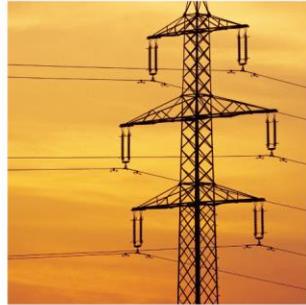# BioGrace II

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

January 2015

BioGrace II Methodological Background Document

Version 2

Content

1 Introduction

This methodological background document clarifies the decisions made by the EU Commission on some of the more complicated elements of the greenhouse gas (GHG) accounting methodology stated in the Commission *Staff Working Document SWD(2014) 259*[1] and in the *report COM(2010) 11*[2]. The BioGrace-II consortium has not added any arguments or opinions.

The starting point for the Commission when setting up a methodology to calculate GHG emissions for heat, electricity and cooling was the methodology stated in the Renewable Energy Directive (RED) for biofuels. This document mainly describes elements that differ in the GHG calculation methodology for heat, electricity and cooling compared to the calculation methodology for biofuels.

The document starts by explaining the Commission's decisions concerning allocation. These sections are followed by information on the fossil fuel comparators and some principal choices concerning 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.

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[1] http://ec.europa.eu/energy/renewables/bioenergy/doc/2014_biomass_state_of_play_.pdf

2 http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1410940793312&uri=CELEX:52010DC0011

2   Allocation

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.

The main disadvantage with energy allocation lies in the ignorance of the different value of different energy carriers and of heat at different temperatures. Energy allocation would not differentiate between 1 MJ of heat and 1 MJ of electricity even if the economic value and the capability of the two energy carriers are not the same. Nor would energy allocation differentiate between 1 MJ of heat at 10 ºC, which is useless, and 1 MJ of heat at 1000 ºC, which can be used for many purposes. This makes it difficult to distinct 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:

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

where

- 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.

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Very low allocation factors for the district heating would give disproportionate high emissions allocated to the electricity. Thus, efficiency measures in combined heat and power plants (CHPs), where the heat temperature is lowered in order to increase the electricity production, would be disfavoured.

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 heat efficiency 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.

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

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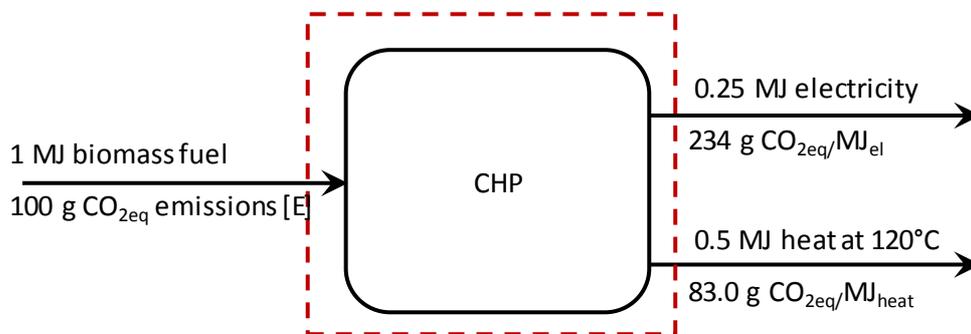

Figure 1. Allocation between electricity and heat at 120°C in a CHP.

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.
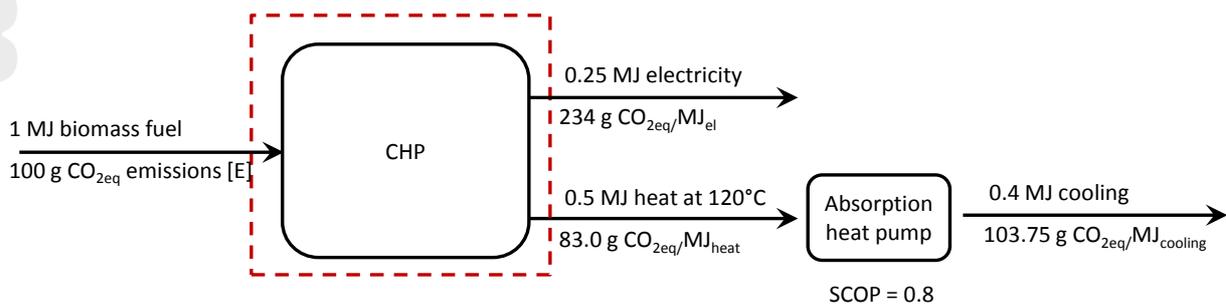

Figure 2. Allocation between electricity and heat and production of cooling from heat.

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 Four sets of fossil fuel comparators

There were several decisions[3] taken by the European Commission in order to define the fossil fuel comparators (FFC). Different alternatives for the geographical scope, the end-use technology and the replaced technologies had to be considered. Finally, four EU wide fossil fuel comparators (FFC) for different energy carriers were set.

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 biomethane[4] 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.

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[3] Formally speaking, the SWD(2014) 259 does not contain any decisions as (see text box 2 in the SWD(2014) 259) "the definition of the GHG methodology is a policy choice which goes beyond the scope of this document".

[4] 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 defined[5]:

- 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.

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[5] 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 this category also improved manure management has been included for gaseous biomass applications according to the SWD(2014) 259.

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 $CO_{2,eq}$/MJ biogas for improved manure management, which has been calculated as the sum of 37g of $CO_{2,eq}$/MJ biogas due to avoided methane emissions plus 8 g $CO_{2,eq}$/MJ biogas due to avoided nitrous oxide emissions. A detailed explanation of how the figures 37 g $CO_{2,eq}$/MJ and 8 g $CO_{2,eq}$/MJ is calculated, is given by the JRC[6].

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. It still has some N content thus allowing lower input of synthetic N-fertiliser. The usable 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 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.

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[6] JRC Report EUR 26696 EN, page 74

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

The mass balance approach is a main principle in the RED and it is also stated in the COM(2010) 11 report. The mass balance approach means that physical mixing of products is allowed, but the products are kept administratively separated. However, in the SWD(2014) 259 it is stated that the mass balance approach should not apply for biogas plants that uses a mixture of substrates.

The reason for suspending the mass balance approach for co-digestion plants is a stakeholder impact. A number of stakeholders have stressed that the mass balance approach creates difficulties for the majority of co-digestion plants[7]. That is the reason of providing a formula generating a weighted average between several default values from single-feedstock biogas.

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.

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[7] Staff Working Document SWD(2014) 259

6   N$_2$0 emissions from soil – IPCC

For pathways with crop cultivation, field N$_2$O 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 N$_2$O 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 N$_2$O 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, 2006[8]. 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., 2012[9].

This approach has been put into practice with an online calculation tool, the Global Nitrous Oxide Calculator, GNOC[10]. Detailed instructions are available in the user manual that can be downloaded from the GNOC website.

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[8] Stehfest, E., Bouwman, L., (2006). N$_2$O 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.

[9] 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.

[10] 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 2014[11] for further details).

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[11] JRC Report EUR 26696 EN

7 Energy content / LHV

While making the GHG calculations, the BioGrace consortium followed JRC in its approach on how to calculate the energy content of wet biomass:

- 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:

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

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

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.

BIOGRACE II

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

Align biofuel GHG emission calculations in Europe (BioGrace)

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