$ shall be 80 gCO_{2eq}/MJ heat.

For biomethane injected into the natural gas grid, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $EC_{F(Biomethane)}$ shall be 72 gCO_{2eq}/MJ biomethane.

For biomass used for useful cooling production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $EC_{F(c)}$ shall be 47 gCO_{2eq}/MJ cooling.

19a In case of co-digestion of maize, manure and/or biowaste in a biogas plant for the production of electricity or biomethane, typical and default values are calculated as follows:

$$E = \sum_1^n S_n \cdot E_n$$

where

E = emissions per MJ electricity or biomethane from biogas

S_n = Share of feedstock n in energy content

E_n = Emission in gCO₂/MJ for pathway n , see (i) below

$$S_n = \frac{P_n \cdot W_n}{\sum_1^n P_n \cdot W_n}$$

Where:

P_n = energy yield [MJ] per kilogram of wet input of feedstock n , see (ii) below

W_n = weighting factor of substrate n defined as:

$$W_n = \frac{I_n}{\sum_1^n I_n} \cdot \left(\frac{1 - AM_n}{1 - SM_n} \right)$$

Where:

I_n = Annual input to digester of substrate n [tonne of fresh matter]

AM_n = Average annual moisture of substrate n [kg water / kg fresh matter]

SM_n = Standard moisture for substrate n , see (iii) below

Notes:

(i) For manure as substrate a bonus of 45 gCO_{2,eq} / MJ manure is added for improved agricultural and manure management

(ii) The P_n values for calculating typical and default values are:

P (maize) = 4.16

P (manure) = 0.50

P (biowastes) = 3.41

(iii) The SM_n are 90% for manure, 65% for maize, and 76% for biowaste.

19b. In case of co-digestion of n substrates in a biogas plant for the production of electricity or biomethane, actual GHG emissions are calculated as follows:

$$E = \sum_1^n S_n \cdot (e_{ec,n} + e_{td,feedstock,n} + e_{l,n} - e_{sca,n}) + e_p + e_{td,product} + e_u - e_{ccs} - e_{ccr},$$

where

E = total emissions from the production of the biogas or biomethane before energy conversion;

S_n = Share of feedstock n , in fraction of input to the digester

$e_{ec,n}$ = emissions from the extraction or cultivation of feedstock n ;

$e_{td,feedstock,n}$ = emissions from transport of feedstock n to the digester;

$e_{l,n}$ = annualised emissions from carbon stock changes caused by land use change, for feedstock n;

e_{sca} = emission savings from improved agricultural management of feedstock n, see (i) below;

e_p = emissions from processing;

$e_{td,product}$ = emissions from transport and distribution of biogas and/or biomethane;

e_u = emissions from the fuel in use, that is greenhouse gases emitted during combustion;

e_{ccs} = emission savings from carbon capture and geological storage; and

e_{ccr} = emission savings from carbon capture and replacement.

Note:

- (j) For manure as substrate a bonus of 45 gCO_{2,eq} / MJ manure is added for improved agricultural and manure management

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