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Solid and gaseous bioenergy pathways: input values and GHG emissions

Calculated according to the methodology set in COM(2016) 767

Version 2

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Title Solid and gaseous bioenergy pathways: input values and GHG emissions.

Abstract

The Commission's legislative proposal for a recast of the Renewable Energy Directive (RED-recast) (COM(2016) 767), in Art. 26(7), specifies the minimum greenhouse gas (GHG) emissions saving thresholds that bioenergy must comply with in order to count towards the renewables targets and to be eligible for public support. Annex V (liquid biofuels) and Annex VI (solid and gaseous biomass) of the RED-Recast describe the methodology for GHG savings calculations needed to comply with the GHG criteria. They also provide a list of Default GHG emission values, aggregated and disaggregated, that operators can use to demonstrate compliance of their product with the GHG criteria.

This report describes the input data, assumptions and methodological approach applied by the JRC when compiling the updated dataset used to calculate GHG emissions for the different biomass pathways. The GHG emissions resulting from the application of the methodology from COM(2016) 767, and presented in Annex VI of the document, are also shown.

The report aims to provide operators, stakeholders ,and the scientific community all the necessary information to explain the assumptions chosen as well as to guarantee reproducibility of the results.

Additional analysis to test the sensitivity of the results to various assumptions is presented in the final section of the report.

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Version 2

Contents

Foreword

Updates from previous version:

This document replaces the previous version of the report EUR 27215EN published in 2015 with ISBN number 978-92-79-47895-6 (PDF) and PUBSY request number JRC95618. The updates in this new document were required by the publication of the European Commission's Proposal of a Directive on the Promotion of the Use of Energy from Renewable Sources (COM(2016)767 – RED Recast). The Annex VI of the Proposal applies methodological and numerical changes compared to the SWD(2014) 259 to which the previous report referred to. In view of these changes, this version was modified in the following parts: i) Executive Summary, Introduction and Conclusions were redrafted; ii) Emission factors for fossil fuels supply were modified; iii) The results in Chapter 7 are updated and coherent with the values in Annex VI of COM(2016) 767; iv) Section 7.3 on the sensitivity analysis was updated and expanded; v) In Chapter 9 some of the points raised by stakeholders have become obsolete in the years since many changes have been applied to the numbers and the assumptions. These points have been removed from this version of the report. The complete list of questions and answers is maintained in Annex 2 and 3.

Acknowledgments

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Executive Summary

Following the European Commission's Communication *'A policy framework for climate and energy in the period from 2020 to 2030'([1])* the European Council agreed in October 2014 on targets of GHG emission reduction, increased use of renewable energy and energy efficiency for the period 2020 - 2030. Among the set of legislative documents produced to achieve these targets, in 2016, the European Commission presented a proposal for a recast of the Renewable Energy Directive (COM(2016)767) – RED Recast.

The RED Recast strengthens the sustainability criteria for agricultural biomass and introduces new sustainability criteria for forest biomass (Art. 26(2) – 26(6)). In addition to those criteria, Art. 26(7) specifies the minimum GHG saving threshold that bioenergy used in different sectors (transport, heat and power) has to comply with in order to count towards the renewables targets and to be eligible for public support. For electricity, heating and cooling produced from biomass fuels the threshold of the minimum GHG savings compared to fossil fuels is fixed at 80% for installations starting operations after 1 January 2021 and at 85% for installations starting operations after 1 January 2026.

The sustainability and greenhouse gas emission criteria for biomass used in electricity and heating sectors apply only to installations with fuel capacity above 20 MW in case of solid biomass fuels, and above 0.5 MW in case of gaseous fuels.

Finally, Art. 26(8) states that electricity from biomass fuels produced in installations above 20 MW will count towards the renewables target and will be eligible for public support only if it is generated applying high efficient cogeneration technology, as defined under Article 2(34) of the Energy Efficiency Directive 2012/27/EU of the European Parliament and of the Council.

Annex VI of the RED Recast provides a simplified GHG accounting methodology as well as typical and default values for a number of solid and gaseous biomass pathways for the production of power, heating and cooling.

This report describes input data, models used, and the assumptions made by the JRC when calculating the updated default and typical GHG emissions for the different solid and gaseous bioenergy pathways applying the harmonized methodology set in Annex VI of the RED Recast, which deals with direct supply-chains emissions (thus excluding biogenic CO_2 emissions). The number and type of pathways described in Annex VI as well as the input datasets used, is the same as described in the SWD(2014) 259 and the accompanying JRC report EUR 27215 EN. However, a number of methodological assumptions, as well as specific emission factors have been updated.

The datasets and analysis reported in this report can be used by stakeholders to better understand and replicate the default GHG emissions of specific bioenergy pathways reported in the RED Recast. The database consists of more than 80 tables detailing the inputs and outputs of the processes used to build the bioenergy pathways[2]. Data were derived from reports and databases of emission inventories produced by international organizations, such as the Intergovernmental Panel for Climate Change (IPCC) and the European Environment Agency (EEA), peer-reviewed journal publications as well as original data provided by stakeholders and industrial associations. The geographical scope is the European Union, therefore the data are aimed at being representative for the EU.

([1]) COM(2014) 15

([2]) All input data and results presented in this report will be made available in an Excel database at the following address: https://ec.europa.eu/jrc/en/alfa.

The database contains data for solid biomass used for power and heat production as well as processes for anaerobic digestion and biogas production. Regarding solid biomass, six woody feedstocks are considered as well as five agricultural materials. A combination of transport distances representing the main routes of biomass trade is included as well as multiple common technology options, for a total of more than ninety pathways.

Data for biogas production include three of the main common substrates, two alternatives for digestate management, and multiple technological options for power and biomethane production, for a total of thirty pathways.

There are several possible sources of uncertainty and data variation. The main factor affecting uncertainty is linked to the geographical variability of some processes (e.g. cultivation techniques and land productivity). Because the data are based on EU averages, the datasets of the default values may not represent exactly each specific national or sub-national condition. In these cases the harmonized GHG methodology allows operators to calculate actual values.

Secondly, technological differences may have significant impact. To limit this source of variation, the pathways presented are separated according to major technological options (e.g. see the disaggregation of biogas upgrading pathways).

Thirdly, for some processes there is a lack or scarcity of data. The largest possible set of modelling and empirical data has been analysed to limit this source of uncertainty (e.g. publications, handbooks, emissions inventory guidebooks, LCA databases and, whenever available, proprietary data from stakeholders).

Finally, the report also contains a section where the sensitivity of the results to specific parameters, such as co-digestion of multiple substrates., co-generation of power and heat and different electrical efficiencies, is extensively analysed.

The results show that biogas and biomethane produced from wet manure can achieve GHG savings above 100% thanks to the emission credits for avoided GHG emissions from the alternative manure management.

GHG savings associated with electricity produced from biogas from maize whole crop span from 10% up to more than 50%. This variation is strongly dependent on the technology adopted. The use of a gas-tight tank for the storage of the residual digestate is essential in most of the pathways to achieve high GHG savings.

When a biogas plant is analyzed in its entirety and the emissions are averaged among multiple substrates (i.e. co-digestion), technological choices are still an important factor but the use of manure in combination with maize is essential to achieve GHG savings higher than 80%. For instance, when biomethane is produced with the best technology (Close Digestate – Off-gas combusted) a mixture of $60\%_{\text{fresh matter}}$ manure and $40\%_{\text{fresh matter}}$ maize will achieve 81% savings. However, when off-gases are simply vented rather than flared, only $20\%_{\text{fresh matter}}$ of maize can be co-digested to achieve savings above 80%.

GHG savings for solid biomass pathways are generally above 60% for both power and heat produced. However, emissions can differ significantly depending on the transportation distance and the energy conversion technologies considered. For many forest-derived feedstocks default values do not reach 80% in case of transportation distance above 2500 km and/or with no use of cogeneration technology for power and heat production (vs electricity-only plants). Pellets would be more affected than wood chips as more processing energy is needed for their production; with a 85% threshold most pellets produced with current technology (Case 2a) would not qualify. However, pellets produced using renewable energy sources (Case 3a) and utilized in co-generating plants would still be able to pass the highest threshold.

1 Introduction

Two major directives were adopted in 2009 as a part of the EU2020 climate and energy package setting up the sustainability scheme for liquid and gaseous biofuels: The Renewable Energy Directive (RED) (2009/28/EC) and the Fuel Quality Directive (FQD) (2009/30/EC). The two documents introduced a set of sustainability criteria that liquid and gaseous biofuels had to comply with in order to count towards renewable energy targets and to be eligible for public support. One of these criteria established a threshold of savings of greenhouse gas (GHG) emissions for biofuels and bioliquids compared to fossil fuels. The legislation also defined a set of rules for calculating the greenhouse gas emissions of biofuels, bioliquids and their fossil fuels comparators. To help economic operators to demonstrate compliance with the GHG emission savings of their products, default and typical values were also listed in the annexes of the RED and FQD directives.

The Commission report on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling (COM(2010)11) recommended Member States to adopt a similar approach also for solid and gaseous bioenergy carriers for power, heating and cooling. A few years later, the Commission published the document *'State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU (SWD(2014)259)*'. In that report, the GHG emission values and the methodology defined in COM(2010)11 were updated to account for the technogical and market developments in the bioenergy sector.

In 2014, following the Commission's Communication *'A policy framework for climate and energy in the period from 2020 to 2030' ([3])* the European council agreed in October 2014 on targets of GHG emission reduction, increased use of renewable energy and energy efficiency for the period 2020 - 2030. Among the set of legislative documents produced to achieve these targets ([4]), in 2016, the European Commission adopted a legislative proposal for a recast of the Renewable Energy Directive (RED Recast) ([5]).

The RED Recast defines sustainability and greenhouse gas emission criteria for liquid biofuels used in transport as well as for solid and gaseous biomass fuels used to produce power, heating and cooling. Compliance with the criteria is mandatory for accounting towards the renewable energy targets and to be eligible for public support.

Sustainability criteria are defined for the production of agricultural and forest derived biomass (Art. 26(2) – 26(6)). In addition to those criteria, Art. 26(7) specifies the minimum GHG saving thresholds that bioenergy used in different sectors have to comply with in order to count towards the EU renewable target and to be eligible for public support. The threshold for electricity, heating and cooling produced from biomass fuels is fixed at 80% for installations starting operations after 1 January 2021 and at 85% for installations starting operations after 1 January 2026.

The sustainability and greenhouse gas emission criteria for biomass fuels used in electricity and heating sector apply only to installations with fuel capacity above 20 MW in case of solid biomass feedstocks, and above 0.5 MW in case of gaseous feedstocks.

Finally, Art. 26(8) states that electricity from biomass fuels produced in installations above 20 MW will count towards the renewables target and will be eligible for public

([3]) COM(2014) 15
([4]) See Communication COM(2016) 860, *Cleaner Energy for All Europeans.*
([5]) COM(2016) 767

support only if it is produced applying high efficient cogeneration technology, as defined under Article 2(34) of the Energy Efficiency Directive 2012/27/EU of the European Parliament and of the Council.

Annex V (liquid biofuels) and Annex VI (solid and gaseous biomass) of the RED-Recast proposal describe the methodology for GHG savings calculations needed to comply with the GHG criteria. They also provide a list of Default GHG emission values, aggregated and disaggregated, that operators can use to demonstrate compliance of their product with the GHG criteria.

For the preparation of the Annex VI of COM(2016) 767, the JRC updated the list of pathways and the relative input database compared to the COM(2010) 11 and the SWD(2014) 259 in order to account for the scientific, technological and economic developments in the solid and gaseous bioenergy sector. A twin report presents similar data relative to GHG emissions for liquid biofuels underpinning the default values in Annex V (Edwards et al., 2017).

This report describes the input data, assumptions and methodological approach applied by the JRC when compiling the updated dataset used to calculate GHG emissions for the different biomass pathways, following the harmonized GHG accounting which deals only with direct supply-chains emissions ([6]).

The report aims to provide economic operators, regulators, researchers and other stakeholders all the necessary information to explain the assumptions chosen as well as to guarantee reproducibility of the results.

In view of this, additional analysis to test the sensitivity of the results to various assumptions is presented in the final section of the report.

Structure of the report

The first part of the report (Chapters 2, 3, and 4) describes the data that are common for all different pathways. These data include emission factors for:

- fossil fuels provision;
- supply of chemical fertilizers, pesticides and process chemicals;
- auxiliary plant processes (such as boilers and power plants);
- fuel consumption and emissions for different means of transportation;

The second part (Chapters 5 and 6) describes the specific input data used for the processes that make up the different solid and gaseous bioenergy pathways.

([6]) It should be noted that the greenhouse gas performance of bioenergy from a lifecycle perspective depends on the emissions from the supply chain of bioenergy (which include emissions from direct land use change, cultivation, transport, processing), as well as on biogenic CO_2 emissions, which include the emissions from combustion of the biomass source and the CO_2 absorbed due to plant regrowth. For more information, see SWD(2016) 418, Impact assessment on *Sustainability of Bioenergy*, Agostini et al. (2014), *Carbon accounting of forest bioenergy*, JRC EUR25354EN; Giuntoli et al. (2015), Domestic heating from forest logging residues: environmental risks and benefits, *Journal of Cleaner Production* 99(2015) 206-216; Giuntoli et al. (2016), Climate change impacts of power generation from residual biomass, *Biomass and Bioenergy* 89(2016) 146-158.

The third part of the report includes methodological details regarding the typical and default values published in Annex VI of the RED-Recast and the resulting GHG emissions for the pathways analysed. Extensive sensitivity analysis is carried out to show the changes in GHG emissions when: i) multiple substrates are co-digested to produce biogas; ii) power, heat and cooling are co- or tri-generated in power plants; iii) efficiency of final electrical conversion increases; iv) different emission factors for electricity supply are used.

The last part of the report details the comments received by experts and stakeholders, and the replies of JRC, during the review process undertaken for the definition of input data and related methodological choices. In particular this process consisted of two meetings where a preview of input data proposed by the JRC was presented to technical experts and stakeholders:

- Expert workshop held in November 2011 in Ispra (IT),
- Stakeholder workshop held in May 2013 in Brussels (BE).

Detailed comments were collected after both meetings and taken into account by the JRC to finalise the dataset and the calculations. Detailed questions/comments from stakeholders and related JRC answers may be found in Annexes 2 and 3.

Excel database

All the values and results presented in this report can be found in numerical format in a JRC Excel database which will be made available at the following address: https://ec.europa.eu/jrc/en/alfa

Part One — General input data and common processes

2 General input data for pathways

This section presents the processes associated with the production and supply of fossil fuels, chemicals and European electricity. Furthermore, data on fuel consumption in auxiliary processes (e.g. boilers and power plants) and in various transport modes are also reported here.

The total emission factors for the whole supply chain are indicated in the comments under each process table and are summarized in Table 16. To be noted that the climate metric utilized is the Global Warming Potential (GWP) at a time horizon of 100 years. The GWP(100) values chosen are the ones detailed in the IPCC 4th AR (2007) and they are equal to 25 for methane and 298 for nitrous oxides.

The processes detailed in this section are used horizontally in the GHG emissions calculations of the pathways analysed in this report.

2.1 Fossil fuels provision

Electricity grid supply and Fossil Fuel Comparator

- The Fossil Fuel Comparator (FFC) considered in COM(2016) 767, for power supplied to the electricity grid considers the **average** mix of future (2030) **fossil** power production technologies and feedstocks as modelled in the EU Reference scenario 2016 ([7]);
- The emission factors used to calculate the FFC are taken from the JEC WTT 4a report.
- For consistency reasons, it is appropriate that the GHG emissions considered for the **supply and consumption** of electricity in the solid biomass pathways are considered to be the same ([8]). This emission factor is defined as "Fossil-mix" in this report;
- Because of consistency reasons with liquid biofuels calculation rules, the emission factor for the supply of electricity in the biogas and biomethane pathways is indicated in Table 5. This emission factor is defined as "EU-mix" in this report.

The fossil mix obtained from the EU Ref. Scenario 2016 is reported in Table 1. To be noted that the emissions reported in Table 1 include both upstream and combustion GHG emissions from fossil fuels and that they refer to the power plant outlet (high voltage) and do not include transmission and distribution losses. They thus appear different from the values reported in JEC WTT 4a report, which refer to low voltage electricity delivered to consumers.

It is important to highlight that the values and approach used in this report are appropriate for the specific goal and purpose of these calculations, i.e. to determine the typical and default GHG emissions and GHG savings for specific solid and gaseous bioenergy pathways in accordance with a methodology designed for regulatory purposes. For example, the electricity mix GHG emission values used in this report will

([7]) Because the calculation only accounts for the relative share of fossil sources, the mix projected by the EU Ref. Scenario 2016 and the mix projected in the EUCO27 scenario give the same value.

([8]) A difference in emission factor between consumption and FFC may create fictitious emissions savings (i.e. consider an extreme example in which the amount of electricity consumed to produce an intermediate energy carrier used for power production is the same as the amount of electricity produced with its final use: if the supply and comparator were different, then the pathway could claim GHG savings even without producing any additional electricity). A simpler alternative could have been to consider only the net electricity produced at the power plant, however this is not possible because the majority of consumption of electricity along the supply chain takes place in pellet mills and not at the power plant.

likely be higher when compared with other literature studies using similar system boundaries and methodology. One reason for this is that the average value of GHG emissions associated to the EU electricity mix supply includes also low or zero-CO_2 emission energy sources (infrastructures are out of the system boundaries) such as other renewables and nuclear, as shown in the values in Table 5.

Table 1. Average fossil mix, emission factors at power plant outlet to the high-voltage grid and final GHG emissions. The pathway code used in the JEC WTT v4a is also reported. The emission factors include upstream and combustion GHG emissions from fossil fuels. The resulting value is considered to be the Fossil Fuel Comparator for electricity production as well as the emission factor (called "Fossil-mix" in this report) for supply of electricity in certain pathways.

Fossil mix (EU Ref. Scenario 2016 at year 2030)				
	Fuel	**Unit**	**Relative share**	
	Solids	% over fossil mix	**45.5%**	
	Oil	% over fossil mix	**1.6%**	
	Gas	% over fossil mix	**52.9%**	
Emission Factors				
Pathway (WTT v4a)	**Electricity production**	**Unit**	**Amount**	**Comment**
KOEL1	Conventional hard coal	$gCO_{2\ eq.}/MJ_{el.}$	**260.8**	43.5% el efficiency
FOEL1	Heavy Fuel Oil	$gCO_{2\ eq.}/MJ_{el.}$	**212.2**	41.5% el efficiency
GPEL1	Natural gas (CCGT)	$gCO_{2\ eq.}/MJ_{el.}$	**114.7**	58.1% el efficiency, 2500 km pipe transport of natural gas (EU Mix)
Total Emissions				
Species		**Unit**		
GHG	Output	$gCO_{2\ eq.}/MJ_{el.}$	**183**	

The transmission and distribution losses considered are reported in Table 2, Table 3 and Table 4.

Table 2. Electricity transmission losses in the high-voltage grid (380 kV, 220 kV, 110 kV)

	I/O	**Unit**	**Amount**	**Source**
Electricity	Input	MJ/MJ_e	**1.015**	1
Electricity (HV)	Output	MJ	**1.0**	

Table 3. Electricity distribution losses in the medium-voltage grid (10 – 20 kV)

	I/O	**Unit**	**Amount**	**Source**
Electricity (HV)	Input	MJ_e/MJ_e	**1.038**	2
Electricity (MV)	Output	MJ	**1.0**	

Table 4. Electricity distribution losses in the low voltage grid (380 V)

	I/O	**Unit**	**Amount**	**Source**
Electricity (MV)	Input	MJ/MJ_e	**1.064**	2
Electricity (LV)	Output	MJ	**1.0**	

Comment

— The final GHG emission factor for electricity supplied to consumers at 380 V is equal to 205 $gCO_{2\ eq.}/MJ_{\ el.}$

Sources:

1. ENTSO-E, 2011;
2. AEEG, 2012;

EU average electricity grid supply

The GHG emissions considered for the supply and consumption of electricity in the biofuel pathways are the ones reported for the EU mix (actual averages) pathway in JEC-WTWv4a (2014).

Table 5. EU mix electricity supply (based on grid average including renewables) emissions

Pathway (JEC)	Emissions	Unit	Amount
EMEL1 (High Voltage)	CO_2	g/MJ	126.8
	CH_4	g/MJ	0.30
	N_2O	g/MJ	0.006
	Total $CO_{2\ eq}$	$gCO_{2\ eq.}/MJ_{el.}$	**136.0**
EMEL2 (Medium Voltage)	CO_2	g/MJ	131.6
	CH_4	g/MJ	0.31
	N_2O	g/MJ	0.006
	Total $CO_{2\ eq}$	$gCO_{2\ eq.}/MJ_{el.}$	**141.1**
EMEL3 (Low Voltage)	CO_2	g/MJ	139.9
	CH_4	g/MJ	0.33
	N_2O	g/MJ	0.01
	Total $CO_{2\ eq}$	$gCO_{2\ eq.}/MJ_{el.}$	**150.1**

Source

1. JEC-WTT v4a, 2014.

Diesel oil, gasoline and heavy fuel oil provision

The GHG emissions associated to diesel and gasoline are the ones reported in Directive (EU) 2015/652 (Part 2, point 5). Emissions associated with heavy fuel oil (HFO) (not reported in the directive) are estimated following the same methodology as in 2015/652, combining refining emissions from JEC-WTTv4a (2014) and figures for crude oil production and transport emissions (EU-mix) from the OPGEE report (ICCT, 2014).

Table 6. Emissions associated to the production, supply and combustion of diesel, gasoline and heavy fuel oil.

[$gCO_{2\ eq.}$/MJ final fuel]	DIESEL	GASOLINE	HFO	Source
Supply emissions	21.9	19.9	13.6	Calculated from [1]
Combustion emissions	73.2	73.4	80.6	2
Total emissions	**95.1**	**93.3**	**94.2**	

Sources

1. ICCT, 2014
2. JEC-WTT v4a.
3. Directive (EU) 2015/652.

Hard coal provision

Table 7. Emission factor: hard coal provision

	I/O	**Unit**	**Amount**
Hard coal	Output	MJ	**1**
Emissions			
CO_2	Output	g/MJ	**6.50**
CH_4	Output	g/MJ	**0.385**
N_2O	Output	g/MJ	**2.50E-04**

Comments

— The total emission factor for the supply of 1 MJ of hard coal is 16.2 $gCO_{2\ eq}$/MJ.

— The emission factor for combustion of 1 MJ of hard coal is 96.1 $gCO_{2\ eq}$/MJ.

Source

JEC-WTT v4; EU coal mix.

Natural gas provision

The GHG emissions associated to natural gas supply are the ones reported in Directive (EU) 2015/652 (Part 2, point 5) for compressed natural gas EU mix, but without the emissions due to the compression of the gas which are taken from the JEC-WTT 4a report (3.3 gCO2 eq/MJ). These emissions are not included since the NG is considered at the level of medium pressure grid.

Table 8. Emission factor: natural gas provision (at MP grid)

	I/O	Unit	Amount
Natural gas	Output	MJ	**1**
Emissions			
CO_2	Output	g/MJ	**5.4**
CH_4	Output	g/MJ	**0.17**
N_2O	Output	g/MJ	**1.67E-04**

Comments

— The total emission factor for the supply of 1 MJ of natural gas is 9.7 $gCO_{2\ eq}$/MJ.

— The emission factor for combustion of 1 MJ of natural gas is 56.2 $gCO_{2\ eq}$/MJ.

— The value represents EU mix with a pipeline distribution distance of 2500 km.

Source

1. JEC-WTT v4.
2. Directive (EU) 2015/652

2.2 Supply of process chemicals and pesticides

This section includes the processes with the input data used for the production and supply of various chemicals, fertilizers and pesticides used in the pathways. The emissions indicated in the following tables refer only to the emissions associated to the specific process. However, many processes are linked in a 'supply chain', in order to supply the final product. Therefore, for ease of reference, total emission factors for the whole supply chain are indicated in table comments and are summarized in Table 16.

The inputs used in the production processes of the chemicals come from the sources mentioned at the end of each paragraph. Such sources have not to be intended as the reference for total emission factors.

2.2.1 Chemical fertilizers

Phosphorus pentoxide (P_2O_5) fertilizer supply

Table 9. Supply of P_2O_5 fertilizer

	I/O	Unit	Amount
P_2O_5 fertilizer	Output	kg	**1.0**
Emissions			
$CO_{2\ eq.}$	-	g/kg	**541.7**

Comment

— The total emission factor includes all supply chains emissions and it is used as reported by Fertilisers Europe (2014)

Source

Fertilizers Europe, 2014

Potassium oxide (K_2O) fertilizer supply

Table 10. Supply of K_2O fertilizer

	I/O	Unit	Amount
K_2O fertilizer	Output	kg	**1.0**
Emissions			
$CO_{2\ eq.}$	-	g/kg	**416.7**

Comments

— The total emission factor includes all supply chains emissions and it is used as reported by Fertilisers Europe (2014)

Source

Fertilizers Europe, 2014

Limestone (aglime–$CaCO_3$) supply chain

The supply chain for the provision of aglime fertilizer includes the processes for the mining, grinding and drying of limestone. The results are quoted per kilogram of CaO in the $CaCO_3$, even though the product is ground limestone. Limestone was once converted to CaO by strong heating (calcining), using fuel. However, at present around 90 % of aglime is ground limestone (or dolomite), and even the small amount of CaO which is used on soil is a by-product of industrial processes.

Table 11. Limestone mining

	I/O	Unit	Amount
Diesel	Input	MJ/kg	**0.1067**
Electricity (LV)	Input	MJ/kg	**0.013**
Limestone	Output	kg	**1**

Source

GEMIS v. 4.93, 2014, '*Xtra-quarrying\limestone-DE-2010*'.

Table 12. Limestone grinding and drying for the production of $CaCO_3$

	I/O	Unit	Amount
Limestone	Input	kg/kg	**1**
Electricity (LV)	Input	MJ/kg	**0.179**
$CaCO_3$	Output	kg	**1**

Comments

— The total emission factor, including upstream emissions, to produce 1 kg of CaO fertilizer is 69.7 $gCO_{2\ eq}/kg_{CaO}$.

Source

GEMIS v. 4.93, 2014, *Nonmetallic minerals\CaCO₃ -powder-DE-2000.*

Since the aglime ($CaCO_3$) inputs to cultivation processes are quoted in terms of the CaO content ('calcium fertilizer as CaO') of the limestone, the inputs per kilogram of CaO are increased by the molecular weight ratio $CaCO_3$/CaO = 1.785.

The total emission factor becomes 39.1 $gCO_{2\ eq}/kg_{CaCO3}$.

Pesticides supply chain

'Pesticides' is the name given to all 'plant health products' including pesticides, herbicides, fungicides and plant hormones.

Table 13. Supply of pesticides

	I/O	**Unit**	**Amount**
Hard coal	Input	MJ/kg	**7.62**
Diesel oil	Input	MJ/kg	**58.1**
Electricity	Input	MJ/kg	**28.48**
Heavy fuel oil (1.8 % S)	Input	MJ/kg	**32.5**
NG	Input	MJ/kg	**71.4**
Pesticides	Output	kg	**1.0**
		Emissions	
CO_2	-	g/kg	**11209.6**
CH_4	-	g/kg	**11.98**
N_2O	-	g/kg	**1.68**

Comment

— The total emission factor, including upstream emissions, to produce 1 kg of pesticides is is 12 010.7 $gCO_{2\ eq}$/kg.

Source

Kaltschmitt, 1997.

2.3 N fertilizer manufacturing emissions calculation

Nitrogen fertilizer production emissions

The emissions associated with mineral nitrogen fertilizer production are calculated according to the following assumptions:

- Emissions represent an average for all N fertilizer **consumed** in the EU, including imports.

- The data are principally from the emissions reporting by Fertilizers Europe (FE([9])) in the frame of ETS. Data from inputs were also provided by FE, who report data from a world survey of fertilizer plant emissions.
- There is only one N fertilizer value including a mix for urea and ammonium nitrate (AN) and a mix of EU production and imports. There are sparse data on which N fertilizers are used, where, and for which crop.
- Other figures for EU fertilizer emissions in the literature are sometimes extrapolated from individual factories, and/or do not include upstream emissions for natural gas.
- By performing our own calculation we ensure that upstream emissions from natural gas use are consistent with values used in other pathways.
- There is much scope for producers to reduce emissions by choosing fertilizers from a low-emission factory.
- Imported urea is assumed to come from the Middle East (expert judgment by Fertilizers Europe).
- The same default N fertilizer emissions are used for fertilizer applied to foreign crops (even though emissions from making fertilizers are generally higher outside EU, and especially in China).

Nitrogen (N) fertilizer supply chain

Table 14. Supply of nitrogen (N) fertilizer used in EU

	I/O	Unit	Amount
N fertilizer	Output	kg N	**1.0**
Emissions			
CO_2	-	g/kg N	**3 079**
CH_4	-	g/kg N	**2.17**
N_2O	-	g/kg N	**2.15**
Emissions from acidification by fertilizer, whether or not aglime is used	-	g/kg N	**798**
TOTAL EMISSIONS PER kg N	-	g CO2 eq./kg N	**4 572**

Comments

([9]) Fertilizers Europe: see http://www.fertilizerseurope.com online.

— For comparison: the previous N fertilizer emissions for RED annex V calculations was equal to about 6 000 gCO_2/kgN, not including acidification emissions. This reduction is due to a real improvement in emissions from fertilizers' factories;

— Fertilizers Europe, 2014 (Ref. 10) estimated average emissions for EU **production** of different fertilizers. The values for urea and AN were 3 365 and 3 576 repectively, if one corrects for the CO2 sequestration that FE assign to sequestration of CO2 in urea production (that is then released again in the field). The slight deviation from the JRC calculation is probably due to FE using different upstream emissions for NG or electricity. Neither FE nor JRC include emissions for fertilizer distribution to farms. Imported fertilizer increases the JRC average emissions for fertilizer **used** in EU.

FERTILIZERS EUROPE 2014 DATA, FOR COMPARISON	Urea	Ammonium nitrate	
FE [10] result in gCO2e/kg PRODUCT	910	1180	gCO2e/kg PRODUCT
CO2 sequestration credit that FE apply in making urea	730	0	gCO2e/kg PRODUCT
Urea figure with sequestration credit removed, to allow comparison	1640	1180	gCO2e/kg PRODUCT
% N in product	46%	33%	
FE [10] result in gCO2e/kg **N**	3565	3576	gCO2e/kg **N**
JRC calculation for average EU fertilizer production mix	3635		gCO2e/kg **N**
JRC CALCULATION FOR ALL EU FERTILIZER, INCLUDING IMPORTS	3774		gCO2e/kg **N**

— Emissions from acidification: N fertilizers cause acidification in the soil. The acid reacts with carbonate in the soil (or downstreams in river-beds or the sea), releasing CO_2. The carbonate can come from rock naturally present in the soil, or from applied agricultural lime. In either case, we attribute these emissions to fertilizer use rather than lime use. That is because in some cases more lime is used to counter natural soil acidity and this would give different emissions per kg of lime. Refer to Section 3.10 of Report xxx for details of this calculation and of emissions from aglime use not attributable to fertilizer.

Source

1. JRC own calculations, 2014.

Figure 1 explains the processes in the calculation of emissions from production of N fertilizer used in EU.

Figure 1. EU Nitrogen fertilizer production sources

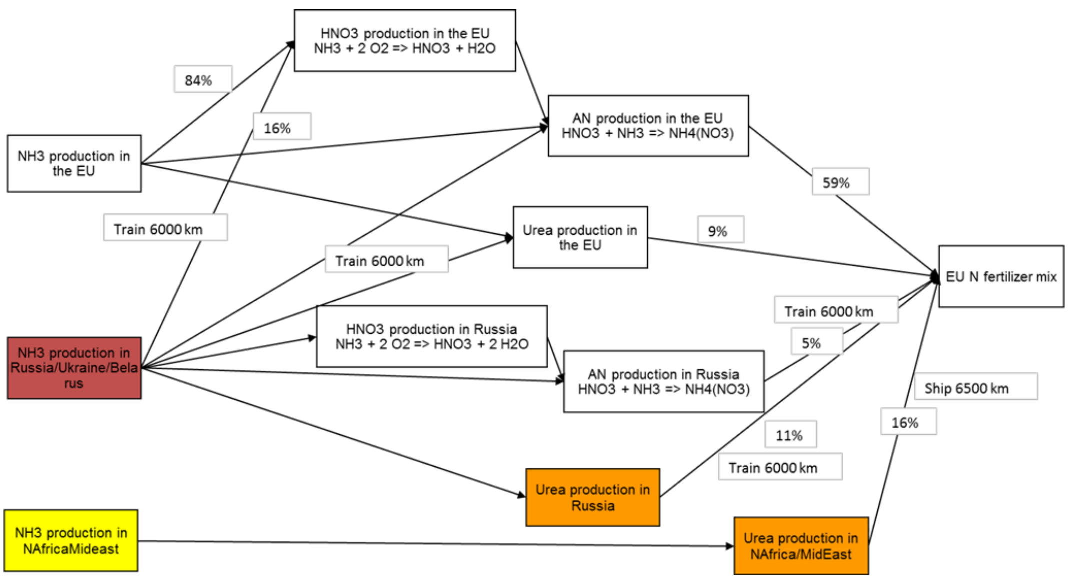

Table 15. Input data for fertilizer manufacturing emissions calculation, based on the ETS

Ammonia production in the EU		
2011 average Fertilizers Europe total-energy use in EU ammonia plants (Ref. 7)*	35.3	GJ/t NH_3
2011 (last available information) energy use for EU ammonia other than NG (Ref. 8)	0.5	GJ/t NH_3
2011 EU NG use for ammonia (latest available information)	34.8	GJ/t NH_3
* Includes NG, electricity and other energy inputs. Does not include upstream energy losses. Assumption: fraction of imports (ammonia and solid fertilizers) remains constant at last-reported values: 2008-9		
N_2O EMISSIONS FROM Nitric acid plants in EU		
2011 EU average (last reported "European reference"emissions reported by Fertilizers Europe, 2014) (Ref. 7)	0.87	kg N_2O/t HNO_3
2020 EU average (ETS benchmark) (Ref. 2)	1.0134	kg N_2O/t HNO_3
For current emissions, we use the latest GHG emissions from EU ammonia and nitric acid plants reported by Fertilisers Europe.		
Minor inputs for EU fertilizer plants (EU data, but assumed the same for outside the EU)		
Electricity for ammonium nitrate plant 'is less than..' (Ref. 3)	1	GJ/t AN
Electricity for urea plant [3]	5	GJ/t Urea
Calcium ammonium nitrate is assumed to have same emissions per tonne of N as ammonium nitrate (emissions from CaO are relatively small)		
Note: urea manufacture reacts to ammonia with otherwise-emitted CO_2. However, the CO_2 is lost when urea decomposes on the field. We count neither the sequestration nor the emission. However, in their carbon footprint calculations, Fertilizers Europe (Ref. 7) account both for CO_2 sequestration in the urea plant and CO_2 emissions when urea is used on the field.		
IMPORTED UREA		
Assumption: The fraction of urea that is imported to EU comes from North Africa, especially Egypt (Ref. 6) (China exports > 50% world urea with much higher (coal) emissions, but it is further away).		
Fraction of EU-consumed Urea-type fertilizers imported (see Trade table below).	**75%**	
Imported ammonium nitrate assumptions		
Imports are mostly from Russia, Ukraine and Belarus (Ref. 6): we represent them with weighted average of data for Russian and Ukrainian production.		
Fraction of EU-consumed AN -type fertilizer imported (Ref. 5)	**8%**	

N_2O emissions from imported AN production are calculated from the total emissions quoted in (Ref. 9) (which we understand come from a complete LCA by Integer Consultants), assuming emissions for AN from other sources are the same as in EU 2007.		
LCA emissions for AN supply 2013 (Ref. 9)		
	Russia	
	3130	g per kg AN
	0.35	N/AN
	8943	g per kg N in AN
Emissions from other-than-N_2O*	3127	gCO2e/kg N in AN
Emissions from N_2O	5816	gCO2e/kg N in AN
Emissions from N_2O	19.52	gN2O/kg N in AN
* calculated by E3database using EU 2007 data on other emissions sources.		
IMPORTED AMMONIA		
Fraction of ammonia used in EU which is imported	**16%**	
<u>Assumption</u>: all ammonia imports are from Russia, Ukraine and Belarus (Ref. 6): we use weighted average data.		
UPSTREAM ELECTRICITY AND TRANSPORT ASSUMPTIONS		
Electricity for fertilizer production generated via a natural gas fuelled combined cycle (CCGT) power plant with an efficiency of 55%		
Transport from Russia to EU via train over a distance of 6000 km		
Maritime transport of urea from Damietta in Egypt to Rotterdam in the EU over a distance of 6500 km		
Electricity for the train derived from the Russian electricity mix		

Natural Gas consumption for ammonia and urea production outside EU (Fertilizers Europe 2012) (on-site NG consumption only).

	NG use MMbtu/tonne NH3 2014 [1]	NG use MMbtu/tonne urea 2014	NG use GJ/tonne NH3 2014	NG use GJ/tonne urea 2014	NG use kWh/kg urea 2014	NG use kWh/kg N in urea 2014
Russia, Ukraine, Belarus	36.9	26.9	34.94	25.5	7.07	15.16
N.Africa	37	not reported	35.1	25.6	7.10	15.22

Trade data								
EU trade (2009) in kilo tonnes of **nitrogen**	Ammonia	Ammonium nitrate	Calcium ammonium nitrate		Urea	Ammonium sulphate		Total
	NH_3 (Ref. 4)	AN (Ref. 5)	CAN (Ref. 4)	AN+CAN	U (Ref. 5)	AS (Ref. 4)	U+AS	
Imports	*3 173*	*165*			1 524			
Exports	*914*							
EU consumption	*13 975*	*2 097*	*2 811*	4 907.5	*2 024*	745	2 769	7 676
% imported per type	**16 %**	**8 %**			**75 %**			
% imports=imports/(use + exports)								
% of AN and urea in EU-consumed N fertilizer (in terms of N content)				**64 %**			**36 %**	

Sources

1. Hoxha, A., Fertilizers Europe, personal communication February 2012 quoting forward projections by Fertecon, a fertilizer consultancy company.
2. Commission proposal for ETS benchmarking of EU fertilizer industry, via Heiko Kunst, Climate Action, December 2010.
3. Werner, A., BASF SE, Chairman of TESC in EFMA, 'Agriculture, fertilizers and Climate change': Presentation at EFMA conference, 12 February 2009, download from EFMA website. Numbers are based on IFA world benchmarking report on fertilizer emissions.
4. IFA statistics for 2009, (http://www.fertilizer.org/ifa/Home-Page/STATISTICS/Production-and-trade-statistics) accessed February 2011.
5. Hoxha, A., Fertilizers Europe (former EFMA), personal communication, 20 February 2010. For agricultural use only (important for urea and AN), average of 2008/9 and 2009/10 data.
6. Palliére, C., Fertilizers Europe (former EFMA), personal communication to JRC, December 2010.
7. Hoxha, A., Fertilizers Europe, personal communication, May 2014.
8. Hoxha, A., Fertilizers Europe, personal communication, February 2011.
9. S. Mackle, Fertilizers Europe, 2013: Trade & economic policy outlook of the EU Nitrogen Fertilizer Industry, presentation on Fertilizers Europe website, accessed May 2014.
10. Fertilizers Europe, 2014, Carbon Footprint reference values. Energy efficiency and greenhouse gas emissions in European mineral fertilizer production and use, 26 March 2014.

Additional INFO nr. 1: Summary of emission factors for the supply of main products

For ease of reference, Table 16 summarizes the emission factors for provision of various fossil fuels and supply of fertilizers.

Table 16. Emission factors for fossil fuels and main fertilizers

Emission factors		Net GHG emitted [g CO_2 $_{eq.}$/MJ]	CO_2 [g/MJ]	CH_4 [g/MJ]	N_2O [g/MJ]
Natural Gas	Supply	9.7	5.4	0.17	1.67E-04
	Combustion	56.24	56.24		
	Total	**66.0**	61.6	0.17	1.67E-04
EU el. mix (HV)	Total	**136.0**	126.8	0.3	6.0E-03
EU el. mix (MV)	Total	**141.1**	131.6	0.31	6.0E-03
EU el. mix (LV)	Total	**150.1**	139.9	0.33	6.4E-03
EU FFC (HV)	Total	**183**			
Hard coal	Supply	16.21	6.50	0.39	2.50E-04
	Combustion	96.11	96.11		
	Total	**112.3**	102.62	0.39	2.50E-04
Lignite	Supply	1.73	1.68	1.44E-03	5.56E-05
	Combustion	115.0	115.0		
	Total	**116.7**	116.68	1.44E-03	5.56E-05
Heavy fuel oil	Supply	13.6	- ([10])	-	-
	Combustion	80.6	80.6	0	0
	Total	**94.2**	-	-	-
Diesel	Supply	21.85	-	-	-
	Combustion	73.25	73.25	0.00	0.00
	Total	**95.1**	-	-	-
CHEMICAL FERTILIZERS AND PESTICIDES					
N fertilizer	Supply [g/kg]	**4 571.9**	3 876.5	2.17	2.15
P2O5 fertilizer	Supply [g/kg]	**547.1 ([11])**			
K2O fertilizer	Supply [g/kg]	**416.7**			
Aglime (as CaO)	Supply [g/kg]	**69.7**	66.06	0.11	2.8E-03
Pesticides	Supply [g/kg]	**12 010.7**	11 209.6	11.98	1.68

([10]) Disaggregated values are not available for Diesel and HFO since the main source used only reports values aggregated as [gCO_2 $_{eq.}$]. However, from the data reported in JEC WTT v.4a, it is clear that the large majority of emissions in diesel and HFO supply are due to CO_2 (>90%) and the rest to methane.

([11]) Disaggregated values are not available for P and K fertilizers. For more information see the original reference from Fertilizers Europe (2014).

3 Utilities and auxiliary processes

This section contains the processes for utilities such as boilers and power plants that are used throughout the various pathways.

3.1 NG boiler

Table 17. Process for a NG boiler

Steam from NG boiler (10 MW)				
	I/O	**Unit**	**Amount**	**Source**
NG	Input	MJ/MJ_{heat}	**1.11**	**1,2**
Electricity	Input	MJ/MJ_{heat}	**0.020**	**2**
Steam	Output	MJ	**1.0**	
Emissions				
CH_4	Output	g/MJ_{heat}	**0.0028**	**1**
N_2O	Output	g/MJ_{heat}	**0.00112**	**1**

Comments

— Electricity taken from the grid at 0.4kV.

— Thermal efficiency = 90 % (based on LHV).

— This process is common to all pathways involving pellet production, case 1.

— CO_2 emissions from natural gas combustion are considered to be 56.2 gCO_2/MJ.

Source

1. GEMIS v. 4.9, 2014, *gas-boiler-DE 2010.*
2. GEMIS v. 4.9, 2014, *gas-heat plant-medium-DE 2010.*

3.2 Industrial wood pellet boiler

Table 18. Process for an industrial wood pellet boiler

Heat from industrial wood pellet boiler (0.5 MW)			
	I/O	**Unit**	**Amount**
Wood pellets	Input	MJ/MJ_{heat}	**1.124**
Electricity	Input	MJ/MJ_{heat}	**0.015**
Steam	Output	MJ	**1.0**
Emissions			
CH_4	Output	g/MJ_{heat}	**0.003336**
N_2O	Output	g/MJ_{heat}	**0.000667**

Comments

— Electricity taken from the grid at 0.4kV.

— Thermal efficiency = 89 % (based on LHV).

— This process is common to all pathways involving pellet production, Case 2.

Source

1. GEMIS v. 4.9, 2014, wood-pellet-wood-industry-heat plant-DE-2010.

3.3 Industrial wood chips boiler

Table 19. Process for an industrial wood chips boiler

Heat from industrial wood chips boiler (1 MW)			
	I/O	**Unit**	**Amount**
Wood chips	Input	MJ/MJ_{heat}	**1.176**
Electricity	Input	MJ/MJ_{heat}	**0.020**
Steam	Output	MJ	**1.0**
Emissions			
CH_4	Output	g/MJ_{heat}	**0.005751**
N_2O	Output	g/MJ_{heat}	**0.001150**

Comments

— Electricity taken from the grid at 0.4kV.
— Thermal efficiency = 85 % (based on LHV).
— Wood chips are considered to be dried prior the use (10% moisture, same as the wood chips for pellet production).
— This process is common to all pathways involving pellet production as alternative to the wood pellet boiler, Case 2a.

Source

1. GEMIS v. 4.9, 2014, wood-chips-forest-heat plant-1 MW-EU - 2005.

3.4 Wood pellet CHP based on ORC technology

Table 20. Process for an industrial CHP based on ORC technology

Heat and electricity from CHP based on ORC engine				
	I/O	**Unit**	**Amount**	**Source**
Wood pellets	Input	$MJ/MJ_{el.}$	**6.135**	1
Electricity	Output	MJ	**1.0**	1
Heat	Output	$MJ/MJ_{el.}$	**4.27**	1
Emissions				
CH_4	Output	$g/MJ_{el.}$	**0.01822**	2
N_2O	Output	$g/MJ_{el.}$	**0.00364**	2

Comments

— Electrical efficiency = 16.3 % (based on LHV).
— Thermal efficiency = 69.6 % (based on LHV).
— This process is common to all pathways involving pellet production, case 3.

Sources

1. Seeger Engineering AG; 2009.
2. GEMIS v. 4.9, 2014, *wood-pellet-wood-industry-heat plant-DE-2010.*

3.5 Wood chips CHP based on ORC technology

Table 21. Process for an industrial CHP based on ORC technology

Heat and electricity from CHP based on ORC engine				
	I/O	**Unit**	**Amount**	**Source**
Wood chips	Input	$MJ/MJ_{th.}$	**1.437**	1
Electricity	Output	$MJ/MJ_{th.}$	**0.234**	1
Heat	Output	MJ	**1.0**	1
Emissions				
CH_4	Output	$g/MJ_{th.}$	**0.0070**	2
N_2O	Output	$g/MJ_{th.}$	**0.00140**	2

Comments

— Electrical efficiency = 16.3 % (based on LHV).

— Thermal efficiency = 69.6 % (based on LHV).

— This process is common to all pathways involving pellet production and is alternative to the wood pellets CHP, case 3a.

Sources

1. Seeger Engineering AG; 2009.
2. GEMIS v. 4.9, 2014, *wood-chips-forest-heat plant-1 MW-EU - 2005.*

3.6 Sawdust boiler

Table 22. Process for an industrial sawdust boiler

Heat from sawdust boiler				
	I/O	**Unit**	**Amount**	**Source**
Sawdust	Input	$MJ/MJ_{th.}$	**1.333**	1
Electricity	Input	$MJ/MJ_{th.}$	**0.02**	2
Heat	Output	MJ	**1.0**	1
Emissions				
CH_4	Output	$g/MJ_{th.}$	**0.0065**	2
N_2O	Output	$g/MJ_{th.}$	**0.0013**	2

Comments

- Thermal efficiency = 75 % (based on LHV).
- This process is common to all pathways involving pellet production from wood industry residues, case 2a.
- Sawdust input moisture is assumed to be equal to 34%.

Sources

1. Mani, S., A System Analysis of Biomass Densification Process, PhD Thesis at the University of British Columbia, 2005. (https://circle.ubc.ca/handle/2429/17106)
2. GEMIS v. 4.9, 2014, *wood-chips-forest-heat plant-1 MW-EU - 2005.*

4 Transport processes

This section contains all the processes that pertain to fuel consumption for all the vehicles and means of transportation used in all the pathways.

The section is structured by road, waterborne (maritime and inland) and rail transportation. The processes are recalled in each pathway.

4.1 Road transportation

40 t truck (27 t payload)

The common means of transport considered for road transport is a 40 t truck with a payload of 27 t.

For the transport of solid materials, a flatbed truck transporting a container is considered. The weight of such a tank is considered, for the sake of simplicity, to be equal to 1 t.

For the transport of liquids and pellets, special tank trucks are used. It is assumed that such trucks have the same general fuel efficiency and general payload of the truck for solids but with a higher, 2 t, weight for the tank, to account for the pneumatic system and characteristics of the tank.

The payload of a typical trailer truck with a gross weight of 40 t for the transport of wood chips with push floor trailer amounts to 90 m³ (e.g. “Schubboden”). The mass of the semitrailer tractor amounts to about 7.6 t (see e.g.: MERCEDES-BENZ 1844 LS 4x2, 400 kW) and the mass of the trailer for the transport of wood chips (92 m³) ranges between 7.5 and 7.9 t. Then the net payload amounts to (40-7.6-7.5…7.9) t = 24.5…24.9 t. For the DAF CF 75.360 the empty mass is indicated with 6.5 t which would lead to a net payload of up to 26t.

The truck considered in this work is a 40 t truck with a payload of 27 t, a part of the 27 t consists of payload specific structure. Assuming a net payload of 26 t leads to a “tank” mass of 1 t.

The truck fuel consumption is assumed to be linear with the weight transported and with the distance. The amount of tonnes per kilometer is calculated from the formula (in this case, for solid fuels transport):

$$\text{Distance}\left[\frac{t \cdot km}{MJ_{goods}}\right] = \frac{(27)[t] \cdot x[km]}{(27 - \text{tank})[t] \cdot LHV_{dry}\left[\frac{MJ_{goods}}{kg_{dry}}\right] \cdot \text{Solids}\left[\frac{kg_{dry}}{kg_{tot}}\right]}$$

This value is calculated and reported for each pathway in the following chapters of this report. The specific LHV and moisture content of the analysed materials is also reported.

In order to obtain the final fuel consumption of the transportation process, the 'distance' process needs to be multiplied by the fuel consumption of the vehicle considered. For the case of a 40 t truck, this value and the associated emissions are reported in Table 23.

Table 23. Fuel consumption for a 40 t truck

	I/O	Unit	Amount	Source
Diesel	Input	MJ/tkm	**0.811**	1
Distance	Output	tkm	**1.00**	
CH_4	Output	g/tkm	**0.0034**	1
N_2O	Output	g/tkm	**0.0015**	1

Comments

— The return voyage (empty) is taken into account in this value.

— This process is commonly used for the transportation of solids and liquids.

— The fuel consumption corresponds to 30.53 l/100 km.

— The fuel consumption and emissions are a weighted average of Tier 2 values among different Euro classes based on the fleet composition indicated in the COPERT model.

Sources

1. EMEP/EEA 2013, air pollutant emission inventory guidebook, Technical report N12/2013. Part B 1.A.3.b.i-iv.

4.2 Maritime transportation

Handysize bulk carrier (26,000 t payload)

Woodchips from a short distances (e.g. 2000 km) are assumed to be transported to Europe via Handysize bulk carriers of 28 000 DWT and 26 000 t of net payload.

The fuel consumption of these carriers is calculated by the JRC via data provided by the International Maritime Organization (IMO, 2009), and it is dependent on several parameters, the most important being the bulk density of the transported goods. In fact, from the calculations, it transpired that for goods with bulk density lower than 750 kg/m^3, the load is volume-limited.

Bulk carriers transport a variety of goods and over a variety of routes. Due to the logistics of such hauling, the ships inevitably travel for certain distances with an empty or partial cargo load. The fuel consumption in these trips under ballast is obviously lower than at full cargo but it still needs to be properly assigned to the transported good.

A common way to approach this is to define a Capacity factor (CF) which indicates the share of distance travelled by the ship under ballast over the total distance travelled.

In order to define a proper CF, cargo manifestos of some carriers delivering biomass have been analysed. From such analysis it has transpired that on the total distance travelled by carriers, an average 20 – 40% of such distance is travelled under ballast. As a consequence an average capacity factor of 30% has been chosen.

In this way the total fuel consumption can be assigned as follows:

$$\text{Total Fuel Consumption } \left[\frac{g_{HFO}}{tkm}\right] = \frac{FC_{@Cargo} + FC_{@Ballast} * (CF/(1\text{-}CF))}{Cargo_{Outward}}$$

Where, $FC_{@Cargo}$ is the fuel consumption at cargo load in the outward journey (generally volume limited for chips), $FC_{@Ballast}$ is the fuel consumption under ballast and CF is the Capacity factor defined as the share of distance travelled by the ship under ballast over total distance travelled. Cargo is the cargo loaded in the outward journey.

By using this formula it is possible to assign to the chips/pellet cargo <u>only a share of the empty trips of the carrier</u> as well as it would be assigned to all other cargos.

The 'distance' parameter (tkm/MJ_{goods}) is calculated by a simple operation, since the tank weight is already included in the calculations of the fuel consumption.

$$Distance\left[\frac{t \cdot km}{MJ_{goods}}\right] = \frac{x[km]}{LHV_{dry}\left[\frac{MJ}{kg_{dry}}\right] \cdot Solids\left[\frac{kg_{dry}}{kg_{tot}}\right]}$$

The distance values for each material are reported in the specific pathways.

Due to the relation of the fuel consumption value with the physical properties of the goods, specific values for each product are reported here.

Table 24. Fuel consumption for a Handysize (28000 DWT) bulk carrier for wood chips with bulk density 0.22 t/m^3

	I/O	**Unit**	**Amount**
Heavy fuel oil	Input	MJ/tkm	**0.257**
Distance	Output	tkm	**1.0**

Comments

— The woodchips are considered to have a moisture content of 30 %, and the bulk density is calculated roughly as proportional to the bulk density dry (0.155 t/m^3), therefore: 0.155/0.7 = 0.221 t/m^3.

— LHV heavy fuel oil = 40.5 MJ/kg.

— Oil consumption = 6.35 gHFO/tkm.

Handysize bulk carrier (26 000 t payload for agri residues)

Table 25. Fuel consumption for a Handysize (28000 DWT) bulk carrier for agri-residues with bulk density of 0.125 t/m^3

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	**0.433**
Distance	Output	tkm	**1.0**

Comments

— Valid for agricultural residues <0.2 t/m^3 (with typical bulk density = 0.125 t/m^3).

— Oil consumption = 10.7 gHFO/tkm.

Table 26. Fuel consumption for a Handysize (28000 DWT) bulk carrier for agricultural residues with a bulk density of 0.3 t/m^3

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	**0.196**
Distance	Output	tkm	**1.0**

Comments

— Valid for agricultural residues >0.2 t/m^3 (with typical bulk density = 0.3 t/m^3).

— Oil consumption = 4.84 gHFO/tkm.

Sources

1. IMO, 2009.
2. JRC own calculations, 2014.

Supramax bulk carrier (54,000 t payload)

Woodchips and pellets shipped to EU from longer distances (e.g. > 8000 km) are assumed to be transported to Europe via Supramax bulk carriers of 57 000 DWT and 54 000 t of net payload.

The fuel consumption of these carriers is calculated by the JRC via data provided by the International Maritime Organization (IMO, 2009), and it is dependent on several parameters, the most important being the bulk density of the transported goods. In fact, from the calculations, it transpired that for goods with bulk density lower than 750 kg/m^3, the load is volume-limited.

The assumptions on the capacity factor are the same as described for Handysize carriers. Except that the basic fuel consumption reported by the IMO is lower due to the larger cargo capacity (1.09 g HFO/tkm fully loaded).

Table 27. Fuel consumption for a Supramax (57000 DWT) bulk carrier for wood chips with bulk density 0.22 t/m^3

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	**0.164**
Distance	Output	tkm	**1.0**

Comments

— The woodchips are considered to have a moisture content of 30 %, and the bulk density is calculated roughly as proportional to the bulk density dry (0.155 t/m^3), therefore: 0.155/0.7 = 0.221 t/m^3.

— LHV heavy fuel oil = 40.5 MJ/kg.

— Oil consumption = 4.04 gHFO/tkm.

Table 28. Fuel consumption for a Supramax (57000 DWT) bulk carrier for wood pellets with bulk density 0.65 t/m^3

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	**0.0656**
Distance	Output	tkm	**1.0**

Comments

— The wood pellets are considered to have a moisture content of 10 %, and the bulk density is considered to be 0.65 t/m^3.

— LHV heavy fuel oil = 40.5 MJ/kg.

— Oil consumption = 1.62 gHFO/tkm.

Supramax bulk carrier (54 000 t payload for agri residues)

Table 29. Fuel consumption for a Supramax (57000 DWT) bulk carrier for agri-residues with bulk density of 0.125 t/m^3

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	**0.273**
Distance	Output	tkm	**1.0**

Comments

— Valid for agricultural residues <0.2 t/m^3 (with typical bulk density = 0.125 t/m^3).

— Oil consumption = 6.75 gHFO/tkm.

Table 30. Fuel consumption for a Supramax (57000 DWT) bulk carrier for agricultural residues with a bulk density of 0.3 t/m^3

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	**0.125**
Distance	Output	tkm	**1.0**

Comments

— Valid for agricultural residues >0.2 t/m^3 (with typical bulk density = 0.3 t/m^3).

— Oil consumption = 3.09 gHFO/tkm.

Sources

1. IMO, 2009.
2. JRC, own calculations, 2014.

4.3 Rail transportation

Freight train (diesel)

The distance parameter is calculated as described above for the road and maritime transport, and the specific values are reported for each pathway in the following sections.

The fuel consumption is reported below.

Table 31. Fuel consumption for a freight train run on diesel fuel

	I/O	Unit	Amount
Diesel	Input	MJ/tkm	**0.252**
Distance	Output	tkm	**1.00**
CH_4	Output	g/tkm	**0.005**
N_2O	Output	g/tkm	**0.001**

Comment

— This process is used for the transportation of pellets, woodchips and agricultural residues from the mill to the harbour in the United States or Canada prior to shipping to Europe.

Source

1. GEMIS v. 4.9, 2014, Train-diesel-freight-CA-2010.

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Part Two — Solid and gaseous biofuels processes and input data

5 Biogas processes and input data

Biogas can be produced by anaerobic digestion of a multitude of feedstocks. The biogas produced can be used for electricity generation or, after an additional upgrading process, injected into the natural gas grid. The biogas upgraded to natural-gas grid quality is defined in this report as biomethane. Biomethane can be injected into the natural-gas grid and utilized exactly as fossil natural gas, or it can be compressed and distributed as compressed natural gas (CNG) for transportation purposes. However, CNG pathways are not considered in this report but they can be found in the JEC-WTT v.4.

Based on the current and most common practices in Europe, three main feedstocks were chosen:

- an energy crop: maize silage;
- an agricultural waste: feedlot manure;
- municipal organic and agro-industrial waste: biowastes.

They were combined with two means of digestate management:

- open tank storage;
- closed tank storage (gas tight).

They were also combined with two end-use processes for the biogas produced:

- biogas for power and heat production;
- biogas upgrading to biomethane.

The biogas-to-electricity pathways are sub-divided depending on the origin of the power and heat consumed to run the plant (e.g. digester and engine auxiliaries).

- Case 1: Electricity and heat are taken directly from the output of the CHP engine (lower net power output but imposed by legislation in some MS);
- Case 2: Electricity is taken from the grid and heat is recovered from the CHP engine (maximum power output but forbidden in some MS);
- Case 3: Electricity is taken from the grid and heat is produced on site with a biogas boiler (biogas produced in decentralised small digesters and transported to a central location for final conversion or upgrading).

The various biogas upgrading technologies available in the market are grouped into two main categories (better defined in Table 40):

- Upgrading without combustion of the off-gas (off-gas vented – OGV)
- Upgrading with combustion of the off-gas (off-gas combusted – OGC)

As a result, the following pathways were studied.

A. Maize silage

1. Biogas for electricity from maize: open digestate
2. Biogas for electricity from maize: closed digestate
3. Biomethane from maize — off-gas vented: open digestate
4. Biomethane from maize — off-gas vented: closed digestate
5. Biomethane from maize — off-gas combusted: open digestate
6. Biomethane from maize — off-gas combusted: closed digestate.

B. Manure

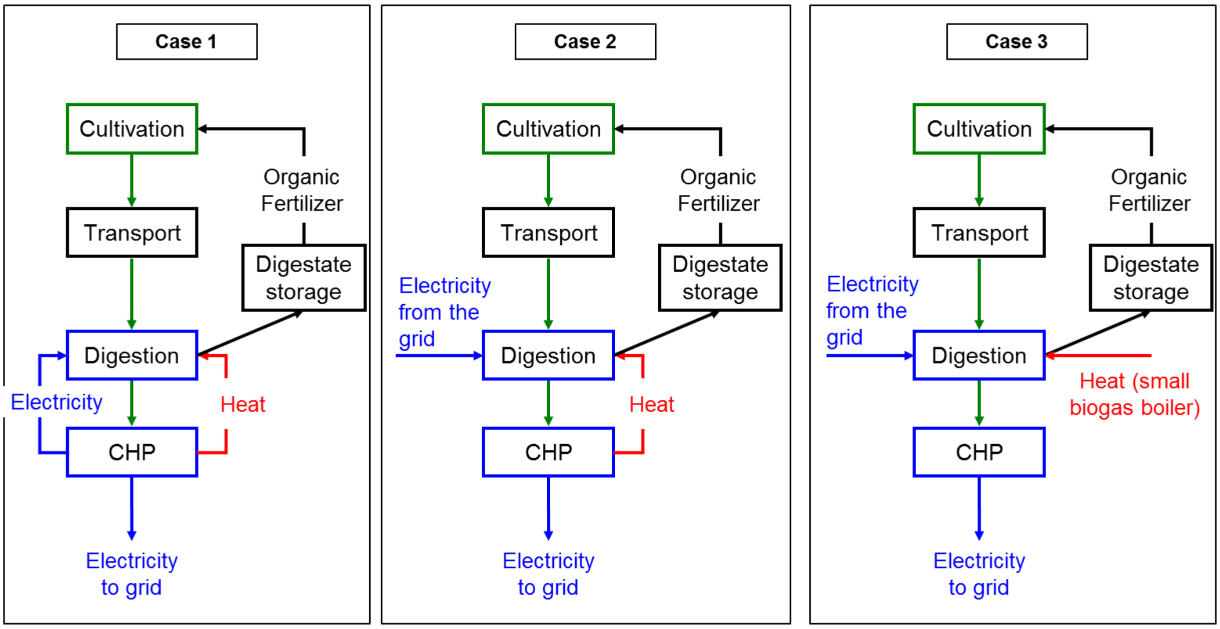
1. Biogas for electricity from wet manure: open digestate
2. Biogas for electricity from wet manure: closed digestate
3. Biomethane from wet manure — off-gas vented: open digestate
4. Biomethane from wet manure — off-gas vented: closed digestate
5. Biomethane from wet manure — off-gas combusted: open digestate
6. Biomethane from wet manure — off-gas combusted: closed digestate.

C. Biowaste

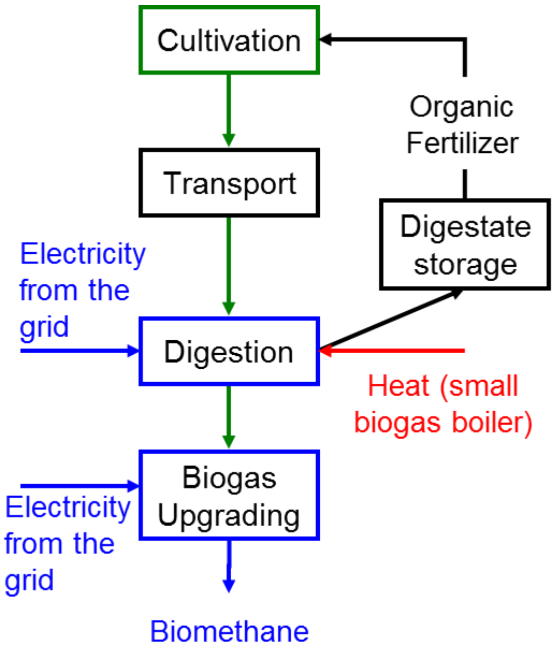
1. Biogas for electricity from biowaste: open digestate
2. Biogas for electricity from biowaste: closed digestate
3. Biomethane from biowaste — off-gas vented: open digestate
4. Biomethane from biowaste — off-gas vented: closed digestate
5. Biomethane from biowaste — off-gas combusted: open digestate
6. Biomethane from biowaste — off-gas combusted: closed digestate.

5.1 Biogas from maize silage

A. Biogas for electricity



B. Biomethane



Step 1: Maize cultivation

The dataset for maize fodder (also called in literature as "green maize" or "maize whole crop") cultivation is presented in Table 32.

The values for diesel consumption and for pesticides/herbicides used are shown in Table 32.

The emissions due to neutralisation of fertilizer acidification and application of aglime are added. CH_4 and N_2O emissions due to the combustion of diesel from agricultural machinery were taken into account.

The amount of synthetic fertilizers derives from the values provided by the European Fertilizers Manufacturers Association.

Table 32. Process for cultivation of maize whole plant

Maize whole plant cultivation				
	I/O	**Unit**	**Amount**	**Source**
Diesel	Input	$MJ/MJ_{Biomass}$	0.01553	1
N fertilizer	Input	$kg/MJ_{Biomass}$	0.00026	2
K_2O fertilizer	Input	$kg/MJ_{Biomass}$	0.00010	2
P_2O_5 fertilizer	Input	$kg/MJ_{Biomass}$	0.00016	2
$CaCO_3$ fertilizer	Input	$kg/MJ_{Biomass}$	0.00160	7
Pesticides	Input	$kg/MJ_{Biomass}$	0.00003	1
Seeding material	Input	$kg/MJ_{Biomass}$	0.00010	3
Maize whole plant	Output	MJ	1.0	
Field N_2O emissions	Output	$g/MJ_{Biomass}$	0.0193	6
Field CO_2 emissions-acidification	Output	$g/MJ_{Biomass}$	0.257	4
CH_4	Output	$g/MJ_{Biomass}$	1.98E-05	5
N_2O	Output	$g/MJ_{Biomass}$	4.90E-05	5

Comment

— The amount of synthetic fertilizer applied accounts already for the application of other organic fertilizers such as manure and digestate (the residue of the anaerobic digestion).

— The yield of maize whole crop is calculated as an average over the EU-27 based on FAOSTAT data for the years 2011 and 2010.

— Yield silage maize = 40.76 t fresh matter / ha [FAO, 2013; EUROSTAT, 2013];

— Diesel consumption = 104.32 l/ha [1];

— The amount of synthetic fertilizers applied is calculated as a weighted average over the total land cultivated with maize for fodder (based on FAOSTAT data) for the EU-27 area, starting from the amounts provided by Fertilizers Europe on a country-per-country basis.

— Mineral N-fertilizer = 63.24 kg N/ha [2]; for maize grains (e.g. corn etanol) the mineral N input is about double;

— Mineral P_2O_5 fertilizer = 38.52 kg P_2O_5/ha [2];

— Mineral K_2O fertilizer = 24.0 kg K_2O/ha [2];

— Moisture content (silage maize) = 65%.

— Field N_2O emissions are calculated from the N inputs and volatilization indicated in Table 34. For the purpose of this calculation, the standard factors from IPCC and EEA have been used (detailed in the "High volatilization scenario").

Sources

1. CAPRI database, data extracted by Markus Kempen of Bonn University, March 2012.
2. Fertilizers Europe, personal communication, Palliére C., 2013.
3. KTBL, 2006;
4. Joint Research Centre, own calculation (JRC-IET), Petten, the Netherlands, April 2015[12].
5. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 – Agricultural machinery.
6. Joint Research Centre (JRC-IET), Petten, the Netherlands, own calculations, based on IPCC, 2006, N_2O Guidelines.
7. EDGAR v4.1 database (JRC/PBL, 2010).

The harvested maize needs to be ensiled for preservation purposes. During this process, dry matter losses are encountered and diesel is consumed for ensiling and de-siling the maize (Table 33).

Table 33. Maize ensiling

Maize whole plant ensiling				
	I/O	**Unit**	**Amount**	**Source**
Maize whole plant	Input	$MJ/MJ_{maize\ silage}$	1.11	1
Diesel	Input	$MJ/MJ_{maize\ silage}$	0.00375	2
Maize silage	Output	MJ	1	
CH_4	Output	$g/MJ_{maize\ silage}$	4.79E-06	3
N_2O	Output	$g/MJ_{maize\ silage}$	1.18E-05	3

[12] Details on the calculation of aglime input and CO_2 emissions from neutralization will be released in a following JRC report currently under preparation.

Comment

- Diesel for ensiling/desiling = 22.1 l/ha = 0.56 l/tonne maize
- 10% dry matter losses

Sources

1. Kohler et al., 2013.
2. Bacenetti et al., 2014.
3. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 – Agricultural machinery.

5.1.1 Maize whole crop nitrogen fertilization

In this section we set out to define explicitly the nitrogen balance associated with maize cultivation, biogas production and digestate recirculation as organic fertilizer. Table 34 summarizes the complete nitrogen balance.

Maize composition: Nitrogen removal and needs

Based on an average maize composition (see e.g. Phyllis, https://www.ecn.nl/phyllis2/), the N content of fresh maize is around **0.37%$_{F.M.}$**

Based on this number, the removal of N by the crop is equal to: 40.8 * 0.0037 = **150.8 kg N/ha**.

IPCC prescribes that below ground residues (BG) for maize amount to 22% of the total above ground (AG) biomass (on a dry basis). We consider a loss of AG material at harvest equal to 1 t dry/ha with a N content equal to 0.6% (IPCC, 2006). Furthermore, the N content in the BG is taken from IPCC and it is slightly higher than for the AG residues, it is equal to 0.7% on a dry matter basis.

Thus, the N content in the BG residues is equal to: ((40.8*0.35)+1)*0.22)*0.007 = **23.5 kg N/ha.**

The N content in the AG residues is equal to: (1*0.6) = **6 kg N/ha.**

The total N demand for the crop is thus equal to **180.3 kg N/ha.**

After harvest, the crop is ensiled for preservation, encountering dry matter losses.

Based on a collection of data we have assumed a dry matter loss of **10%** (Kohler, 2013; Herrmann, 2011; Styles, 2014). However, we assume no significant losses of N (it is possible that a little organic N is mineralized to ammoniacal N during the processes but eventual leachate is assumed to be recirculated to the digester). The N content after ensiling thus is assumed to remain the same at 150.8 kg N/ha.

Nitrogen losses

N losses of about 6% are considered to happen during digestion (Schievano, 2011; Battini, 2014). This leaves around **141.7 kg N/ha** in the digestate sent to storage.

During the storage period, direct emissions of N_2O and volatilization losses to NH_3 and NO_x are expected.

The IPCC Guidelines were originally designed for manure management and thus may not be directly applicable to energy crops digestates. However, this could work as a first assumption.

IPCC recommends a value of 0.005 N-N2O/N_{slurry} (IPCC, 2006, Vol.10, Table 10.21).

Furthermore, the latest EMEP/EEA guidelines (EEA, 2013, Vol. 3.B, Table 3.7), indicate (for dairy slurry) emissions of N-NH3 as 20% of Total Ammoniacal Nitrogen (TAN), 0.01% of TAN as N-NO and 0.3% of TAN as N2.

Considering a TAN level of 60% in the maize digestate, this would lead to a total loss of digestate – N equal to: 0.2*0.6 + 0.0001 * 0.6 + 0.003 * 0.6 + 0.005 = **12.7 % of digestate-N.** (*High Volatile Scenario)*

Therefore, the N available for field spreading in the digestate (in the *high volatile scenario)* is equal to: **123.8 kg N/ha.**

However, this could be considered as an upper limit, other values around 2-3% of total losses have been reported [e.g. Corrè, 2010]. (*Low volatile scenario)*

In this second case the N available for spreading would be equal to: 141.7 * 0.97 = **137.5 kg N/ha.**

From the IPCC guidelines, at the moment of field spreading, 20% of available N from organic fertilizer, is volatilized as NH_3 and NO and 30% is leached. In addition to the 1% N that is emitted directly as N_2O. (*High volatile scenario)*

This would mean additional N losses on the field equal to 51% of applied N. This would leave **60.6 kg N/ha.** *(High volatile scenario)*

Alternatively, Battini et al., 2014 reports the following losses from field spreading of digestate: 1% to N-N2O, 0.55% to N-NO, 5% to N-NH3 and about 30% of leaching. This leads to total losses of 36.55% of the applied N.

This would leave available: 137.5 * 0.6345 = **87.2 kg N/ha** *(low volatile scenario).*

Nitrogen fertilization balance

Considering all associated N losses, thus, it appears that effectively only **60.6 kg N/ha** or **87.2 kg N/ha** are available on the field. Of this amount, a fraction will be directly available while the rest of the organic N will be released over time. Anyway, we assume that this entire N is available for the plant (in the present or future rotations).

Additional to this amount, we consider the application of **63.2 kg N/ha** of mineral-N fertilizer. This number is the EU-27 average resulting from the values provided to us from Fertilizers Europe for the category "Silage Maize" ([13]).

Our assumption in this case is that the fertilizing power of raw slurry and manure is the same as for digestate in the long-term. This is still debated and long-term trials are currently under way (Fouda et al., 2013; Gutser et al., 2005; Lukehurst et al., 2010; Schröder et al., 2007; Smith et al., 2010), however, we think this assumption is valid for the level of accuracy required in this study.

Nitrogen losses from mineral fertilization are considered by the IPCC guidelines, to be equal to 1% as N-N2O, 10% as volatilization to N-NH3 and N-NO and 30% as leached. *(High volatile scenario)*

This would leave **37.3 kg N/ha** available for plant absorption (*High volatile scenario).*

So, considering 100% efficiency of the remaining N, the apported N by organic and mineral fertilization would be equal to **97.9 kg N/ha**.

([13]) Mr. Christian Pallière, pers. Comm., 2014: "*Our Forecast is an expert based approach (attached a brief document on explanations/references for use, and the EEA report which has compared with other model based system), it is therefore our national experts who locally make investigation for each crop, visiting generally the crop institutes and the main agriculture universities when it comes for application rates, the same organizations plus the national administration which are reporting statistics when it comes to acreages. They report the outcomes of these several contacts. These data have been provided to several specialist (Wageningen university, UN ECE Task Force on reactive Nitrogen)".*

Alternatively, nitrogen losses from mineral fertilization are considered to be equal to 0.6% as N-N2O (Battini et al., 2014), 5.6% as volatilization to N-NH3(EEA, 2013, 3.D – average value based on share of sold fertilizers in Europe), 0.9% N-NO (Battini et al., 2014) and 30% as leached (Battini et al., 2014). *(Low volatile scenario)*

This would leave **39.8 kg N/ha** available for plant absorption (*Low volatile scenario).*

So, considering 100% efficiency of the remaining N, the apported N by organic and mineral fertilization would be equal to **127.0 kg N/ha** *(Low volatile scenario)*.

The IPCC indicates that the N remaining in the crop residues is equal, for our condition, to about **29.5 kg N/ha**. Of this amount of nitrogen, the IPCC indicates that a fraction equal to 1% will be released as N_2O and that a fraction equal to 30% will be leached away. So, the resulting available N from residues is equal to: 29.5*(1– 0.31) = **20.4 kg N/ha**

The final N balance would indicate thus (see also Table 34 for all the relevant data):

<u>High Volatile Scenario:</u>

- Plant needs = -180.3 kgN/ha;
- Mineral N (available on field) = +37.3 kgN/ha;
- Digestate N (available on field) = +60.6 kgN/ha;
- AG+BG residues N (available on field) = +20.4 kgN/ha;
- N to close balance = **62.0 kg N/ha** (of which about/up to 20 kg may be from atmospheric deposition)

<u>Low volatile scenario:</u>

- Plant needs = -180.3 kgN/ha;
- Mineral N (available on field) = +39.8 kgN/ha;
- Digestate N (available on field) = +87.2 kgN/ha;
- AG + BG residues N (available on field) = +20.4 kgN/ha;
- N to close balance = **32.9 kg N/ha** (of which about/up to 20 kg may be from atmospheric deposition)

For the purposes of the calculations of N_2O emissions (direct and indirect) from maize whole crop cultivation (reported in Table 32 and used for calculations in Chapter 7), the IPCC methodology described in the 2006 Guidelines, Vol. 4, Ch. 11 is used. For coherence, thus, all emission factors in the *High volatilization scenario* are used to calculate both N_2O emissions and the actual amount of N available in the digestate at field.

Table 34. Summary of input data, assumptions and N balance for the cultivation of Maize whole crop.

	High volatile scenario			*Low volatile scenario*		
	Value	***Unit***	***Source***	***Value***	***Unit***	***Source***
Yield (AG removal)	40.8	t F.M./ha	EUROSTAT	40.8	t F.M./ha	EUROSTAT
TS	35%	% F.M.	JRC	35%	% F.M.	JRC
BG residues (kg dry/kg dry AG)	22%	% AG dry	IPCC	22%	% AG dry	IPCC
AG residues (t dry/ha)	1	t dry/ha	Taube, 2014	1	t dry/ha	Taube, 2014
N content (AG maize whole crop)	0.37%	% F.M.	Hermann, 2005	0.37%	% F.M.	Hermann, 2005
N content (AG residues)	0.6%	% dry AG	IPCC	0.6%	% dry AG	IPCC
N content (BG residues)	0.7%	% dry BG	IPCC	0.7%	% dry BG	IPCC
N losses ensiling	0%	% N crop	JRC	0%	% N crop	JRC
N losses digester	6%	% N crop	Battini, 2014	6%	% N crop	Battini, 2014
TAN (maize digestate)	60%	% N digestate	Taube, pers. Comm. 2014	60%	% N digestate	Taube pers. Comm. 2014
Mineral-N fertilizer applied	63.2	kg N/ha	Fertilizers Europe	63.2	kg N/ha	Fertilizers Europe
N Losses digestate storage						
N-N2O direct (digestate storage)	0.5%	%N digestate	IPCC (Dairy manure, slurry with crust)	3.0%	%N digestate	Battini, 2014
N-NH3 (digestate storage)	20%	% TAN digestate	EEA, 2013 (3.B)		% TAN digestate	
N-NO (digestate storage)	0.01%	% TAN digestate	EEA, 2013 (3.B)		% TAN digestate	
N-N2 (digestate storage)	0.3%	% TAN digestate	EEA, 2013 (3.B)		% TAN digestate	
N Losses Field application – Organic fertilizer						
N-N2O direct (field application organic)	1%	% N at field	IPCC	1%	% N at field	IPCC
N-NH3 + N-NO (field application organic)	20%	% N at field	IPCC	5.55%	% N at field	Battini,2014
N-NO3-- (field application organic)	30%	% N at field	IPCC	30%	% N at field	Battini, 2014
N Losses Field application – Crop residues						
N-N2O direct (field crop residues)	1%	% N at field	IPCC	1%	% N at field	IPCC
N-NO3-- (field crop residues)	30%	% N at field	IPCC	30%	% N at field	IPCC
N Losses Field application – Mineral fertilizer						
N-N2O direct (field application mineral)	1%	% N mineral	IPCC	0.6%	% N mineral	Battini, 2014
N-NH3 + N-NO (field application mineral)	10%	% N mineral	IPCC	6.5%	% N mineral	EEA,2013 (3.D) + Battini, 2014
N-NO3-- (field application mineral)	30%	% N mineral	IPCC	30%	% N mineral	Battini, 2014
N Balance						
N needs (AG + BG + AGR)	180.3	kg N/ha		180.3	kg N/ha	
N (AG maize - removal)	150.8	kg N/ha		150.8	kg N/ha	
N (AG + BG residues)	29.5	kg N/ha		29.5	kg N/ha	
N (maize silage)	150.8	kg N/ha		150.8	kg N/ha	
N digestate	141.7	kg N/ha		141.7	kg N/ha	
N after storage - at field	123.8	kg N/ha		137.5	kg N/ha	
N available for plants (digestate)	60.6	kg N/ha		87.2	kg N/ha	

N available for plants (crop residues)	19.3	kg N/ha	19.3	kg N/ha
N mineral - available for plant	37.3	kg N/ha	39.8	kg N/ha
Final Balance				
Total N needs	180.3	kg N/ha	180.3	kg N/ha
Total N applied	118.3	kg N/ha	147.4	kg N/ha
N deficit (deposition)	62.0	kg N/ha	32.9	kg N/ha

Sources:

- [Battini, 2014] Battini F., Agostini A., Boulamanti A.K., Giuntoli J., Amaducci S.; Mitigating the environmental impacts of milk production via anaerobic digestion of manure: Case study of a dairy farm in the Po Valley. Science of the Total Environment 481 (2014) 196 – 208.
- [EEA, 2013] EMEP/EEA air pollutant emission inventory guidebook — 2013. Vol. 3.B & 3.D.
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Step 2: Transport

The description of the road transport processes is given in Chapter 6 and it is not repeated here. Only the value of the 'distance' parameter is given.

The average transport distance considered for maize from the field to the biogas plant is equal to **20 km.**

The values are reported in the following table (Table 35).

Table 35. Transport distance for maize to biogas plant

Transport of wet maize via a 40 t truck over a distance of 20 km (one way)			
	I/O	**Unit**	**Amount**
Distance	Input	$tkm/MJ_{maize\ (65\%\ H2O)}$	0.0035
Maize silage	Input	$MJ/MJ_{maize\ (65\%\ H2O)}$	1.0
Maize silage	Output	MJ	1.0

Comments

— LHV (maize silage) = 16.9 MJ/kg dry.

— Moisture (maize silage) = 65 %.

Source

1. Consensus during the workshops and comments received by IEA Task 37.

Step 3: Digestion

The electricity consumption for the digestion process is differentiated between manure and maize.

Below is the process considered for maize digestion.

Table 36. Process for anaerobic digestion of maize silage.

Anaerobic digester (maize silage)				
	I/O	**Unit**	**Amount**	**Ref**
Electricity	Input	MJ/MJ_{biogas}	0.0250	1,3
Heat	Input	MJ/MJ_{biogas}	0.10	1,2
Maize silage	Input	MJ/MJ_{biogas}	1.429	See comment
Biogas	Output	MJ	1.0	

Comment

- The efficiency of the digestion is considered to be equal to 70 % (in terms of energy content). The details for this calculation are explained in the following section (Step 4: Digestate storage).
- Biogas yield = 651 l_{biogas} / kg_{VS}
- Methane yield = 345 l_{CH4} / kg_{VS} [1]

Source

1. IEA Bioenergy; The biogas handbook, 2013.
2. GEMIS 4.9, 2014. *Fermenter\biogas-maize-(no LUC)-DE-2010.*
3. Boulamanti et al., 2013

Biogas boiler

In the case of production of biomethane, the heat for the digester is provided by an external biogas boiler. For the purposes of this work, the input data are taken equal to a natural gas boiler.

Table 37. Process for a biogas boiler

Steam from biogas boiler			
	I/O	**Unit**	**Amount**
Biogas	Input	MJ/MJ_{heat}	1.11
Heat	Output	MJ	1.0
Emissions			
CH_4	Output	g/MJ_{heat}	0.0028
N_2O	Output	g/MJ_{heat}	0.00112

Comments

- Thermal efficiency = 90 % (based on LHV).

Source

1. GEMIS v. 4.9, 2014, *gas-boiler-DE 2010.*

Step 4: Digestate storage

Digestate is the name generally assigned to the residue from the anaerobic digestion. It is a liquid product that is generally used as organic fertilizer on the fields. Once collected from the digester, the digestate must be stored before it is again applied to the fields. However, the digestion process actually continues during the storage period, and the gases released can have an important impact on the final GHG balance of the pathway.

The digestate can be stored in either an open or a closed tank: with the latter option, the additional biogas released during storage is recovered; with the former, the methane is released to the atmosphere.

Table 38. Process for open-tank storage of digestate from maize

Open-tank storage of digestate from maize			
	I/O	**Unit**	**Amount**
Biogas	Input	MJ/MJ_{biogas}	1.0
CH4	Output	MJ/MJ_{biogas}	0.022
N2O	Output	g/MJ_{biogas}	0.008
Biogas	Output	MJ	1.0

Digestate methane emissions.

Calculations were based on the following data:

- LHV dry (maize): 16.9 MJ/kg
- Moisture (maize): 65 $\%_{f.m.}$
- VS (maize): 33.6 $\%_{f.m.}$ (96% of total solids)
- Methane yield: 345 l CH_4/kgVS
- Biogas composition: CH_4 = 53 %vol., CO_2 = 47 %vol.
- VS reduction in digestion (calculated from carbon balance): 72 %
- Density of digestate: 1 000 kg/m^3
- Temperature in digestate: ca. 20°C
- Based on various sources, the residual methane potential of digestate was established to be equal to 30 l CH_4 / kg VS (residual)
- VS (digestate): 0.25 kg VS / kg VS substrate
- Final result: 7.6 / 345 l CH4 digestate / l CH4 produced = 0.022 $MJCH_4$/MJbiogas = **0.44 g CH4 / MJbiogas**

This result derives from a series of measurements on various plants using different substrates. The results obtained from Weiland, 2009, Gioelli et al., 2011 and Amon et al. 2006a all converge towards the value chosen in this pathway.

The value obtained following the IPCC Guidelines would instead be higher (using a B_0 potential of 360 l CH4/kg VS, the results would range between 0.03 $MJCH_4$/MJbiogas at an average ambient temperature of 10°C and 0.077 $MJCH_4$/MJbiogas at 20°C). But the values of IPCC are expected to be overestimated since the method only accounts for the reduction in absolute amount of VS but non for the difference in quality of such VS (with the majority of digestible compounds being already digested in the reactor).

Sources

1. IPCC, IPCC Guidelines for National Greenhouse Gas Inventory, Vol. 4, Emissions from Livestock and Manure Management, 2006.
2. Joint Research Centre (JRC-IET), Petten, the Netherlands, own calculations.
3. Weiland, 2009.
4. Amon, B. et al., 2006a
5. Amon, B. et al.; 2006b
6. Gioelli et al., 2011
7. Amon, Th. et al., 2007a
8. Amon, Th. et al., 2007b
9. Khalid et al., 2011
10. Oechsner et al., 2003
11. Braun et al. 2009
12. Bruni et al., 2010

Digestate N_2O emissions.

Based on the IPCC guidelines, direct and indirect emissions of N_2O (from re-deposition of volatilized ammonia and nitrogen oxides) are considered.

Total N content in maize is considered to be equal to 0.37%$_{f.m.}$, and the content in digestate is assumed to be equal to 3.48 gN/kg silage fed to the digester (including a 6% losses in the digester and equivalent to an initial N content in the harvested maize of 1.06%$_{dry}$) (see Table 34). The total ammoniacal nitrogen is considered to be equal to 60% of the total N content.

A factor of 0.005 of total N is emitted directly as N_2O (IPCC, 2006, Vol. 10).

Volatilization factors used are indicated in Table 34.

Step 5: Biogas use

A. Electricity production — combined heat and power (CHP)

Table 39. Process for electricity generation via a biogas-fuelled gas engine CHP

Electricity generation via biogas-fuelled gas engine CHP				
	I/O	**Unit**	**Amount**	**Source**
Biogas	Input	$MJ/MJ_{el.}$	2.78	1
Electricity	Output	MJ	1.0	
Methane slip	Output	MJ/MJ_{biogas}	0.017	2,4
N_2O	Output	$g/MJ_{biogas.}$	0.00141	3

Comments

— The gross electrical efficiency of the CHP engine is considered to be 36 % based on a pool of references gathered by the JRC. From this efficiency, 1 % is considered to be internal consumption and should be subtracted.

— When the results are provided on the basis of a MJ of biogas, the final conversion efficiency is not relevant for the final emissions.

Sources

1. Murphy et al., Biogas from Crop Digestion, IEA Bioenergy Task 37, September 2011.
2. Liebetrau et al., Eng. Life Sci. 10 (2010) 595–599.
3. GEMIS v. 4.9, 2014, *biogas-maize-noLUC-ICE-500-DE-2010/gross.*
4. Boulamanti et al., 2013

B. Biomethane production

There are currently many different technologies used to remove CO_2 from the biogas stream in order to obtain a gas with the quality needed to be injected in the natural gas grid.

None of these technologies are actually prominent in the market yet, since biogas upgrading is still developing, albeit at a fast pace. Therefore, for the purposes of this work, several different techniques of biogas upgrading are grouped into two broad categories, as follows:

- **Upgrading with venting of the off-gas [OVG – off-gas vented]:** this group includes the following upgrading techniques in case a system to oxidize the methane in the off-gas is not installed: pressure swing adsorption, pressure water scrubbing, membranes and organic physical scrubbing. The methane lost in the off-gas is considered to be emitted to the atmosphere.
- **Upgrading with oxidation of the off-gas [OGO – off-gas oxidized]:** this group includes the following upgrading techniques in case the methane in the off-gas is oxidized: pressure water scrubbing if the water is recycled, pressure

swing adsorption, organic physical scrubbing, chemical scrubbing and cryogenic. In this case, the off-gases are considered to be flared with a high efficiency of methane conversion, so that no methane is released in the atmosphere.

The biogas that is lost in the process is considered to amount to: 3–10 % PSA; 1–2 % water scrubbing; 2–4 % organic physical scrubbing; 0.1 % chemical scrubbing; <1 % cryogenic, 1-15 % membranes.

Table 40. Process for upgrading with venting of the off-gas

Upgrading OGV					
	I/O	**Unit**	**Amount**	**Source**	**Comment**
Biogas	Input	MJ/MJ_{CH4}	1.03	1, 2, 3, 4, 5, 6, 7	**3 % of the methane is emitted from upgrading**
Electricity	Input	MJ/MJ_{CH4}	0.03		
Biomethane	Output	MJ	1.0		
CH_4	Output	MJ/MJ_{CH4}	0.03		

Table 41. Process for upgrading with oxidation of the off-gas

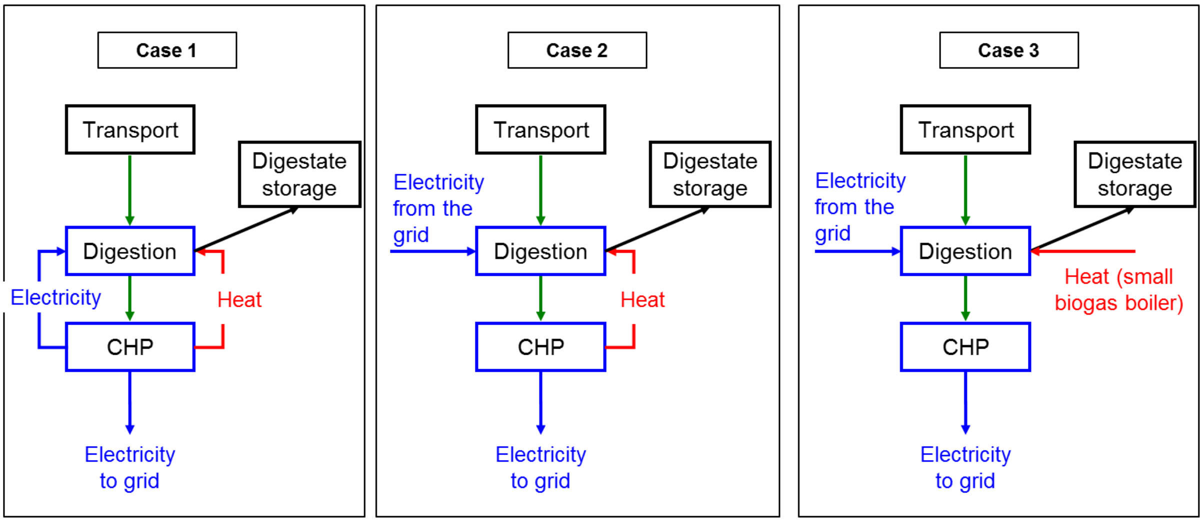
Upgrading OGO					
	I/O	**Unit**	**Amount**	**Source**	**Comment**
Biogas	Input	MJ/MJ_{CH4}	1.03	1, 2, 3, 4, 5, 6, 7	**No methane emitted from upgrading**
Electricity	Input	MJ/MJ_{CH4}	0.03		
Biomethane	Output	MJ	1.00		

Sources

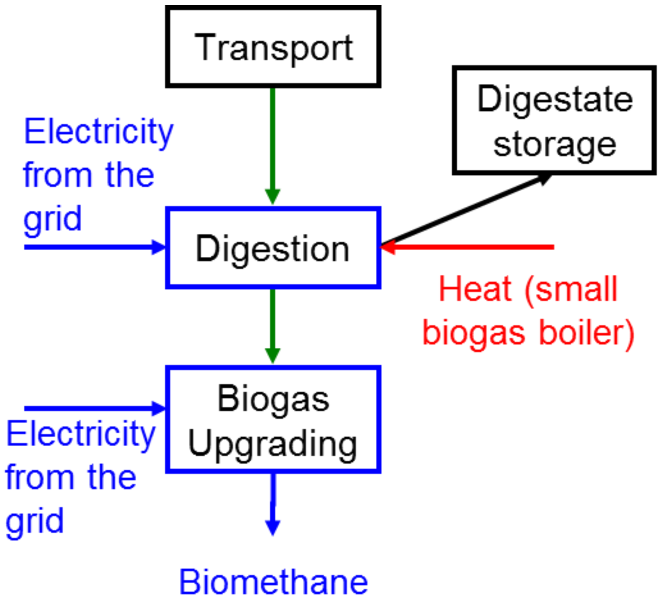
1. Petersson and Wellinger, 2009.
2. De Hullu et al., 2008.
3. Berglund M., 2006.
4. Patterson et al., 2011.
5. Lukehurst et al., 2010.
6. Schulz, W., 2004.
7. IEA Bioenergy; The biogas handbook, 2013.

5.2 Biogas from manure

A. Biogas for electricity



B. Biomethane



Manure is considered to be a residue, so no production step is required.

Step 1: Transport

The description of the road transport processes is given in Chapter 6 and will not be repeated here. Only the value of the 'distance' parameter is given. The distance for manure transport is set to 5 km.

Table 42. Transport distance for manure to biogas plant

Transport of wet manure via a 40 t truck over a distance of 5 km (one way)			
	I/O	**Unit**	**Amount**
Distance	Input	$tkm/MJ_{manure\ (90\%\ H2O)}$	0.0045
Manure	Input	$MJ/MJ_{manure\ (90\%\ H2O)}$	1.0
Manure	Output	MJ	1.0

Comments

- LHV (manure) = 12 MJ/kg dry.
- Moisture (manure) = 90 %.

Step 2: Digestion

Below is the process considered for manure digestion.

Table 43. Process for anaerobic digestion of manure

Anaerobic digester (manure)				
	I/O	**Unit**	**Amount**	**Sources**
Electricity	Input	MJ/MJ_{biogas}	0.020	1
Heat	Input	MJ/MJ_{biogas}	0.10	2
Manure	Input	MJ/MJ_{biogas}	2.38	See comment
Biogas	Output	MJ	1.0	

Sources

1. IEA Bioenergy; The biogas handbook, 2013.
2. GEMIS 4.9, 2014. Fermenter\biogas-maize-0LUC-DE-2010.

3. Boulamanti et al., 2013

Comments

The efficiency of the digestion is considered to be equal to 42 % (in terms of energy content). The details for this calculation are explained in the following section (Step 3: Digestate storage).

Step 3: Digestate storage

Digestate is the name generally assigned to the residue from the anaerobic digestion. It is a liquid product that is generally used as fertilizer on the fields. Once it is collected from the digester, the digestate must be stored before it is applied again to the fields. However, the digestion process actually continues during the storage period, and the gases released can have an important impact on the final GHG balance of the pathway.

The digestate can be stored either in an open or a closed tank: in the latter case, the additional biogas released during storage is recovered; in the former, the methane is released into the atmosphere.

Table 44. Process for open-tank storage of digestate from manure

Open-tank storage of digestate from manure			
	I/O	**Unit**	**Amount**
Biogas	Input	MJ/MJ_{biogas}	1.00
CH4	Output	MJ/MJ_{biogas}	0.10
N2O	Output	g/MJ_{biogas}	0.066
Biogas	Output	MJ	1.00

Digestate methane emissions.

Calculations were based on the following data:

- LHV dry (slurry): 12 MJ/kg
- Moisture (slurry): 90 $\%_{f.m.}$
- VS (manure): 7 $\%_{f.m.}$ (70% of total solids)
- Methane yield: 200 l CH_4/kgVS
- Biogas composition: CH_4 = 51 %vol., CO_2 = 49 %vol.
- VS reduction in digestion (calculated from carbon balance): 43 %
- Density of digestate: 1 000 kg/m^3
- Temperature in digestate: ca. 20°C
- Based on various sources, the residual methane potential of digestate was established to be equal to 35 l CH_4 / kg VS (residual)
- VS (digestate): 0.57 kg VS / kg VS substrate

- Final result: 20 / 200 l CH4 digestate / l CH4 produced = 0.10 $MJCH_4$/MJbiogas = **2.0 g CH4 / MJbiogas**

This result derives from a series of measurements on various plants using different substrates. The results obtained from Weiland, 2009, Gioelli et al., 2011 and Amon et al. 2006a all converge towards the value chosen in this pathway.

The value obtained is also consistent with the number obtained following IPCC Guidelines at an average ambient temperature of 14°C.

Sources

1. IPCC, IPCC Guidelines for National Greenhouse Gas Inventory, Vol. 4, Emissions from Livestock and Manure Management, 2006.
2. Joint Research Centre (JRC-IET), Petten, the Netherlands, own calculations.
3. Weiland, 2009.
4. Amon, B. et al., 2006a
5. Amon, B. et al.; 2006b
6. Amon, B. et al.; 2006c
7. Gioelli et al., 2011
8. Amon, Th. et al., 2006
9. Amon, Th. et al., 2007a
10. Sami et al., 2001
11. Kaparaju et al., 2011
12. Braun R., 1982
13. El-Mashad et al., 2010
14. Wang et al., 2011

Digestate N_2O emissions.

Based on the IPCC guidelines, direct and indirect emissions of N_2O (from re-deposition of volatilized ammonia and nitrogen oxides) are considered.

Total N content in the original slurry is assumed to be equal to 3.6 gN/kg slurry (Battini, 2014) (equivalent to $3.6\%_{dry}$) while the content in the digestate is assumed to be equal to 3.38 gN/kg slurry fed to the digester. The total ammoniacal nitrogen (TAN) is considered to be equal to 60% of the total N content.

A factor of 0.005 of total N is emitted directly as N_2O (IPCC, 2006, Vol. 10).

Volatilization factors used are taken from the latest EMEP/EEA guidelines (2013), and correspond to 20% of TAN released as ammonia and 0.01% of TAN as nitrogen oxides. No leaching is considered to happen from the storage tank.

According to the IPCC guidelines 0.01 of the volatilized N is converted into $N\text{-}N_2O$.

Step 4: Biogas use

This step is considered to be the same as in the pathway for maize.

5.2.1 Manure methane credits

When raw (solid) manure or raw (liquid) slurry is stored, waiting to be spread on the fields, it releases gases in the atmosphere as result of bacterial activity.

Methane is the main gas released by manure decomposition, but also nitrogen compounds such as N_2O, NH_3 and nitrogen oxides are released.

When the manure is treated in an anaerobic digester, the methane produced is collected as biogas and either distributed in the natural gas grid or burned on-site in a gas engine to produce power and heat. The biogenic methane produced can be considered to be oxidised to CO_2 (except for the losses during production, accounted in the calculations).

It is unquestionable that if biogas is not produced, the raw manure/slurry management would cause higher GHG emissions compared to digestate management. This is mostly due, though, to common, less than optimal agricultural practices rather than to pure merits of the biogas pathway.

Another important factor to keep into account is that biogas can be produced using solid manure or liquid slurry as feedstock material. While the processes leading to the GHG emissions from liquid slurry and digestate storage can be considered similar (also recommended by the IPCC Guidelines), emissions from solid manure piles are known to be significantly lower (due to more aerobic conditions); however the liquid part of the excreta has to be managed in a similar way to untreated slurry.

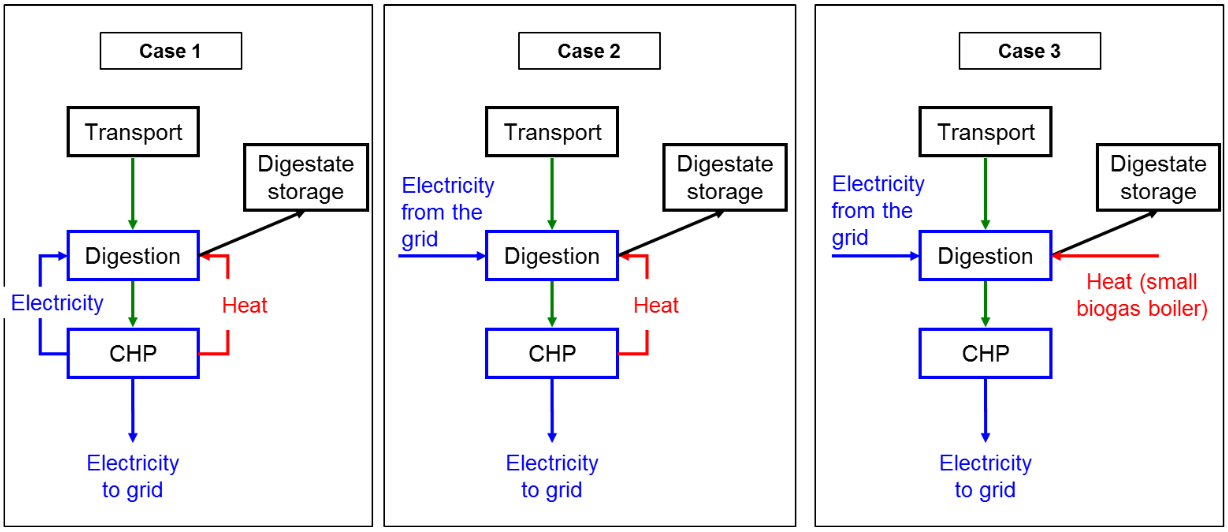
Based on IPCC Guidelines, the ratio between the methane emissions due to slurry storage and the emissions due to digestate storage is simply given by the reduction of volatile solids (VS) during digestion (methane yield and methane conversion factor are suggested to be kept the same between the two situations). This implies that with the specific conditions assumed in our calculations (VS reduction = 43%) the credits would be equal to 1/0.57 = 1.76 times the emissions from digestate storage.

Considering that the methane emissions from digestate are equal to 10.0% of the produced methane, thus, the credits would be equal to **17.5% of the methane produced = 0.175 MJ CH4 / MJ biogas = 3.5 g CH4/MJ biogas = 1.5 g CH4 / MJ manure = -36.8 g CO2 eq. / MJ manure**.

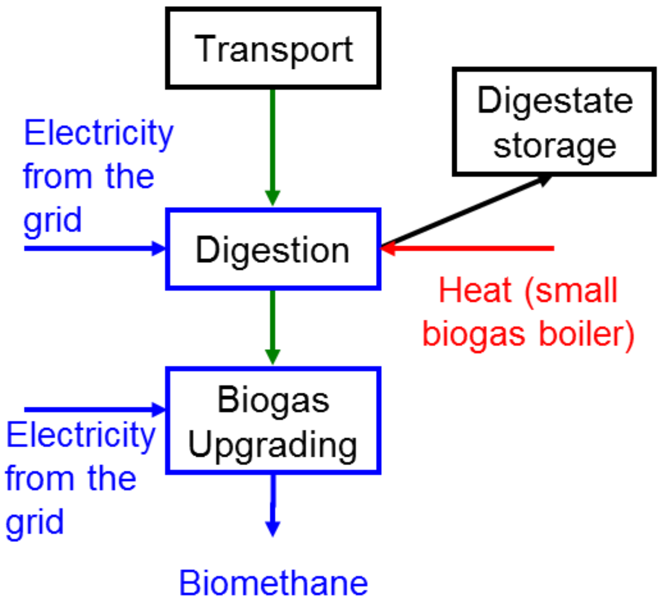
Concerning N_2O emissions, instead, considering that the proportion of ammoniacal nitrogen in the digestate is supposed to increase and that the total N is decreased due to losses in the digester, we assume that the net emissions from raw slurry and digestate are equal and thus the credit would simply balance out the N_2O emissions assigned to digestate storage. Numerically this would be equal to **0.066 g N2O / MJ biogas = 19.8 g CO2 eq. / MJ biogas = 0.03 g N2O / MJ manure = 8.3 g CO2 eq. / MJ manure.**

5.3 Biogas from biowaste

A. Biogas for electricity



B. Biomethane



Biowastes are considered to be a residue, so no production step is required.

Bio-waste is defined as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants and agroindustrial processing. It does not include forestry residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood. It also excludes those by-products of food production that never become waste.

The pathways described here for the production of biogas and biomethane from the anaerobic digestion of biowastes are modelled mainly over Source Separated-Food Waste (SS-FW).

Step 1: Transport

The description of the road transport processes is given in Chapter 6 and will not be repeated here. Only the value of the 'distance' parameter is given. The distance for municipal organic waste transport is set to 20 km.

This value should not be interpreted as the fuel consumption due to the collection door-to-door of the waste because the collection would have happened independently from the choice of producing biogas. This fuel consumption should be interpreted as additional transport of the feedstock from the waste collection/separation point to the plant where the digestion happens.

Table 45. Transport distance for biowaste to biogas plant

Transport of biowaste via a 40 t truck over a distance of 20 km (one way)			
	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{mow\ (76\%\ H2O)}$	0.0042
Biowaste	Input	$MJ/MJ_{mow\ (76\%\ H2O)}$	1.0
Biowaste	Output	MJ	1.0

Comments

— LHV (Biowaste) = 20.7 MJ/kg dry.

— Moisture (Biowaste) = 76.3 %.

Sources

1. Zhang et al., 2012.

Step 2: Digestion

Below is the process considered for Biowaste digestion.

Table 46. Process for anaerobic digestion of biowaste

Anaerobic digester (biowaste)			
	I/O	**Unit**	**Amount**
Electricity	Input	MJ/MJ_{biogas}	0.030
Heat	Input	MJ/MJ_{biogas}	0.10
Biowaste	Input	MJ/MJ_{biogas}	1.45
Biogas	Output	MJ	1.0

Comments

The efficiency of the digestion is considered to be equal to 69 % (in terms of energy content). The details for this calculation are explained in the following section (Step 3: Digestate storage).

Sources

1. GEMIS v. 4.9, 2014, fermenter/biogas–org. wastes–DE–2005.
2. Zhang et al., 2012.

Step 3: Digestate storage

The digestate can be stored in either an open or a closed tank: in the latter case, the additional biogas released during storage is recovered; in the former, the methane is released in the atmosphere. The use of the digestate from the digestion of municipal organic wastes as fertilizer depends from its composition, since there are limit values for heavy metals, organic pollutants and pathogens in materials used as crop fertilizers.

Table 47. Process for open-tank storage of digestate from biowaste

Open-tank storage of digestate from biowaste			
	I/O	**Unit**	**Amount**
Biogas	Input	MJ/MJ_{biogas}	1.0
CH4	Output	MJ/MJ_{biogas}	0.025
N2O	Output	g/MJ_{biogas}	0.032
Biogas	Output	MJ	1.0

Digestate methane emissions.

Calculations were based on the following data:

- LHV dry (Biowaste): 20.7 MJ/kg
- Moisture (Biowaste): 76.3 $\%_{f.m.}$
- VS (Biowaste): 21.7 $\%_{f.m.}$
- Methane yield: 438 l CH_4/kgVS
- Biogas composition: CH_4 = 60 %vol., CO_2 = 40 %vol.
- VS reduction in digestion (based on carbon balance): 75.5 %
- Density of digestate: 1 000 kg/m^3
- Temperature in digestate: ca. 20°C
- Based on various sources, the residual methane potential of digestate was established to be equal to 44 l CH_4 / kg VS (residual)
- VS (digestate): 0.245 kg VS / kg VS substrate
- Final result: 11 / 438 l CH4 digestate / l CH4 produced = 0.025 $MJCH_4$/MJbiogas = **0.49 g CH4 / MJbiogas**

This result derives from a mix of sources. The results obtained from Hansen et al., 2006 and Amon et al. 2006a converge towards the value chosen in this pathway.

The value obtained following the IPCC Guidelines would be slightly higher (using a B_0 potential of 460 l CH4/kg VS, the results would range between 0.026 $MJCH_4$/MJbiogas at an average ambient temperature of 10°C and 0.052 $MJCH_4$/MJbiogas at 20°C).

Sources

1. IPCC, IPCC Guidelines for National Greenhouse Gas Inventory, Vol. 4, Emissions from Livestock and Manure Management, 2006.
2. Joint Research Centre (JRC-IET), Petten, the Netherlands, own calculations.
3. Weiland, 2009.
4. Amon, B. et al., 2006a
5. Amon, B. et al.; 2006b
6. Amon, B. et al.; 2006c
7. Amon, Th. et al., 2006
8. Amon, Th. et al., 2007a
9. Rapport et al., 2012
10. Zhang et al., 2012
11. Zhu et al., 2009
12. El-Mashad et al., 2010

Digestate N_2O emissions

Based on the IPCC guidelines, direct and indirect emissions of N_2O (from re-deposition of volatilized ammonia and nitrogen oxides) are considered.

Total N content in the original biowaste is assumed to be equal to 8.17 gN/kg biowaste (Zhang, 2012) (equivalent to 3.44$\%_{dry}$) while the content in the digestate is assumed to be equal to 7.68 gN/kg biowaste fed to the digester.

A factor of 0.005 of total N is emitted directly as N_2O (IPCC, 2006, Vol. 10).

Volatilization factors used are taken from the IPCC guidelines, and correspond to 40% of the nitrogen content. No leaching is considered to happen from the storage tank.

According to IPCC, 0.01 of the volatilized N is converted into N-N_2O.

Step 4: Biogas use

This step is considered to be the same as in the pathway for maize and manure.

Additional INFO nr. 2: Co-Digestion of multiple substrates

Biogas plants with only one substrate are in practice rare, due to limited availability of any single feedstock and also for the convenience of simply disposing of multiple residues from the agricultural activities into the digester. This paragraph describes the methodology that could be applied to estimate the GHG emissions of biogas obtained by co-digestion between maize, manure and other biowastes.

A way to flexibly apply the GHG emissions calculated for pathways employing a single substrate (Table 99 and Table 100) to pathways using co-digested multiple substrates is to treat the co-digestion as a simple weighted average of the results obtained for single-substrate pathways. The underlying assumption is that no significant synergies exist among the different substrates in the digester to change dramatically the overall productivity of biogas. This assumption is within the accuracy of the results needed for these calculations.

The important methodological issue, however, resides in the choice of the basis for the weighted average. In fact, it would not be correct to simply use the LHV of the feedstocks as a basis, since maize and manure have very different biogas productivities and the typical GHG emissions are calculated on the basis of the biogas (energy) produced.

Therefore, the methodology proposed is to base the average upon the share of biogas produced by each feedstock. The following formulas describe the calculations needed:

$$P_n = \text{Biogas yield}_n \left[\frac{m^3_{biogas}}{kg_{VS}}\right] \cdot \text{Volatile solids}_n \left[\frac{kg_{VS}}{kg_{wet\ feedstock}}\right] \cdot LHV_{biogas} \left[\frac{MJ_{biogas}}{m^3_{biogas}}\right]$$

Where P_n is the productivity of biogas each substrate n.

The following standard values have been used in JRC calculations:

- Biogas yield (maize) = 0.65 [m3 biogas / kg volatile solids]
- Biogas yield (manure) = 0.39 [m3 biogas / kg volatile solids]
- Biogas yield (biowaste) = 0.73 [m3 biogas / kg volatile solids]
- Volatile solids (maize) = 0.336 [kg volatile solids / kg maize] (or 96% of dry matter content)
- Volatile solids (manure) = 0.07 [kg volatile solids / kg manure] (or 70% of dry matter content)
- Volatile solids (biowaste) = 0.22 [kg volatile solids / kg biowastes]
- LHV biogas (maize) (53% CH4) = 19.0 [MJ / m3 biogas (@0°C, 1 atm)]
- LHV biogas (manure) (51% CH4) = 18.3 [MJ / m3 biogas (@0°C, 1 atm)]
- LHV biogas (biowaste) (60% CH4) = 21.5 [MJ / m3 biogas (@0°C, 1 atm)]

This produces as a result:

- P (maize) = 4.16 [MJ $_{biogas}$/kg $_{wet\ feedstock}$]
- P (manure) = 0.50 [MJ $_{biogas}$/kg $_{wet\ feedstock}$]
- P (biowaste) = 3.41 [MJ $_{biogas}$/kg $_{wet\ feedstock}$]

The final share of each substrate *n* to be used for the weighted average is then given for each feedstock n (maize, manure, biowastes) as:

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

Where the W_n is considered to be the 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 ([14]).

This formula is implemented in the Annex VI point 1(b) of the COM(2016) 767.

([14]) The moisture content used are: Manure 90%, Maize 65%, Biowaste 76%.

Figure 2. Relation between the initial wet mass share of maize (and manure) (variable *'I'* in the formula) and the share of energy produced by both co-substrates (variable *'W'*).

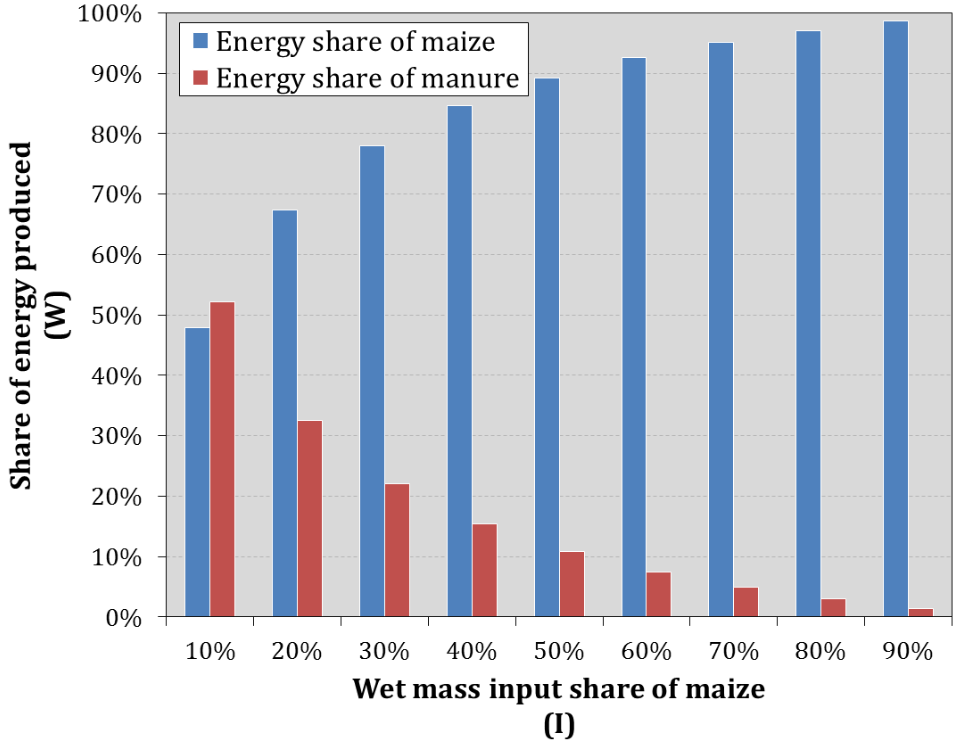


Figure 2 presents the relationship between I_n and W_n for the example in which manure and maize are co-digested.

The final typical or default GHG emissions for a co-digestion case, starting from single-feedstock values, would then be given by the following formula:

$$\text{GHG emissions (co-digestion)} \left[\frac{gCO_{2\ eq.}}{MJ_{biogas}}\right] = \sum_{1}^{n} S_n \cdot E_n$$

Where E_n represents the GHG emissions calculated for each single feedstock pathways (maize, manure, biowastes).

Using this general formula it is possible to extract the typical or default value for any arbitrary composition of the feedstock mix to the digester.

6 Biomass and solid densified biomass pathways

For this study, three types of biomass based energy carriers are considered:

1. Chips;
2. Pellets;
3. Bales.

These are considered in combination with nine different raw materials:

- Forest logging residues
- Short rotation coppice (SRC): Eucalyptus
- Short rotation coppice (SRC): Poplar
- Wood industry residues
- Stemwood
- Agricultural residues
- Straw
- Sugar cane bagasse
- Palm kernel meal.

As a result, the following pathways are studied:

1. Woodchips from forest logging residues
2. Woodchips from Eucalyptus
3. Woodchips from Poplar
4. Woodchips from wood industry residues
5. Woodchips from stemwood
6. Wood pellets from forest logging residues
7. Wood pellets from Eucalyptus
8. Wood pellets from Poplar
9. Wood pellets from wood industry residues
10. Wood pellets from stemwood
11. Agricultural residues with bulk density < 0.2 t/m^3
12. Agricultural residues with bulk density > 0.2 t/m^3
13. Straw pellets
14. Bagasse pellets/briquettes
15. Palm kernel meal.

Transport scheme for solid biomass

Table 48. Transport scheme for solid biomass pathways; distances are to plant gate ([15])

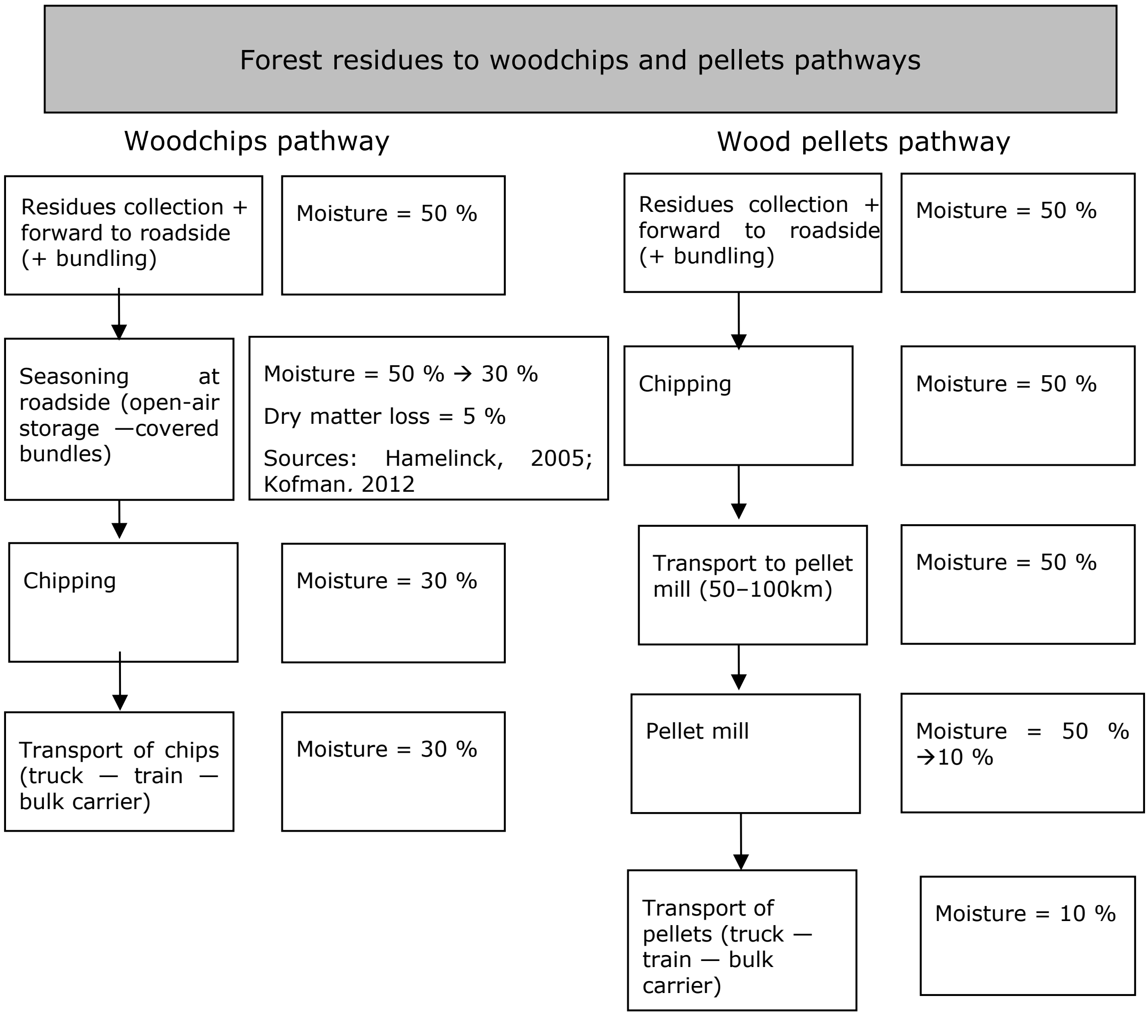
Pathways	Distance tag	Representative geographic origin	Typical distances (km)			
			Truck (chips/raw)	Truck (pellets/finished product)	Train (chips/pellets)	Bulk carrier (chips/pellets)
Woodchips	1–500 km	Intra-EU	500	-	-	-
	500–2 500 km	Russia	250	-	-	2 000
	2 500–10 000 km	Brazil	200	-	-	8 000
	> 10 000 km	Western Canada	-	-	750	16 500
Wood pellets	1–500 km	Intra-EU	50	500	-	-
	500 – 2500 km	Russia	50	250		2 000
	2500–10 000 km	Brazil	50	200	-	8 000
	> 10 000 km	Western Canada	100	-	750	16 500
Agricultural residues	1–500 km	Intra-EU	500	-	-	-
	500–2 500 km	Russia	250	-	-	2 000
	2 500–10 000 km	Brazil	200	-	-	8 000
	> 10 000 km	Western Canada	-	-	750	16 500
Charcoal	1–50 km	Intra-EU	-	50	-	-
	> 10 000 km	Brazil	-	700	-	10 186
Straw pellets	1–500 km	Intra-EU	50	500	-	-
	500–10 000 km	Brazil	50	200	-	8 000
	> 10 000 km	Western Canada	100	-	750	16 500
Bagasse pellets/briquettes	500–10 000 km	Brazil	-	200	-	8 000
	> 10 000 km	Brazil	-	700	-	10 186
Palm kernel meal	> 10 000 km	Malaysia — Indonesia	50	700		13 000

([15]) Specific combinations of feedstocks and transport schemes are excluded from the results because they would not represent any realistic situation.

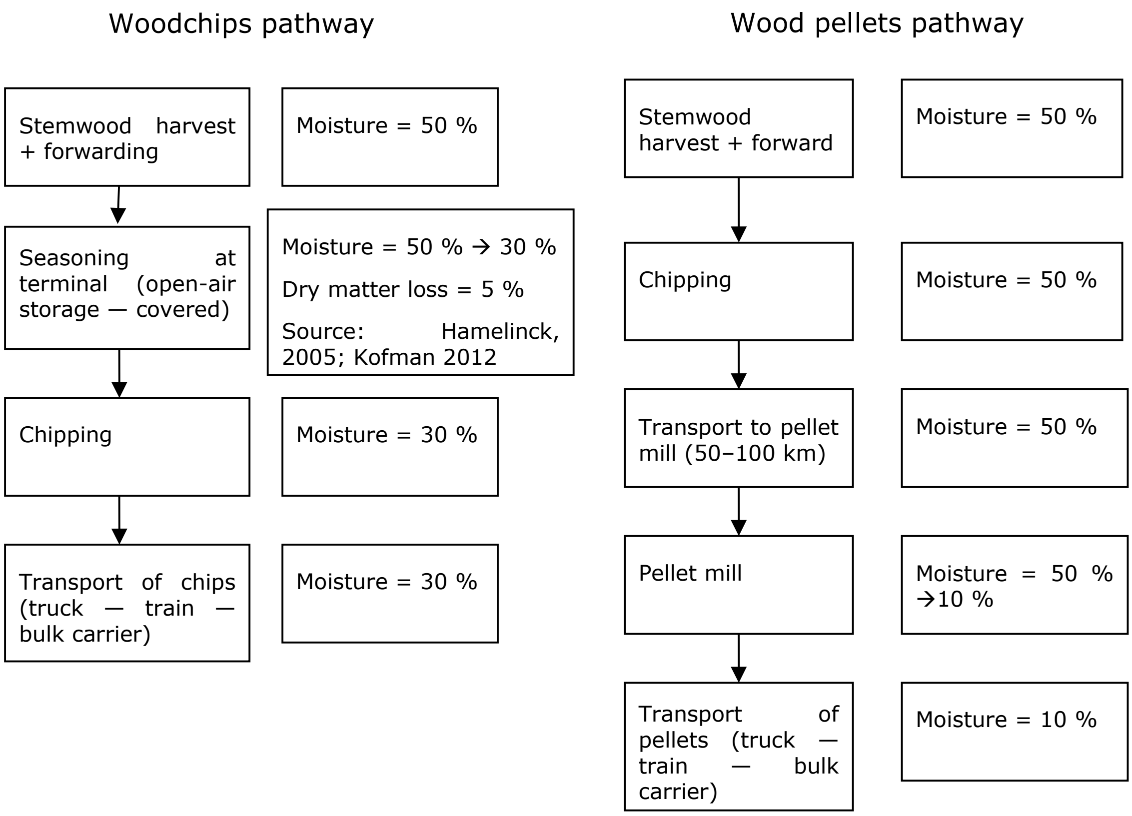
Moisture schemes for solid biomass

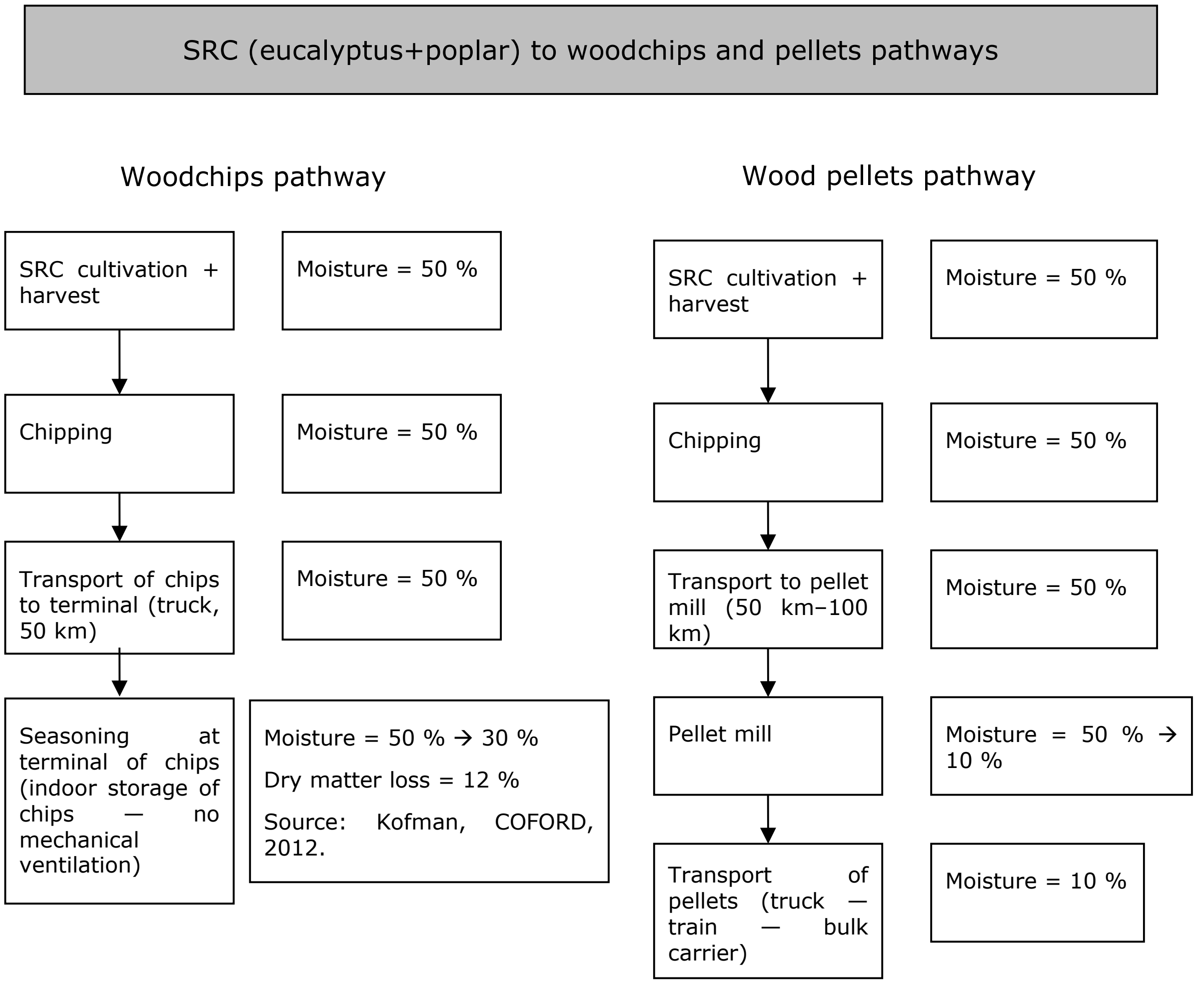
The moisture content of solid biomass fuels is a very important parameter throughout the pathways. Its effect is significant, especially on long-distance hauling of woodchips.

The following figures aim to define the moisture content of the woody fuels along their production chain.



Stemwood to wood chips and pellets pathways




SRC (eucalyptus+poplar) to woodchips and pellets pathways
Woodchips pathway
SRC cultivation + harvest
Moisture = 50 %
Chipping
Moisture = 50 %
Transport of chips to terminal (truck, 50 km)
Moisture = 50 %
Seasoning at terminal of chips (indoor storage of chips — no mechanical ventilation)
Moisture = 50 % → 30 %
Dry matter loss = 12 %
Source: Kofman, COFORD, 2012.
Wood pellets pathway
SRC cultivation + harvest
Moisture = 50 %
Chipping
Moisture = 50 %
Transport to pellet mill (50 km–100 km)
Moisture = 50 %
Pellet mill
Moisture = 50 % → 10 %
Transport of pellets (truck — train — bulk carrier)
Moisture = 10 %

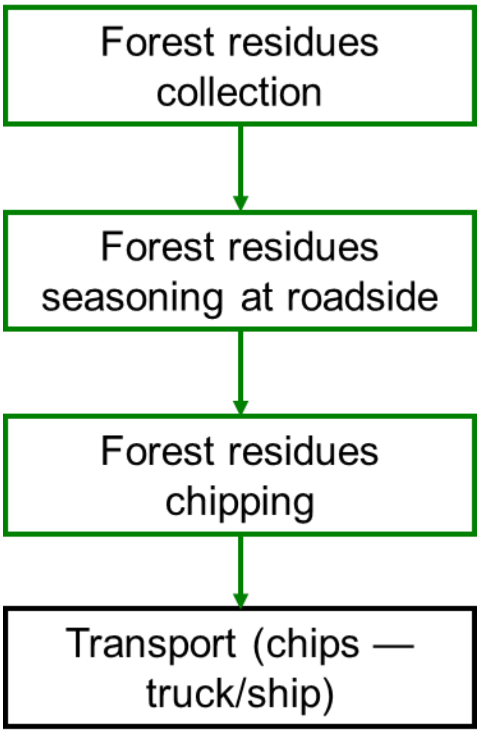
6.1 Woodchips

The transportation schemes in the case of woodchips are shown in Table 53.

Table 49. Transportation scheme for woodchips pathways

	Total travel-distance range	Truck (chips)	Truck (pellets)	Train	Ship	Notes
Woodchips pathways	1–500 km	500				Intra-EU
	500–2 500 km	250			2 000	E.g. Russia
	2 500–10 000 km	200			8 000	E.g. Brazil
	Above 10 000 km			750	16 500	E.g. Western Canada

6.1.1 Woodchips from forest logging residues (Pathway no 1)



Step 1: Forest residues collection

In the case of forest residues, a specific process is needed to account for the energy spent for their collection. In Table 50, the process depicted includes stump harvesting. Moreover, various logistic choices that are being developed, especially in Scandinavian countries, are considered, including the use of bundled and loose residues. The following steps are included in the process:

- Forwarding
- Bundling/lifting
- Oil use
- Forestry machinery transport
- Load/unload.

Table 50. Process for forest residues collection

Forestry residues collection including stump harvesting and chipping				
	I/O	**Unit**	**Amount**	**Source**
Wood	Input	$MJ/MJ_{woodchips}$	1.0	2
Diesel	Input	$MJ/MJ_{woodchips}$	0.0120	1
Woodchips	Output	MJ	1.0	1
CH_4	Output	$g/MJ_{woodchips}$	9.20E-6	3
N_2O	Output	$g/MJ_{woodchips}$	3.85E-5	3

Comments

— LHV dry = 19 MJ/kg.

— Moisture = 50 %.

— This step is common for Pathways no 1, no 5 and no 9.

Sources

1. Lindholm et al., 2010.
2. Sikkema et al., 2010.
3. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 -Forestry.

Step 2: Forest residues seasoning

By storage of bundled residues at the roadside over a period of 3 to 12 months, it is possible to reduce the moisture of the wood from 50 % down to about 30 %. This is essential to reduce costs and energy use in long-distance hauling of low-bulk, high-moisture biomass such as woodchips. However, the moisture loss is accompanied by dry matter losses due to bacterial activity within the stored wood.

The storage technique is essential in order to minimise dry matter losses; that is why, in this pathway, it was decided to consider the open-air storage of bundled residues (covered with plastic or paper wrap), for a period of 3 to 8 months.

Table 51. Process for forest residues bundles seasoning at forest roadside

Forestry residues seasoning at roadside				
	I/O	Unit	Amount	
Wood	Input	MJ/MJ_{wood}	1.053	1, 2, 3
Wood	Output	MJ	1.0	

Comments

— LHV dry = 19 MJ/kg.
— Moisture = from 50 % to 30 %.
— It includes open air seasoning at roadside with the residues covered from rain.
— Storage is usually for a period of 3 to 8 months.
— 5 % of dry matter losses is considered.
— This process is used for the woodchips pathways prior to chipping and prior to long-distance hauling.

Sources

1. Hamelinck et al., 2005.
2. Kofman, 2012.
3. Lindholm et al., 2010.

Step 3: Forest residues chipping

In the case of forest residues, the output of the collection is loose or bundled residues. As a result, an additional process for chipping is necessary.

Table 52. Process for woodchipping

Wood chipping				
	I/O	**Unit**	**Amount**	**Source**
Wood	Input	$MJ/MJ_{woodchips}$	1.025	1,2
Diesel	Input	$MJ/MJ_{woodchips}$	0.00336	1
Woodchips	Output	MJ	1.0	
CH_4	Output	$g/MJ_{woodchips}$	2.57E-06	3
N_2O	Output	$g/MJ_{woodchips}$	1.07E-05	3

Comments

— LHV dry = 19 MJ/kg.
— Moisture = 30 %.
— Bulk density (chips) = 0.155 dry tonne/m^3.
— The process covers a range of scenarios including roadside chipping with small-scale diesel chipper and comminution at the power plant, using a large-scale electrical chipper.
— This step is common for Pathways no 1, no 2, no 4, no 6, no 8 and no 10.

Sources

1. Lindholm et al., 2010.
2. Sikkema et al., 2010.
3. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 –Forestry.

Step 4: Transport

The description of the transport processes is set out in Chapter 6 and will not be repeated here.

The transport distances, calculated as explained in Chapter 6, for all the road cases, are reported in Table 53, while the ones for maritime transport are detailed in Table 54. Table 55 instead reports the distance value for the train transport section.

Table 53. Transport distances via a 40 t truck of woodchips to final destination

	I/O	Unit	200 km	250 km	500 km
Distance	Input	$tkm/MJ_{woodchips}$	0.0156	0.0195	0.0390
Woodchips	Input	$MJ/MJ_{woodchips}$	1.0	1.0	1.0
Woodchips	Output	MJ	1.0	1.0	1.0

Table 54. Transport distances via bulk carrier of woodchips to final destination

Maritime transport of woodchips over the planned distances (one way)					
	I/O	**Unit**	**2 000 km**	**8 000 km**	**16 500 km**
Distance	Input	$tkm/MJ_{woodchips}$	0.1504	0.6015	1.2406
Wood pellets	Input	$MJ/MJ_{woodchips}$	1.0	1.0	1.0
Wood pellets	Output	MJ	1.0	1.0	1.0

Table 55. Transport distances via freight train of woodchips to port

Transport of woodchips via a train over a distance of 750 km (one way)			
	I/O	**Unit**	**Amount**
Distance	Input	$tkm/MJ_{wood\ pellets}$	0.0564
Woodchips	Input	$MJ/MJ_{wood\ pellets}$	1.0
Woodchips	Output	MJ	1.0

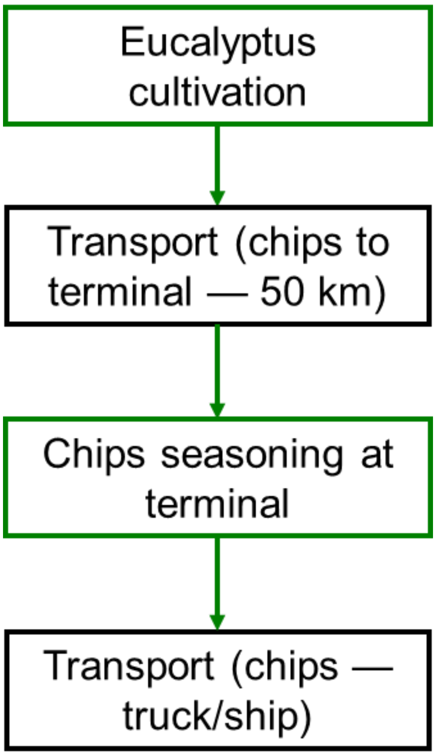
Comments

— LHV (woodchips) = 19 MJ/kg dry.

— Moisture (woodchips) = 30 %.

These values are valid for any pathway which involves the transportation of woodchips to a final destination.

6.1.2 Woodchips from SRC - Eucalyptus (Pathway no 2a)



Step 1: Eucalyptus cultivation

Short rotation coppice (SRC) is defined, according to Regulation (EU) No 1307/2013, as: *"areas planted with tree species of CN code 06029041 to be defined by Member States, that consist of woody, perennial crops, the rootstock or stools remaining in the ground after harvesting, with new shoots emerging in the following season and with a maximum harvest cycle to be determined by the Member States."*

Regarding the difference between fast-growing species under short rotation coppice and short rotation forestry, the Delegated Act C(2014) 1460 final explains that: *"as regards fast-growing species, Member States shall define the minimum and maximum time before felling. The minimum time shall not be less than 8 years and the maximum shall not exceed 20 years; This implies that "short rotation coppice" are expected to have a growing cycle : between 2 and 7 years".*

The various practices are thus characterized in this document as follows:

- Short rotation coppice: rotations between 2 and 7 years;
- Short rotation forestry: rotations between 8 and 20 years;
- Conventional forestry operations: rotations above 20 years.

In practical terms, SRC practices for bioenergy pruposes entail growing of trees in extremely dense stands, harvested at specific intervals and regenerated from the stools, which are expected to survive five rotations at least. They differ from common forestry operations (i.e. for logging or for pulp and paper), because the rotation between harvests is shortened to about 3 to 5 years.

The most common species generally cultivated for wood pulp are willow, poplar and eucalyptus; however, their use for bioenergy (with the management changes that this entails) is not yet commercially widespread.

Currently, the cultivation of eucalyptus in tropical areas is common for charcoal and wood pulp production (Couto et al., 2011). Interest is rising to implement denser plantations for bioenergy production from eucalyptus. Poplar with relatively longer rotations is already extensively cultivated for wood furniture in Italy (González-García et al., 2012).

After investigating several publications concerning eucalyptus plantations under short rotation, it was concluded that the data available in literature are scattered.

The values for the yields of Eucalyptus were found to vary: from 5.5 t dry substance/(ha*yr) (Patzek and Pimentel, 2005) up to 22 t dry substance/(ha*yr) (Franke, B. et al., 2012). Depending on the soil quality, the GEF study indicates yields as low as 6.8 t dry substance/(ha*yr) for Mozambique and as high as 22 t dry substance/(ha*yr) for suitable land in Brazil.

The data in the GEF report (Franke et al., 2012) are considered of high quality and thus form the basis for both eucalyptus and poplar cultivation processes.

The process defined for the cultivation of eucalyptus is reported in Table 56.

Table 56. Process for cultivation of eucalyptus

Plantation of eucalyptus				
	I/O	**Unit**	**Amount**	**Source**
Diesel	Input	$MJ/MJ_{wood\ chips}$	5.98E-03	4
N fertilizer	Input	$kg/MJ_{wood\ chips}$	9.29E-04	4
P_2O_5 fertilizer	Input	$kg/MJ_{wood\ chips}$	3.56E-04	4
K_2O fertilizer	Input	$kg/MJ_{wood\ chips}$	7.43E-04	4
CaO fertilizer	Input	$kg/MJ_{wood\ chips}$	1.08E-03	4
Pesticides	Input	$kg/MJ_{wood\ chips}$	6.39E-06	4
Seeds	Input	$kg/MJ_{wood\ chips}$	7.15E-05	4
Wood chips	Output	MJ	1.0	-
Field N_2O emissions	-	$g/MJ_{wood\ chips}$	0.0193	4,5
Field CO_2 emissions-acidification	-	$g/MJ_{wood\ chips}$	0.3030	4,6
CH_4	Output	$g/MJ_{wood\ chips}$	7.63E-06	7
N_2O	Output	$g/MJ_{wood\ chips}$	1.89E-05	7

Comments

- This process represents an average between the values reported in Franke et al., 2012 for three different conditions: Mozambique, Brazil (suitable fertile land), Brazil (less suitable land).
- LHV dry = 19 MJ/kg.
- Moisture = 50 %.
- Yield = 12.9 t dry substance/(ha*yr) [4].
- Diesel = 1 469 MJ diesel/(ha*yr) [4].
- N- fertilizer = 228.2 kg N/(ha*yr) [4].
- P_2O_5 fertilizer = 87.5 kg P_2O_5/(ha*yr) [4].
- K_2O fertilizer = 182.6 kg K_2O/(ha*yr) [4].
- Pesticides / herbicides = 1.6 kg/(ha*yr) [4].
- Cao fertilizer = 266.3 kg CaO/(ha*yr) [4].
- This step is common for Pathways no 2, no 6 and nr 10.
- This process considers the use of a combined harvester-chipper, so that the final products are directly wood chips.

Sources

1. Patzek, T. W. and D. Pimentel, Critical Reviews in Plant Sciences 24(2005) 327-364.
2. van den Broek, R. et al. Biomass and Bioenergy 19(2000) 311-335.
3. van den Broek, R. et al. Biomass and Bioenergy 21(2001) 335-349.
4. Franke, B.; Reinhardt, G.; Malavelle, J.; Faaij, A.; Fritsche, U. Global Assessments and Guidelines for Sustainable Liquid Biofuels. A GEF Targeted Research Project. Heidelberg/Paris/Utrecht/Darmstadt, 29 February 2012.
5. IPCC, 2006, N_2O Guidelines.
6. Joint Research Centre, (JRC-IET), Petten, the Netherlands, August 2012.
7. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 – Agricultural machinery.

Step 2: Transport to terminal

The chips are transported from plantation roadside to a central terminal where they are stored to decrease the moisture content before long-distance hauling.

Table 57. Transport of woodchips from roadside to terminal

Transport of woodchips via a 40 t truck over 50 km			
	I/O	**Unit**	**50 km**
Distance	Input	$tkm/MJ_{woodchips}$	0.0055
Woodchips	Input	$MJ/MJ_{woodchips}$	1.0
Woodchips	Output	MJ	1.0

Comments

— LHV (woodchips) = 19 MJ/kg dry.

— Moisture (woodchips) = 50 %.

Step 3: Woodchips storage

Storage conditions for woodchips can cause severe dry matter losses. This pathway considers indoor storage of a pile of chips, covered by plastic or paper wrap and with good natural ventilation in the room.

Bacterial reactions in woodchips piles can cause emissions of methane. However, the data available are very limited (Wihersaari, 2005; Jäppinen et al., 2013, Röder et al., 2015) and the emissions have been shown to depend strongly on the storage conditions, ambient temperature and initial moisture content.

With the conditions considered in this report, it is assumed that aeration is sufficient to minimize anaerobic conditions in the pile. Therefore, methane emissions are considered to be negligible. However, as more research is being carried out on the topic and more reliable data are gathered, this process may be updated and emissions may increase.

Table 58. Storage and seasoning of woodchips at terminal

SRC chips seasoning at terminal				
	I/O	**Unit**	**Amount**	Sources
Woodchips	Input	MJ/MJ_{wood}	1.136	1
Woodchips	Output	MJ	1.0	

Comments

— LHV (woodchips) = 19 MJ/kg dry.
— Moisture (woodchips) = from 50 % to 30 %.
— It includes storage at central terminal in a closed environment without artificial ventilation, but with good natural ventilation.
— The most common harvesting technique for SRC at present is a combined harvester and chipper, so chips need to be stored.
— Storage is usually for a period of 3 to 8 months.
— 12 % dry matter losses are considered
— Emissions of methane from storage are considered to be negligible in these conditions.

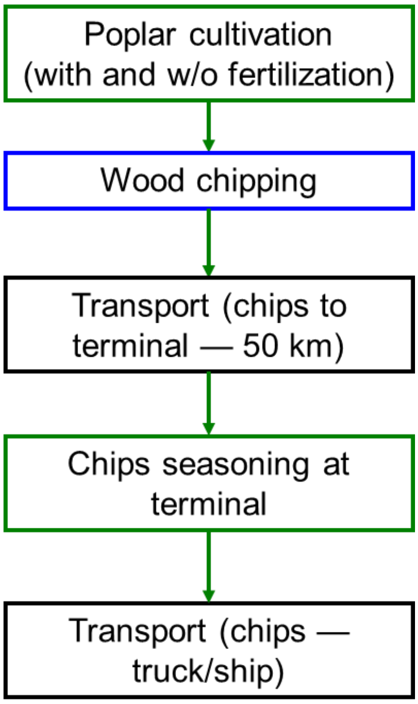
Source

1. Kofman, 2012.

Step 4: Transport to end user

See Table 53, Table 54 and Table 55 for the detailed values.

6.1.3 Woodchips from SRC - Poplar (Pathway no 2b-c)



Step 1: Poplar cultivation

As explained above, poplar is currently cultivated in EU mostly for pulp and for furniture with rotations ranging typically around 9 – 12 years.

However, poplar has been considered also as a species suitable for biomass for energy production under short rotation practices. Significant variations in yields and agricultural practices can be found in the literature, since interest in woody biomass for bioenergy is still recent (see for example Hauk et al., 2014).

Dedicated SRC cultivation of poplar can undergo a rather intensive management (irrigation, weed and pest control, fertilization). However, poplar can also be cultivated in marginal land or in areas where other cultures cause significant nitrogen leaching (e.g. buffer strips).

In order to reflect these two possible situations, two processes are proposed and described in Table 59 and Table 60.

Table 59. Process for cultivation of poplar (fertilized)

Plantation of poplar				
	I/O	**Unit**	**Amount**	**Source**
Diesel	Input	$MJ/MJ_{wood\ chips}$	0.0126	1
N fertilizer (synthetic)	Input	$kg/MJ_{wood\ chips}$	0.0	1
Organic fertilizer (manure)	Input	$kg/MJ_{wood\ chips}$	0.0752	1
Pesticides	Input	$kg/MJ_{wood\ chips}$	0.000015	1
Poplar cuttings	Input	$kg/MJ_{wood\ chips}$	0.00021	1
Woodchips	Output	MJ	1.0	-
Field N_2O emissions	-	$g/MJ_{wood\ chips}$	0.0067	1,2
CH_4	Output	$g/MJ_{wood\ chips}$	1.61E-05	3
N_2O	Output	$g/MJ_{wood\ chips}$	3.98E-05	3

Comments

— LHV dry = 19 MJ/kg.

— Moisture = 50 %.

— Yield = 14 t dry substance/(ha*yr) [1].

— Diesel = 93.5 l diesel/(ha*yr) [1].

— Manure = 20000 kg /(ha*yr) [1].

— Assumed total N = 0.4% N over wet manure. Total = 80 kgN/ha/yr.

— Pesticides / herbicides = 4 kg/(ha*yr) [1].

— This step is common for Pathways no 2b, no 6b and nr 10b.

— The process models poplar cultivated in Ukraine on suitable land using organic fertilizer.

— This process considers the use of a combined harvester-chipper, so that the final products are directly wood chips.

Table 60. Process for cultivation of poplar (No fertilization)

Plantation of poplar				
	I/O	**Unit**	**Amount**	**Source**
Diesel	Input	$MJ/MJ_{wood\ chips}$	0.0176	1
N fertilizer (synthetic)	Input	$kg/MJ_{wood\ chips}$	0.0	
Organic fertilizer (manure)	Input	$kg/MJ_{wood\ chips}$	0.0	
Pesticides	Input	$kg/MJ_{wood\ chips}$	2.11E-05	1
Poplar cuttings	Input	$kg/MJ_{wood\ chips}$	2.89E-4	1
Wood chips	Output	MJ	1.0	-
Field N_2O emissions	-	$g/MJ_{wood\ chips}$	0.0	
CH_4	Output	$g/MJ_{wood\ chips}$	2.25E-05	3
N_2O	Output	$g/MJ_{wood\ chips}$	5.57E-05	3

Comments

— LHV dry = 19 MJ/kg.

— Moisture = 50 %.

— Yield = 10 t dry substance/(ha*yr) [1].

— Yield is considered about 30% lower than the fertilized case as reported by Di Candilo et al., 2010.

— Diesel = 93.5 l diesel/(ha*yr) [1].

— Manure = 20000 kg /(ha*yr) [1].

— Pesticides / herbicides = 4 kg/(ha*yr) [1].

— This step is common for Pathways no 2b, no 6b and nr 10b.

— The process models poplar cultivated in Ukraine on suitable land using no fertilizer.

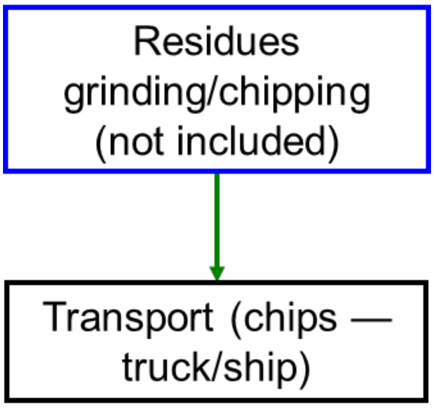
— This process considers the use of a combined harvester-chipper, so that the final products are directly wood chips.

Sources (for Table 59 and Table 60)

1. Franke, B.; Reinhardt, G.; Malavelle, J.; Faaij, A.; Fritsche, U. Global Assessments and Guidelines for Sustainable Liquid Biofuels. A GEF Targeted Research Project. Heidelberg/Paris/Utrecht/Darmstadt, 29 February 2012.
2. IPCC, 2006, N_2O Guidelines.
3. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 – Agricultural machinery.

The other steps are the same as described for the pathway 2a (Eucalyptus).

6.1.4 Woodchips from wood industry residues (Pathway no 3)

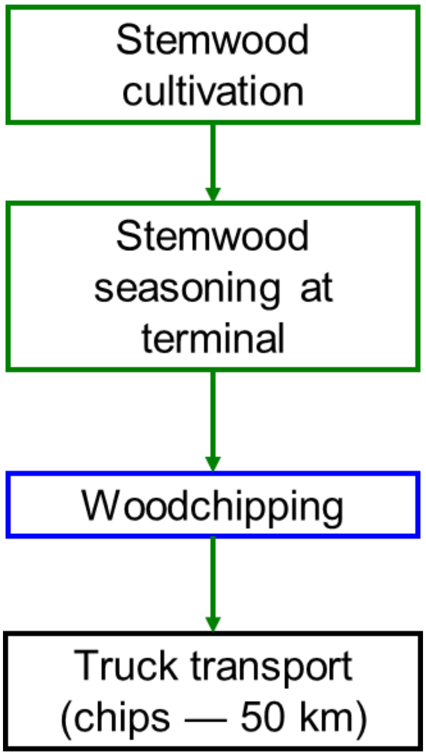


Residues from the wood industry such as sawdust and wood shavings are indeed considered as residues, and so no emissions are allocated to these products from their upstream processes. Moreover, they are already delivered as small chips, and thus do not require any additional processing before being delivered and transported.

Step 1: Transport

See Table 53, Table 54 and Table 55 for the detailed values.

6.1.5 Woodchips from stemwood (Pathway no 4)



Step 1: Cultivation and harvest of stemwood

Table 61. Process for cultivation and harvesting of stemwood

Cultivation of stemwood (mainly pine)				
	I/O	**Unit**	**Amount**	**Source**
Diesel	Input	MJ/MJ_{bio}	0.0107	1, 2
Biomass	Output	MJ	1.0	
CH_4	Output	g/MJ_{bio}	8.16E-06	3
N_2O	Output	g/MJ_{bio}	3.41E-05	3

Comments

— LHV dry = 19 MJ/kg.

— Moisture = 50 %.

— The effects of standing carbon stock change are not included in the calculations. See for example (Agostini et al., 2014) for a discussion on the issue.

— Even though fertilisation is included in the operations considered (diesel consumption), no N_2O emissions are included in the process nor emissions for N-fertilizer production because fertilisation of native forests with urea is not a common practice in Europe but it is limited to a few parts of Scandinavia.

Sources

1. Berg and Lindholm, 2005.
2. Aldentun, 2002.
3. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 – Forestry.

The data collected include diesel, petrol, engine oil and electricity consumption for the following steps:

— Seedling production and cultivation (from Aldentun (2002))
— Soil scarification
— Cut-over clearing
— Fertilisation (energy for application of fertiliser)
— Cleaning
— Regeneration
— Logging
— Forwarding to terminal.

The value for energy consumption in stemwood cultivation and harvesting was checked against additional literature sources. The investigation concluded that the value chosen is appropriate for several cases in European countries.

Other sources indicate values of diesel consumption for forestry harvesting in the range of 0.6 % to 0.8 % [MJdiesel/MJstemwood], but most of these values are only for the actual mechanical harvesting and primary hauling (Schwaiger and Zimmer, 2001; Michelsen et al., 2008). The value chosen by the JRC also includes energy consumption for seedling establishment and forest regeneration. Values for non-Scandinavian countries might differ slightly regarding the latest processes, but we do not expect large variations on the harvesting/logging operations, which are the most energy intensive processes.

Possible future improvements might include the use of urea as nitrogen fertilizer, if this practice becomes more common in European forests. This would imply additional emissions of N_2O from the soil and the emissions associated to the production and application of urea balanced by the increased productivity of the forest (Sathre et al., 2010; Adams et al., 2005; Nohrstedt, 2001).

Sources

1. Schwaiger, H. and Zimmer, B., 2001.
2. Michelsen et al., 2008.
3. Nohrstedt, H-Ö., 2001.
4. Adams et al., 2005.
5. Sathre et al., 2010.

Step 2: Wood seasoning

By storage of stemwood stems at a central terminal for a period of 3 to 12 months, it is possible to reduce the moisture of the wood, from 50 % down to about 30 %. This is essential to bring down costs and energy use in long-distance hauling of low-bulk, high-moisture biomass such as woodchips. The moisture loss is, however, accompanied by dry matter losses due to bacterial activity within the stored wood.

The storage technique is essential in order to minimise dry matter losses; for this reason, this pathway is considered as the open-air storage of stems, covered with plastic or paper wrap, for a period of 3 to 8 months.

Table 62. Process for seasoning of stemwood at central terminal

Stemwood seasoning at roadside				
	I/O	**Unit**	**Amount**	Source
Wood	Input	MJ/MJ_{wood}	1.053	1, 2
Wood	Output	MJ	1.0	

Comments

- LHV dry = 19 MJ/kg.
- Moisture = from 50 % to 30 %.
- It includes open air seasoning at terminal with the stems covered from rain.
- Storage is usually for a period of 3 to 8 months.
- 5 % of dry matter losses are considered.
- No emissions of methane are considered for this step in these conditions.
- This process is used for the woodchips pathways prior to chipping and prior to long-distance hauling.

Sources

1. Hamelinck, 2005.
2. Kofman, 2012.

Step 3: Transport

See Table 53, Table 54 and Table 55 for the detailed values.

6.2 Pellets

Pellets are a solid biofuel with consistent quality — low moisture content, high energy density and homogeneous size and shape.

The transportation schemes for the pathways involving the use of pellets are shown in Table 63.

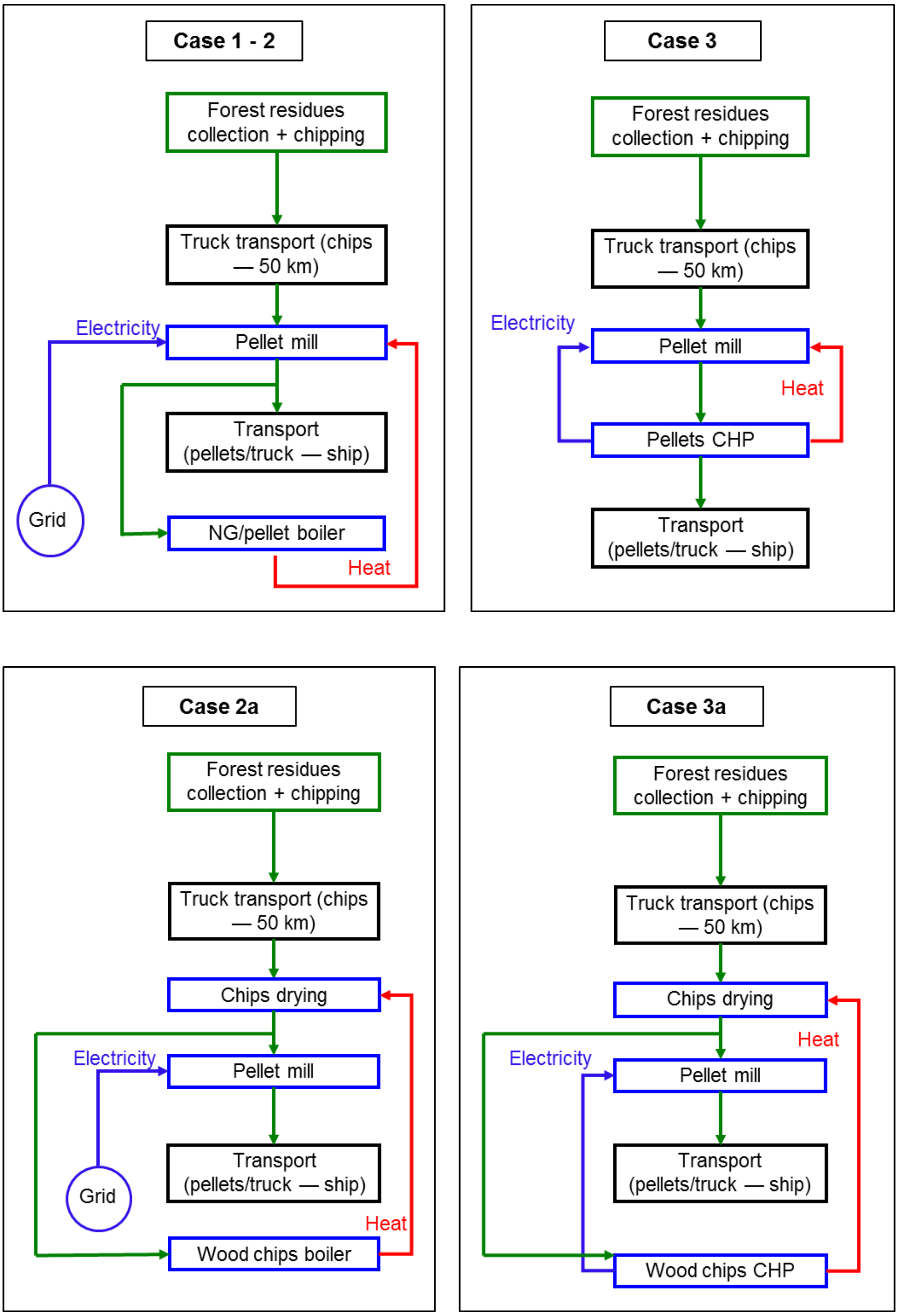
Table 63. Transportation scheme for pellets pathways

	Total travel-distance range	**Truck (chips)**	**Truck (pellets)**	**Train**	**Ship**	**Notes**
Pellets pathways	1–500 km	50	500			Intra-EU
	500 – 2500 km	50	250		2 000	E.g. Russia
	2500–10 000 km	50	200		8 000	E.g. Brazil
	Above 10 000 km	100		750	16 500	E.g. Western Canada

Three cases are considered for the pellets pathways, depending on the fuel source used for drying the feedstock in the pellet mill:

- **Case 1:** Process heat from a fossil-fuelled boiler (usually NG);
- **Case 2:** Process heat from an industrial pellet boiler;
- **Case 2a:** Process heat from an industrial wood chips boiler;
- **Case 3:** Process heat and electricity from a pellet CHP based on ORC technology.
- **Case 3a:** Process heat and electricity from a wood chips CHP based on ORC technology.

6.2.1 Pellets from forest logging residues and stumps (Pathway no 5)



Step 1: Forest residues collection and chipping

The same processes are used as in Pathway no 1; see Table 50 and Table 52.

Step 2: Transport

The transport processes are described in detail in Chapter 4 and are not repeated here.

Transportation distances are calculated as explained in Chapter 4, and are reported in Table 64, Table 65, Table 66 and Table 67.

These processes are common to all the pellet pathways, including the woodchips transport to the pellet mill.

Table 64. Transport distance via a 40 t truck for woodchips to pellet mill

Transport of wood pellets via a 40 t truck over the planned distances (one way)				
	I/O	**Unit**	**50 km**	**100 km**
Distance	Input	$tkm/MJ_{woodchips}$	0.0055	0.0109
Woodchips	Input	$MJ/MJ_{woodchips}$	1.0	1.0
Woodchips	Output	MJ	1.0	1.0

Comments

— LHV (woodchips) = 19 MJ/kg dry.

— Moisture (woodchips) = 50 %.

Table 65. Transport distance via a 40 t truck for wood pellets to final destination

Transport of wood pellets via a 40 t truck over the planned distances (one way)				
	I/O	**Unit**	**200 km**	**500 km**
Distance	Input	$tkm/MJ_{wood\ pellets}$	0.0126	0.0316
Woodchips	Input	$MJ/MJ_{wood\ pellets}$	1.0	1.0
Wood pellets	Output	MJ	1.0	1.0

Table 66. Transport distance via a bulk carrier for wood pellets to final destination

Maritime transport of wood pellets over the planned distances (one way)				
	I/O	**Unit**	**8 000 km**	**16 500 km**
Distance	Input	$tkm/MJ_{wood\ pellets}$	0.4678	0.9649
Wood pellets	Input	$MJ/MJ_{wood\ pellets}$	1.0	1.0
Wood pellets	Output	MJ	1.0	1.0

Table 67. Transport distance via a freight train for wood pellets to port

Transport of wood pellets via a train over a distance of 750 km (one way)			
	I/O	**Unit**	**Amount**
Distance	Input	$tkm/MJ_{wood\ pellets}$	0.0439
Wood pellets	Input	$MJ/MJ_{wood\ pellets}$	1.0
Wood pellets	Output	MJ	1.0

Comments

- LHV (wood pellets) = 19 MJ/kg dry.
- Moisture (wood pellets) = 10 %.

Step 3: Pellet mill

The JRC received data for pellet mills energy inputs from Dr Sven-Olov Ericson for Swedish sources, and from Mr. Yves Ryckmans from Laborelec. These data are representative of more than 50 pellet plants worldwide, processing different feedstocks in various combinations (from sawmill residues to 100 % stemwoodchips), and are based on real figures audited by an accredited independent company.

According to this new information, the data for electricity consumption in a pellet mill using fresh chips (considered at 50 % moisture) have been defined as shown in Table 68.

Table 68. Process for the production of pellets from fresh woodchips

Production of wood pellets & briquettes from fresh forest chips: moisture ~ 50 %, and final pellet moisture 10 %				
	I/O	**Unit**	**Amount**	**Source**
Woodchips	Input	$MJ/MJ_{wood\ pellets}$	1.01	4
Electricity	Input	$MJ/MJ_{wood\ pellets}$	0.050	5
Heat	Input	$MJ/MJ_{wood\ pellets}$	0.185	1,2
Diesel	Input	$MJ/MJ_{wood\ pellets}$	0.0020	1,3
Wood pellets	Output	MJ	1.00	
CH_4	Output	$g/MJ_{pellets}$	1.53E-06	6
N_2O	Output	$g/MJ_{pellets}$	6.40E-06	6

Sources

1. Hagberg et al.,2009.
2. Obernberger, I. and Thek, G., *The Pellet Handbook*, 2010.
3. Mani, 2005.
4. Sikkema et al., 2010.
5. Ryckmans, 2012.
6. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 – Forestry.

The values for a pellet mill using a mix of wet and dry sawdust have been left unchanged, since the current values were confirmed by the new information received.

The values for heat and fuel for internal consumption have also remained unchanged, and they are in the range indicated by several independent sources (Hagberg et al., 2009; Obernberger and Thek, 2010; Mani, 2005). The heat demand is based on the value of 1100 kWh/tonne of evaporated water (as indicated by Obernberger and Thek

(2010)) and considering a drying of the feedstock from 50% moisture input down to 10% moisture in output.

All the wood chips delivered at 50% at the plant are considered to be dried down to 10% before being utilised either in the pellet mill or in the chips boiler or CHP.

The addition of a limited amount of organic additives is permitted under international standards; however, the use of such materials is generally limited to pellets for domestic use, since they need better characteristics to work efficiently in small-scale domestic stoves. The amounts used are also limited, and vary greatly throughout the market; additives can also be avoided with proper mixing and steam conditioning of the feedstocks (Obernberger and Thek, 2010). The JRC decided therefore not to include the energy and emissions due to additives. If their use becomes more important in future, the JRC will update the pathways.

Comments

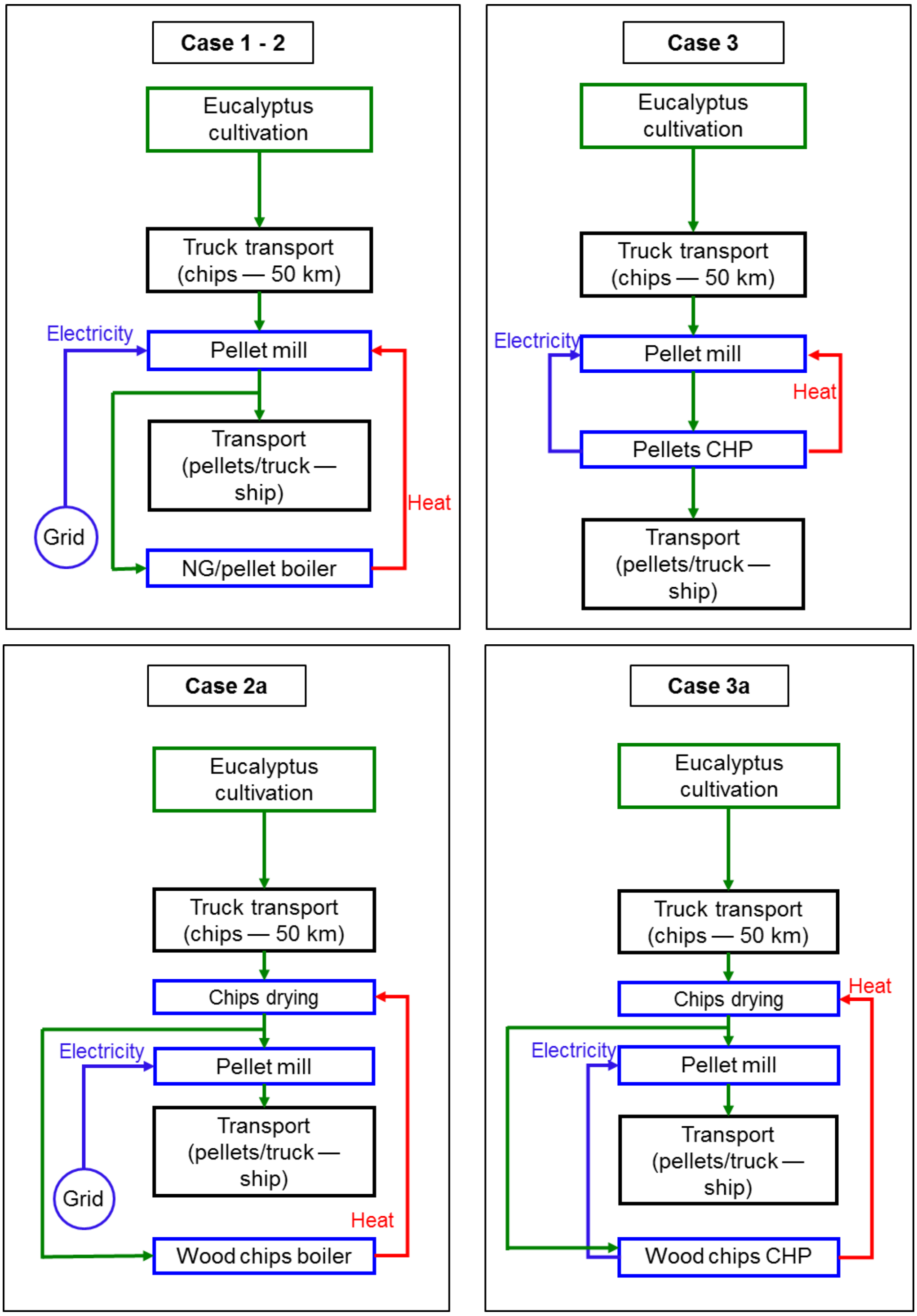
- Pellets LHV dry = 19 MJ/kg.
- Moisture woodchips = 50 %.
- Moisture pellets = 10 %.
- Bulk density (chips) = 0.155 dry tonne/m^3.
- Bulk density (pellets) = 0.650 dry tonne/m^3.
- Fuel: diesel for internal handling of wood.
- Electricity consumption was measured at the plant gates and it thus includes not only consumption by the pellet press but also consumption from all auxiliaries (drying, boilers offices etc…).
- This process is similar for all pathways involving pellet production from fresh chips.

The electricity needed for the process can be either taken from the grid at 0.4kV (cases 1, 2 and 2a) or produced internally by CHP (Case 3 and 3a).

The heat needed can be produced by a NG boiler (Case 1), by a pellet boiler (Case 2), by a chips boiler (Case 2a), by pellet CHP (Case 3) or by chips CHP (Case 3a).

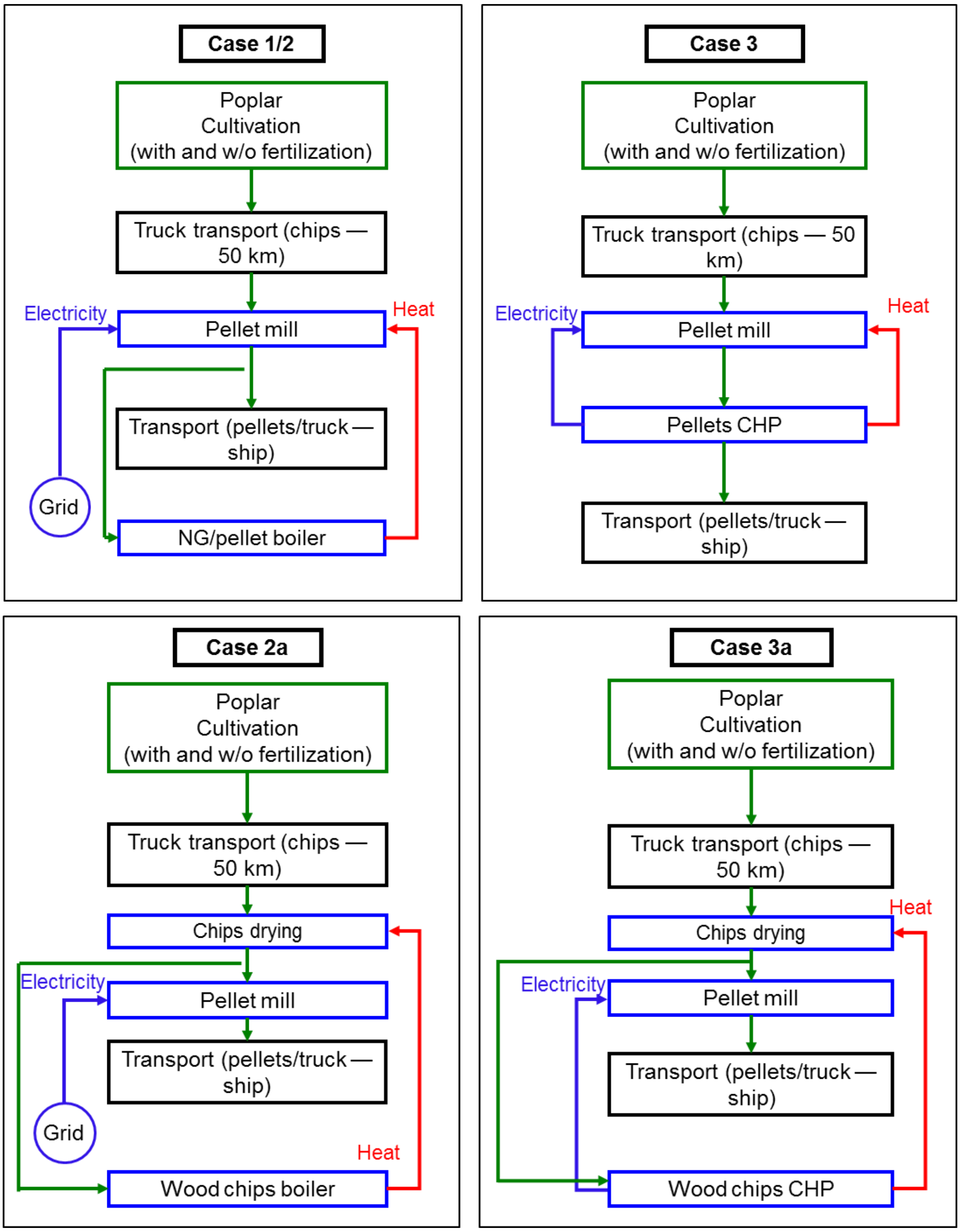
The processes for these auxiliary components are summarised in Table 17, Table 18, Table 19, Table 20 and Table 21.

6.2.2 Pellets from SRC - Eucalyptus (Pathway no 6a)



The processes involved in this pathway have been all previously described in Table 56, Table 57 and Table 68. The transport distances are indicated in Table 64, Table 65, Table 66 and Table 67.

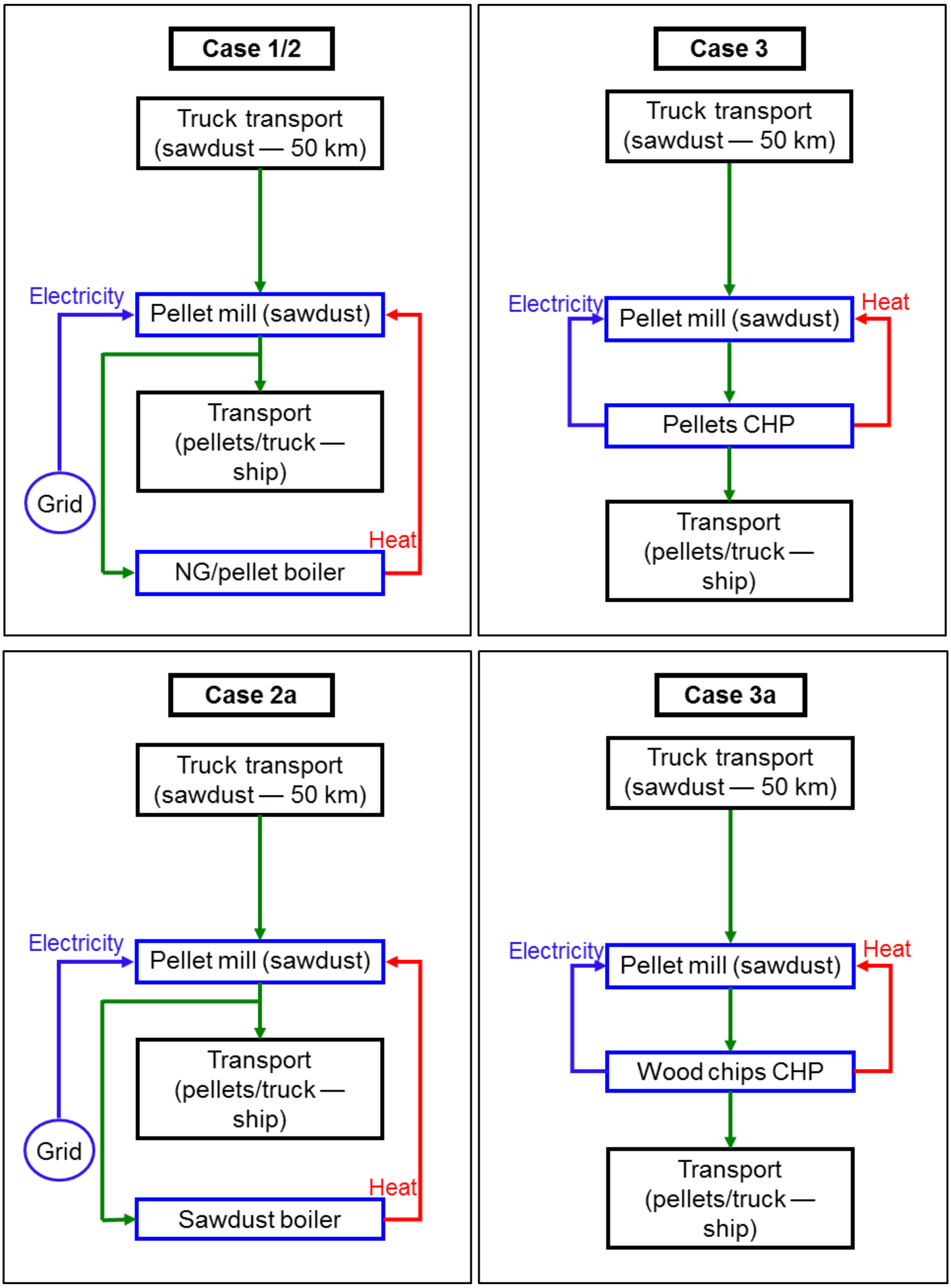
6.2.3 Pellets from SRC - Poplar (Pathway no 6b-6c)



The processes involved in this pathway have been all previously described in Table 59, Table 57 and Table 68.

The transport distances are indicated in Table 64, Table 65, Table 66 and Table 67

6.2.4 Pellets from wood industry residues (Pathway no 7)



Step 1: Pellet mill

For this pathway, a different process for the pellet mill is needed, because of the lower consumption of electricity (less power is needed for the grinding phase, compared to chips), and of heat (since the mix of wet and dry feedstock has a lower moisture content than fresh chips).

Table 69. Process for the production of pellets from a mix of wet and dry residues

Production of wood pellets & briquettes from wood industry residues				
	I/O	**Unit**	**Amount**	**Source**
Sawdust	Input	$MJ/MJ_{wood\ pellets}$	1.01	5
Electricity	Input	$MJ/MJ_{wood\ pellets}$	0.028	1, 3, 4
Heat	Input	$MJ/MJ_{wood\ pellets}$	0.111	1, 2
Diesel fuel	Input	$MJ/MJ_{wood\ pellets}$	0.0016	1, 3
Wood pellets	Output	MJ	1.00	
CH_4	Output	$g/MJ_{pellets}$	1.23E-06	6
N_2O	Output	$g/MJ_{pellets}$	5.12E-06	6

Comments

— Chips/pellets LHV dry = 19 MJ/kg.

— Moisture pellets = 10 %.

— Moisture wet sawdust = 50 %.

— Moisture dry sawdust = 10 %.

— Fuel: diesel internal transport.

— Bulk density (chips) = 0.155 dry t/m^3.

— Bulk density (pellets) = 0.650 dry t/m^3.

— The results are a weighted average between the process for dry and wet industry residues. The weight was based on market research and it amounts to 60 % wet and 40 % dry sawdust. [4]

— For the cases 2a and 3a it is considered that only the dry part of sawdust is used to fuel the boiler and the CHP.

— Electricity consumption was measured at plant gate so it includes both consumption for pellet press but also for auxiliaries (drying, boilers, offices etc…).

Sources

1. Hagberg et al., IVL, 2009;
2. Obernberger and Thek, 2010;

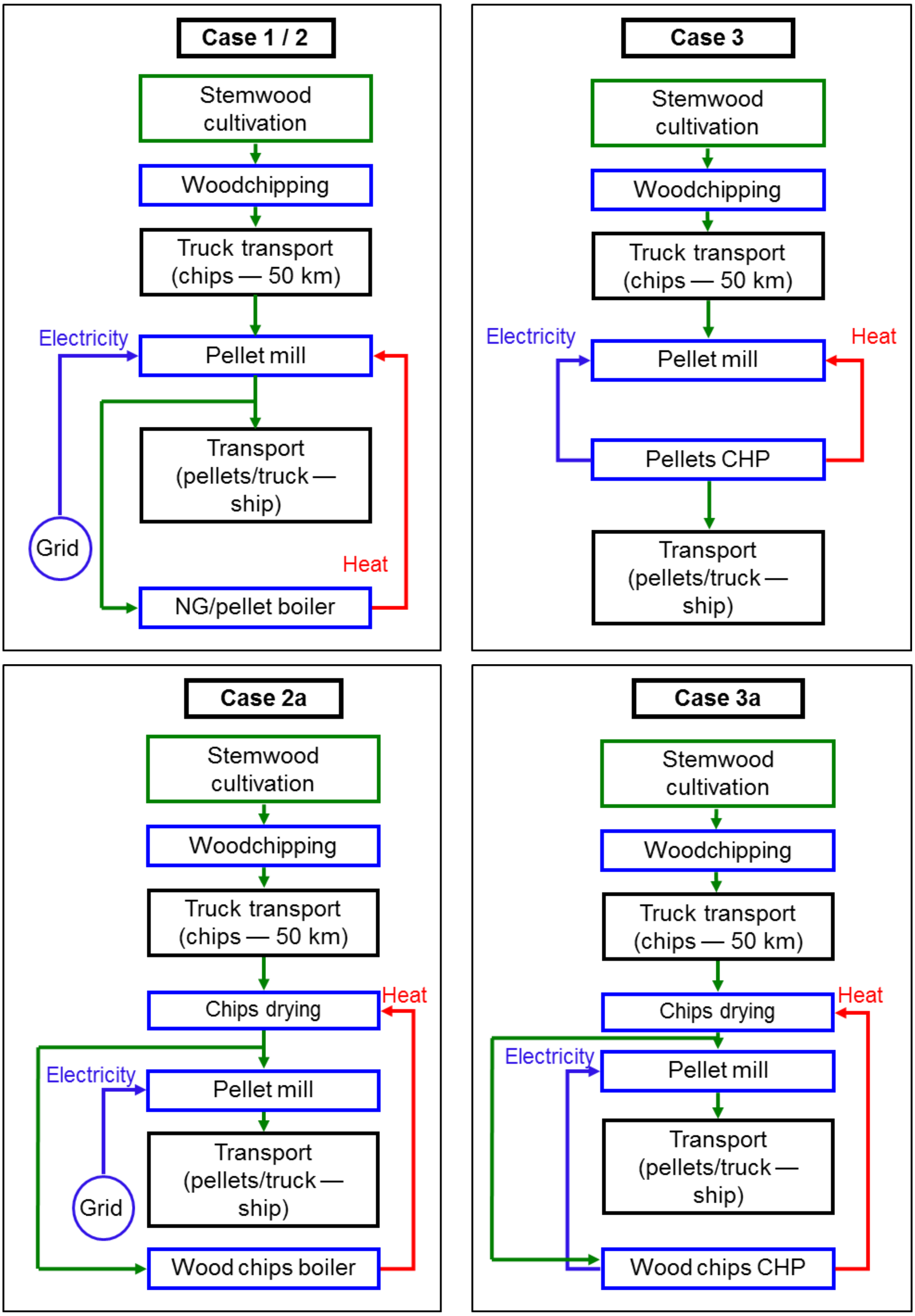
3. Mani, S., 2005;
4. Christian Rakos, Propellets Austria, personal communication, 27 June 2011.
5. Sikkema et al., 2010.
6. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 – Forestry.

The electricity needed for the process can be taken either from the grid at 0.4 kV (cases 1, 2 and 2a) or produced internally by CHP (Case 3 and 3a). The heat needed can be produced by a NG boiler (Case 1), by a pellet/sawdust boiler (Case 2/2a) or by CHP (assumed equal to the process used for wood chips) (Case 3/3a).

Step 2: Transport

The transport distances are indicated in Table 64, Table 65, Table 66 and Table 67.

6.2.5 Pellets from stemwood (Pathway no 8)



All the processes of this pathway have been already described and can be found in Table 61, Table 57 and Table 68.

The transport distances are indicated in Table 64, Table 65, Table 66 and Table 67.

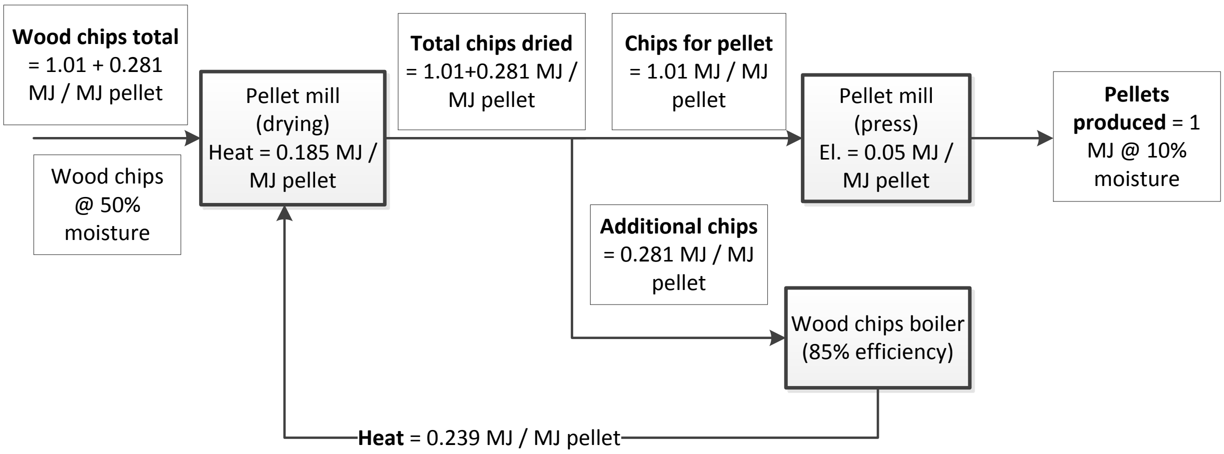
Additional INFO nr. 3: Details on calculations for cases 2a and 3a and exergy allocation.

Calculation of additional feedstock needed to fuel internal boiler/CHP

Cases 2a and 3a.

In these cases the intermediate product of the pellet mill (dried wood chips) are used to supply the power and heat needed by the mill itself. This solution is the most commonly used in practice. Other residues are generally used for power and heat production, such as bark, but pre-drying is often still necessary (since the fresh bark has a moisture >50%) and the only bark is generally not enough to provide energy for the whole mill. So, in this calculation it is assumed that all the power and heat are supplied by wood chips.

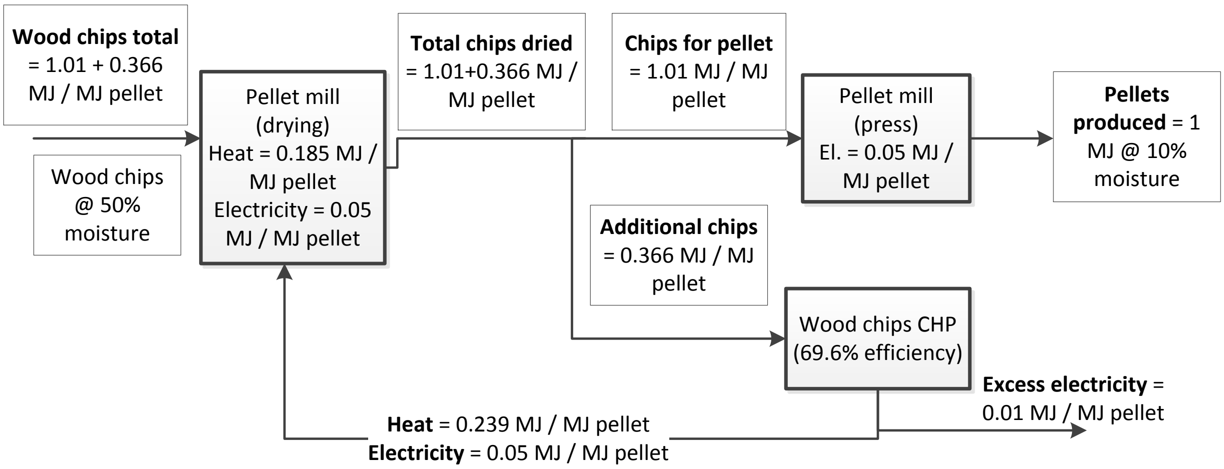
Case 2a:



The additional chips to be supplied can be calculated as:

$$Additional\ chips = \frac{Heat_{mill} * 1.01}{(\eta_{th.} - Heat_{mill})} = \frac{0.185 * 1.01}{(0.85 - 0.185)} = 0.281\ MJ/MJ_{pellet\ produced}$$

Case 3a:



In the case of a CHP engine fuelled with wood chips it is not possible anymore to dimension the CHP on the power needs only, because the heat requirement would not be fulfilled. Therefore, the CHP is dimensioned over the heat demand and an excess electricity is exported to the grid.

The additional chips required can be calculated as follows:

$$Additional\ chips = \frac{Heat_{mill} * 1.01}{(\eta_{th.} - Heat_{mill})} = \frac{0.185 * 1.01}{(0.696 - 0.185)} = 0.366\ \ MJ/MJ_{pellet\ produced}$$

This amount of wood chips would produce the following excess electricity:

$$Excess\ electricity = (additional\ chips *\ \eta_{el.}) - El._{mill} = (0.366 * 0.163) - 0.05$$
$$= 0.096\ \ MJ/MJ_{pellet\ produced}$$

Calculation of exergy allocation for internal CHP

The use of a CHP internally to any pathways to produce process heat and electricity and excess heat or electricity requires emissions to be properly allocated between the produced heat and power.

In the case 3a or case 1 of the biogas pathways, this has been done for the default values calculations.

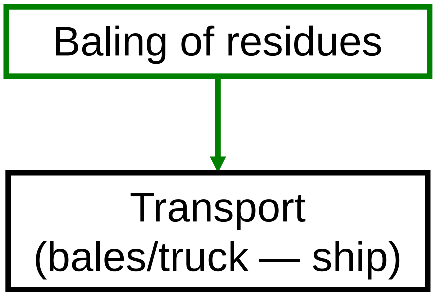
The Case 1 of biogas pathways is particular because the CHP is the last step of chain and also the excess electricity is in this case the main functional unit. In this case, considering only the net power produced, and assigning no emissions to the process heat and electricity used in the digester, produces the same result as solving an exergy allocation. This simpler approach is what was used to calculate the results in Table 103.

Case 3a for pellet mills using CHPs instead requires the solution of an algebraic system of equations to calculate the exergy allocation of emissions between process heat and electricity used for pellet production and exported electricity from the pellet mill.

In both cases, the heat needed is at low temperature and thus allocation is done considering a temperature of 150°C or lower.

6.3 Other raw materials

6.3.1 Agricultural residues with bulk density <0.2 tonne/m^3 (Pathway no 11)

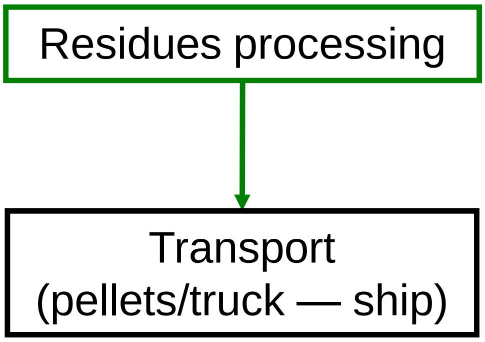


This group of materials includes agricultural residues with a low bulk density; it includes materials such as: *straw bales (chosen as a model component), oat hulls, rice husks and sugar cane bagasse bales*.

Properties of model compound:

- bulk density: 0.125 tonne/m^3
- LHV dry = 18 MJ/kg
- moisture = 13 %.

6.3.2 Agricultural residues with bulk density >0.2 tonne/m^3 (Pathway no 12)



The group of agricultural residues with higher bulk density includes materials such as: *corn cobs, nut shells, soybean hulls and palm kernel shells*.

Properties of model compound:

- bulk density: 0.3 tonne/m^3
- LHV dry = 18 MJ/kg
- moisture = 13 %.

Step 1: Processing

Since all of these materials require a preprocessing step before being transported, whether this be baling or additional grinding or clustering, one single process was chosen, and it was assimilated to the process for baling straw.

Table 70. Process for agri-residues preprocessing

Baling/processing				
	I/O	**Unit**	**Amount**	**Source**
Agri-residue	Input	MJ/MJ_{bale}	1.0	1
Diesel	Input	MJ/MJ_{bale}	0.010	1
Bales	Output	MJ	1.0	1
CH_4	Output	g/MJ_{bale}	1.23E-05	2
N_2O	Output	g/MJ_{bale}	3.03E-05	2

Comments

— This process is valid for straw baling, but can also be considered valid for other processes such as nut crushing.

— This process is used in both agricultural residues pathways (no 11 and no 12), but also for straw baling in the straw pellets pathway (no 13).

Sources

1. GEMIS v. 4.9, 2014, Xtra-residue\straw bales-DE-2010.
2. EMEP/EEA Guidebook 2013, Chapter 1.A.4.c.ii - Tier 1 - Table 3-1 – Agricultural Machines.

Step 2: Transport

Table 71. Transport distances via a 40 t truck of agri-residues to final destination

Transport of agri-residues via a 40 t truck over the planned distances (one way)					
	I/O	**Unit**	**200 km**	**250 km**	**500 km**
Distance	Input	$tkm/MJ_{residues}$	0.0133	0.0166	0.0332
Agri-residues	Input	$MJ/MJ_{residues}$	1.0	1.0	1.0
Agri-residues	Output	MJ	1.0	1.0	1.0

Table 72. Transport distances via a bulk carrier of agri-residues to final destination

Maritime transport of agri-residues over the planned distances (one way)					
	I/O	**Unit**	**2 000 km**	**8 000 km**	**16 500 km**
Distance	Input	$tkm/MJ_{residues}$	0.1277	0.5109	1.0536
Agri-residues	Input	$MJ/MJ_{residues}$	1.0	1.0	1.0
Agri-residues	Output	MJ	1.0	1.0	1.0

Table 73. Transport distance via a freight train of agri-residues to port

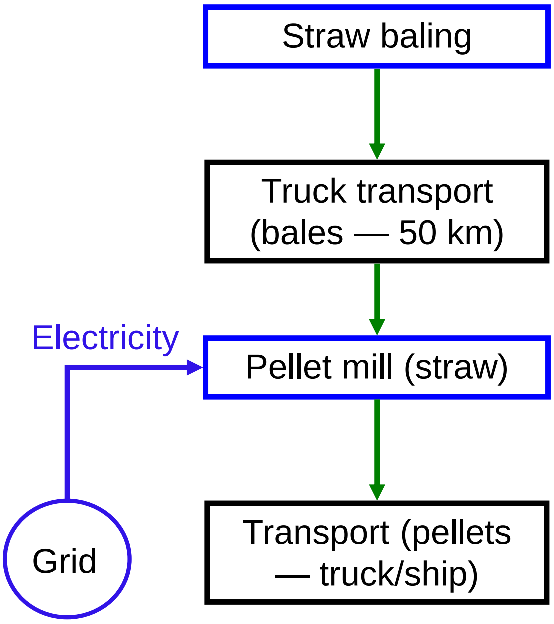
Transport of agri-residues via a train over a distance of 750 km (one way)			
	I/O	**Unit**	**Amount**
Distance	Input	$tkm/MJ_{residues}$	0.0479
Agri-residues	Input	$MJ/MJ_{residues}$	1.0
Agri-residues	Output	MJ	1.0

Comments

— LHV dry (residues) = 18 MJ/kg.

— Moisture (residues) = 13 %.

6.3.3 Straw pellets (Pathway no 13)



Step 1: Baling

The process for straw baling is assumed to be the same as the process illustrated in Table 70.

Step 2: Pellet mill

Table 74. Process for the production of pellets from straw bales

Production of straw pellets				
	I/O	Unit	Amount	Source
Straw bales	Input	MJ/MJ_{pellet}	1.01	1,4
Electricity EU mix LV	Input	MJ/MJ_{pellet}	0.020	1,2,3,5
Straw pellets	Output	MJ	1.0	

Comments

- LHV dry (straw) = 17.2 MJ/kg.
- Moisture pellets = 10 %.
- Moisture bales = 13.5 %.
- Bulk density (bales): 0.125 dry tonne/m^3.
- Bulk density (pellets): 0.650 dry tonne/m^3.
- The electricity needed is taken from the grid.
- No process heat is needed since straw is already sufficiently dry by nature.
- The electricity consumption is an average value among the sources 1 to 4.

Sources

1. Sultana et al., 2010.
2. GEMIS v. 4.9, 2014, *processing/straw-EU-pellets-2020.*
3. Pastre, O., Analysis of the technical obstacles related to the production and the utilisation of fuel pellets made from agricultural residues, EUBIA, Pellets for Europe, 2002.
4. Sikkema et al., 2010.
5. Giuntoli et al., 2013.

Step 3: Transport

Table 75. Transport distances via a 40 t truck of straw bales to pellet mill

Transport of straw bales via a 40 t truck over the planned distances (one way)				
	I/O	**Unit**	**50 km**	**100 km**
Distance	Input	tkm/MJ_{bales}	0.0035	0.0070
Straw bales	Input	MJ/MJ_{bales}	1.0	1.0
Straw bales	Output	MJ	1.0	1.0

Table 76. Transport distances via a 40 t truck for straw pellets to final destination or port

Transport of straw pellets via a 40 t truck over the planned distances (one way)				
	I/O	**Unit**	**200 km**	**500 km**
Distance	Input	$MJ/MJ_{straw\ pellet}$	0.0140	0.0349
Straw pellets	Input	$MJ/MJ_{straw\ pellet}$	1.0	1.0
Straw pellets	Output	MJ	1.0	1.0

Table 77. Transport distances via a bulk carrier for straw pellets to final destination

Maritime transport of straw pellets over the planned distances (one way)				
	I/O	**Unit**	**8 000 km**	**16 500 km**
Distance	Input	$MJ/MJ_{straw\ pellet}$	0.5168	1.0659
Straw pellets	Input	$MJ/MJ_{straw\ pellet}$	1.0	1.0
Straw pellets	Output	MJ	1.0	1.0

Table 78. Transport distances via a freight train for straw pellets to port

Transport of straw pellets via a train over a distance of 750 km (one way)			
	I/O	**Unit**	**Amount**
Distance	Input	$MJ/MJ_{straw\ pellet}$	0.0484
Straw pellets	Input	$MJ/MJ_{straw\ pellet}$	1.0
Straw pellets	Output	MJ	1.0

Comments

— LHV dry (straw) = 17.2 MJ/kg.

— Moisture (straw bales) = 13.5 %.

— Moisture (straw pellets) = 10 %.

Straw bales transportation

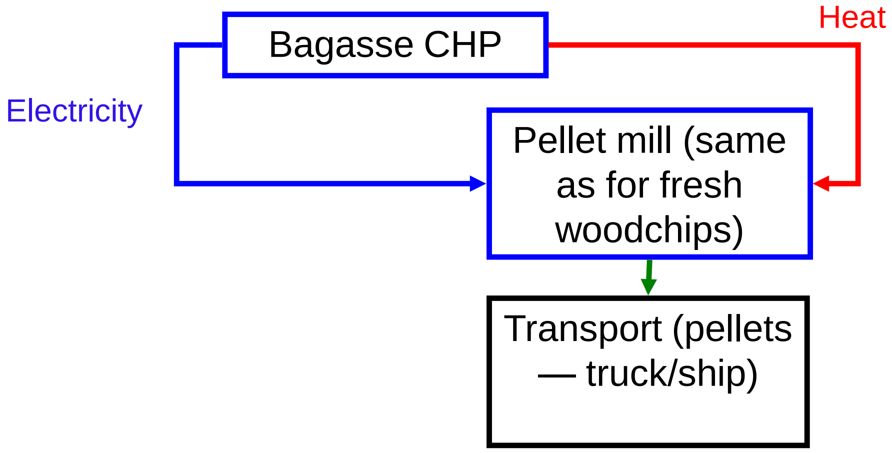
It was suggested during the workshop that, due to the limited scales of projected straw pellets production facilities, the distance for transport of bales could be reduced from the originally stated 50 km. However, in view of future development with larger-scale plants and with the objective of being conservative in the choice of values, the JRC decided to maintain the value of 50 km for transportation of straw bales from the field to the processing plant.

Moreover, Sultana and Kumar (2011) indicate that for a Canadian situation, the optimum radius of straw collection could even be as high as 94 km. In another reference, Monforti et al. (2013) have suggested an average transport distance of 70 km to supply a CHP straw-fired power plant of 50 MWth capacity.

Sources

1. Sultana, A. and A. Kumar, 2011.
2. Monforti et al., 2013.

6.3.4 Bagasse pellets/briquettes (Pathway no 14)



Step 1: Utilities

While bagasse bales are included in Pathway no 12 with other similar residues, the production of pellets requires an additional process and thus a different pathway.

For the purposes of this work, the process for a pellet mill is considered to be the same as the one for pellets from fresh woodchips described in Table 68.

Moreover, no transport of the bagasse bales is considered, because it is assumed that the production of pellets is carried out in the sugar mill and thus the associated emissions do not need to be allocated to the bagasse.

Table 79. Process for bagasse CHP

Bagasse CHP				
	I/O	**Unit**	**Amount**	**Source**
Bagasse	Input	MJ/MJ_{heat}	2.1676	2
Heat	Output	MJ_t	1.0	2
Electricity	Output	MJ/MJ_{heat}	0.3621	2
CH_4 emissions	-	g/MJ_{heat}	0.0053	1
N_2O emissions	-	g/MJ_{heat}	0.0027	1

Comments

— LHV dry (bagasse) ([16]) = 17.0 MJ/kg.

— Moisture = 50 %.

— Thermal efficiency (on LHV) = 46.1 %.

— Electrical efficiency (on LHV) = 16.7 %.

— The process produces excess electricity which is exported to the grid.

— The process heat is fully provided by the CHP.

— Methane and N_2O, despite being biogenic, are included in the GHG emissions from the process.

([16]) See for example: Phyllis database https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#bagasse (last accessed July 2014)

Sources

1. GEMIS v. 4.9, 2014. *Bagasse-ST-BR-2010*.
2. Fulmer, 1991.

Step 2: Transport

Table 80. Transport distances via a 40 t truck for bagasse pellets/briquettes to final destination

Transport of bagasse briquettes via a 40 t truck over the planned distances (one way)				
	I/O	**Unit**	**200 km**	**700 km**
Distance	Input	$tkm/MJ_{bagasse\ pellets}$	0.0141	0.0494
Bagasse pellets	Input	$MJ/MJ_{bagasse\ pellets}$	1.0	1.0
Bagasse pellets	Output	MJ	1.0	1.0

Table 81. Transport distances via a bulk carrier for bagasse pellets/briquettes to final destination

Maritime transport of bagasse pellets over the planned distances (one way)				
	I/O	**Unit**	**8 000 km**	**10 186 km**
Distance	Input	$tkm/MJ_{bagasse\ pellets}$	0.523	0.666
Bagasse pellets	Input	$MJ/MJ_{bagasse\ pellets}$	1.0	1.0
Bagasse pellets	Output	MJ	1.0	1.0

Comments

— LHV dry (bagasse) = 17.0 MJ/kg.

— Moisture (bagasse pellets) = 10 %.

— Bulk density (bagasse pellets) = 0.65 t/m^3.

— Bulk density dry (exit mill) ([17]) = 0.12 t/m^3

— Bulk density dry (bales) ([18]) = 0.17 kg/m^3

([17]) See for example: http://www.sugartech.co.za/density/index.php (last accessed July 2014)
([18]) See for example: http://www.sulekhab2b.com/viewoffer/sell/381529/biomass-briquettes-ground-nut-and-sugar-cane.htm (last accessed July 2014)

6.3.5 Palm kernel meal (Pathway no 15)

Palm kernel meal is a co-product from the production of palm oil together with palm kernel oil and nut shells, that is sometimes imported to be used for energy production. According to the RED, the allocation of emissions to the co-products needs to be carried out on the wet LHV of the products.

This leads to the following allocation factors, indicated in Table 82.

Table 82. Allocation to co-products of palm oil extraction from FFB

Component	**Wt. fraction (kg/kgFFB)**	**Moisture**	**Source**	**LHV wet (MJ/kg)**	**Outputs in wet LHV (MJ/kg FFB)**
Palm oil	0.200	0 %	1, 6	37	7.393
Palm kernel meal	0.029	10 %	2,3	16.4	0.481
Nutshells (used as fuel)	0.074	10 %	4, 5	17.1	0.00
Palm kernel oil	0.024	0 %		37	0.888
Total for allocation					**8.762**

Sources

1. Schmidt, 2007.
2. Chin, 1991,
3. JRC calculation.
4. Panapanaan, 2009.
5. Choo, 2011.
6. Pramod, 2009.

This leads to the allocated upstream process emissions, as indicated in Table 83.

Table 83. FFB cultivation emissions allocated by energy to all co-products

	I/O	Unit	Amount	Sources
FFB	Input	MJ/MJ_{PKM}	1.8079	See process POFA
Electricity	Input	MJ/MJ_{PKM}	6.6 E-05	
Diesel	Input	MJ/MJ_{PKM}	0.00375	
Palm kernel meal	Output	MJ	1.0	
Emissions				
CH_4 (open pond)	Output	g/MJ_{PKM}	0.8306	1
CH_4 (closed pond)	Output	g/MJ_{PKM}	0.1246	1

Comment

— The methane emissions come from the effluent stream. An additional pathway is created where these emissions are avoided.

Source

1. Choo, 2011.

For the upstream processes of FFB, see the pathway 'Palm oil to biodiesel'.

PKM is then transported by a 40 t truck (see Table 23 for fuel consumption) for 700 km, and by a bulk carrier for 16 287 km.

Table 84. Transport of PKM via a 40 t truck over 700 km

Transport of PKM via a 40 t truck over the planned distances (one way)			
	I/O	**Unit**	**700 km**
Distance	Input	tkm/MJ_{PKM}	0.0437
PKM	Input	MJ/MJ_{PKM}	1.0
PKM	Output	MJ	1.0

Table 85. Maritime transport of PKM via a bulk carrier over 16 287 km

Maritime transport of PKM via a bulk carrier over the planned distances (one way)			
	I/O	**Unit**	**16 287 km**
Distance	Input	tkm/MJ_{PKM}	0.7808
PKM	Input	MJ/MJ_{PKM}	1.0
PKM	Output	MJ	1.0

Additional INFO nr. 4: Non-CO_2 GHG emissions from the combustion of solid biomass fuels.

Table 86. Non-CO_2 GHG emissions from the combustion of solid biomass fuels.

Wood chips combustion	Unit	Amount	Source
CH_4	g/MJ fuel	0.005	1
N_2O	g/MJ fuel	0.001	1
$CO_{2\ eq.}$	g/MJ fuel	0.41	1
Wood pellets combustion	**Unit**	**Amount**	**Source**
CH_4	g/MJ fuel	0.003	2
N_2O	g/MJ fuel	0.0006	2
$CO_{2\ eq.}$	g/MJ fuel	0.25	2
Agri-residues combustion	**Unit**	**Amount**	**Source**
CH_4	g/MJ fuel	0.002	3
N_2O	g/MJ fuel	0.0007	3
$CO_{2\ eq.}$	g/MJ fuel	0.24	3

Sources:

1. GEMIS, version 4.9; 2014; wood-chips-forest-heat plant-1 MW-EU-2005
2. GEMIS, version 4.9; 2014; wood-pellet-wood-industry-heat plant-DE-2010
3. GEMIS, version 4.9; 2014; straw-pellet-heating-15 kW-DE-2030

Part Three — Results

7 GHG emissions calculation methodology and results: typical and default values

7.1 Methodology

The results reported in this part of the document are obtained using the input values detailed in the previous sections of the report and applying the simplified LCA methodology published in the Commission's *Proposal for a Directive on the use of energy from renewable sources (recast)* (COM(2016)767). A number of methodological choices previously introduced in SWD(2014) 259 were maintained in this document. A detailed description of the methodology can be found in Annex VI of COM(2016)767.

For clarity, the main relevant points of the methodology in the document are summarised below:

1. The methodology follows a simplified attributional life cycle assessment approach and it accounts only for direct GHG emissions associated with the supply chain of the bioenergy carriers.
2. Three main, long-lived GHG are considered: CO_2, CH_4 and N_2O. The climate metric utilized is the Global Warming Potential (GWP) at a time horizon of 100 years. The GWP(100) values chosen are the ones detailed in the IPCC AR4 (2007) and they are equal to 25 for methane and 298 for nitrous oxides *[Annex VI point 4].*
3. Allocation of emissions to power and heat produced simultaneously in CHP plants is based on exergy content *[Annex VI point 1(d) and point 16].*
4. Anaerobic digestion of feedlot manure is considered as an improved agricultural management technique and the avoided emissions of CH_4 and N_2O from the management of the raw manure are considered as a credit to the bioenergy pathway *[Annex VI point 1(b)].*
5. Non-CO_2, long-lived GHG emissions from the combustion of solid biomass and biogas are included in the calculations *[Annex VI point 13]*.
6. For the calculation of default values for solid biomass pathways, emissions from processing, from transport and from the fuel in use are increased by 20% in comparison to the typical values. In the case of biogas, considering that: biogas can be used in the three energy sectors (transport, heating and cooling and electricity), the impact of transport emissions is very limited, and that biogas plant technologies and efficiencies are highly variable, the approach is kept consistent with other transport biofuels and an increment of 40% in emissions from processing (including upgrading) is applied to the typical values *[SWD(2014) 259 - Box 3]*.
7. The formula described in section 5.4 is used to calculate typical and default GHG emissions for biogas and biomethane produced by anaerobic co-digestion of multiple substrates *[Annex VI point 1(b)].* The formula calculates a weighted average of the GHG emissions of single-substrate pathways based on the biogas potential of each substrate and can be applied to any arbitrary mixture of the three substrates assessed in this report.
8. Results are presented on a energy basis considering the LHV of the dry fraction of the biomass fuel. In the tables below the results are given on the basis of the biomass fuel at plant gate (e.g. per MJ of pellet or chips) *[Annex VI point 2]*. In order to present results on a final energy basis (e.g. per MJ electricity or heat) a standard conversion efficiency is applied. The standard electrical efficiency applied is considered to be equal to 25% and the standard thermal efficiency is considered to be equal to 85% (Ecofys, 2010) *[SWD(2014) 259 section 4.3]*. A sensitivity analysis of the results to this assumption is presented in section 7.3.

9. GHG savings are calculated according to the formula reported in *Annex VI point 3* as:

$$GHG\ savings\ (\%) = \frac{FFC\text{-}GHG\ bioenergy}{FFC} \cdot 100$$

10. Where *FFC* represents the Fossil Fuel Comparator as defined in the COM(2016) 767 and *GHG bioenergy* represents the typical or default GHG emissions calculated for the bioenergy pathway. The FFC defined in the *Annex VI point 19* are the following:

    — FFC electricity = 183 $gCO_{2\ eq.}$ / $MJ_{el.}$

    — FFC heat = 80 $gCO_{2\ eq.}$ / MJ_{heat}

    — FFC cooling ([19]) = *

    — FFC transport fuels (valid for compressed biomethane) = 94 $gCO_{2\ eq.}$ / MJ_{fuel}

11. Biogenic CO_2 emissions from processing and from the combustion of the biomass fuel are not included in the methodology and in the results. Therefore, all values reported are calculated without considering any land management change and associated carbon emissions. Direct and indirect land use change emissions are not included as well. Neither are other indirect impacts on other markets (displacement).

For the calculations reported below, the following applies:

- Emission factors considered for the supply and utilization of fossil fuels and chemicals are the ones described in Part One of this document (Table 16) ([20]).
- N_2O emissions from application of N-fertilizers for the cultivation of green maize, poplar and eucalyptus are calculated according to the methodology detailed in IPCC Guidelines (2006), Vol. 4, Ch. 11.2. They include direct and indirect emissions of nitrous oxides.
- The methodology and values for manure methane and nitrous oxide credits are detailed in Section 5.2.1 of this document.
- Combustion emission factors of CH_4 and N_2O for solid biomass fuels are reported in Table 86. Combustion emission factors of CH_4 and N_2O for biogas are reported in Table 37 and Table 39.

([19]) Heat or waste heat is used to generate cooling (chilled air or water) through absorption chillers. Therefore, it is appropriate to calculate only the emissions for the heat produced, per MJ of heat, and the associated GHG savings, irrespectively if the end-use of the heat is actual heating or cooling via absorption chillers.

([20]) Except for the supply of electricity for solid biomass pathways which is considered equal to the FFC for electricity.

7.2 Results

7.2.1 Typical and default values for solid biomass pathways

Absolute GHG emissions

Table 87. Typical and default GHG emission values for forest systems producing wood chips [21]. Values of emissions are provided at plant gate (excl. final conversion efficiency) and based on a MJ of wood chips delivered at the plant. No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects.

	Forest biomass production system	Transport distance	TYPICAL [gCO_2 eq./MJ]	DEFAULT [gCO_2 eq./MJ]
Woodchips	Forest residues	1 to 500 km	5	**6**
		500 to 2500 km	7	**9**
		2500 to 10 000 km	12	**15**
		Above 10000 km	22	**27**
	SRC (Eucalyptus)	2500 to 10 000 km	25	**27**
	SRC (Poplar - Fertilised)	1 to 500 km	8	**9**
		500 to 2500 km	10	**11**
		2500 to 10 000 km	15	**18**
		Above 10000 km	25	**30**
	SRC (Poplar – No fertilisation)	1 to 500 km	6	**7**
		500 to 2500 km	8	**10**
		2500 to 10 000 km	14	**16**
		Above 10000 km	24	**28**
	Stemwood	1 to 500 km	5	**6**
		500 to 2500 km	7	**8**
		2500 to 10 000 km	12	**15**
		Above 10 000 km	22	**27**
	Wood industry residues	1 to 500 km	4	**5**
		500 to 2500 km	6	**7**
		2500 to 10 000 km	11	**13**
		Above 10000 km	21	**25**

(21) Specific unrealistic combinations of feedstock and transport distances have been excluded from the table.

Table 88. Typical and default GHG emission values for forest systems producing wood pellets or briquettes (Part 1) ([22]). Values of emissions are provided at plant gate (excl. final conversion efficiency) and based on a MJ of wood pellets delivered at the plant. No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects.

Wood pellets or briquettes (Part 1)	Forest biomass production system		Transport distance	TYPICAL [$gCO_{2\,eq.}$/MJ]	DEFAULT [$gCO_{2\,eq.}$/MJ]
	Forest residues	**case 1**	1 to 500 km	29	**35**
			500 to 2500 km	29	**35**
			2500 to 10000 km	30	**36**
			Above 10000 km	34	**41**
		case 2a	1 to 500 km	16	**19**
			500 to 2500 km	16	**19**
			2500 to 10000 km	17	**21**
			Above 10000 km	21	**25**
		case 3a	1 to 500 km	6	**7**
			500 to 2500 km	6	**7**
			2500 to 10000 km	7	**8**
			Above 10000 km	11	**13**
	SRC Eucalyptus	**case 1**	2500 to 10000 km	41	**46**
		case 2a	2500 to 10000 km	30	**33**
		case 3a	2500 to 10000 km	21	**22**
	SRC Poplar (Fertilised)	**case 1**	1 to 500 km	31	**37**
			500 to 10000 km	32	**38**
			Above 10000 km	36	**43**
		case 2a	1 to 500 km	18	**21**
			500 to 10000 km	20	**23**
			Above 10000 km	23	**27**
		case 3a	1 to 500 km	8	**9**
			500 to 10000 km	10	**11**
			Above 10000 km	13	**15**

([22]) Specific unrealistic combinations of feedstock and transport distances have been excluded from the table.

Table 89. Typical and default GHG emission values for forest systems producing wood pellets or briquettes (Part 2). Values of emissions are provided at plant gate (excl. final conversion efficiency) and based on a MJ of wood pellets delivered at the plant. No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects.

Wood pellets or briquettes (Part 2)	Forest biomass production system		Transport distance	TYPICAL [$gCO_{2\ eq.}/MJ$]	DEFAULT [$gCO_{2\ eq.}/MJ$]
	SRC Poplar (No fertilizers)	case 1	1 to 500 km	30	**35**
			500 to 10000 km	31	**37**
			Above 10000 km	35	**41**
		case 2a	1 to 500 km	16	**19**
			500 to 10000 km	18	**21**
			Above 10000 km	21	**25**
		case 3a	1 to 500 km	6	**7**
			500 to 10000 km	8	**9**
			Above 10000 km	11	**13**
	Stemwood	case 1	1 to 500 km	29	**35**
			500 to 2500 km	29	**34**
			2500 to 10000	30	**36**
			Above 10000 km	34	**41**
		case 2a	1 to 500 km	16	**18**
			500 to 2500 km	15	**18**
			2500 to 10000	17	**20**
			Above 10000 km	21	**25**
		case 3a	1 to 500 km	5	**6**
			500 to 2500 km	5	**6**
			2500 to 10000	7	**8**
			Above 10000 km	11	**12**
	Wood industry residues	case 1	1 to 500 km	17	**21**
			500 to 2500 km	17	**21**
			2500 to 10000	19	**23**
			Above 10000 km	22	**27**
		case 2a	1 to 500 km	9	**11**
			500 to 2500 km	9	**11**
			2500 to 10000	10	**13**
			Above 10000 km	14	**17**
		case 3a	1 to 500 km	3	**4**
			500 to 2500 km	3	**4**
			2500 to 10000	5	**6**
			Above 10000 km	8	**10**

Comments (valid for all tables on solid biomass pathways)

— **Case 1** refers to pathways in which a natural gas boiler is used to provide the process heat to the pellet mill. Process electricity is purchased from the grid.

— **Case 2a** refers to pathways in which a boiler fuelled with pre-dried wood chips is used to provide the process heat to the pellet mill. Process electricity is purchased from the grid.

— **Case 3a** refers to pathways in which a CHP, fuelled with pre-dried wood chips, is used to provide heat and power to the pellet mill.

— Transport and moisture schemes are detailed in Table 48 and Table 49.

Table 90. Typical and default values for agricultural biomass production systems. Values of emissions are provided at plant gate (excl. final conversion efficiency) and based on a MJ of biomass delivered at the plant. No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects.

	Agriculture biomass production system	Transport distance	TYPICAL [$gCO_{2\ eq.}$/MJ]	DEFAULT [$gCO_{2\ eq.}$/MJ]
Agricultural systems	**Agricultural Residues with density <0.2 t/m³ ([23])**	1 to 500 km	4	**4**
		500 to 2500 km	8	**9**
		2500 to 10 000 km	15	**18**
		Above 10000 km	29	**35**
	Agricultural Residues with density > 0.2 t/m³ ([24])	1 to 500 km	4	**4**
		500 to 2500 km	5	**6**
		2500 to 10 000 km	8	**10**
		Above 10000 km	15	**18**
	Straw pellets	1 to 500 km	8	**10**
		500 to 10000 km	10	**12**
		Above 10000 km	14	**16**
	Bagasse briquettes	500 to 10 000 km	5	**6**
		Above 10 000 km	9	**10**
	Palm Kernel Meal	Above 10000 km	54	**61**
	Palm Kernel Meal (no CH_4 emissions from oil mill)	Above 10000 km	37	**40**

([23]) This group of materials includes agricultural residues with a low bulk density and it comprises materials such as straw bales, oat hulls, rice husks and sugar cane bagasse bales (not exhaustive list).
([24]) The group of agricultural residues with higher bulk density includes materials such as corn cobs, nut shells, soybean hulls, palm kernel shells (not exhaustive list).

Disaggregated GHG emissions solid biomass

Table 91. Disaggregated GHG emission values for forest systems producing wood chips. Values are expressed on the basis of MJ wood chips delivered. Total emission values can be found in Table 87.

Woodchips – Disaggregated values			TYPICAL [$gCO_{2\ eq.}$/MJ]				DEFAULT [$gCO_{2\ eq.}$/MJ]			
	Biomass system	**Transport distance**	Cultivation	Processing	Transport	Non-CO_2 emissions from the fuel in use	Cultivation	Processing	Transport	Non-CO_2 emissions from the fuel in use
	Forest residues	1 to 500 km	0.0	1.6	3.0	0.4	0.0	1.9	3.6	0.5
		500 to 2500 km	0.0	1.6	5.2	0.4	0.0	1.9	6.2	0.5
		2500 to 10 000	0.0	1.6	10.5	0.4	0.0	1.9	12.6	0.5
		Above 10000 km	0.0	1.6	20.5	0.4	0.0	1.9	24.6	0.5
	SRC (*) (Eucalyptus)	2500 to 10 000 km	13.1	0.0	11.0	0.4	13.1	0.0	13.2	0.5
	SRC (Poplar - Fertilised)	1 to 500 km	3.9	0.0	3.5	0.4	3.9	0.0	4.2	0.5
		500 to 2500 km	3.9	0.0	5.6	0.4	3.9	0.0	6.8	0.5
		2500 to 10 000	3.9	0.0	11.0	0.4	3.9	0.0	13.2	0.5
		Above 10000 km	3.9	0.0	21.0	0.4	3.9	0.0	25.2	0.5
	SRC (Poplar – No fertilisation)	1 to 500 km	2.2	0.0	3.5	0.4	2.2	0.0	4.2	0.5
		500 to 2500 km	2.2	0.0	5.6	0.4	2.2	0.0	6.8	0.5
		2500 to 10 000	2.2	0.0	11.0	0.4	2.2	0.0	13.2	0.5
		Above 10000 km	2.2	0.0	21.0	0.4	2.2	0.0	25.2	0.5
	Stemwood	1 to 500 km	1.1	0.3	3.0	0.4	1.1	0.4	3.6	0.5
		500 to 2500 km	1.1	0.3	5.2	0.4	1.1	0.4	6.2	0.5
		2500 to 10 000	1.1	0.3	10.5	0.4	1.1	0.4	12.6	0.5
		2500 to 10 000	1.1	0.3	20.5	0.4	1.1	0.4	24.6	0.5
	Wood industry residues	1 to 500 km	0.0	0.3	3.0	0.4	0.0	0.4	3.6	0.5
		500 to 2500 km	0.0	0.3	5.2	0.4	0.0	0.4	6.2	0.5
		2500 to 10 000	0.0	0.3	10.5	0.4	0.0	0.4	12.6	0.5
		Above 10000 km	0.0	0.3	20.5	0.4	0.0	0.4	24.6	0.5

(*) A combined harvester+chipper is considered to be used for the harvest of SRC. The disaggregated values for "cultivation" of eucalyptus and poplar thus include the production of chipped wood

Table 92. Disaggregated GHG emission values for forest systems producing wood pellets or briquettes (Part 1). Values are expressed on the basis of MJ wood pellets delivered. Total emission values can be found in Table 88.

Wood pellets – Disaggregated values (Part 1)

Forest biomass system		Transport distance	TYPICAL [$gCO_{2\,eq.}$/MJ]				DEFAULT [$gCO_{2\,eq.}$/MJ]			
			Cultivation	Processing	Transport	Non-CO_2 emissions from the fuel in use	Cultivation	Processing	Transport	Non-CO_2 emissions from the fuel in use
Forest residues	**case 1**	1 to 500 km	0.0	25.8	2.9	0.3	0.0	30.9	3.5	0.3
		500 to 2500 km	0.0	25.8	2.8	0.3	0.0	30.9	3.3	0.3
		2500 to 10000 km	0.0	25.8	4.3	0.3	0.0	30.9	5.2	0.3
		Above 10000 km	0.0	25.8	7.9	0.3	0.0	30.9	9.5	0.3
	case 2a	1 to 500 km	0.0	12.5	3.0	0.3	0.0	15.0	3.6	0.3
		500 to 2500 km	0.0	12.5	2.9	0.3	0.0	15.0	3.5	0.3
		2500 to 10000 km	0.0	12.5	4.4	0.3	0.0	15.0	5.3	0.3
		Above 10000 km	0.0	12.5	8.1	0.3	0.0	15.0	9.8	0.3
	case 3a	1 to 500 km	0.0	2.4	3.0	0.3	0.0	2.8	3.6	0.3
		500 to 2500 km	0.0	2.4	2.9	0.3	0.0	2.8	3.5	0.3
		2500 to 10000 km	0.0	2.4	4.4	0.3	0.0	2.8	5.3	0.3
		Above 10000 km	0.0	2.4	8.2	0.3	0.0	2.8	9.8	0.3
SRC (Eucalyptus)	**case 1**	2500 to 10000 km	11.7	24.5	4.3	0.3	11.7	29.4	5.2	0.3
	case 2a	2500 to 10000 km	14.9	10.6	4.4	0.3	14.9	12.7	5.3	0.3
	case 3a	2500 to 10000 km	15.5	0.3	4.4	0.3	15.5	0.4	5.3	0.3
SRC (Poplar – Fertilised)	**case 1**	1 to 500 km	3.4	24.5	2.9	0.3	3.4	29.4	3.5	0.3
		500 to 10000 km	3.4	24.5	4.3	0.3	3.4	29.4	5.2	0.3
		Above 10000 km	3.4	24.5	7.9	0.3	3.4	29.4	9.5	0.3
	case 2a	1 to 500 km	4.4	10.6	3.0	0.3	4.4	12.7	3.6	0.3
		500 to 10000 km	4.4	10.6	4.4	0.3	4.4	12.7	5.3	0.3
		Above 10000 km	4.4	10.6	8.1	0.3	4.4	12.7	9.8	0.3
	case 3a	1 to 500 km	4.6	0.3	3.0	0.3	4.6	0.4	3.6	0.3
		500 to 10000 km	4.6	0.3	4.4	0.3	4.6	0.4	5.3	0.3
		Above 10000 km	4.6	0.3	8.2	0.3	4.6	0.4	9.8	0.3

Table 93. Disaggregated GHG emission values for forest systems producing wood pellets (Part 2). Values are expressed on the basis of MJ wood pellets delivered. Total emission values can be found in Table 89.

Wood pellets – Disaggregated values (Part 2)	Forest biomass system		Transport distance	TYPICAL [$gCO_{2\ eq.}/MJ$]				DEFAULT [$gCO_{2\ eq.}/MJ$]			
				Cultivation	Processing	Transport	Non-CO_2 emissions from the fuel in use	Cultivation	Processing	Transport	Non-CO_2 emissions from the fuel in use
	SRC Poplar – No fertilisation	case 1	1 to 500 km	2.0	24.5	2.9	0.3	2.0	29.4	3.5	0.3
			500 to 10000 km	2.0	24.5	4.3	0.3	2.0	29.4	5.2	0.3
			Above 10000 km	2.0	24.5	7.9	0.3	2.0	29.4	9.5	0.3
		case 2a	1 to 500 km	2.5	10.6	3.0	0.3	2.5	12.7	3.6	0.3
			500 to 10000 km	2.5	10.6	4.4	0.3	2.5	12.7	5.3	0.3
			Above 10000 km	2.5	10.6	8.1	0.3	2.5	12.7	9.8	0.3
		case 3a	1 to 500 km	2.6	0.3	3.0	0.3	2.6	0.4	3.6	0.3
			500 to 10000 km	2.6	0.3	4.4	0.3	2.6	0.4	5.3	0.3
			Above 10000 km	2.6	0.3	8.2	0.3	2.6	0.4	9.8	0.3
	Stemwood	case 1	1 to 500 km	1.1	24.8	2.9	0.3	1.1	29.8	3.5	0.3
			500 to 2500 km	1.1	24.8	2.8	0.3	1.1	29.8	3.3	0.3
			2500 to 10000 km	1.1	24.8	4.3	0.3	1.1	29.8	5.2	0.3
			Above 10000 km	1.1	24.8	7.9	0.3	1.1	29.8	9.5	0.3
		case 2a	1 to 500 km	1.4	11.0	3.0	0.3	1.4	13.2	3.6	0.3
			500 to 2500 km	1.4	11.0	2.9	0.3	1.4	13.2	3.5	0.3
			2500 to 10000 km	1.4	11.0	4.4	0.3	1.4	13.2	5.3	0.3
			Above 10000 km	1.4	11.0	8.1	0.3	1.4	13.2	9.8	0.3
		case 3a	1 to 500 km	1.4	0.8	3.0	0.3	1.4	0.9	3.6	0.3
			500 to 2500 km	1.4	0.8	2.9	0.3	1.4	0.9	3.5	0.3
			2500 to 10000 km	1.4	0.8	4.4	0.3	1.4	0.9	5.3	0.3
			Above 10000 km	1.4	0.8	8.2	0.3	1.4	0.9	9.8	0.3
	Wood industry residues	case 1	1 to 500 km	0.0	14.3	2.8	0.3	0.0	17.2	3.3	0.3
			500 to 2500 km	0.0	14.3	2.7	0.3	0.0	17.2	3.2	0.3
			2500 to 10000 km	0.0	14.3	4.2	0.3	0.0	17.2	5.0	0.3
			Above 10000 km	0.0	14.3	7.7	0.3	0.0	17.2	9.2	0.3
		case 2a	1 to 500 km	0.0	6.0	2.8	0.3	0.0	7.2	3.4	0.3
			500 to 2500 km	0.0	6.0	2.7	0.3	0.0	7.2	3.3	0.3
			2500 to 10000 km	0.0	6.0	4.2	0.3	0.0	7.2	5.1	0.3
			Above 10000 km	0.0	6.0	7.8	0.3	0.0	7.2	9.3	0.3
		case 3a	1 to 500 km	0.0	0.2	2.8	0.3	0.0	0.3	3.4	0.3
			500 to 2500 km	0.0	0.2	2.7	0.3	0.0	0.3	3.3	0.3
			2500 to 10000 km	0.0	0.2	4.2	0.3	0.0	0.3	5.1	0.3
			Above 10000 km	0.0	0.2	7.8	0.3	0.0	0.3	9.3	0.3

Table 94. Disaggregated GHG emission values for agricultural biomass production systems. Values are expressed on the basis of MJ biomass delivered. Total emission values can be found in Table 90.

Agricultural systems – Disaggregated values

Agriculture biomass production system	Transport distance	TYPICAL [$gCO_{2\ eq.}/MJ$]				DEFAULT [$gCO_{2\ eq.}/MJ$]			
		Cultivation	Processing	Transport	Non-CO_2 emissions from the fuel in use	Cultivation	Processing	Transport	Non-CO_2 emissions from the fuel in use
Agricultural Residues with density <0.2 t/m^3	1 to 500 km	0.0	0.9	2.6	0.2	0.0	1.1	3.1	0.3
	500 to 2500 km	0.0	0.9	6.5	0.2	0.0	1.1	7.8	0.3
	2500 to 10 000 km	0.0	0.9	14.2	0.2	0.0	1.1	17.0	0.3
	Above 10000 km	0.0	0.9	28.3	0.2	0.0	1.1	34.0	0.3
Agricultural Residues with density > 0.2 t/m^3	1 to 500 km	0.0	0.9	2.6	0.2	0.0	1.1	3.1	0.3
	500 to 2500 km	0.0	0.9	3.6	0.2	0.0	1.1	4.4	0.3
	2500 to 10 000 km	0.0	0.9	7.1	0.2	0.0	1.1	8.5	0.3
	Above 10000 km	0.0	0.9	13.6	0.2	0.0	1.1	16.3	0.3
Straw pellets	1 to 500 km	0.0	5.0	3.0	0.2	0.0	6.0	3.6	0.3
	500 to 10000 km	0.0	5.0	4.6	0.2	0.0	6.0	5.5	0.3
	Above 10000 km	0.0	5.0	8.3	0.2	0.0	6.0	10.0	0.3
Bagasse briquettes	500 to 10 000 km	0.0	0.3	4.3	0.4	0.0	0.4	5.2	0.5
	Above 10 000 km	0.0	0.3	8.0	0.4	0.0	0.4	9.5	0.5
Palm Kernel Meal	Above 10000 km	21.6	21.1	11.2	0.2	21.6	25.4	13.5	0.3
Palm Kernel Meal (no CH_4 emissions from oil mill)	Above 10000 km	21.6	3.5	11.2	0.2	21.6	4.2	13.5	0.3

Figure 3. GHG emissions for wood chips pathways: contribution of various steps in the supply chain. Based on the default values reported in Table 87 and Table 91.

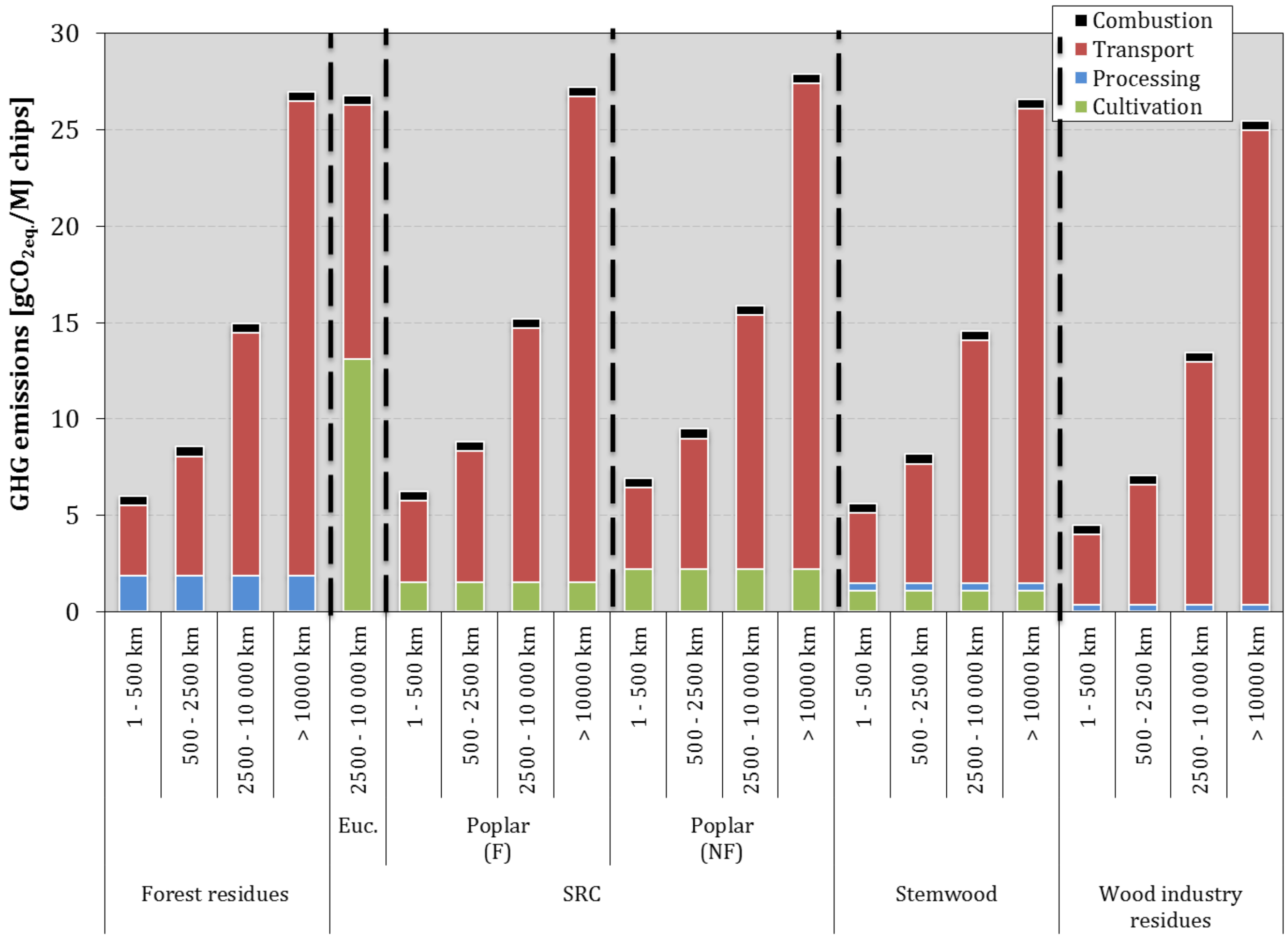


Figure 4. GHG emissions for the most relevant wood pellets pathways: contribution of various steps in the supply chain. Based on the default values reported in Table 88, Table 89, Table 92 and Table 93.

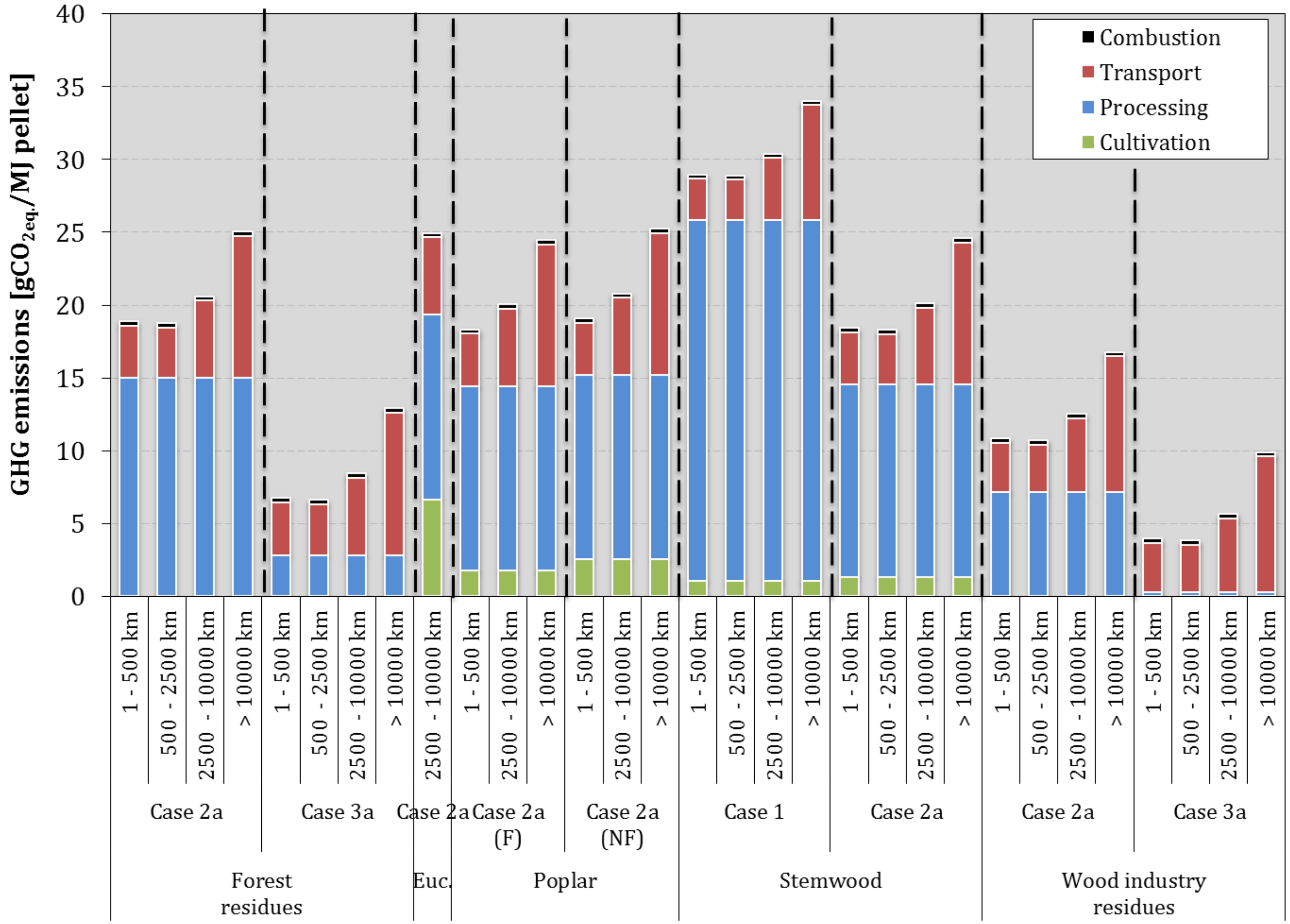
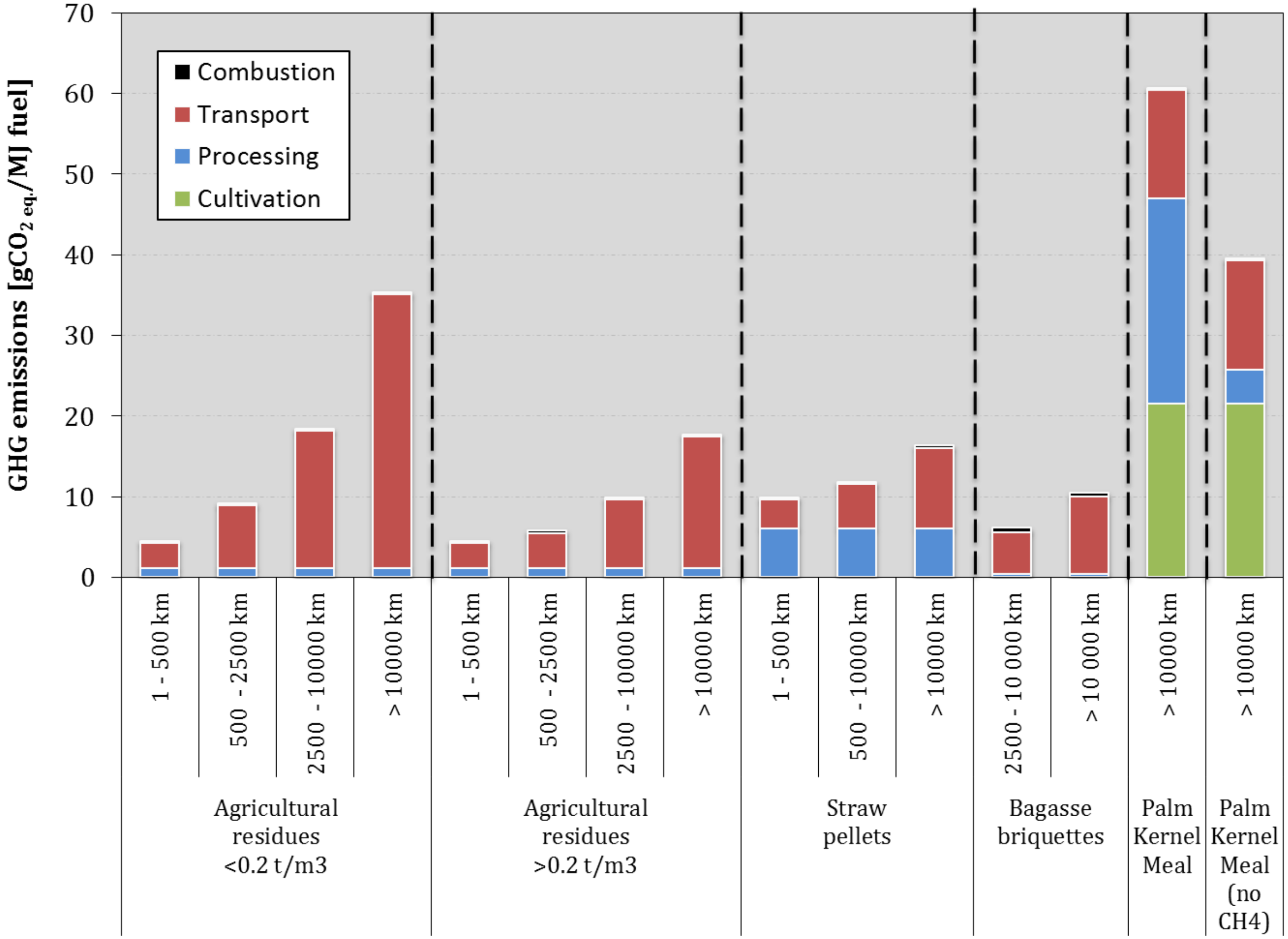


Figure 5. GHG emissions for the most relevant agricultural pathways: contribution of various steps in the supply chain. Based on default values in Table 90 and Table 94.



GHG savings ([25]) for solid biomass pathways

Table 95. GHG savings for forest systems producing wood chips. GHG savings are calculated according to the COM(2016) 767. Standard electrical efficiency of 25% and standard thermal efficiency of 85% are applied for biomass pathways. GHG savings are calculated relative to the FFC reported in COM(2016) 767 (also listed in section 7.1 of this report). No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects.

Woodchips – GHG savings: Forest biomass production system	Transport distance	TYPICAL [%]		DEFAULT [%]	
		Heat	Electricity	Heat	Electricity
Forest residues	1 to 500 km	93	89	**91**	**87**
	500 to 2500 km	89	84	**87**	**81**
	2500 to 10 000 km	82	73	**78**	**67**
	Above 10000 km	67	51	**60**	**41**
SRC (Eucalyptus)	2500 to 10 000 km	64	46	**61**	**41**
SRC (Poplar - Fertilised)	1 to 500 km	89	83	**87**	**81**
	500 to 2500 km	85	78	**84**	**76**
	2500 to 10 000 km	78	67	**74**	**62**
	Above 10000 km	63	45	**57**	**35**
SRC (Poplar – No fertilisation)	1 to 500 km	91	87	**90**	**85**
	500 to 2500 km	88	82	**86**	**79**
	2500 to 10 000 km	80	70	**77**	**65**
	Above 10000 km	65	48	**59**	**39**
Stemwood	1 to 500 km	93	89	**92**	**88**
	500 to 2500 km	90	85	**88**	**82**
	2500 to 10 000 km	82	73	**79**	**68**
	2500 to 10 000 km	67	51	**61**	**42**
Wood industry residues	1 to 500 km	94	92	**93**	**90**
	500 to 2500 km	91	87	**90**	**85**
	2500 to 10 000 km	83	75	**80**	**71**
	Above 10000 km	69	54	**63**	**44**

([25]) The use of 'GHG savings' as a metric to assess climate change mitigation effects of bioenergy pathways compared to fossil fuels has been designed and defined by the EU in several legislative documents (RED, FQD, COM(2010) 11, COM(2016) 767). While this may have merits of simplicity and clarity for regulatory purposes, it should be remembered that: "*analyses that report climate-mitigation effects based on Attributional LCA generally have assumed away all indirect and scale effects on $CO_{2\text{-}eq}$ emission factors and on activity within and beyond the targeted sector. Unfortunately, there is no theoretical or empirical basis for treating indirect and scale effects as negligible*." (Plevin et al., 2013)

Table 96. GHG savings for forest systems producing wood pellets or briquettes (Part 1). GHG savings are calculated according to the COM(2016) 767. Standard electrical efficiency of 25% and thermal efficiency of 85% are applied. GHG savings are calculated relative to the FFC reported in COM(2016) 767 (also listed in section 7.1 of this report). No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects.

Wood pellets – GHG savings (Part 1)	Forest biomass production system		Transport distance	TYPICAL [%] Heat	TYPICAL [%] Electricity	DEFAULT [%] Heat	DEFAULT [%] Electricity
	Forest residues	case 1	1 to 500 km	58	37	**49**	**24**
			500 to 2500 km	58	37	**49**	**25**
			2500 to 10000 km	55	34	**47**	**21**
			Above 10000 km	50	26	**40**	**11**
		case 2a	1 to 500 km	77	66	**72**	**59**
			500 to 2500 km	77	66	**72**	**59**
			2500 to 10000 km	75	62	**70**	**55**
			Above 10000 km	69	54	**63**	**45**
		case 3a	1 to 500 km	92	88	**90**	**85**
			500 to 2500 km	92	88	**90**	**86**
			2500 to 10000 km	90	85	**88**	**81**
			Above 10000 km	84	76	**81**	**72**
	SRC (Eucalyptus)	case 1	2500 to 10000 km	40	11	**32**	**-2**
		case 2a	2500 to 10000 km	56	34	**51**	**27**
		case 3a	500 to 10000 km	70	55	**68**	**53**
	SRC Poplar (Fertilised)	case 1	1 to 500 km	54	32	**46**	**20**
			500 to 10000 km	52	29	**44**	**16**
			Above 10000 km	47	21	**37**	**7**
		case 2a	1 to 500 km	73	60	**69**	**54**
			500 to 10000 km	71	57	**67**	**50**
			Above 10000 km	66	49	**60**	**41**
		case 3a	1 to 500 km	88	82	**87**	**81**
			500 to 10000 km	86	79	**84**	**77**
			Above 10000 km	80	71	**78**	**67**

Table 97. GHG savings for forest systems producing wood pellets or briquettes (Part 2). GHG savings are calculated according to the COM(2016) 767. Standard electrical efficiency of 25% and thermal efficiency of 85% are applied. GHG savings are calculated relative to the FFC reported in COM(2016) 767 (also listed in section 7.1 of this report). No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects.

Wood pellets – GHG savings (Part 2)

Forest biomass production system		Transport distance	TYPICAL [%] Heat	TYPICAL [%] Electricity	DEFAULT [%] Heat	DEFAULT [%] Electricity
SRC Poplar (No fertilisation)	case 1	1 to 500 km	56	35	**48**	**23**
		500 to 10000 km	54	32	**46**	**20**
		Above 10000 km	49	24	**40**	**10**
	case 2a	1 to 500 km	76	64	**72**	**58**
		500 to 10000 km	74	61	**69**	**54**
		Above 10000 km	68	53	**63**	**45**
	case 3a	1 to 500 km	91	86	**90**	**85**
		500 to 10000 km	89	83	**87**	**81**
		Above 10000 km	83	75	**81**	**71**
Stemwood	case 1	1 to 500 km	57	37	**49**	**24**
		500 to 2500 km	58	37	**49**	**25**
		2500 to 10000 km	55	34	**47**	**21**
		Above 10000 km	50	26	**40**	**11**
	case 2a	1 to 500 km	77	66	**73**	**60**
		500 to 2500 km	77	66	**73**	**60**
		2500 to 10000 km	75	63	**70**	**56**
		Above 10000 km	70	55	**64**	**46**
	case 3a	1 to 500 km	92	88	**91**	**86**
		500 to 2500 km	92	88	**91**	**87**
		2500 to 10000 km	90	85	**88**	**83**
		Above 10000 km	84	77	**82**	**73**
Wood industry residues	case 1	1 to 500 km	75	62	**69**	**55**
		500 to 2500 km	75	62	**70**	**55**
		2500 to 10000 km	72	59	**67**	**51**
		Above 10000 km	67	51	**61**	**42**
	case 2a	1 to 500 km	87	80	**84**	**76**
		500 to 2500 km	87	80	**84**	**77**
		2500 to 10000 km	85	77	**82**	**73**
		Above 10000 km	79	69	**75**	**63**
	case 3a	1 to 500 km	95	93	**94**	**91**
		500 to 2500 km	95	93	**94**	**92**
		2500 to 10000 km	93	90	**92**	**88**
		Above 10000 km	88	82	**85**	**78**

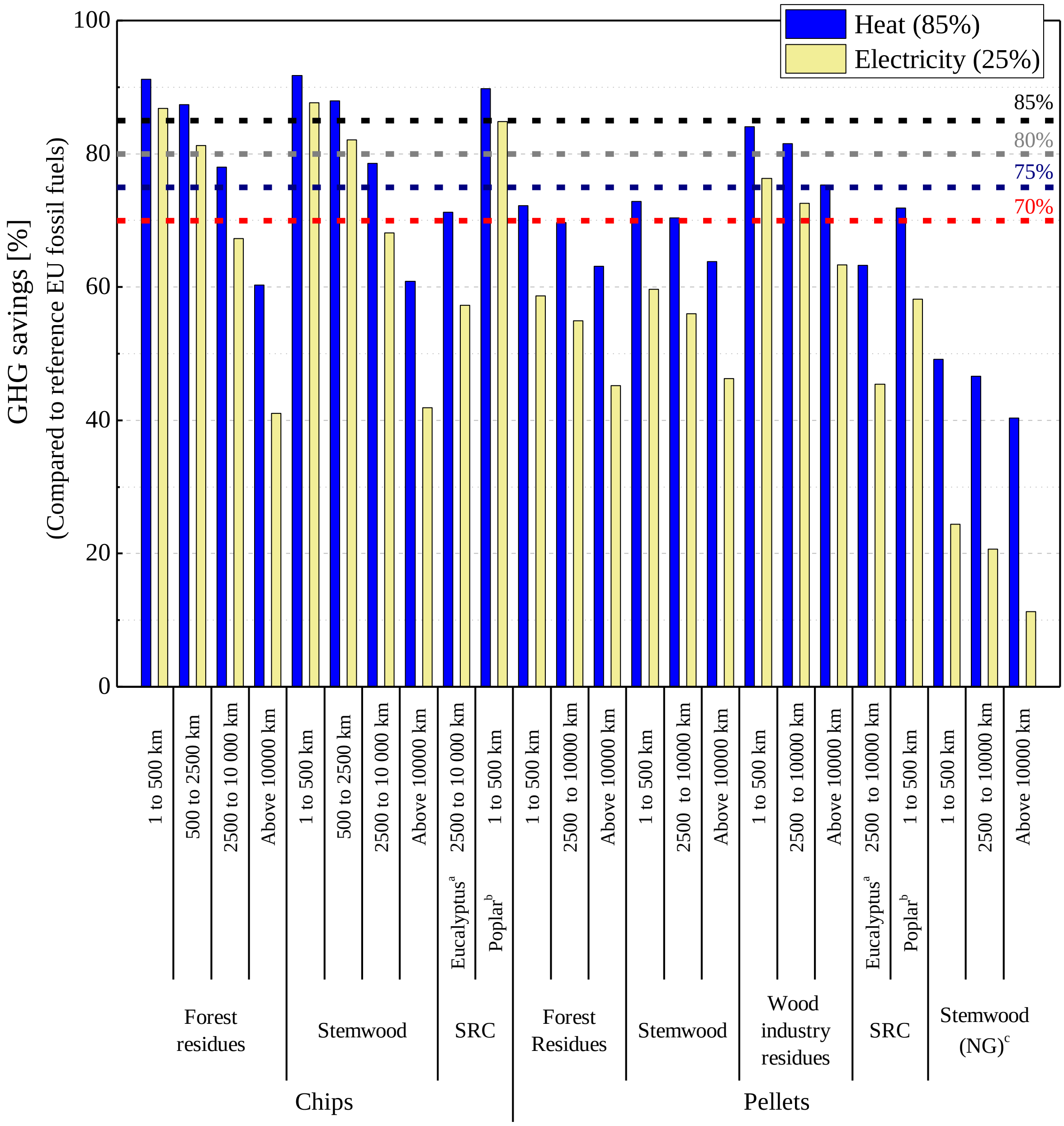
Table 98. GHG savings for agricultural biomass systems. GHG savings are calculated according to the COM(2016) 767. Standard electrical efficiency of 25% and thermal efficiency of 85% are applied. GHG savings are calculated relative to the FFC reported in COM(2016) 767 (also listed in section 7.1 of this report). No land use emissions are included in these results nor are CO2 emissions from the combustion of biomass or other indirect effects. Negative values indicate that the bioenergy pathway emits more than the fossil comparator.

Agricultural systems – GHG savings

Agriculture biomass production system	Transport distance	TYPICAL [%]		DEFAULT [%]	
		Heat	Electricity	Heat	Electricity
Agricultural Residues with density <0.2 t/m³ ([26])	1 to 500 km	95	92	**93**	**90**
	500 to 2500 km	89	83	**86**	**80**
	2500 to 10 000 km	77	66	**73**	**60**
	Above 10000 km	57	36	**48**	**23**
Agricultural Residues with density > 0.2 t/m³ ([27])	1 to 500 km	95	92	**93**	**90**
	500 to 2500 km	93	89	**92**	**87**
	2500 to 10 000 km	88	82	**85**	**78**
	Above 10000 km	78	68	**74**	**61**
Straw pellets	1 to 500 km	88	82	**85**	**78**
	500 to 10000 km	86	79	**83**	**74**
	Above 10000 km	80	70	**76**	**64**
Bagasse briquettes	500 to 10 000 km	93	89	**91**	**87**
	Above 10 000 km	87	81	**85**	**77**
Palm Kernel Meal	Above 10000 km	20	-18	**11**	**-33**
Palm Kernel Meal (no CH_4 emissions from oil mill)	Above 10000 km	46	20	**42**	**14**

([26]) This group of materials includes agricultural residues with a low bulk density and it comprises materials such as straw bales, oat hulls, rice husks and sugar cane bagasse bales (not exhaustive list).
([27]) The group of agricultural residues with higher bulk density includes materials such as corn cobs, nut shells, soybean hulls, palm kernel shells (not exhaustive list).

Figure 6. Illustration of GHG supply chain emissions compared to reference fossil fuel emissions for the most representative solid biomass pathways (values reported in Table 95 to Table 98). Values exclude combustion and all emissions and removals of biogenic carbon in the supply chain, except methane. Values are based on the default GHG emission values. SRC = Short Rotation Coppice. a) The calculations are based on greenhouse gas data from eucalyptus cultivation in tropical areas. b) Data are based on poplar cultivated in EU without any synthetic fertilization. c) Stemwood (NG) = pellets produced using natural gas as process fuel, all the other pathways are based on wood as process fuel (case 2a).



7.2.2 Typical and default values for biogas pathways

Absolute GHG emissions for biogas pathways

Table 99. Typical and default GHG emission values for non-upgraded biogas. Values of emissions are provided at plant gate (excl. final conversion efficiency) and based on a MJ of biogas produced. No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects. Negative values indicate bioenergy pathways that save GHG emissions compared to the alternative in which the biomass is not used for bioenergy production (i.e. credits for improved manure management higher than the biogas supply chain emissions).

	Biogas production system		Technological option	TYPICAL [$gCO_{2\ eq,}$/MJ]	DEFAULT [$gCO_{2\ eq,}$/MJ]
Biogas for electricity – GHG emissions	Wet manure ([28])	case 1	Open digestate ([29])	-28	**3**
			Close digestate ([30])	-88	**-84**
		case 2	Open digestate	-23	**10**
			Close digestate	-84	**-78**
		case 3	Open digestate	-28	**9**
			Close digestate	-94	**-89**
	Maize whole plant ([31])	case 1	Open digestate	38	**47**
			Close digestate	24	**28**
		case 2	Open digestate	43	**54**
			Close digestate	29	**35**
		case 3	Open digestate	47	**59**
			Close digestate	32	**38**
	Biowaste	case 1	Open digestate	31	**44**
			Close digestate	9	**13**
		case 2	Open digestate	37	**52**
			Close digestate	15	**21**
		case 3	Open digestate	41	**57**
			Close digestate	16	**22**

([28]) The values for biogas production from manure include negative emissions for emissions saved from raw manure management. The value of e_{sca} considered is equal to -45 $gCO_{2eq.}$/MJ manure used in anaerobic digestion (see section 5.2.1 for more details).
([29]) Open storage of digestate accounts for additional emissions of methane and N_2O. The magnitude of these emissions changes with ambient conditions, substrate types and the digestion efficiency (see chapter 5 for more details).
([30]) Close storage means that the digestate resulting from the digestion process is stored in a gas-tight tank and the additional biogas released during storage is considered to be recovered for production of additional electricity or biomethane. No emissions of GHG are included in this process.
([31]) Maize whole plant should be interpreted as maize harvested as fodder and ensiled for preservation.

Comments

- **Case 1** refers to pathways in which power and heat required in the process are supplied by the CHP engine itself.
- **Case 2** refers to pathways in which the electricity required in the process is taken from the grid and the process heat is supplied by the CHP engine itself. In some Member States, operators are not allowed to claim the gross production for subsidies and Case 1 is the more likely configuration.
- **Case 3** refers to pathways in which the electricity required in the process is taken from the grid and the process heat is supplied by a biogas boiler. This case applies to some installations in which the CHP engine is not on-site and biogas is sold (but not upgraded to biomethane).

Table 100. Typical and default GHG emission values for biogas upgraded to biomethane and injected into the natural gas grid. Values of emissions are provided at the grid outlet (excl. final conversion efficiency, the grid is considered to be neutral to the GHG emissions) and based on a MJ of biomethane produced. Negative values indicate bioenergy pathways that save GHG emissions compared to the alternative in which the biomass is not used for bioenergy production (i.e. credits for improved manure management higher than the biogas supply chain emissions).

Biomethane – GHG emissions

Biomethane production system	Technological option		TYPICAL [gCO_2 eq./MJ]	DEFAULT [gCO_2 eq./MJ]
Wet manure	Open digestate	no off-gas combustion (32)	-20	**22**
		off-gas combustion (33)	-35	**1**
	Close digestate	no off-gas combustion	-88	**-79**
		off-gas combustion	-103	**-100**
Maize whole plant	Open digestate	no off-gas combustion	58	**73**
		off-gas combustion	43	**52**
	Close digestate	no off-gas combustion	41	**51**
		off-gas combustion	26	**30**
Biowaste	Open digestate	no off-gas combustion	51	**71**
		off-gas combustion	36	**50**
	Close digestate	no off-gas combustion	25	**35**
		off-gas combustion	10	**14**

In case of biomethane used as Compressed Biomethane as a transport fuel, a value of 3.3 $gCO_{2eq.}$/MJ biomethane needs to be added to the typical values and a value of 4.6 $gCO_{2eq.}$/MJ biomethane to the default values.

(32)This category includes the following categories of technologies for biogas upgrade to biomethane: Pressure Swing Adsorption (PSA), Pressure Water Scrubbing (PWS), Membranes, Cryogenic, and Organic Physical Scrubbing (OPS). It includes an emission of 0.03 MJCH4/MJbiomethane for the emission of methane in the off-gases.

(33)This category includes the following categories of technologies for biogas upgrade to biomethane: Pressure Water Scrubbing (PWS) when water is recycled, Pressure Swing Adsorption (PSA), Chemical Scrubbing, Organic Physical Scrubbing (OPS), Membranes and Cryogenic upgrading. No methane emissions are considered for this category (the methane in the off gas is combusted, if any).

Disaggregated values for biogas pathways

Table 101. Disaggregated values for biogas for electricity. Values are expressed on the basis of the biogas produced. Total emission values can be found in Table 99.

Biogas for electricity – Disaggregated values

Production system		Technology	TYPICAL [$gCO_{2\ eq.}$/MJ]					DEFAULT [$gCO_{2\ eq.}$/MJ]				
			Cultivation	Processing	Non-CO_2 emissions from the fuel in use [a]	Transport	Credits	Cultivation	Processing	Non-CO_2 emissions from the fuel in use [a]	Transport	Credits
Wet manure	**case 1**	Open digestate	0.0	69.6	8.9	0.8	-107.3	0.0	97.4	12.5	0.8	-107.3
		Close digestate	0.0	0.0	8.9	0.8	-97.6	0.0	0.0	12.5	0.8	-97.6
	case 2	Open digestate	0.0	74.1	8.9	0.8	-107.3	0.0	103.7	12.5	0.8	-107.3
		Close digestate	0.0	4.2	8.9	0.8	-97.6	0.0	5.9	12.5	0.8	-97.6
	case 3	Open digestate	0.0	83.2	8.9	0.9	-120.7	0.0	116.4	12.5	0.9	-120.7
		Close digestate	0.0	4.6	8.9	0.8	-108.5	0.0	6.4	12.5	0.8	-108.5
Maize whole plant	**case 1**	Open digestate	15.6	13.5	8.9	0.0[b]	-	15.6	18.9	12.5	0.0	-
		Close digestate	15.2	0.0	8.9	0.0	-	15.2	0.0	12.5	0.0	-
	case 2	Open digestate	15.6	18.8	8.9	0.0	-	15.6	26.3	12.5	0.0	-
		Close digestate	15.2	5.2	8.9	0.0	-	15.2	7.2	12.5	0.0	-
	case 3	Open digestate	17.5	21.0	8.9	0.0	-	17.5	29.3	12.5	0.0	-
		Close digestate	17.1	5.7	8.9	0.0	-	17.1	7.9	12.5	0.0	-
Biowaste	**case 1**	Open digestate	0.0	21.8	8.9	0.5	-	0.0	30.6	12.5	0.5	-
		Close digestate	0.0	0.0	8.9	0.5	-	0.0	0.0	12.5	0.5	-
	case 2	Open digestate	0.0	27.9	8.9	0.5	-	0.0	39.0	12.5	0.5	-
		Close digestate	0.0	5.9	8.9	0.5	-	0.0	8.3	12.5	0.5	-
	case 3	Open digestate	0.0	31.2	8.9	0.5	-	0.0	43.7	12.5	0.5	-
		Close digestate	0.0	6.5	8.9	0.5	-	0.0	9.1	12.5	0.5	-

([a]) For actual values calculations, the heat and electricity from the CHP engine used in the biogas plant can be considered free of emissions at consumption (e.g. digester); however all the emissions should be included in the CHP / combustion emissions category

([b]) Transport of agricultural raw materials to the transformation plant is, according to the methodology in COM(2016) 767, included in the "cultivation" value. The value for transport of maize silage accounts for 0.4 $gCO_{2\ eq.}$/MJ biogas.

Table 102. Disaggregated values for biomethane injected into the grid. Values are expressed on the basis of the biogas produced. Total emission values can be found in Table 100.

Biomethane – Disaggregated values			TYPICAL [$gCO_{2\ eq.}/MJ$]						DEFAULT [$gCO_{2\ eq.}/MJ$]					
Raw material	**Technological option**		Cultivation	Processing	Upgrading	Transport	Compression at filling station[a]	Credits	Cultivation	Processing	Upgrading	Transport	Compression at filling station[a]	Credits
Wet manure	Open digestate	no off-gas combustion	0.0	84.2	19.5	1.0	3.3	-124.4	0.0	117.9	27.3	1.0	4.6	-124.4
		off-gas combustion	0.0	84.2	4.5	1.0	3.3	-124.4	0.0	117.9	6.3	1.0	4.6	-124.4
	Close digestate	no off-gas combustion	0.0	3.2	19.5	0.9	3.3	-111.9	0.0	4.4	27.3	0.9	4.6	-111.9
		off-gas combustion	0.0	3.2	4.5	0.9	3.3	-111.9	0.0	4.4	6.3	0.9	4.6	-111.9
Maize whole plant	Open digestate	no off-gas combustion	18.1	20.1	19.5	0.0	3.3	-	18.1	28.1	27.3	0.0	4.6	-
		off-gas combustion	18.1	20.1	4.5	0.0	3.3	-	18.1	28.1	6.3	0.0	4.6	-
	Close digestate	no off-gas combustion	17.6	4.3	19.5	0.0	3.3	-	17.6	6.0	27.3	0.0	4.6	-
		off-gas combustion	17.6	4.3	4.5	0.0	3.3	-	17.6	6.0	6.3	0.0	4.6	-
Biowaste	Open digestate	no off-gas combustion	0.0	30.6	19.5	0.5	3.3	-	0.0	42.8	27.3	0.5	4.6	-
		off-gas combustion	0.0	30.6	4.5	0.5	3.3	-	0.0	42.8	6.3	0.5	4.6	-
	Close digestate	no off-gas combustion	0.0	5.1	19.5	0.5	3.3	-	0.0	7.2	27.3	0.5	4.6	-
		off-gas combustion	0.0	5.1	4.5	0.5	3.3	-	0.0	7.2	6.3	0.5	4.6	-

([a]) This value is not included in the total GHG emissions in Table 100. These values should only included when biomethane is used as a transport fuel.

Figure 7. Default GHG emission values for electricity production from non-upgraded biogas. The figure refers to Case 1. The net electrical efficiency considered is equal to 33% for wet manure, 32.5% for maize and 32% for biowaste. Substrate characteristics are the ones detailed in Part Three of this document.

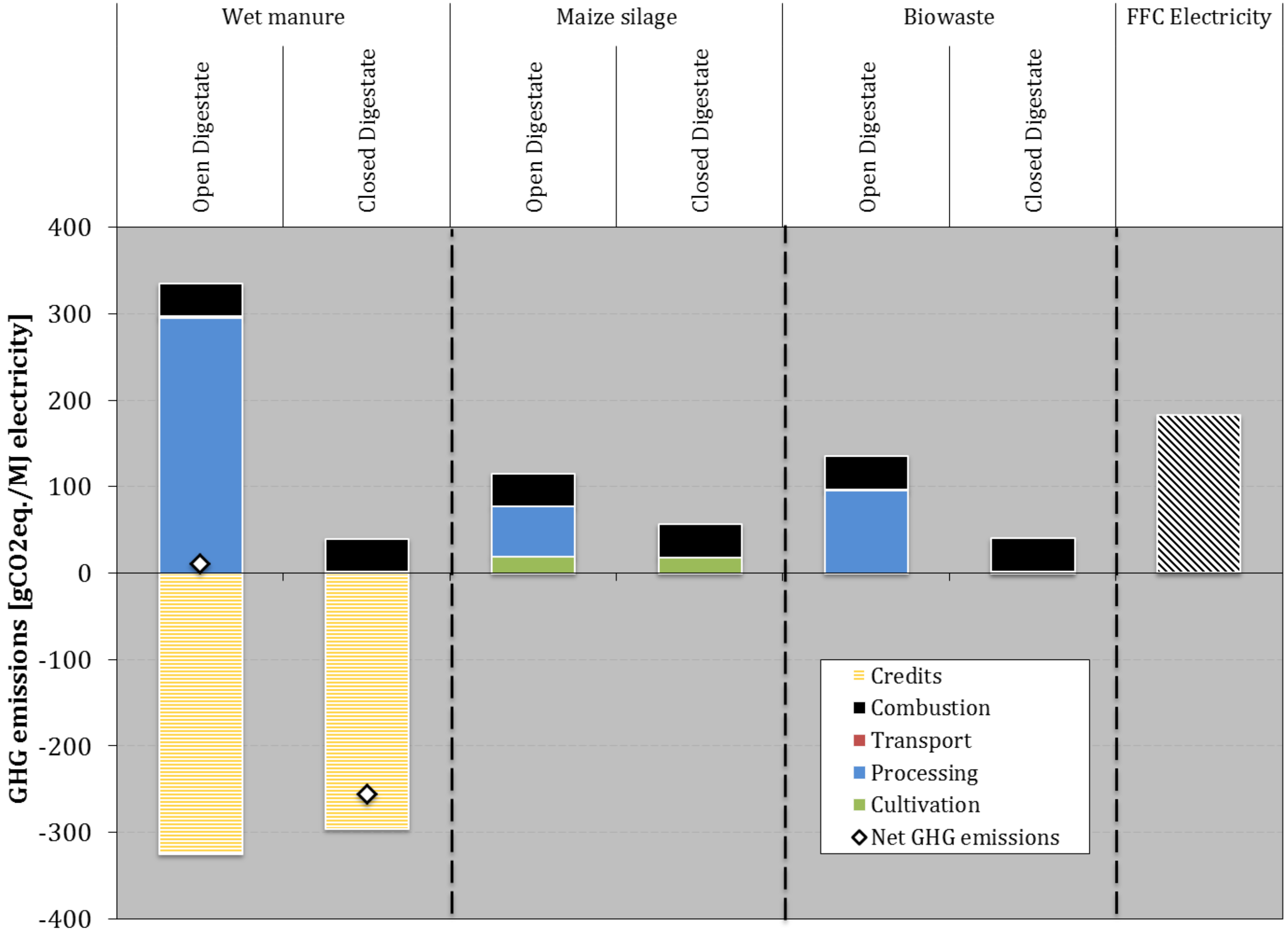
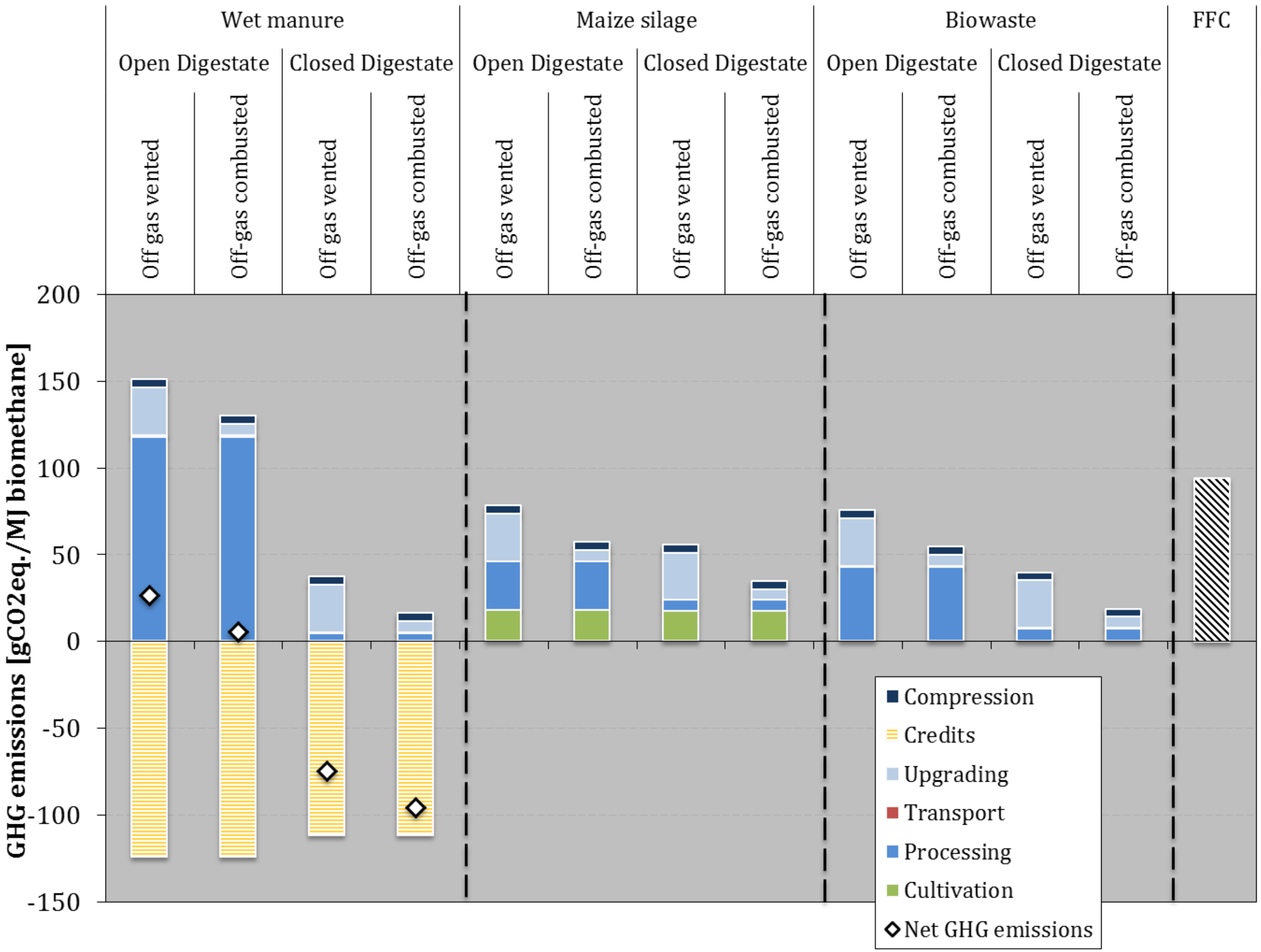


Figure 8. Default GHG emissions values for the production of compressed biomethane. FFC considered is equal to 94 $gCO_{2\ eq.}/MJ$. Substrate characteristics are the ones detailed in Part Three of this document.



GHG savings for biogas pathways

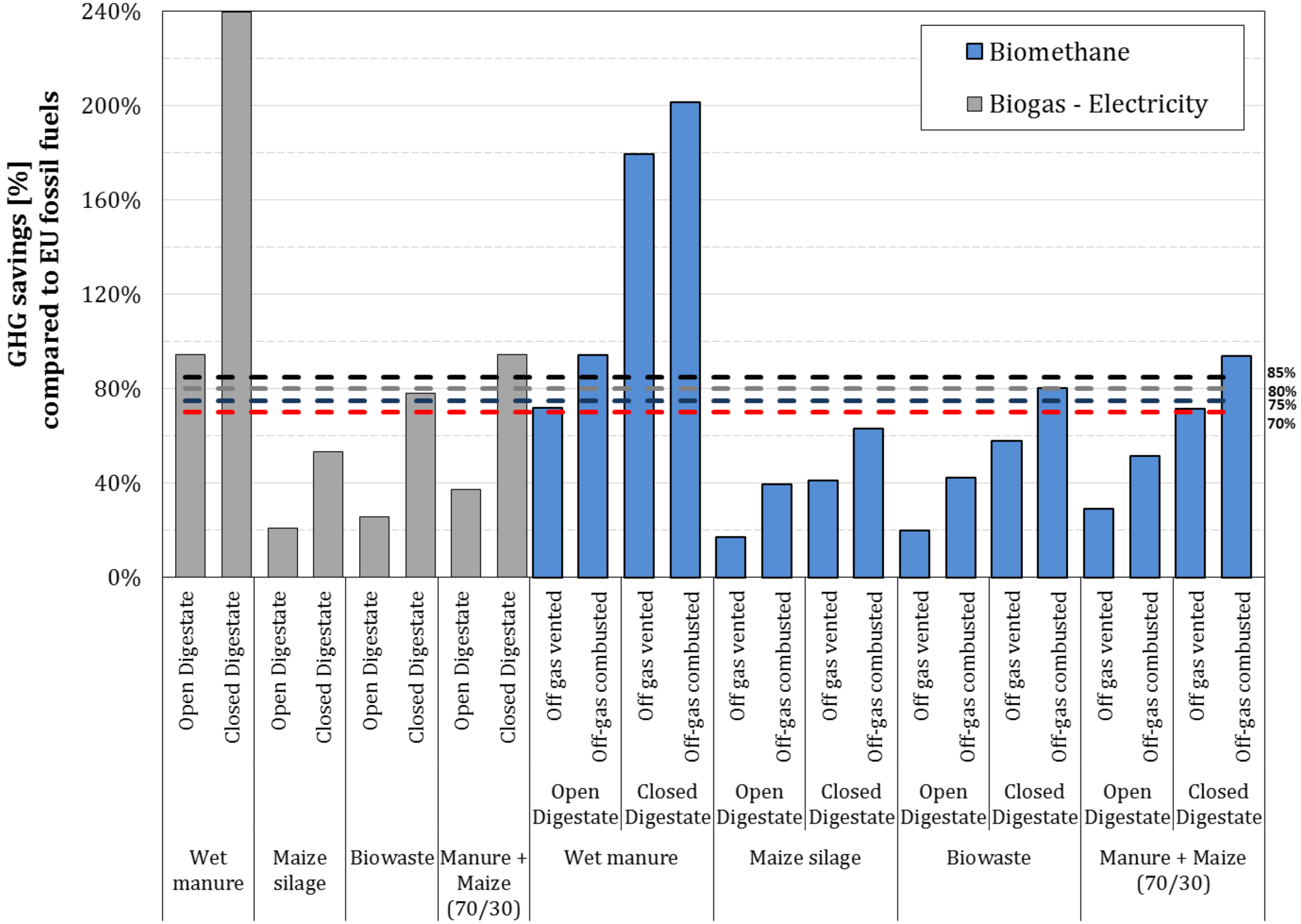
Table 103. GHG savings for electricity produced from non-upgraded biogas. No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects. Values higher than 100% indicate pathways in which the credits for improved agricultural management more than offset the supply chain emissions.

	Biogas production system	Technological option		TYPICAL [%]	DEFAULT [%]
Biogas for electricity – GHG savings	**Wet manure**	**case 1**	Open digestate	146	**94**
			Close digestate	246	**240**
		case 2	Open digestate	136	**85**
			Close digestate	227	**219**
		case 3	Open digestate	142	**86**
			Close digestate	243	**235**
	Maize whole plant	**case 1**	Open digestate	36	**21**
			Close digestate	59	**53**
		case 2	Open digestate	34	**18**
			Close digestate	55	**47**
		case 3	Open digestate	28	**10**
			Close digestate	52	**43**
	Biowaste	**case 1**	Open digestate	47	**26**
			Close digestate	84	**78**
		case 2	Open digestate	43	**21**
			Close digestate	77	**68**
		case 3	Open digestate	38	**14**
			Close digestate	76	**66**

Table 104. GHG savings (compared to FFC for transport fuels) for upgraded biogas injected into the grid. No land use emissions are included in these results nor are CO_2 emissions from the combustion of biomass or other indirect effects. Values higher than 100% indicate pathways in which the credits for improved agricultural management more than offset the supply chain emissions. Negative values indicate pathways that emit more than the fossil fuel comparator.

Biomethane – GHG savings	Biomethane production system	Technological option		TYPICAL [%]	DEFAULT [%]
	Wet manure	Open digestate	no off-gas combustion	117	**72**
			off-gas combustion	133	**94**
		Close digestate	no off-gas combustion	190	**179**
			off-gas combustion	206	**202**
	Maize whole plant	Open digestate	no off-gas combustion	35	**17**
			off-gas combustion	51	**39**
		Close digestate	no off-gas combustion	52	**41**
			off-gas combustion	68	**63**
	Biowaste	Open digestate	no off-gas combustion	43	**20**
			off-gas combustion	59	**42**
		Close digestate	no off-gas combustion	70	**58**
			off-gas combustion	86	**80**

Figure 9. Illustration of GHG savings for the most representative biogas and biomethane pathways(values reported in Table 103 and Table 104). Values for biogas – electricity represent the Case 1. Values are based on default GHG emission values. Values higher than 100% represent systems in which credits from improved agricultural management more than offset any supply chain emission. For illustrative purposes, values obtained for the co-digestion of a mixture of 70% (wet mass) manure and 30% (wet mass) maize are also included.



7.3 Sensitivity

7.3.1 Co-digestion of multiple substrates

In section 5.4 a methodology for the assessment of the GHG emissions for biogas plants running on more than 1 feedstock was presented. Applying the formula defined in Annex VI Point 1(b) to the results for a single biogas pathway (presented in the previous section 7.2.2) it is possible to calculate the default and typical GHG emissions, (and therefore the GHG savings according the methodology explained in section 7.10) of biogas plants running on more than one substrate. Figure 10 and Figure 11 present an example of the results obtained for an increasing share of maize co-digested with manure.

The codigestsion calculation methodology presented here still follows an 'attributional'-LCA approach, but the resulting GHG savings are attributes of the biogas installations, rather than of the single substrates.

For ease of use, we present in Figure 12 and Figure 13 the default GHG savings resulting for any arbitrary combination of the three substrates for the production of electricity or compressed biomethane. Users can find the default value that applies to their specific annual mixture of substrates by simply looking at the figures.

Figure 10. Default GHG emission values for non-upgraded biogas to electricity for various mixtures of substrates (maize silage and wet manure). The columns represent results obtained with increasing shares of maize silage in the mix, calculated as wet mass (@35% moisture for maize and 90% moisture for manure).

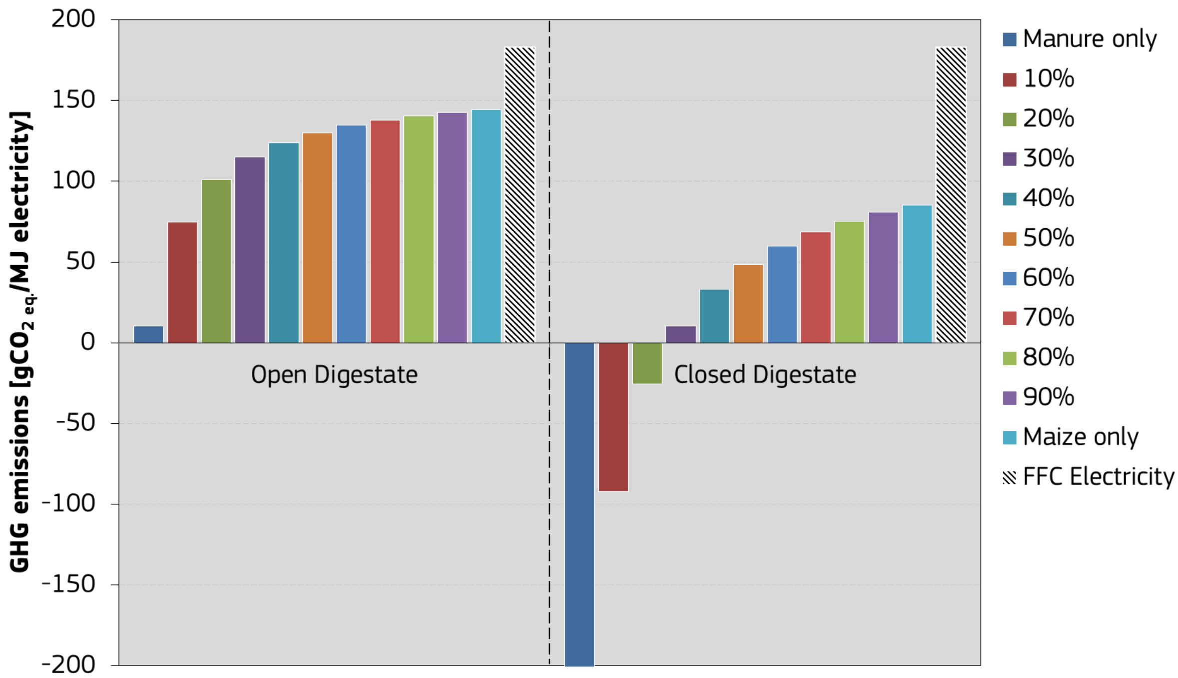


Figure 11. Default GHG emission values for compressed biomethane for various mixtures of substrates (maize silage and wet manure). The columns represent results obtained with increasing shares of maize whole plant in the mix, calculated as wet mass (@35% moisture for maize and 90% moisture for manure).

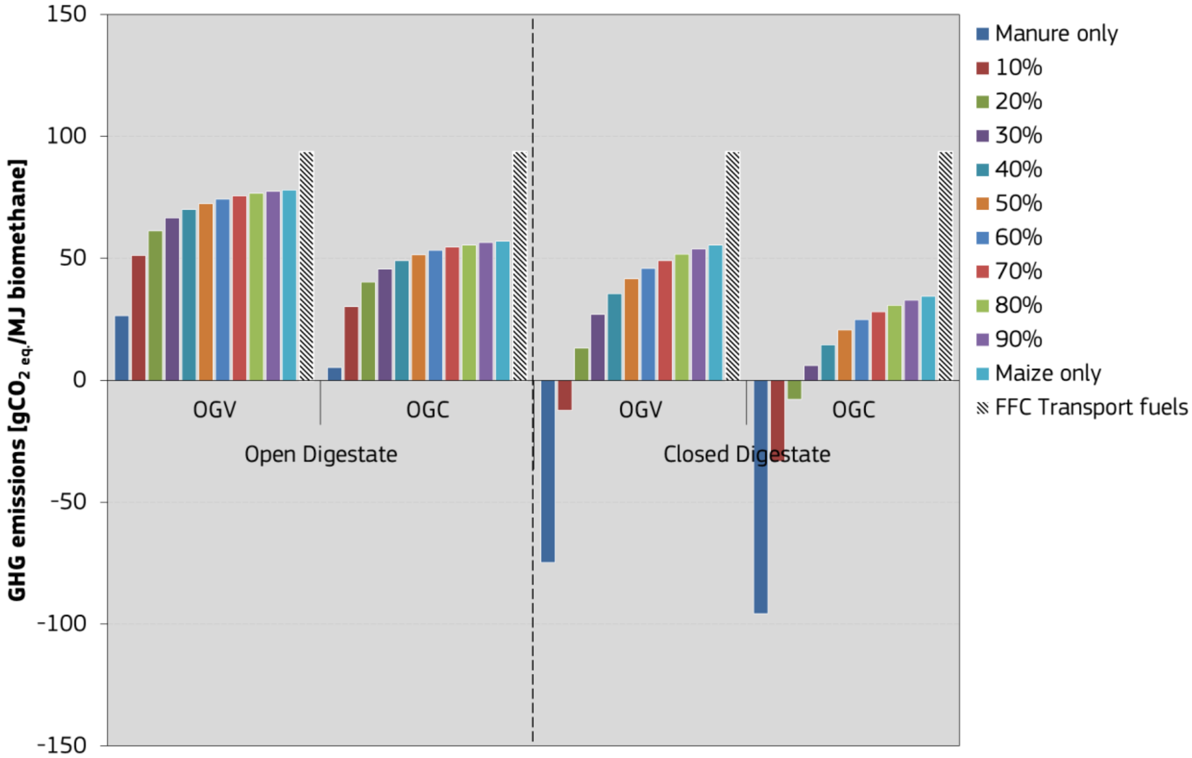


Figure 12. Representation of the GHG savings achieved by combination of any mixture of the three substrates considered(via the formula described in section 5.4). Graphs represent GHG savings based on default values for non-upgraded biogas pathways to electricity (referring to the values in Table 103 for Case 1 and Case 2).

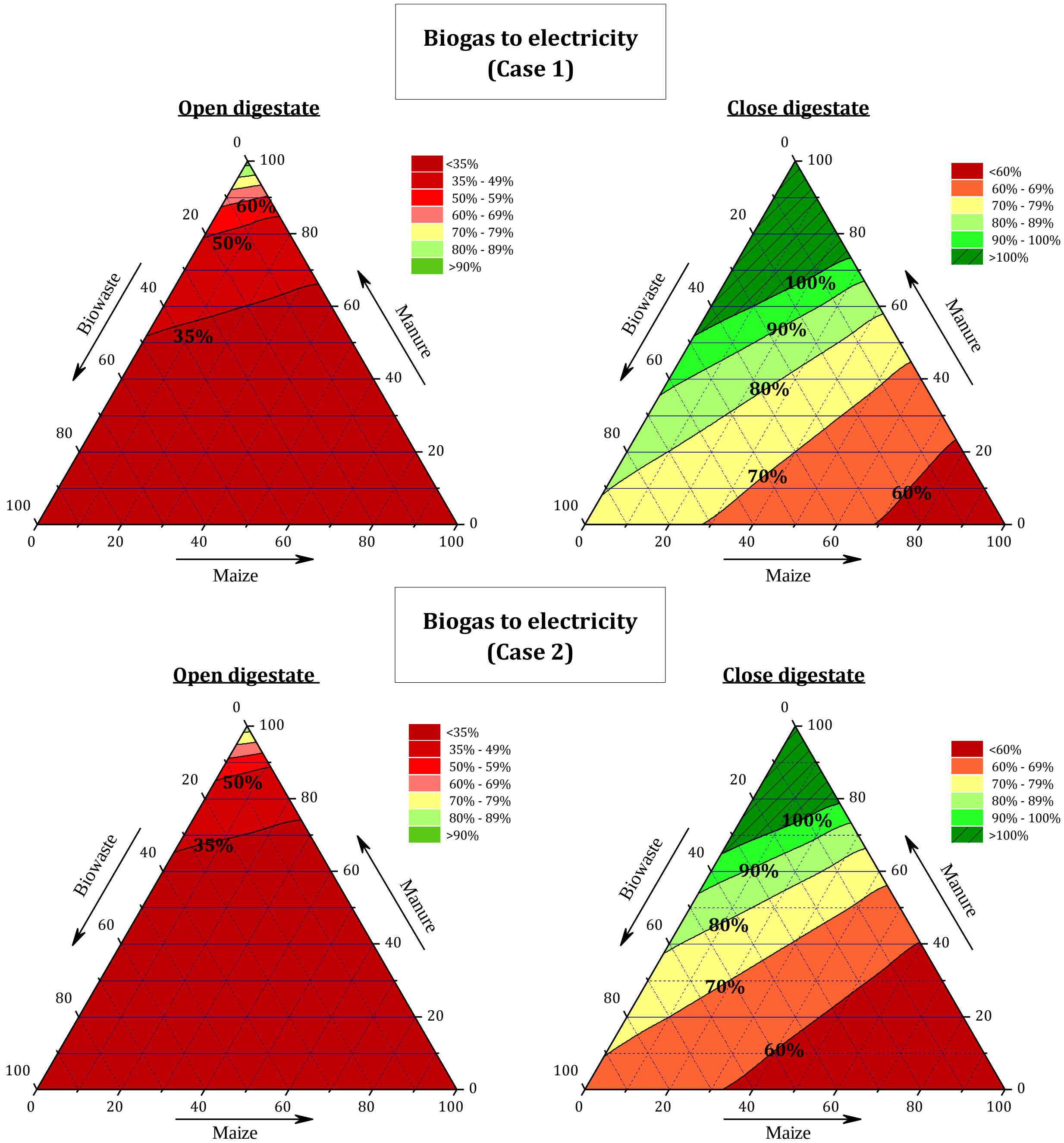
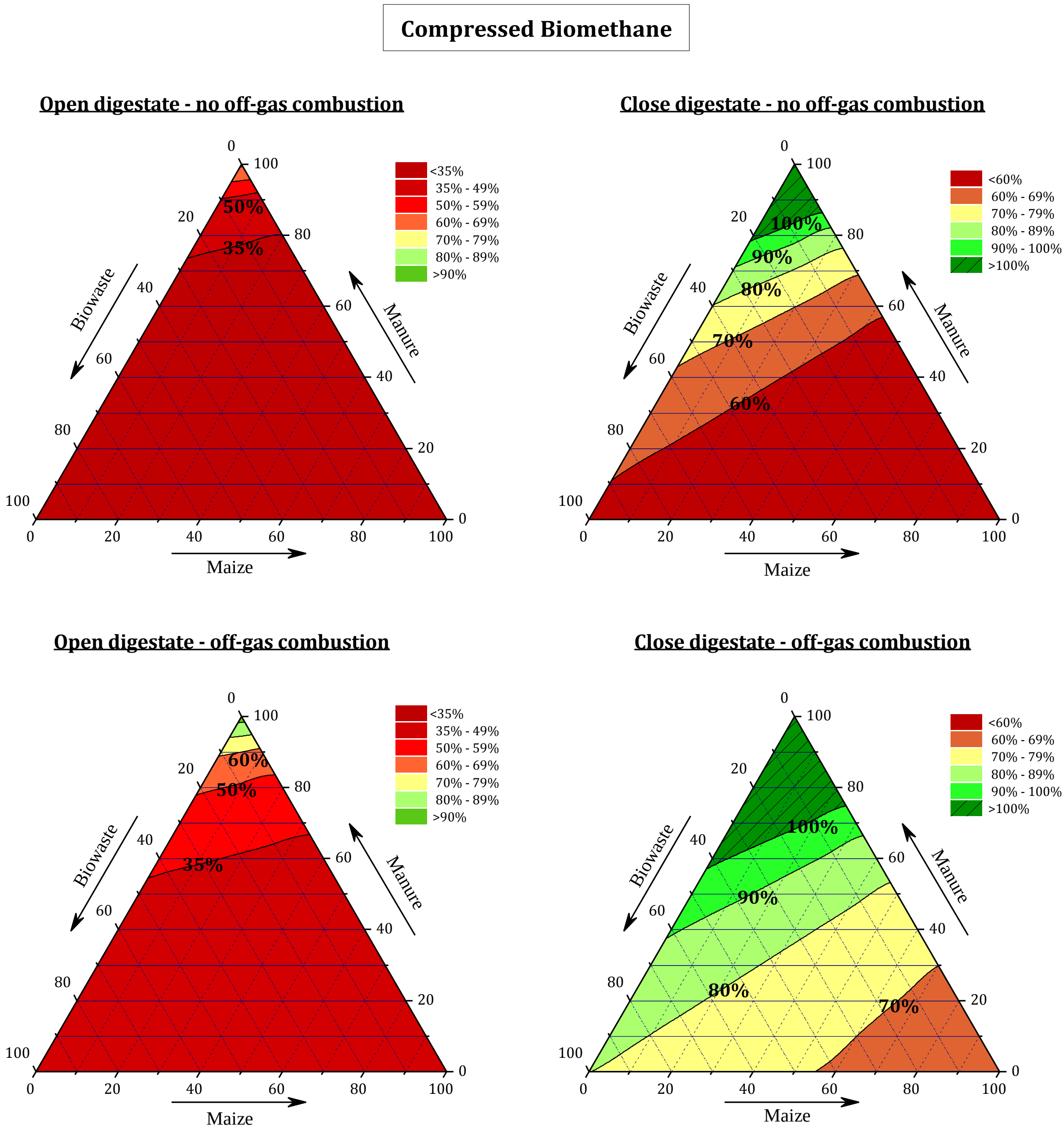


Figure 13. Representation of the GHG savings achieved by combination of any mixture of the three substrates considered(via the formula described in section 5.4). Graphs represent GHG savings based on default values for compressed biomethane pathways used as transport fuel (referring to the values in Table 104).



7.3.2 Co-generation of power, (useful) heat and cooling.

As mentioned in section 7.2, the GHG emission values presented in Table 87 to Table 100 are calculated at plant gate (not considering the final energy conversion). Furthermore, the GHG savings (as presented in Table 95 to Table 104) refer only to conversion to 100% electricity or 100% heat.

However, provided that a demand and infrastructure for heat distribution exist, there is large potential to increase the total energy efficiency of power plants by exploiting the available waste heat in domestic or industrial applications. An efficient system integration could potentially provide simultaneously power, heat (in the form of hot water or steam) and cooling (in the form of refrigerated water). In fact Art. 26(8) of COM(2016) 767 states that electricity from biomass should only be accounted towards the renewable energy targets and to be eligible for public support only if used in a co-generating plant starting from the third year from the adoption of the Directive (without prejudice to support schemes approved until then).

The methodology in Annex VI of COM(2016) 767 recommends, in case of a co-generating plant, to allocate the total GHG emissions on the basis of the exergy content of heat and electricity. Any user can thus, applying the formula defined in the Annex VI point 1(d) of the COM(2016) 767, obtain the allocated emissions (and associated GHG savings) to electricity, heat and cooling from the values provided in this report.

In this section two parameters are assessed: the amount of available heat generated that is used (useful heat) and the temperature at which this heat is co-generated with electricity.

Every thermal process uses the chemical energy stored in a fuel to produce work that is then converted into electrical energy via a generator. The amount of energy that is produced from the combustion of the fuel is always much larger than the energy which is converted into electricity. This available "waste heat" can be collected and used for the production of hot water or steam for domestic heating. Domestic heaters require only a temperature of about 80°C.

Figure 14 and Figure 15 show the dependence of GHG savings for heat and power co-generated from a biogas engine (Figure 14) and from a Rankine cycle fuelled by wood pellets (Figure 15). In both cases it is assumed in this example that the heat is extracted at low temperature and that thus this does not influence the electrical efficiency of the engine or of the cycle. To be noticed that the total recover of heat may not be possible due to thermodynamical efficiency of heat exchangers involved.

However, co-generation of heat is not always a neutral process in respect to the power cycle. For example, the supply of high temperature steam (e.g. 300°C) involves drawing off steam from the expanding turbine with consequent decrease in power produced in the cycle. Figure 16 and Figure 17 explore this effect. To be noticed that while overall "energy" efficiency may appear lower in the case of steam export at 300°C, this has a much higher exergy than waste heat exported at 80°C and thus the exergy efficiency of the cycle will increase.

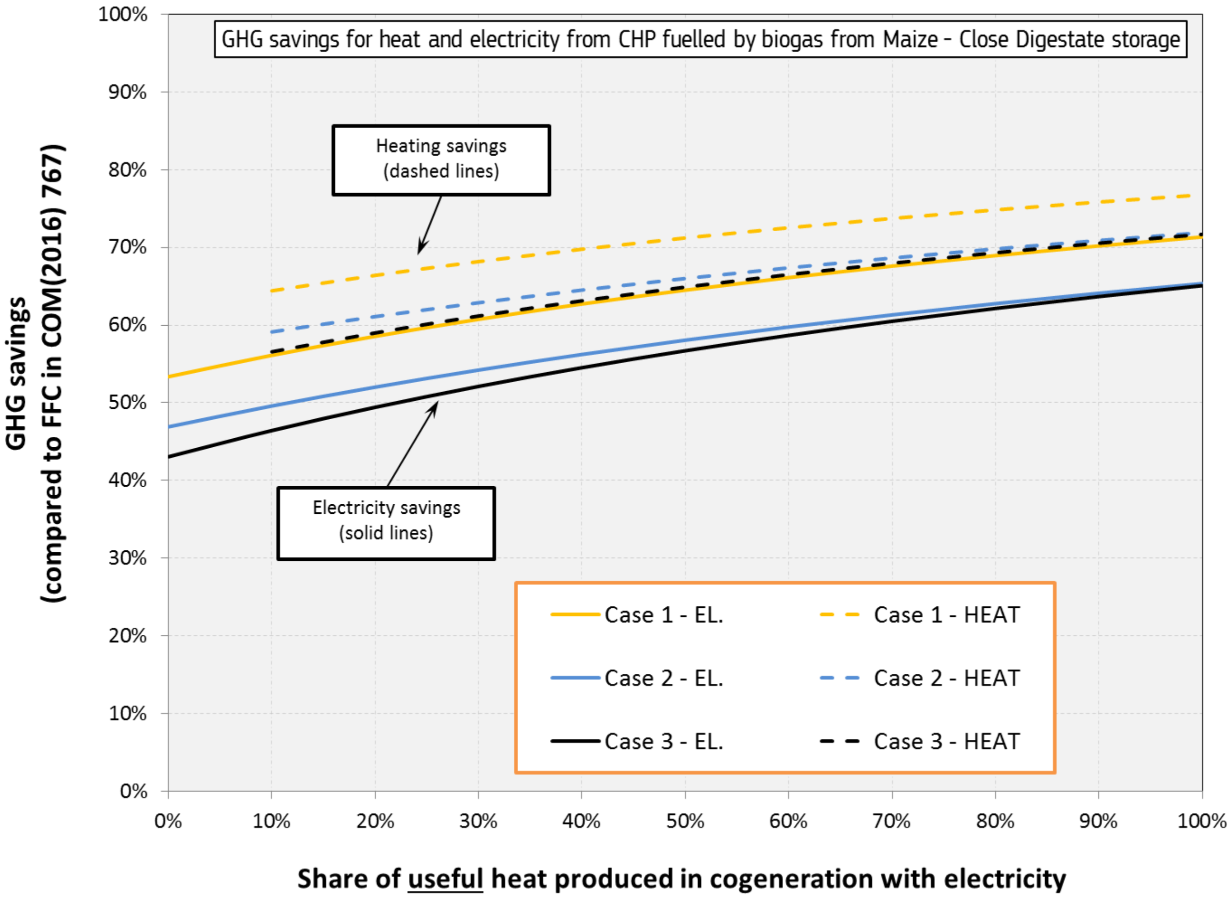
The examples portrayed here are illustrative as actual conditions in power plants could differ significantly for the ones assumed. However, several interesting general trends can be individuated.

Firstly, the co-generation of heat increases, in every case, the GHG savings associated to the electricity generated.

Secondly, a trade-off appears when considering the temperature of heat exported. Because the exergy associated to the steam is higher, the GHG emissions assigned to it are higher than when considering the use of low-T heat. Furthermore, because the production of high-T steam has an impact on the electricity production, also the GHG emissions allocated to electricity decrease less than when low-T heat is produced. The result is an apparently lower overall energy efficiency but a higher exergy efficiency.

Thirdly, a win-win case is found when the amount of heat utilized increases[34]: in this case both the GHG savings for electricity and for heat increase making this an intrinsic incentive to recover as much heat as possible, especially waste heat at low temperature.

Figure 14. Default GHG savings for electricity and heat co-generated from a gas engine fuelled by biogas produced from maize whole plant (close digestate) as a function of the share of available heat which is exported as useful heat (for heating or cooling purposes). The heat is assumed to be produced at a temperature equal or lower than 150°C. Note that the electrical efficiency is maintained constant irrespective of the amount of useful heat produced. For an internal combustion engine such as the one considered for biogas combustion and for low temperatures of the heat needed, this assumption is reasonable. High shares of useful heat may be difficult to reach due to efficiency of heat exchangers involved.



34 "Useful heat" is defined here as the heat generated in a co-generation process to satisfy an economical justifiable demand for heating or cooling.

Figure 15. Default GHG savings for electricity and heat co-generated from a Rankine cycle fuelled by pellets produced from various pathways as a function of the share of available heat which is exported as useful heat (for heating or cooling purposes). Where not indicated, the pellet production pathways consider a transport distance of 500 km by truck. The heat is assumed to be produced at a temperature equal or lower than 150°C. Note that the electrical efficiency is maintained constant irrespective of the amount of useful heat produced. This assumption is reasonable when the heat is exported at low temperatures. High shares of useful heat may be difficult to reach due to efficiency of heat exchangers involved.

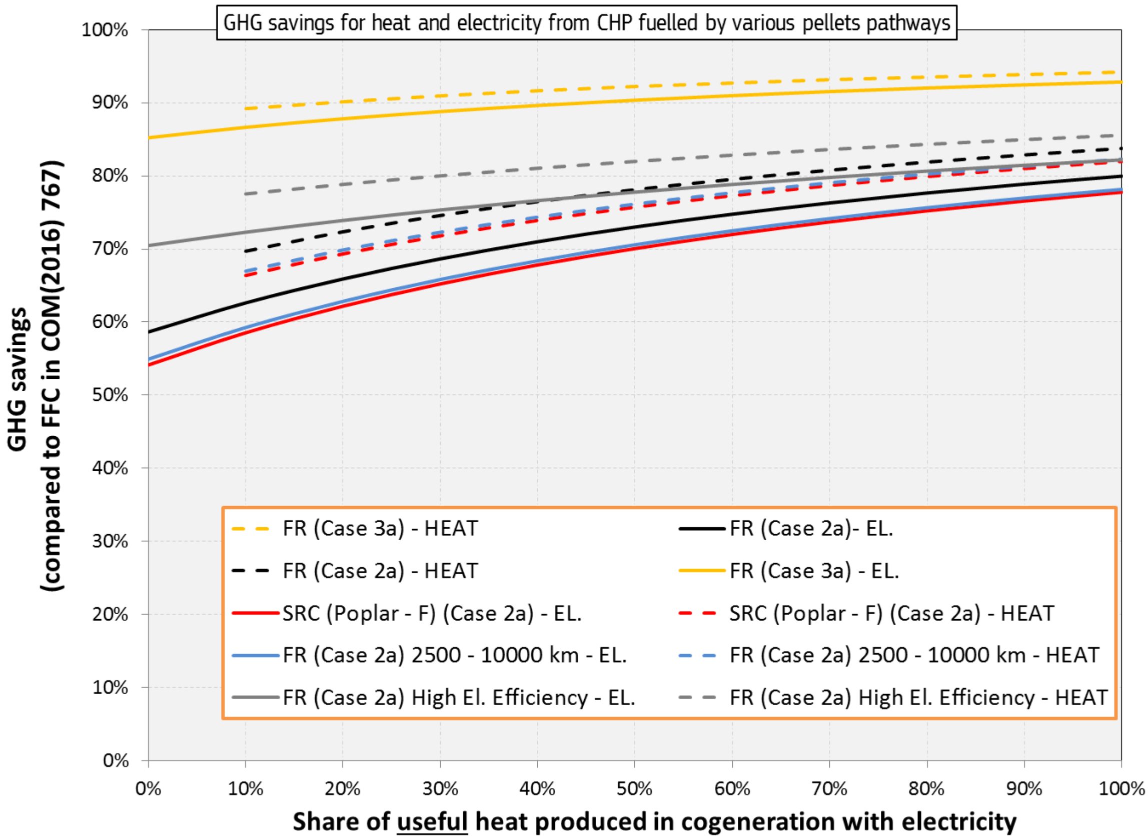


Figure 16. Default GHG emissions for electricity and heat co-generated from a Rankine cycle fuelled by pellets as a function of the share of available heat which is exported as useful heat at different temperatures. The pellet production pathways consider a transport distance of 500 km by truck. Two alternative configurations are explored: the blue lines represent the same case as in Figure 15 and the heat is assumed to be produced at a temperature equal or lower than 150°C. The orange lines represent the case in which steam is drawn off the turbine at 300°C and thus the electrical efficiency of the cycle is affected.

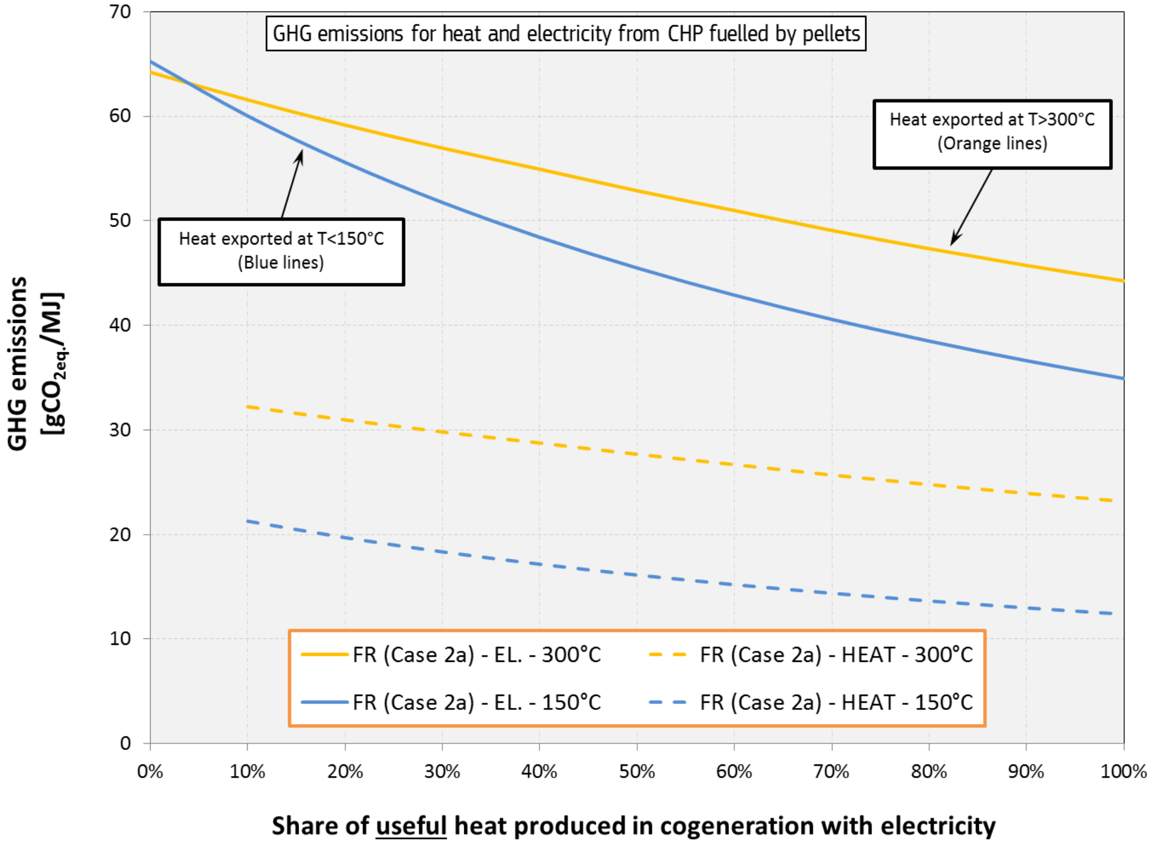
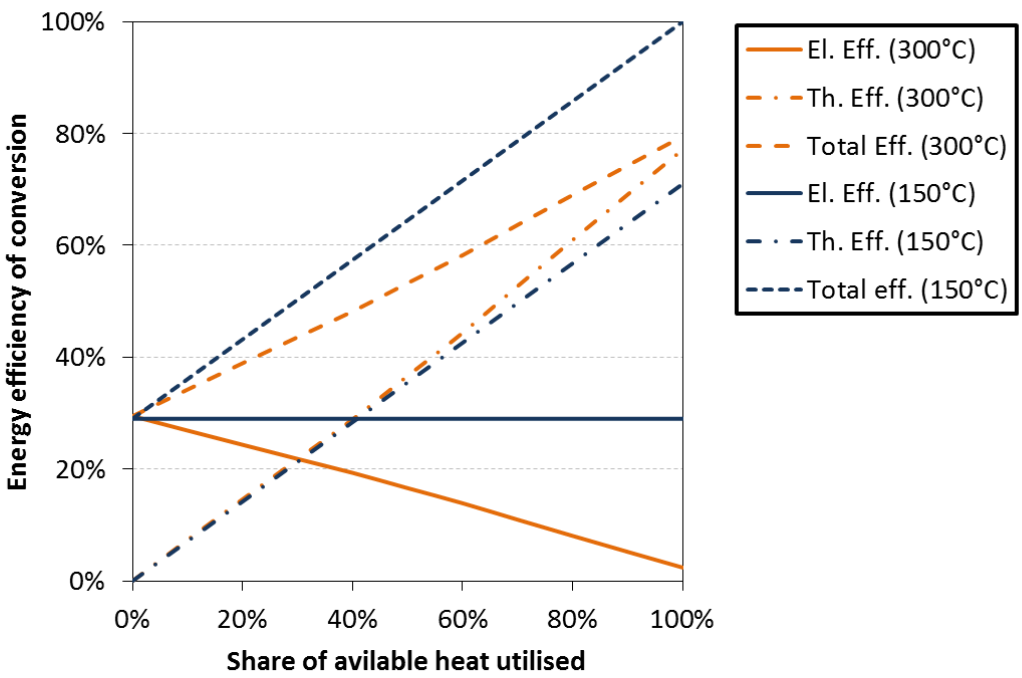


Figure 17. Energy efficiency of conversion to power and heat for the two configurations represented in Figure 16. The details of the Rankine cycle considered are: i) Max Pressure: 100 bar(g); ii) Max Temperature of steam: 450°C; iii) Isoentropic expansion; iv) Steam condensed/return of the exported steam at 120°C.



Tri-generation

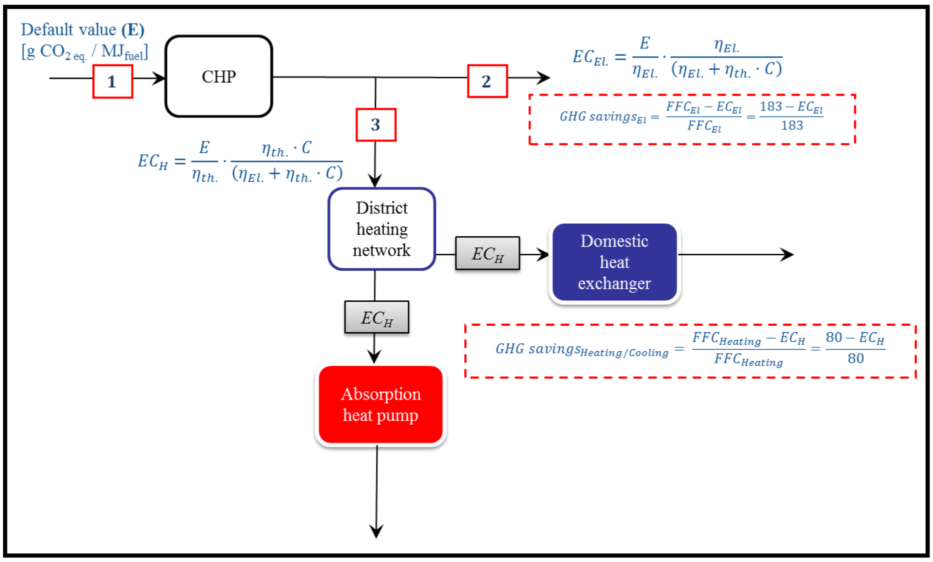
Not many projects at significant scale exist for co-generation of power and cooling or even tri-generation of power, heat and cooling.

However, most of the concepts for co-generation of cold water from biomass power plants rely on the use of the waste heat from the process to supply the necessary thermal energy to a decentralized absorption chiller[35]. Therefore, even the production of useful cooling basically relies on the use of the waste heat from the power cycle. The heat can then be distributed in the form of steam or hot water via a network of pipelines and can then be used to supply domestic heat, domestic cooling or both.

For this reason, in an hypothetical tri-generative system, the upstream emissions could be allocated among the products as illustrated in Figure 18: emissions are allocated on the basis of the exergy content of power and heat at the CHP outlet and the emissions allocated to the unit of heat are valid irrespective if the heat is used for domestic heating or cooling by absorption pump. These emissions can then be compared to the FFC_{heat} as indicated in Annex VI point 2 of COM(2016) 767.

[35] See for example http://www.polycity.net/en/downloads-supply.html

Figure 18. Schematic of allocation of upstream GHG emissions in a tri-generative system (producing power, useful heat and useful cooling via an absorption chiller). *E* represents the total upstream GHG emissions on the basis of the energy content of the energy carrier (e.g. pellets, chips etc…); EC_i represents the GHG emissions of a final commodity: electricity or heat. FFC_i represents the fossil fuel comparators. *C* represents the Carnot factor associated to the produced heat, as defined in the COM(2016) 767. η_i represents the electrical and thermal (for heating and for cooling) conversion efficiencies. All efficiencies should be interpreted as annual output over annual input as defined in COM(2016) 767 (e.g. $\eta_{El.}$ = yearly quantity of electricity produced / yearly amount of fuel energy input; η_{Cool} = yearly quantity of cooling delivered / yearly amount of heat input). Once emissions are allocated on the unit of heating produced (EC_H) they apply both for domestic heating and for cooling.



7.3.3 Efficiency of final conversion

When reporting the GHG emissions associated to a specific pathway the choice of the functional unit to which such emissions are referred to is important.

For example, the values reported in Table 87 to Table 90, are based on a MJ of bioenergy carrier at plant gate (e.g. MJ of wood chips, pellets, bales etc…). These values, thus, do not account for the final energy conversion efficiency and the emissions associated with the combustion of the biofuel.

However, when a comparison needs to be reported (e.g. GHG savings compared to a fossil source), it may not always be possible to clearly identify a meaningful comparators.

In the case of liquid biofuels, regulated in the RED, comparing the biofuels at the pump with fossil diesel or gasoline at the pump avoids including the large variability of final conversion to mechanical power in automotive engines and instead focuses on the supply chain emissions. The same is valid for biomethane injected into the natural gas grid.

When solid biomass is used for power and heat generation, though, it was defined in the COM(2010) 11 that the comparison should have been with appropriate fossil fuel comparators on the basis of the final energy (i.e. electricity or heat). So, in order to convert the GHG emission values from a "plant-gate" basis to a "final-energy" basis, for indicative purposes two standard conversion efficiencies were used (see section 7.1 for more details).

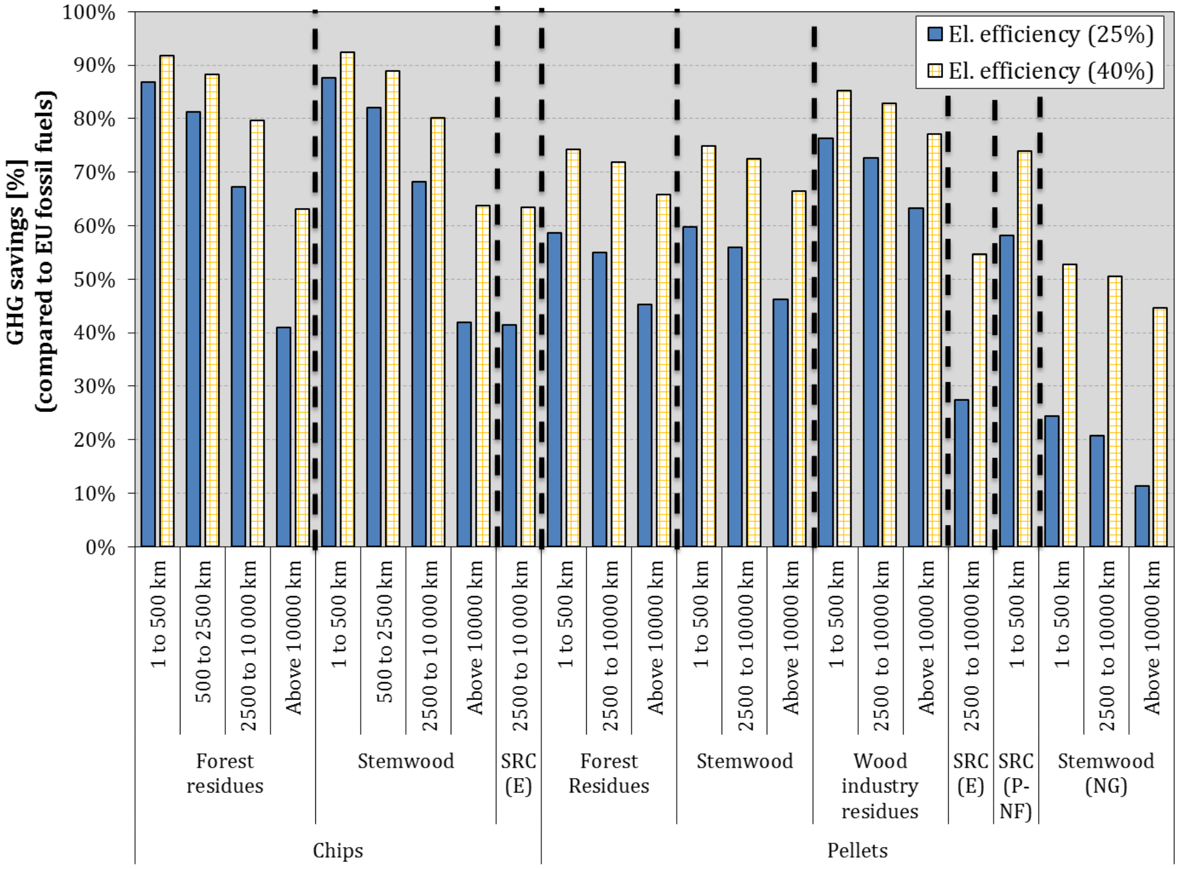
However, the choice of the value for a standard conversion efficiency can have important consequences; for example, pathways that may be below a certain GHG savings threshold with a determined efficiency may well be above it when a more efficient plant is considered.

The value chosen as a representative electrical efficiency for bioenergy plants is equal to 25%. This may be a representative value for small and medium-scale plants running on bioenergy feedstocks only. However, more efficient and larger-scale installations may reach higher efficiencies even running on biomass only (30-35%) and when considering the share of biomass that is co-fired with coal, the plant efficiency can be above 40%.

For this purpose, Figure 19 presents the GHG savings obtained for some of the most representative solid biomass pathways in case of final conversion efficiencies of 25% and 40%.

As expected, the GHG saving values increase for all the pathways when the final efficiency increases. Most importantly, the effect is more marked for the pathways for which the supply emissions are higher. For pathways based on wood industry residues, an increased conversion efficiency would allow them to achieve GHG savings above 80%.

Figure 19. GHG savings for the most representative forest based solid biomass pathways applying alternative efficiencies of conversion. The same pathways and specifications apply as in Figure 6. The columns represent two alternative efficiencies of energy conversion to power: the blue columns are obtained applying the standard efficiency of 25%, the checkered bars consider a final conversion equal to 40%. SRC (E) = Short Rotation Coppice based on Eucalyptus cultivation. SRC (P-NF) = Short Rotation Coppice based on non-fertilised poplar cultivation.



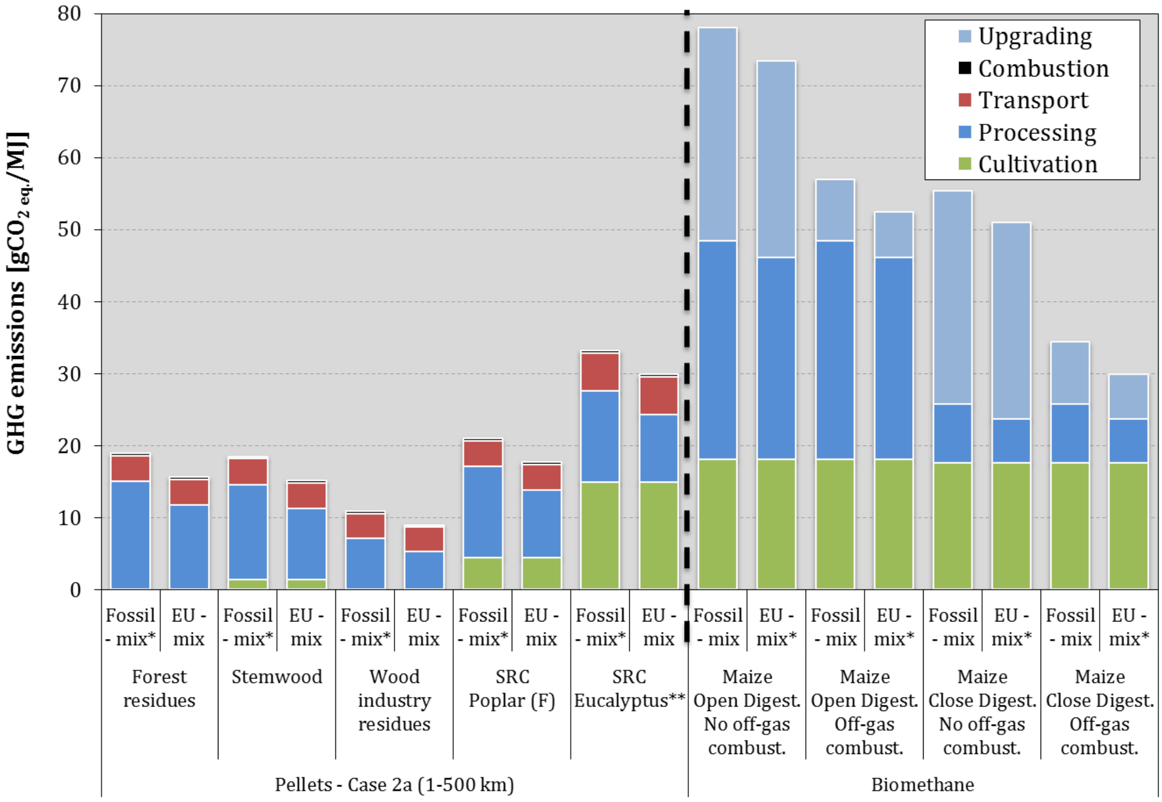
7.3.4 Choice of emission factor for the electricity supply: Fossil-mix vs. EU-mix

Section 2.1 introduced the emission factors associated to the supply and consumption of electricity that were used in this report, defined as "Fossil-mix" and "EU-mix". In order to estimate the influence of the choice of this emission factor on total GHG emissions, calculations were performed for a selected number of pathways using both alternatives (Figure 20).

For some pathways, where no or limited power from the grid is used, the differences are minimal or non-existent. For example the woodchips pathways, the pellets pathways utilizing a CHP (case 3a) and the biogas pathways that use their own electricity (case 1) are not affected.

In general, total typical GHG emissions using the EU-mix values are between 6% and 18% lower than the values obtained using the Fossil-mix factor, with the largest differences shown for the pathways whose main contribution is actually constituted by processing emissions (e.g. forest residues pellets and pellets from wood industry residues). The emissions associated only with processing, in fact, are found to decrease between 22% and 26% for solid pathways. For biomethane pathways, processing emissions using Fossil-mix can be as much as 37% higher compared to using EU-mix.

Figure 20. Analysis of the influence of the choice of emission factor for the EU electricity mix supply on the default GHG emission values for some of the most relevant (affected) pathways both for solid biomass and for biomethane. All pellets pathways are considered for the Case 2a and for a transport distance of 500 km. The pathway for SRC (Eucalyptus) considers transport from tropical regions. The values indicated as "Fossil - mix" consider that supply of electricity has the same emission factor as the FFC. The values indicated as "EU - mix" use the the average EU electricity mix emissions. Chemicals, diesel and HFO are kept constant. Values marked with an asterisk (*) are the default values used in the COM(2016) 767 and represented in Table 96 for pellets and in Table 100 for biomethane.



Part Four: review process

8 Consultation with experts and stakeholders

The following sections present the main issues raised by experts and stakeholders during the consultations held by the Commission in the past years.

Some of the points raised have become obsolete in the years since many changes have been applied to the numbers and the assumptions. These points have been removed from this current version of the report. The complete list of questions and answers can be found in Annex 2 and 3.

8.1 Main outcomes of the discussions during the Expert Consultation of November 2011, Ispra (IT).

General issues

The main issues raised at the workshop are described below (JRC responses are shown in italic font).

- Shipping emissions: the JRC considered that the return journey of the means of transport was empty. It was argued that the return trip is often used to transport other goods. While this may apply to container ships, it is not the case for chemical tankers or grain carriers: these are specialist ships, which will not easily find a suitable export commodity from the EU for the return journey.

  Updated ship data based on International Maritime Organization (IMO) data have been used for crop, vegetable oil and ethanol shipping. Sugar cane ethanol, palm oil and soya figures have also been adjusted.

- Bonn University's Common Agricultural Policy Regional Impact Analysis (CAPRI) database provides a number of relevant input data for EU cultivation processes, and particularly on diesel use, that may be useful for supplementing the JRC data set.

  CAPRI data on diesel use in cultivation, drying and pesticide use have been included in many of the pathways.

- It was proposed that the JRC create and make available a specific database for emissions deriving from the production of fertilizers in use (not only ammonium nitrate and urea), using International Fertilizer Association (IFA) data.

  JRC is now using emission factors based on data published by Fertilizers Europe.

- The JRC was asked to clarify how the LHV data for feedstocks (e.g. wood, and dried distillers' grains with solubles (DDGS)) are calculated.

  Tables of LHV values are included in Appendix 1 of this report.

Comments on biogas pathways

- Transport distances of wet manure and silage maize must be checked, and if necessary, updated

  The JRC has checked the distances and the updates are included in this report.

- A new pathway on 'Biogas from grass' should be added to the list; this could be relevant as grass is increasingly used in co-digestion.

  This pathway is not common in Europe, we think we cover a large share of the biogas market with the three substrate categories considered. JRC is available to interact further with stakeholedrs for actual values calculations if needed.

- Data for the digestion process need to be verified and improved. In particular, they should be differentiated by feedstock.

The JRC has taken this into consideration and the updates are included in this report.

- Concerns were raised about the directives **not** considering emissions from the fuel in use; this would affect the emissions of methane from biogas engines, in particular. The JRC has already raised this issue in a note recently sent to DG Energy.

  This has been updated and is included in this report.

Comments on biomass pathways

- The Swedish Ministry of Energy commented that the consumption of electricity in the pellet mill used by the JRC appears to be too high, and offered to provide data from Swedish industry.

  The value for electricity consumption has been revised according to new information received

- It was also suggested that the need and use of additives in pellets be considered. However, for the current market of pellets from wood, this is unlikely to be necessary.

  JRC agrees with the experts that at present, this is not a common practice in the industrial pellet market.

- Eucalyptus pathway: JRC values for yields and the N-fertilizer input need to be checked against additional literature data.

  JRC has updated the data for Eucalyptus cultivation based on updated available literature.

- Diesel consumption for stemwood logging: the JRC used data from Sweden, but it was argued that the numbers could be higher for operations in Germany or other parts of the EU. Additional data (e.g. reports from the University of Hamburg) may be provided to the JRC.

  JRC has checked additional literature against the values proposed during the meeting but it has come to the conclusion that the values chosen are appropriate within the required precision on a EU-wide scale.

- It was suggested that a pathway be constructed for torrefied biomass — in particular, pelletised torrefied biomass.

  JRC will monitor technological development in the area of torrefied biomass and will build a pathway when reliable, i.e. at least when demonstration-scale data will be available. *This is not yet the case.*

- *Miscanthus*: GEMIS will remove its *Miscanthus* data from version 4.8 because these were 'potential' values, rather than 'real' values. The data will be updated once the literature sources are updated.

  JRC has evaluated several sources and judged that the data available in the literature are not reliable enough to be used to define a default value with legal value. The pathway will be updated once data from larger-scale plantations will be available.

8.2 Main comments from the stakeholders meeting of May 2013, Brussels (BE).

Comments on biogas pathways

- **Methane emissions from storage of digestate**

JRC has analysed additional studies (e.g. Weiland, 2009 and Gioelli et al., 2011) which have confirmed a few points:

- *Many parameters come into play, making it very difficult to find any significant correlation between digestate emissions and other process parameters.*
- *For example, the ambient temperature has a minimal influence on slurry temperature. Due to the constant supply of warm digestate from the reactor, the storage tank temperature rarely falls below 20°C, even with ambient temperature close to 0°C (Gioelli et al., 2011; Hansen et al., 2006).*
- *The hydraulic retention time of the process has a significant influence on volatile solids reduction (and with the share of energy crops in the substrate) but it is difficult to find a correlation with residual digestate methane potential (Weiland, 2009).*
- *Measurement errors or incoherencies should not be forgotten. It is possible to find reported values for VS in input, methane production, share of methane and CO2 in biogas and VS reduction. The system is thus over-defined and with the first four of these values it is possible, for example, via a simple carbon balance, to find the VS reduction. Or vice-versa, calculate the methane yield. However, these numbers are rarely found to be coherent in literature.*
- *For the reasons above, we do not think it is appropriate to compare the values in the form of "% of methane produced" since this indicator aggregates at least two specific data: residual methane potential of the digestate and methane productivity of the plant.*
- *Therefore, we have re-elaborated the data for digestate emissions taking as starting point the* ***residual methane potential of digestates.*** *Applying a carbon balance with a fixed methane productivity, we have then calculated VS reduction and final methane emissions from digestate. These can then be related to the total production of biogas.*

The values chosen are detailed in the table below:

	Maize silage	Manure	Biowaste
Methane yield [Nl_{CH4}/kg_{VS}] ([36])	345	200	438
CH4 share in biogas ([37]) [$\%_{vol.}$]	53	51	60
VS reduction [%] ([38])	75	43	75.5
Digestate residual potential [l_{CH4}/kg_{VS} residual]	30	35	44
Share of CH_4 from storage over total CH_4 produced [%]	2.2	10.0	2.5

([36]) Nm3 at 0°C and 1 atm.
([37]) For simplicity, the rest of the biogas is assumed to be composed only by CO2
([38]) Calculated via a carbon balance considering 0.49 gC/kgVS for manure, 0.47 gC/kgVS for maize and 0.52 gC/kgVS for Biowastes

- Emissions of N2O from the digestates are based on the IPCC and EEA guidelines based on the following assumptions:

	Maize silage	**Manure**	**Biowaste**
Total N content [kg N/dry kg]	*1.1%*	*3.6%*	*3.4%*
Total ammoniacal N (TAN) [kg N-NH4/kg N]	*50%*	*60%*	
N losses in digestion	*6%*	*6%*	*6%*
N2O direct emissions [kg N-N2O/kg N] (IPCC,2006)	*0.5%*	*0.5%*	*0.5%*
N volatilization to NH3 and NO [kg N-NH3+kg N-NO/kg TAN] (EEA, 2013)	*20%+0.01%*	*20%+0.01%*	*40% ([39])*

- **Manure-to-biogas: methane credits**

The GHG methodology set in the 2010 Biomass Report includes certain emission savings from carbon accumulation via improved agriculture management. For the SWD 259, the JRC was asked to include in this category also the avoided methane and nitrous oxide emissions resulting from improved manure management via anaerobic digestion.

However, JRC has reworked methane and N_2O emissions from digestate storage for all the pathways. We have also decided to recalculate the manure avoided emissions based on IPCC guidelines.

Based on the IPCC Guidelines, the ratio between the methane emissions due to slurry storage and the emissions due to digestate storage is simply given by the reduction of volatile solids during digestion (methane yield and methane conversion factor are suggested to be kept the same between the two situations). This implies that with the specific conditions assumed in our calculations (VS reduction = 43%) the credits would be equal to 1/0.57 = 1.76 times the emissions from digestate storage.

Considering that the methane emissions from digestate are equal to 10.0% of the produced methane, thus, the credits would be equal to ***17.5% of the methane produced = 0.175 MJCH4/MJ biogas = 3.5 gCH4/MJ biogas = 1.5 g CH4/MJ manure = -37 g CO2 eq./MJ manure.***

Concerning N_2O emissions, instead, considering that the proportion of ammoniacal nitrogen in the digestate is supposed to increase and that the total N is decreased due to losses in the digester, we assume that the net emissions from raw slurry and digestate are equal and thus the credit would simply balance out the N2O

([39]) For biowastes the value of volatilization from IPCC (for liquid slurry) is used *emissions assigned to digestate storage. Numerically this would be equal to* ***0.066 gN2O/MJ biogas = 19.8 g CO2 eq./MJ biogas = -8 g CO2 eq./MJ manure.***

— **Digestate fertilizing potential, fertilizer credits and maize whole crop nitrogen fertilization balance.**

An extensive nitrogen balance for the cultivation of maize whole crop is added in section 6.1.1

— **Biogas plants useful heat production and utilisation.**

JRC has not inserted the exported heat as a structural part of the default values (thus allocating part of the emissions to heat and part to electricity) because while waste heat is generally used for the heating of the digester (included in the JRC values), export of such heat to other users is still scarce and it depends mostly on the presence of a district heating network and on the presence of a sufficient demand.

However, because of the structure of the methodology, operators can, without declaring the whole actual value, apply their own final conversion efficiencies to the values presented as default (which are presented on the basis of the energy carrier, e.g. 1 MJ of pellet, 1 MJ biogas etc…). In addition to this, in case of a CHP producing useful heat and electricity, operators can apply the allocation formula given in the methodology. The formula itself provides a lot of flexibility so that with a relatively simple calculation any possible situation can be reproduced.

Comments on solid biomass pathways

— Torrefied pellets patyhways.

JRC also recognizes the future relevance of torrefied pellets especially for import routes. Nonetheless, the technology is not yet available at commercial level and thus even with valid datasets on the current technology status, this is far from the general, average validity that a 'default value' should have. For this reason we believe that it is too early to provide a default value for torrefied pellets.

— Trucks fuel consumption and payload.

We have found in the literature values for diesel consumption for large trucks in the range of 0.21-0.26 l/km for empty cargo and between 0.29 – 0.35 l/km for full cargo. When combined, we obtain the value indicated in the report.
However, we have looked into the data provided by the EEA/EMEP inventory guidebook 2013. Based on the values for Tier 2 fuel consumption and N2O emissions and Tier 3 CH4 emissions and based on the fleet composition obtained from the database COPERT, we have modified our fuel consumption to:

- *Weighted average (over distance per truck type) for fuel consumption:* ***30.53 l/100*** *km (including empty return trip)*

Longer and Heavier Vehicles (LHVs)(up to 60 tonnes of total weight) are allowed in Finland and Sweden with some trials in The Netherlands and Germany. However, these trucks are not allowed within the Directive 96/53/EC and are also not included in the new Commission proposal for the amendment of such directive (COM(2013) 195 from April 2013). LHVs are allowed to circulate in single MS and also to cross one border if the two MS allow it. However, this is not the standard in EU and thus it cannot be included among the default values. Operators in countries that allow LHV can declare an actual value for the transport step.

— Shipping fuel consumption.

We have now introduced a new category of bulk carrier, SUPRAMAX, with a DWT of 57000 tonnes and calculated a new specific fuel consumption from the IMO data

equal to 1.09 g_{HFO}/tkm (FULLY LOADED, one-way). This new category will be used for all trans-oceanic shipping while the smaller HANDYSIZE carriers will be used for shorter distances (e.g. import from Baltics and Russia).
Furthermore, most of the SUPRAMAX carriers are designed with a stowage ration of about 0.75, which means that also the density of pellets (ca. 650 kg/m^3) is not enough to guarantee a weight-limited cargo but it will be volume-limited. Considering the data received from stakeholders regarding cargo manifests of two of their bulk carriers, it is possible to estimate the average distance that the carriers have travelled with an empty cargo (under ballast) during their lifetime. This results in a percentage over the total distance covered of 22% and 31% for the two carriers. These data can be used to assign to each cargo a share of the total empty travel of the cargo.
In this way the total consumption can be assigned as follows:

$$Total\ Fuel\ Consumption\ \left[\frac{g_{HFO}}{tkm}\right] = \frac{FC_{@Cargo} + FC_{@Ballast} * (CF/(1-CF))}{Cargo_{Outward}}$$

Where, $FC_{@Cargo}$ is the fuel consumption at cargo load in the outward journey, $FC_{@Ballast}$ is the fuel consumption under ballast and CF is the Capacity factor defined as the share of distance travelled by the ship under ballast over total distance travelled. Cargo is the cargo loaded in the outward journey.
By using this formula it is possible to assign to the pellet cargo only a share of the empty trips of the carrier as well as it would be assigned to all other cargos.
The complex issue is to choose a relevant CF: according to the GDF Suez data, this should be between 22 – 31%; according to other stakeholders this value is about 30%; according to the average values provided by IMO, this value is about 45%. Based on these considerations we have opted for a value of 30% for the Capacity Factor.
This leads to the following update fuel consumption for shipping of pellets and wood chips by bulk carriers:

- Pellets shipped by Supramax (@ 650 kg/m3) = 1.62 gHFO/tkm (incl. empty fraction)
- Chips shipped by Supramax (@ 220 kg/m3) = 4.06 gHFO/tkm (incl. empty fraction)
- Chips shipped by Handysize (@ 220 kg/m3) = 6.38 gHFO/tkm (incl. empty fraction)

— Pelleting process heat and power consumption.

The data on heat supply in pellet mills received from stakeholders indicate that US and Canadian mills are actually using their own pellets to supply heat to the process, while in European mills it appears that mostly fresh chips/bark are used. Further, it is interesting to see that actually some CHP plants are already registered to be operating in mills. The Wood Pellet Association of Canada confirmed to JRC that the pellet mills in Canada use either planer shavings or sawdust/chips as feedstocks for drying. The Wood Pellet Association of Canada claims that around 15% of the feedstock is used for drying and 85% is used for pellet making. This is lower than JRC number (28% is used for chips boiler) but that is because JRC considers fresh wood chips to have 50% moisture, while the particular situation of Canada (using Mountain Pine Beetle killed stems and wood that has already been air dried in the forest) allows them to have feedstocks at 35% moisture content at the mill gate.
JRC values for power consumption in pellet mills are confirmed to be within the ranges recorded by stakeholders.

9 Conclusions

The datasets and analysis reported in this report can be used by economic operators, regulators and other stakeholders to better understand and replicate the default GHG emissions reported in the Commission Proposal for a recast of the Renewable Energy Directive (COM(2016) 767)[40].

The results show that biogas and biomethane produced from wet manure can achieve GHG savings above 100% thanks to the emission credits for avoided GHG emissions from the alternative manure management.

GHG savings associated with electricity produced from biogas from maize whole crop span from 10% up to more than 50%. This wide variation is strongly dependent on the technology adopted. The use of a gas-tight tank for the storage of the residual digestate is essential in most of the pathways to achieve high GHG savings.

When a biogas plant is analyzed in its entirety and the emissions are averaged among multiple substrates (i.e. co-digestion), technological choices and the use of manure in combination with maize are the two key drivers for achieving GHG savings higher than 80%. For instance, when biomethane is produced with the best technology (Close Digestate – Off-gas combusted), a mixture of $60\%_{\text{fresh matter}}$ manure and $40\%_{\text{fresh matter}}$ maize will achieve 81% savings. However, when off-gases are simply vented rather than flared, only $20\%_{\text{fresh matter}}$ of maize can be co-digested to achieve savings above 80%.

GHG savings for solid biomass pathways are generally above 60% both for power and heat produced. Emission drivers include: transportation distance, the efficiency of final energy conversion, eventual cultivation emissions, and the carbon intensity of the production process.

For many forest biomass pathways default values do not reach 80% GHG savings for transportation distances above 2500 km (e.g. overseas) and/or for electricity-only generation (assuming a standard 25% conversion efficiency). Pellets would be more affected than wood chips as more processing energy is needed for their production; with a 85% threshold most pellets produced with current technology (Case 2a) would not qualify. However, pellets produced using renewable energy sources (Case 3a) and utilized in co-generating plants would still be able to pass the highest threshold.

Cultivation emissions can also affect GHG savings. For instance, certain pathways using intensely cultivated short rotation coppice feedstocks do not reach GHG savings above 60% in electricity-only plants. Other pathways based on less intensely cultivated, domestic species (e.g. poplar) could generally achieve GHG savings above 80%, especially for pathways with high conversion efficiencies and best practices for pellet mills. The GHG savings presented in this report (especially the ones relative to power production) are based on an assumed conversion efficiency of 25%. A higher conversion efficiency or co-generation of power and (a large share of) useful heat would allow also pathways fuelled by wood pellets produced with current technology (Case 2a) to reach GHG savings higher than 80%.

([40]) All input data and results presented in this report will be made available in an Excel database at the following address: https://ec.europa.eu/jrc/en/alfa

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Glossary

AG	Above-ground
BG	Below-ground
BGN	Below-ground Nitrogen
CAPRI	Common Agricultural Policy Regional Impact
CFB	Circulating Fluidised Bed
CHP	Combined Heat and Power
DG Climate Action	Directorate-General for Climate Action
DG Energy	Directorate-General for Energy
ENTSO-E	European Network of Transmission System Operators for Electricity
EPA	Environmental Protection Agency
ETS	Emissions Trading Scheme
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FQD	Fuel Quality Directive (2009/30/EC)
GEMIS	Globales Emissions-Modell Integrierter Systeme (Global Emission Model of Integrated Systems)
GHG	Greenhouse gas
GWP	Global Warming Potential
HV	High Voltage
IEA	International Energy Agency
IES	Institute for the Environment and Sustainability
IET	Institute of Energy and Transport
IFA	International Fertilizer Association
IFEU	Institute for Energy and Environmental Research
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
JEC	JRC-EUCAR-CONCAWE consortium
JRC	European Commission, Joint Research Centre
LBST	Ludwig-Bölkow-Systemtechnik GmbH
LCA	Life Cycle Assessment
LHV	Lower Heating Value
LPG	Liquefied Petroleum Gas
LV	Low Voltage
MV	Medium Voltage
NG	Natural Gas
NREL	National Renewable Energy Laboratory
NUTS	Nomenclature of Territorial Units for Statistics
PKM	Palm Kernel Meal
RED	Renewable Energy Directive (2009/28/EC)
WTT	Well-to-Tank
WTW	Well-to-Wheels

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Annex 1. Fuel/feedstock properties

Table A. 1. Fossil fuels properties as utilized in this report

Fossil Fuel	Property	Value	Unit
Crude	LHV (mass)	42	MJ/kg
	LHV (volume)	34	MJ/l
	Density	0.820	kg/l
Diesel	LHV (mass)	43.1	MJ/kg
	LHV (volume)	36	MJ/l
	Density	0.832	kg/l
DME	LHV (mass)	28.4	MJ/kg
	LHV (volume)	19	MJ/l
	Density	0.670	kg/l
Ethanol	LHV (mass)	26.8	MJ/kg
	LHV (volume)	21	MJ/l
	Density	0.794	kg/l
FT - diesel	LHV (mass)	44	MJ/kg
	LHV (volume)	34	MJ/l
	Density	0.785	kg/l
Gasoline	LHV (mass)	43.2	MJ/kg
	LHV (volume)	32	MJ/l
	Density	0.745	kg/l
Methane	LHV (mass)	50	MJ/kg
	Density (STP)	0.717	kg/Nm^3
	Density (NTP)	0.668	kg/m^3
	LHV (vol.)	35.9	MJ/Nm^3
Methanol	LHV (mass)	19.9	MJ/kg
	LHV (volume)	16	MJ/l
	Density	0.793	kg/l

Table A. 2. Material properties for biomass materials and energy carriers. Part 1: Feedstocks and bioenergy carriers for gaseous pathways.

Material	Property	Value	Unit
Biogas (from maize digestion)	Methane content (vol.)	53 %	m^3 CH_4/m^3 biogas
	CO_2 (vol.)	47 %	m^3 CO_2/m^3 biogas
	LHV (vol.)	19.0	MJ/Nm^3
	Density (NTP)	1.31	kg/Nm^3
	LHV (mass)	14.5	MJ/kg
Maize kernels	LHV dry	17	MJ/kg dry
	Moisture	35 %	kg water/kg total
	LHV wet (RED)	10.4	MJ/kg wet
	Yield share	46 %	kg kernels/kg whole plant
Corn stover	LHV dry	16.5	MJ/kg dry
	Moisture	75 %	kg water/kg total
	LHV wet (RED)	2.3	MJ/kg wet
	Yield share	54 %	kg stover/kg whole plant
Maize whole crop	LHV dry	16.9	MJ/kg dry
	Moisture	65 %	kg water/kg total
	LHV wet (RED)	4.3	MJ/kg wet
	Yield	40.8	wet tonne (@ 65%)/ha
	N content	0.37%	kg N/kg wet tonne
	VS	96%	kg VS/kg TS
Wet manure	LHV dry	12	MJ/kg dry
	Moisture	90 %	kg water/kg total
	LHV wet (RED)	-0.3	MJ/kg wet
	VS	70 %	kg VS/kg TS
	N content	3.6 %	kg N/kg TS
Biogas (from manure digestion)	Methane content (vol.)	51 %	m^3 CH_4/m^3 biogas
	CO_2 (vol.)	49 %	m^3 CO_2/m^3 biogas
	LHV (vol.)	18.3	MJ/Nm^3
	Density (NTP)	1.33	kg/Nm^3
	LHV (mass)	13.7	MJ/kg
Biowaste	LHV dry	20.7	MJ/kg dry
	Moisture	76 %	kg water/kg total
	LHV wet (RED)	3.0	MJ/kg wet
	VS	91.4 %	kg VS/kg TS
	N content	3.4 %	kg N/kg TS
Biogas (from biowaste digestion)	Methane content (vol.)	60 %	m^3 CH_4/m^3 biogas
	CO_2 (vol.)	40 %	m^3 CO_2/m^3 biogas
	LHV (vol.)	21.5	MJ/Nm^3
	Density (NTP)	1.22	kg/Nm^3
	LHV (mass)	17.6	MJ/kg
Biomethane	Methane content (vol.)	97 %	m^3 CH_4/m^3 biogas
	CO_2 (vol.)	3 %	m^3 CO_2/m^3 biogas
	LHV (vol.)	34.8	MJ/Nm^3
	Density (NTP)	0.75	kg/Nm^3
	LHV (mass)	46.1	MJ/kg

Table A. 3. Material properties for biomass materials and energy carriers. Part 2: Feedstocks and bioenergy carriers for woody biomass pathways.

Material	Property	Value	Unit
Woodchips (general)	LHV dry	19	MJ/kg dry
	Moisture (after seasoning)	30 %	kg water/kg total
	LHV wet (RED)	12.6	MJ/kg wet
	Bulk density dry	155	kg/m^3
Wood pellets (general)	LHV dry	19	MJ/kg dry
	Moisture	10 %	kg water/kg total
	LHV wet (RED)	16.9	MJ/kg wet
	Bulk density dry	650	kg/m^3
Sawdust (wet)	LHV dry	19	MJ/kg dry
	Moisture	50 %	kg water/kg total
	LHV wet (RED)	8.3	MJ/kg wet
	Share at pellet mill	60 %	kg sawdust wet/sawdust pool
Sawdust (dry)	LHV dry	19	MJ/kg dry
	Moisture	10 %	kg water/kg total
	LHV wet (RED)	16.9	MJ/kg wet
	Share at pellet mill	40 %	kg sawdust wet/sawdust pool
Eucalyptus	LHV dry	19	MJ/kg dry
	Moisture wood chips (fresh)	50 %	kg water/kg total
	LHV wet (RED)	8.3	MJ/kg wet
	Yield	12.9	dry tonne/ha year
Poplar	LHV dry	19	MJ/kg dry
	Moisture wood chips (fresh)	50 %	kg water/kg total
	LHV wet (RED)	8.3	MJ/kg wet
	Yield (No fertilization)	10	dry tonne/ha year
	Yield (fertilized)	14	dry tonne/ha year
Stemwood (pine)	LHV dry	19	MJ/kg dry
	Moisture	50 %	kg water/kg total
	LHV wet (RED)	8.3	MJ/kg wet

Table A. 4. Material properties for biomass materials and energy carriers. Part 3: Feedstocks and bioenergy carriers for agricultural biomass pathways.

Material	Property	Value	Unit
Straw	LHV dry	17.2	MJ/kg dry
	Moisture	13.5 %	kg water/kg total
	LHV wet (RED)	14.3	MJ/kg wet
	Bulk density dry (chopped)	50	kg/m^3
	Bulk density dry (bales)	125	kg/m^3
	Bulk density dry (pellets)	600	kg/m^3
Bagasse	LHV dry	17.0	MJ/kg dry
	Moisture (pellets)	10 %	kg water/kg total
	LHV wet (RED)	15.1	MJ/kg wet
	Bulk density dry (exit mill)	120	kg/m^3
	Bulk density dry (bales)	165	kg/m^3
	Bulk density dry (pellets)	650	kg/m^3
Agri residues with density <200 kg/m^3 (husks, straw bales, bagasse bales, oat hulls)	LHV dry	18	MJ/kg dry
	Moisture	13 %	kg water/kg total
	LHV wet (RED)	15.3	MJ/kg wet
	Bulk density dry	125	kg/m^3
Agriresidues with density >200 kg/m^3 (corn cobs, nut shells, soybean hulls, coconut shells)	LHV dry	18	MJ/kg dry
	Moisture	13 %	kg water/kg total
	LHV wet (RED)	15.3	MJ/kg wet
	Bulk density dry	300	kg/m^3
Palm kernel meal	LHV dry	18.5	MJ/kg dry
	Moisture	10 %	kg water/kg total
	LHV wet (RED)	16.4	MJ/kg wet
	Bulk density dry	570	kg/m^3

Annex 2: Stakeholder comments on Biogas pathways

This annex contains all the questions/comments received by various stakeholders, and the relative JRC answers/rebuttal, relative to biogas and biomethane pathways, following the presentation of the first draft of input data proposed by the JRC to calculate GHG savings from solid biomass and biogas pathways (Brussels, May 2013 and following bilateral discussions).

The questions/comments are grouped by topic.

II.1 Methane emissions from storage of digestate

Q1) Methane emissions from storage of digestate: Methane emissions from storage of digestate in open or closed tanks vary substantially based on a number of factors including type of feedstock, pH, degree of digestion and most importantly temperature. Sweden and other north European countries have a much cooler climate and hence the data presented in the JRC draft report corresponds poorly with our actual emission data from existing biogas plants here in Sweden.

JRC: *We recommend to calculate "actual emisisons" if "actual data" are available. On the other hand, the data proposed here are representative for "local" conditions (Sweden) and may not be valid for an EU perspective to make and EU average. However, we would, we would appreciate to receive these data or a reference to them.*

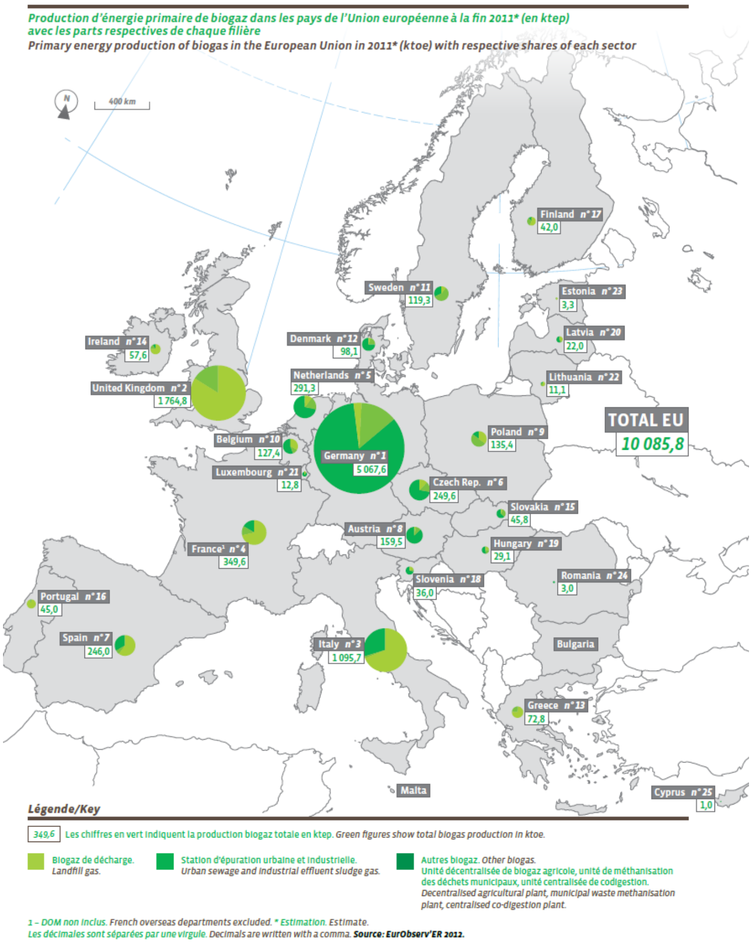
Q2) The figures presented in the draft report regarding methane emissions from storage of digestate are very high, e.g. 3.5% from digested crops (maize) (Table 295) and 5% from digested manure (Table 301). Contrary, new research shows that emissions of methane from storage of digestate are on average 1% for both these systems (digested crops and digested manure stored in open tanks). The reason is that Sweden has a very efficient biogas system (with "post-digestion" reactors), which means that the methane production potential is low in the digestate resulting in low methane emissions. For Swedish conditions, and based on current biogas systems, emission data of around 1% is more reasonable and relevant.

JRC: *We recommend to calculate "actual emisisons" if "actual data" are available. On the other hand, the data proposed here are representative for "local" conditions (Sweden) and may not be valid for an EU perspective to make and EU average. However, we would, we would appreciate to receive these data or a reference to them.*

Rebuttal): *Swedish data should be taken into account when calculating the EU average.*

JRC: *Indeed data from Sweden are taken into consideration for the calculations. However, while the data for 1% emissions fits in the low-range of emissions measured/calculated, it is possible also to find values for badly managed operations, in higher-T regions (e.g. Italy) where emissions from digestate storage can reach 10-12%. Our values stem from some of the very few empirical data available on the matter. The data were collected in Germany which admittedly has a higher average Temperature than Sweden but surely lower than other important biogas producing MS such as Italy. Our values take the temperature variations into account by averaging emissions in summer and winter conditions.*

Regarding relative share and importance of biogas producers in EU-27, the picture painted by Eur'observer (albeit two years in a dynamic field like biogas are a rather long-time) indicates that Italy and Germany are definitely the major players regarding agricultural biogas production.



We have re-elaborated our numbers regarding methane and N2O emissions from digestate storage.

We have analysed additional studies (e.g. Weiland, 2009 and Gioelli et al., 2011) which have confirmed a few points:

- *Many parameters come into play, making it very difficult to find any significant correlation between digestate emissions and other process parameters.*
- *For example, the ambient temperature has a minimal influence on slurry temperature. Due to the constant supply of warm digestate from the reactor, the storage tank temperature rarely falls below 20°C, even with ambient temperature close to 0°C (Gioelli et al., 2011; Hansen et al., 2006).*
- *The hydraulic retention time of the process has a significant influence on volatile solids reduction (and with the share of energy crops in the substrate) but it is difficult to find a correlation with residual digestate methane potential (Weiland, 2009).*
- *Measurements errors or incoherencies should not be forgotten. It is possible to report the amount of Volatile Solids (VS) in input, methane production, share of methane and CO2 in biogas and VS reduction. The system is thus over-defined and with the first four of these values it is possible, for example, via a simple carbon balance, to find the VS reduction. Or vice-versa, calculate the methane yield. However, these numbers are rarely coherent in literature.*

- *For the reasons above, we do not think it is appropriate to compare the values in the form of "% of methane produced" since this indicator aggregates at least two specific data: residual methane potential of the digestate and methane productivity of the plant.*
- *Therefore, we have re-elaborated the data for digestate emissions taking as starting point the* ***residual methane potential of digestates.*** *Applying a carbon balance with a fixed methane productivity, we have then calculated VS reduction and final methane emissions from digestate. These can then be related to the total production of biogas.*

- *The values chosen are detailed in the table:*

	Maize silage	Manure	Biowaste
Methane yield [Nl (41) CH_4/kg VS]	345	200	438
CH4 share in biogas (42) [$\%_{vol.}$]	53	51	60
VS reduction [%] (43)	75	43	75.5
Digestate residual potential [l CH4/kg VS residual]	30	35	44
Share of CH_4 from storage over total CH_4 produced [%]	2.2	10.0	2.5

(41) Nm^3 at 0°C and 1 atm.
(42) For simplicity, the rest of the biogas is assumed to be composed only by CO_2
(43) Calculated via a carbon balance considering 0.49 gC/kgVS for manure, 0.47 gC/kgVS for maize and 0.52 gC/kgVS for Biowastes

- Emissions of N2O from the digestates are based on the IPCC and EEA guidelines based on the following assumptions:

	Maize silage	Manure	Biowaste
Total N content [kg N/dry kg]	*1.1%*	*3.6%*	*3.4%*
Total ammoniacal N (TAN) [kg N-NH4/kg N]	*50%*	*60%*	
N losses in digestion	*6%*	*6%*	*6%*
N2O direct emissions [kg N-N2O/kg N] (IPCC,2006)	*0.5%*	*0.5%*	*0.5%*
N volatilization to NH_3 and NO [kg N-NH3+kg N-NO/kg TAN] (EEA, 2013)	*20%+0.01%*	*20%+0.01%*	*40% ([44])*

Q3) Regarding biogas storage emissions: Based on current systems, emissions of around 1% is more reasonable and relevant. Emissions equivalent to 5% is not relevant for normal Swedish conditions.

JRC: *Digestate storage emissions are calculated according to data available in literature for central Europe. We recommend to calculate "actual emisisons" if "actual data" are available.. On the other hand they would not represent the EU average. We would, however, really appreciate if a reference for the emissions mentioned above could be provided.*

See also answer nr. 2.

II.2 Manure-to-biogas: methane credits

Q4) Manure credits:

Regarding the calculation of indirect GHG savings resulting from anaerobic digestion of manure due to lower methane emissions in comparison to conventional manure management and storage the JRC chooses data from the lower range corresponding to "15%" reduction (p. 287). JRC has thus applied the precautionary principle in order not to overestimate the benefits with biogas. If JRC shall be consistent they should also apply the precautionary

([44]) For biowastes the value of volatilization from IPCC (for liquid slurry) is used principle on “the other side” and not overestimate negative emissions when there is a lot of uncertainty (e.g. biogenic N2O, methane emissions, etc.). When converted into g CH4/MJ, the JRC’s estimates (15%) corresponds to 1.1g CH4/MJ, which is low compared to the estimates we normally expect based on a compilation of various measurements (Swedish and Danish).

JRC: *The GHG methodology set in the 2010 Biomass Report includes certain emission savings from carbon accumulation via improved agriculture management. For the SWD (2014) 259, JRC was asked to include in this category also the avoided methane and nitrous oxide emissions resulting from improved manure management via anaerobic digestion. As explained in answer nr. 2, we have reworked methane and N_2O emissions from digestate storage for all the pathways. We have also decided to recalculate the manure avoided emissions based on IPCC guidelines.*

Based on the IPCC Guidelines, the ratio between the methane emissions due to slurry storage and the emissions due to digestate storage is simply given by the reduction of volatile solids during digestion (methane yield and methane conversion factor are suggested to be kept the same between the two situations). This implies that with the specific conditions assumed in our calculations (VS reduction = 43%, see answer nr. 2) the credits would be equal to 1/0.57 = 1.76 times the emissions from digestate storage.

Considering that the methane emissions from digestate are equal to 10.1% of the produced methane, thus, the credits would be equal to ***17.5% of the methane produced = 0.175 MJCH4/MJ biogas = 3.5 gCH4/MJ biogas = 1.7 g CH4/MJ manure****.*

Concerning N2O emissions, instead, considering that the proportion of ammoniacal nitrogen in the digestate is supposed to increase and that the total N is decreased due to losses in the digester, we assume that the net emissions from raw slurry and digestate are equal and thus the credit would simply balance out the N2O emissions assigned to digestate storage. Numerically this would be equal to ***0.043 gN2O/MJ biogas = 12.8 g CO2 eq./MJ biogas.***

Q5) It is important to consider also the avoided emissions owing to biogas production when greenhouse gas emissions for biogas are calculated. When digestate is spread on fields, instead of raw manure, methane emissions can be reduced and odours mitigated. In addition, storage of manure in properly covered tanks – which is standard today - also significantly prevents methane emissions. We therefore welcome the draft update of the Annex V that considers the avoided methane emissions by giving a credit for it.

JRC: *As explained in previous question, the GHG methodology set in the 2010 Biomass Report includes certain emission savings from carbon accumulation via improved agriculture management. For the SWD(2014) 259, the JRC was asked to include in this category also the avoided methane and nitrous oxide emissions resulting from improved manure management via anaerobic digestion.*

It should be noted that, covered manure storage is not standard, and for sure gas tight coverage of manure tanks is rare (if any). Moreover, it is important to stress that if (and when) raw manure gas-tight storage were to become a standard procedure in agriculture (independently from thepresence of a biogas digester) then the "manure methane credits" for biogas would actually cease to exist! In fact, these credits are not an intrinsic property of the biogas pathway but the result of a common, although less than optimal, agricultural practice (of storing raw manure/slurry in open tanks)!

Q6) We think that methane credits should be taken into account that result from the anaerobic digestion of manure in a biogas plant and the avoidance of methane emissions associated with the storage of manure for fertiliser use.

JRC: *See answers above: they are included in the updated methodology.*

II.3 Digestate fertilizing potential, fertilizer credits and maize whole crop nitrogen fertilization balance.

Q7) Instead of by-products like distillers grain from EtOH production or rape seed cake from Biodiesel that can be utilised in dairy cattle diets, biogas production generates digestate with a high fertiliser value. Use of local feedstock for biogas and digestate production for fertilising purposes closes the nutrient cycle in regional ecosystems and saves the CO2 emissions that would be released during the production of mineral fertiliser. Thus, this positive fertilising effect of the digestate should be taken into account based on its nutrient content. The current methodology for biofuels does not account for that; there are no credits for the fertilising effect of digestate since only mineral fertilisation is included. Therefore, we very much welcome the draft update of the Annex V that considers the fertilising effect of digestate. However, we cannot agree with some of the given figures:

On page 277 it is written that 63.6 kg N from synthetic fertiliser and 250 kg N from digestate are applied per hectare when 40.9t maize is harvested per hectare. The amount of fertiliser does not seem to coincide with the harvest. If the nutrient removal during growth is counted, only around 170 kg N per hectare can be obtained from the digestate when 40.9t maize is harvested. The assumed amount of fertiliser applied of totally 313.6kg is far beyond the need of the plants, not realistic, and would also be in conflict with the fertiliser regulation. In addition, with this amount, field N2O emissions double, giving biogas much higher overall emissions than justified. We therefore suggest that the amount of applied fertiliser will be adjusted so that depending on the harvest, only the nutrients that are removed during growth are replaced with an optional, additional amount of maximum 20% of synthetic fertiliser.

Additional comments: Indeed, on P. 277 it is stated that N2O emissions are calculated from 63.6 kg N/ha of synthetic fertiliser and 250 kg N/ha from digestate (my emphasis). The question is whether a total N input of 313.6 kg N/ha was considered to be the basis for the calculation of N2O emissions. This would indeed correspond to illegal over-fertilisation. Where do the 250 kg N/ha come from?

Additional comments: According to information from Prof. Taube (Institute of Crop Science and Plant Breeding, Univ. Kiel), first this percentage (share of ammoniacal nitrogen in digestate, note of authors) is slightly higher, but more importantly, the remaining N is made available to the plants over longer periods of time. Altogether, it is only necessary to add some 30-50 kg of additional artificial fertiliser if all of the digestate is used Please refer to ftaube@email.uni-kiel.de for exact values.This seems to be supported by Clare Lukehurst from IEA Task 37.

JRC) *About the figures: we have already noticed the overestimated use of digestate fertiliser (250 kgN/ha).*

The amount of synthetic fertilizers applied is the EU-27 average resulting from the values provided to us from Fertilizers Europe *(the European fertilisers* *manufacturers association)* for the category "Silage Maize" ([45]). *This value clearly already accounts for the application of organic fertilizers: in fact, the value indicated for fodder maize is considerably lower than the amount indicated by the same source, for maize grain. For example, considering the application of fertilizers in Italy, Fertilizers Europe indicates a value of synthetic-N use equal to 182 kg N/ha for grain maize and only 80 kg N/ha for fodder maize.*

Therefore, we consider that the values for fodder maize fertilization already include the recycling of the nutrients via manures or digestates (See pg 277).

However, the value of synthetic-N applied has been slightly modified (as well as the average yield of maize for fodder) to 63.24 kN/ha according to slightly updated FAOSTAT statistics that the JRC received at the end of 2013.

For manure, on the other hand, we assume that the fertilizer potential is the same as digestate, therefore credits shall not be given.

The detailed nitrogen balance for maize fodder to biogas would look like this:

Maize whole crop nitrogen fertilization

Maize composition: Nitrogen removal and needs

Based on an average maize composition (see e.g. Phyllis, https://www.ecn.nl/phyllis2/), the N content of fresh maize is around ***0.37%$_{F.M.}$***

*Based on this number, the removal of N by the crop is equal to: 40.8 * 0.0037 =* ***150.8 kg N/ha****.*

IPCC prescribes that below ground residues (BG) for maize amount to 22% of the total above ground (AG) biomass (on a dry basis). We consider a loss of AG material at harvest equal to 1 t dry/ha with a N content equal to 0.6% (IPCC, 2006). Furthermore, the N content in the BG is taken from IPCC and it is slightly higher than for AGR, it is equal to 0.7% on a dry matter basis.

*Thus, the N content in the BG residues is equal to: ((40.8*0.35)+1)*0.22)*0.007 =* ***23.5 kg N / ha.***

*The N content in the AG residues is equal to: (1*0.6) =* ***6 kg N/ha.***

The total N demand for the crop is thus equal to ***180.3 kgN/ha.***

After harvest, the crop is ensiled for preservation, encountering dry matter losses.

Based on a collection of data we have assumed a dry matter loss of ***10%*** *(Kohler, 2013; Herrmann, 2011; Styles, 2014). However, we assume no significant losses of N (it is possible that a little organic N is mineralized to ammoniacal N during the processes but eventual leachate is assumed to be recirculated to the digester). The N content after ensiling thus remains the same at 150.8 kg N/ha.*

([45]) Mr. Christian Pallière, pers. comm., 2014: "*Our Forecast is an expert based approach, it is therefore our national experts who locally make investigation for each crop, visiting generally the crop institutes and the main agriculture universities when it comes for application rates, the same organizations plus the national administration which are reporting statistics when it comes to acreages. They report the outcomes of these several contacts. These data have been provided to several specialist (Wageningen university, UN ECE Task Force on reactive Nitrogen)".*

Nitrogen losses

*N losses of about 6% are considered to happen during digestion (Schievano, 2011; Battini, 2014). This leaves around **141.7 kgN/ha** in the digestate sent to storage.*

During the storage period, direct emissions of N_2O and volatilization losses to NH_3 and NO_x are expected.

The IPCC Guidelines were originally designed for manure management and thus may not be directly applicable to energy crops digestates. However, this could work as a first assumption.

IPCC recommends a value of 0.005 N-N2O/N_{slurry} (IPCC, 2006, Vol.10, Table 10.21).

Furthermore, the latest EMEP/EEA guidelines (EEA, 2013, Vol. 3.B, Table 3.7), indicate (for dairy slurry) emissions of N-NH3 as 20% of Total Ammoniacal Nitrogen (TAN), 0.01% of TAN as N-NO and 0.3% of TAN as N2.

*Considering a TAN level of 60% in the maize digestate, this would lead to a total loss of digestate – N equal to: 0.2*0.6 + 0.0001 * 0.6 + 0.003 * 0.6 + 0.005 = **12.7 % of digestate-N.** (High Volatile Scenario)*

*Therefore, the N available for field spreading in the digestate (in the high volatile scenario) is equal to: **123.8 kgN/ha.***

However, this could be considered as an upper limit, other values around 2-3% of total losses have been reported [e.g. Corrè, 2010]. (Low volatile scenario)

*In this second case the N available for spreading would be equal to: 141.7 * 0.97 = **137.5 kgN/ha.***

From the IPCC guidelines, at the moment of field spreading, 20% of available N from organic fertilizer, is volatilized as NH_3 and NO and 30% is leached. In addition to the 1% N that is emitted directly as N_2O. (High volatile scenario)

*This would mean additional N losses on the field equal to 51% of applied N. This would leave **60.6 kg N/ha.** (High volatile scenario)*

Alternatively, Battini et al., 2014 reports the following losses from field spreading of digestate: 1% to N-N2O, 0.55% to N-NO, 5% to N-NH3 and about 30% of leaching. This leads to total losses of 36.55% of the applied N.

*This would leave available: 137.5 * 0.6345 = **87.2 kgN/ha** (low volatile scenario).*

Nitrogen fertilization balance

*Considering all associated N losses, thus, it appears that effectively only **60.6 kgN/ha** or **87.2 kgN/ha** are available on the field. Of this amount, a fraction will be directly available while the rest of the organic N will be released in time. Anyway, we assume that this entire N is available for the plant (in the present or future rotations).*

*Additional to this amount, we consider the application of **63.2 kgN/ha** of mineral-N fertilizer. This number is the EU-27 average resulting from the values provided to us from Fertilizers Europe for the category "Silage Maize" ([46]).*

([46]) Mr. Christian Pallière, pers. Comm., 2014: "*Our Forecast is an expert based approach (attached a brief document on explanations/references for use, and the EEA report which has compared with other model based system), it is therefore our national experts who locally make investigation for each crop, visiting generally the crop institutes and the main agriculture universities when it comes for application rates, the same organizations plus the national administration which are reporting statistics when it comes to acreages. They report the outcomes of these several contacts. These data have been provided to several specialist (Wageningen university, UN ECE Task Force on reactive Nitrogen)*".

Our assumption in this case is that the fertilizing power of raw slurry and manure is the same as for digestate in the long-term. This is still debated and long-term trials are currently under way (Fouda et al., 2013; Gutser et al., 2005; Lukehurst et al., 2010; Schröder et al., 2007; Smith et al., 2010), however, we think this assumption is valid for the level of accuracy required in this study.

Nitrogen losses from mineral fertilization are considered by the IPCC guidelines, to be equal to 1% as N-N2O, 10% as volatilization to N-NH3 and N-NO and 30% as leached. (High volatile scenario)

This would leave ***37.3 kgN/ha*** *available for plant absorption (High volatile scenario).*

So, considering 100% efficiency of the remaining N, the apported N by organic and mineral fertilization would be equal to ***97.9 kgN/ha****.*

Alternatively, nitrogen losses from mineral fertilization are considered to be equal to 0.6% as N-N2O (Battini et al., 2014), 5.6% as volatilization to N-NH3(EEA, 2013, 3.D – average value based on share of sold fertilizers in Europe), 0.9% N-NO (Battini et al., 2014) and 30% as leached (Battini et al., 2014). (Low volatile scenario)

This would leave ***39.8 kgN/ha*** *available for plant absorption (Low volatile scenario).*

So, considering 100% efficiency of the remaining N, the apported N by organic and mineral fertilization would be equal to ***127.0 kgN/ha*** *(Low volatile scenario).*

The IPCC indicates that the N remaining in the crop residues is equal, for our condition, to about ***29.5 kgN/ha****. Of this, the IPCC prescribes that 1% N-N2O and 30% is leached away. So, the available N from residues is equal to: 29.5*(1– 0.31) =* ***20.4 kgN/ha***

The final N balance would indicate thus (see also Table A. 5 *for all the relevant data):*

<u>*High Volatile Scenario:*</u>

- *Plant needs = -180.3 kgN/ha;*
- *Mineral N (available on field) = +37.3 kgN/ha;*
- *Digestate N (available on field) = +60.6 kgN/ha;*
- *AG+BG residues N (available on field) = +20.4 kgN/ha;*
- *N to close balance =* ***62.0 kgN/ha*** *(of which about/up to 20 kg may be from atmospheric deposition)*

<u>*Low volatile scenario:*</u>

- *Plant needs = -180.3 kgN/ha;*
- *Mineral N (available on field) = +39.8 kgN/ha;*
- *Digestate N (available on field) = +87.2 kgN/ha;*
- *AG + BG residues N (available on field) = +20.4 kgN/ha;*
- *N to close balance =* ***32.9 kgN/ha*** *(of which about/up to 20 kg may be from atmospheric deposition)*

Table A. 5. Summary of input data, assumptions and nitrogen balance for the cultivation of Maize whole crop.

	High volatile scenario			*Low volatile scenario*		
	Value	***Unit***	***Source***	***Value***	***Unit***	***Source***
Yield (AG removal)	40.8	t F.M./ha	EUROSTAT	40.8	t F.M./ha	EUROSTAT
TS	35%	% F.M.	JRC	35%	% F.M.	JRC
BG residues (kg dry/kg dry AG)	22%	% AG dry	IPCC	22%	% AG dry	IPCC
AG residues (t dry/ha)	1	t dry/ha	Taube, 2014	1	t dry/ha	Taube, 2014
N content (AG maize whole crop)	0.37%	% F.M.	Hermann, 2005	0.37%	% F.M.	Hermann, 2005
N content (AG residues)	0.6%	% dry AG	IPCC	0.6%	% dry AG	IPCC
N content (BG residues)	0.7%	% dry BG	IPCC	0.7%	% dry BG	IPCC
N losses ensiling	0%	% N crop	JRC	0%	% N crop	JRC
N losses digester	6%	% N crop	Battini, 2014	6%	% N crop	Battini, 2014
TAN (maize digestate)	60%	% N digestate	Taube, pers. Comm. 2014	60%	% N digestate	Taube pers. Comm. 2014
Mineral-N fertilizer applied	63.2	kg N/ha	Fertilizers Europe	63.2	kg N/ha	Fertilizers Europe
N Losses digestate storage						
N-N2O direct (digestate storage)	0.5%	%N digestate	IPCC (Dairy manure, slurry with crust)		%N digestate	
N-NH3 (digestate storage)	20%	% TAN digestate	EEA, 2013 (3.B)	3.0%	% TAN digestate	Battini, 2014
N-NO (digestate storage)	0.01%	% TAN digestate	EEA, 2013 (3.B)		% TAN digestate	
N-N2 (digestate storage)	0.3%	% TAN digestate	EEA, 2013 (3.B)		% TAN digestate	
N Losses Field application – Organic fertilizer						
N-N2O direct (field application organic)	1%	% N at field	IPCC	1%	% N at field	IPCC
N-NH3 + N-NO (field application organic)	20%	% N at field	IPCC	5.55%	% N at field	Battini,2014
N-NO3-- (field application organic)	30%	% N at field	IPCC	30%	% N at field	Battini, 2014
N Losses Field application – Crop residues						
N-N2O direct (field crop residues)	1%	% N at field	IPCC	1%	% N at field	IPCC
N-NO3-- (field crop residues)	30%	% N at field	IPCC	30%	% N at field	IPCC
N Losses Field application – Mineral fertilizer						
N-N2O direct (field application mineral)	1%	% N mineral	IPCC	0.6%	% N mineral	Battini, 2014
N-NH3 + N-NO (field application mineral)	10%	% N mineral	IPCC	6.5%	% N mineral	EEA,2013 (3.D) + Battini, 2014
N-NO3-- (field application mineral)	30%	% N mineral	IPCC	30%	% N mineral	Battini, 2014
N Balance						
N needs (AG + BG + AGR)	180.3	kg N/ha		180.3	kg N/ha	
N (AG maize - removal)	150.8	kg N/ha		150.8	kg N/ha	
N (AG + BG residues)	29.5	kg N/ha		29.5	kg N/ha	
N (maize silage)	150.8	kg N/ha		150.8	kg N/ha	
N digestate	141.7	kg N/ha		141.7	kg N/ha	
N after storage - at field	123.8	kg N/ha		137.5	kg N/ha	

N available for plants (digestate)	60.6	kg N/ha	87.2	kg N/ha
N available for plants (crop residues)	19.3	kg N/ha	19.3	kg N/ha
N mineral - available for plant	37.3	kg N/ha	39.8	kg N/ha
Final Balance				
Total N needs	180.3	kg N/ha	180.3	kg N/ha
Total N applied	118.3	kg N/ha	147.4	kg N/ha
N deficit (deposition)	62.0	kg N/ha	32.9	kg N/ha

Q8) **Digestate as a fertiliser:** The digestate is an integral part of biogas production. Although some reduction in volume may occur during digestion, there is likely to be a similar quantity to the original tonnage of maize input. However, the nutrient value of the digestate needs to be taken into account and the amount of mineral fertiliser applied reduced in consequence. The resulting EF for fertilisers are therefore too high as they have failed to take into account the recycling of the NP and K in the digestate.

JRC: *The amount of fertilizers is supplied by Fertilizers Europe and is specific for silage maize. See answer nr. 7.*

Q9) **Manure credit : storage and fossil N substitution**

CEPM and AGPM welcome the proposal to give a manure credit (page 286) to take into account the CH4 savings due to the biogas process compared to spreading raw manure.

We would like to suggest to take into account another credit, based on the substitution of fossil N by organic N. As a matter of fact, and contrary to the liquid biofuel case, energy crops are bringing an extra organic N production that will replace fossil N, in addition to the manure already avalaible.

The 2012 french LCA study on biomethane (page 60) has measured the emissions related to 2 cases:

- X : Reference case : 9 kg of N coming from manure and 1 kg of fossil N
- Y : Biogas case : 10 kg of N from digestate with 1 N kg coming from energy crops and 9 from manure

Emissions from the Y case are less than the X case and give a credit that AGPM and CEPM think it should be taken into account in the biogas methodology

JRC: *There are many reasons why generalising such credit as a structural part of the default values calculations would be unreasonable:*

- *Results from experimental trials on slurry vs. digestate N_2O emissions are very variable depending on site specific conditions, climate, measurement techniques and length of measurement campaign.*
- *The measurement campaign should be based not only on direct measurements (total kg N/ha applied) but also on indirect measurements such as resulting yields over many rotations.*
- *N_2O emissions from field studies appear to be lower for digestate than for raw slurry BUT it should be considered that emissions from storage of digestate appear to be higher compared to storage of raw slurry.*

Considering all these various level of uncertainties, we have approached the problem according to the following assumptions which we think reflect the current understanding of the issue:

- *N_2O emissions from storage are equal both for digestate and for raw manure/slurry;*
- *The fertilizing potential of digestate is considered equal to the one of raw manure in the long term;*
- *N_2O emissions from field application are out of the boundaries of the manure-biogas pathway. When digestate is applied for the cultivation of an energy crop (such as it happens in the maize-biogas pathway) then the emissions from field application are taken from the IPCC guidelines and they are based solely on the total-N applied.*

When calculating actual emissions of a manure-biogas pathway, field emissions are out of the analysis and thus this "credit" would not appear. When calculating actual emissions of a maize-biogas pathway or of a co-digested plant, the "credit" would not appear as such but simply the declared actual emissions will be lower than an hypothetical equal pathway using only raw manure as organic fertilizer. So the effect will be accounted for.

II.4 Maize whole plant cultivation inputs

Q10) **Application of the EFs for maize for ethanol to biogas:** The EF for ethanol includes energy for maize drying and for the harvesting of stalks. This needs to be clarified in the light of harvesting and storage methods. Maize for biogas is harvested as a whole crop and chopped as part of the harvesting process. If used for ethanol, are the stalks considered a residue? If yes, emissions associated with use of machinery (chopping) and removal from the field would need to be taken into account. The whole crop maize for biogas (grain and stems) is transported direct to the silage clamp for storage. It is not dried and therefore any emissions for drying need to be excluded

JRC: *The data on maize cultivation for biogas are specific for silage maize. The data on fertilizers use are supplied by Fertilizers Europe. There is no drying involved but rather mass losses during ensiling are taken into account and the residues left on the field (only belowground biomass for the case of whole crop harvest) are included in the analysis when it comes to N supply and N2O emissions.*

II.5 Digestate additional benefits

Q11) Moreover, digestate represents a best practice in preventing contamination. In many Member States manure is spread out on fields directly without any treatment against pathogens causing potential biological contamination. Treatment through anaerobic digestion in most cases destroys viruses or at least greatly reduces the number of plant and animal pathogens within the feedstock. At the same time also weeds are killed.

JRC: *We recognise the added value of anaerobic digestion of manure, but the integration of these aspects in the GHG emissions assessment is not straight forward. It would call for a deep investigation into indirect effects (such as yield improvals due to avoidance of pests).*

II.6 Biogas: Co-digestion of substrates and additional default values

Q12) Only three biogas feedstocks are considered in the JRC's draft report: Maize, manure and municipal organic waste. We suppose that for example biogas from grass silage, wheat silage or any other crop feedstock is covered by the values for maize, but since their savings may significantly vary and as it is important that all feedstocks can be used for biogas production, we would recommend the inclusion of GHG calculation for all broadly used feedstocks such as sewage sludge and different crops (including catch crops) into the Annex V. The variety of feedstock fed simultaneously into a digester must be taken into account: In many countries, the biogas plants are usually fed with a mixture of different substrates depending on the availability of feedstock at the site. In Germany for example, there are very few biogas plants (less than 10%) using only one type of feedstock but a variety of mixtures ranging from energy plants like maize or barley silage over grass silage to manure in different proportions. The methodology has to be designed in a way that the greenhouse gas emissions for all the different feedstocks and their mixtures can be calculated easily with low administrative burden.

JRC: *We agree, there are many feedstocks that 'can' be used, but in order to limit the number of default values, the most common were modelled (manure, silage maize and* *biowaste). The request for further pathways should be addressed to the European Commission - DG ENER.*

Concerning the issue of codigestion, the GHG methodology set in the 2010 Biomass Report (COM(2010) 11) uses a mass balance approach, whereby physical mixing of certified and non-certified products is permitted but products are kept administratively segregated. The system ensures that for the volume of biomass for which sustainability claims are made at the end of the supply chain, sufficient certified material has been added to the supply chain, taking into account relevant conversion factors. However, a number of stakeholders have highlighted that this approach creates difficulties for the majority of existing biogas plants that typically use a mixture of locally-produced feedstock, ranging from animal manure, to food/feed energy crops (such as silage maize) and to residues from the agro-food industry. They claim that given the operational characteristics of biogas plants, a mass balance approach results in lower GHG saving performances compared to an alternative approach whereby the GHG emission default values are calculated for the entire mixture within a given biogas plant.

Biogas from sewage sludge (as well as landfill gas) is not subject to sustainability criteria.

Q13) In connection with the two previous points, there is a need for more flexibility when sustainability of some advanced substrates is defined: For example, catch crops (e.g. ley, buckwheat, ryegrass etc.) deliver valuable environmental advantages as they can be integrated into crop rotations and in this way improve the overall productivity of the farm. Therefore, the use of catch crops should be promoted even though they may not always be able to reach the 60 % threshold of greenhouse gas savings due to their low yield per hectare. Thus, for the evaluation of biogas, it is essential that also the crop rotation systems are taken into account.

***JRC:** According to the Directive, in case actual values exist, they should be used for the calculations. This way there is full flexibility. The default pathways are aimed at representing the most common feedstocks.*

Q14) DG ENER considers proposing a modification of the application of the mass balance system in the case of mixed feedstocks in biogas plants. According to this approach, GHG savings could be calculated jointly for a mixture of feedstocks. This would require an adjustment of the GHG methodology.

***JRC:** Please see answer to Q12.*

Q15) **Biogas feedstock and methodology**
Biogas is usually produced from a mix of feedstock and not on a single one. It seems therefore difficult to calculate default values only on specific raw substrates. The methodology to calculate GHG default values of different feedstocks should take into account this point specific to biogas. Furthermore, the range of feedstock of feedstock should be enlarge before any publication.

***JRC:** We agree, there are many feedstocks that 'can' be used, but in order to limit the number of default values, the most common were modelled (manure, silage maize and biowaste). Concerning codigestion, see answer to Q12.*

Q16) **Catch crops, second crops, intermediate crops, multicropping systems.** Sustainability approaches have to be adapted to specific cropping systems. Energy crops can be inserted into crop rotations without competing the global food potential production. They can also give environmental benefits, such as cover crops. The sustainability methodology must take into account these crop rotation systems that do not take areas from food production. Crop rotation systems such as barley/maize can produce 2 crops a year and be very efficient not only for animal production but for biogas also.

JRC: *According to the Directive actual values can be used for the calculations. This allows full flexibility in the calculations.*

Be aware, however, that according to a recently published work (Jacopo Bacenetti, Alessandra Fusi, Marco Negri, Riccardo Guidetti, Marco Fiala, Environmental assessment of two different crop systems in terms of biomethane potential production, Science of The Total Environment, Volumes 466–467, 1 January 2014, Pages 1066-1077), double cropping appears to worsen the GHG emissions of biogas production.

II.7 Biogas Upgrading to biomethane: technologies and methane emissions.

Q17) Upgrading biogas to biomethane
When it comes to upgrading biogas the draft report distinguishes between "chemical" upgrade which is expected not to cause any methane emissions (same assumption is made regarding oxidation) and "physical" upgrade via PSA, water scrubbers etc. which are assumed to cause emissions corresponding to 3%. Continuous measurements at an existing PSA plant in southern Sweden shows a variation between 0.7-1.4%. Reasonable average data for the current Swedish situation should be around 1.5-2%. If marginal data is applied, which JRC does in an inconsistent manner, emissions should rather be below or at 1% for "physical" upgrade for new upgrading plants (not using "chemical" upgrade or additional oxidation).

JRC: *The upgrading techniques are grouped in two categories and they are not distinguished in physical and chemical upgrading. The difference of the two groups is the treatment of the off-gas. If the off-gas is vented it is assumed to cause 3%* CH_4 *emissions. If the off-gas is combusted there are no emissions assumed. This latter assumption is actually very optimistic since flaring efficiency in removing methane is rarely 100%.*

In order to make this difference clearer and avoid further misunderstanding, the two groups of technologies are now renamed in OGV (Off Gas Vented) and OGC (Off Gas Combusted). In any case, if actual data on methane slip are available, actual values should be used. On the other hand they would not represent the EU average. We would, however, really appreciate if you could send those data to us or provide a reference.

Q18) As regards the upgrading technologies mentioned on page 274 and consequently in the rest of the report, two different options for upgrading technologies - physical upgrading without combustion of the off-gas and physical or chemical upgrading with combustion of the off-gas - are considered. However, any upgrading technology can, in principle, be equipped with combustion (or catalytic oxidation) of the off-gas. And in the same way, any upgrading technology can, if savings are desired, be supplied without combustion (or oxidation) of the off-gas. Therefore we would suggest considering two different scenarios instead:

- o Biogas upgrading (any technology) without combustion of the off-gas
- o Biogas upgrading (any technology) with combustion of the off-gas.

The catalytic oxidation of the off-gas is used when the off-gas contains too small amount of methane to allow combustion usually up to 1.5 resp. 3% depending on the methods.

JRC: *The comment is taken into consideration and as a result the two groups of technologies are now renamed in OGV (Off-gas Vented) and OGC (Off-gas Combusted).*

Q19) **Maturity of the biogas upgrading market:** Regarding biogas upgrading they write the report states, "There are currently many different technologies used to remove CO2 from the biogas stream in order to obtain a gas with the quality needed to be injected in the natural gas grid. None of these technologies are actually prominent in the market yet, since biogas upgrading is still developing".

This is not true. According to the information published by IEA Bioenergy Task 37, more than 220 biogas upgrading units exist today and they are installed in commercial operations. In Figure 2 below it can be seen that most of the upgrading plants are located in Germany and Sweden. Elsewhere there are several countries with less than 20 upgrading units each. Although this is the most updated available list, information about some units may be missing (IEA Bioenergy Task 37 2012).

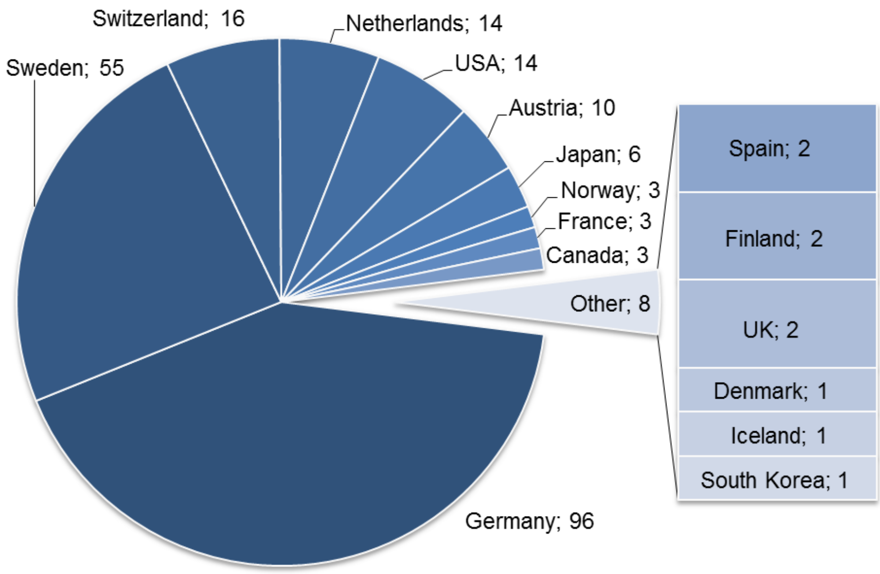


Figure: The geographical location of the 221 biogas upgrading plants that has been identified by IEA Bioenergy Task 37

The figure shows the technologies that are used by the upgrading plants that are in operation today and which year they were commissioned. Until 2008 it was mainly the water scrubbing and PSA technologies that dominated the market, but lately chemical scrubbers, and to a minor extent also membrane separation units, have increased their market share. The majority of the chemical scrubbers are amine scrubbers, but other chemical scrubbers are also included in this category.

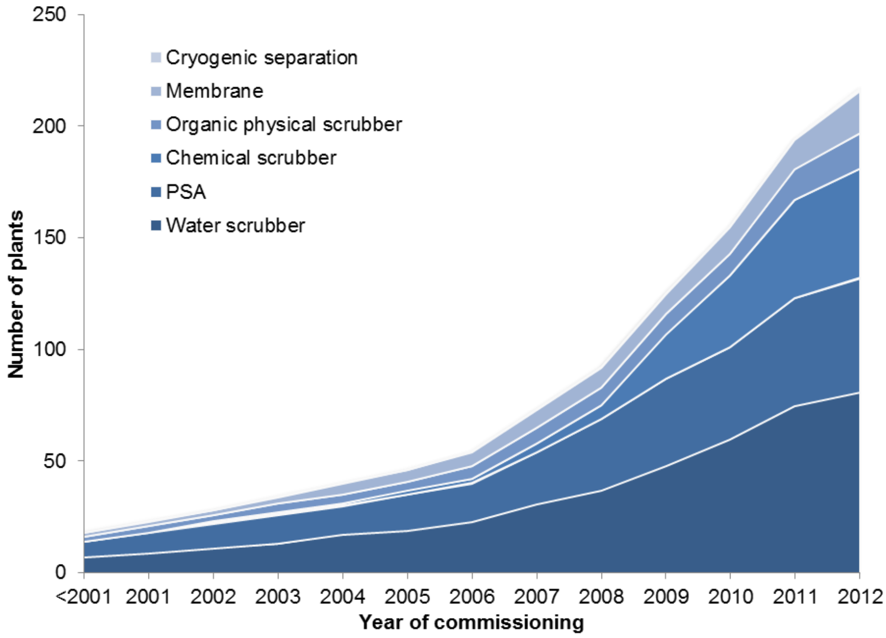


Figure: Evolution of the technologies that are used in the biogas upgrading plants taken into service in different years. Only plants that are in operation today are included. Data from IEA Task 37

***JRC:** The data reported confirm that there actually is not a specific dominating technology with PSA, chemical and water scrubber technology sharing the top 90% of the share.*

The grouping of technologies is aimed at limiting the number of default pathways. (the 18 pathways should be multiplied by 3, or 5 if all the technologies were considered separately).

Furthermore, we have seen that the difference of emissions due to the oxidation of off-gases is much larger compared to the variability of emissions among the various different technologies; that is why the choice was to divide the values along these chategories.

Q20) **Methane slip:** The data given below mainly represent typical values for modern and well-operated up-grading plants. It would be advisable to use values higher than those quoted for the calculation of default GHG savings. The methane slip is quite high in the PSA case with 1.5-2% reported as mean and median values. The water scrubber has a slip of about 1-2% in modern plants. Values much higher than this are not likely in a well-functioning plant. The chemical amine scrubber system has a much lower methane slip of 0.1-0.2%. Organic physical scrubbers have a higher slip than water scrubbers (1.5-2%), and so the methane slip is used internally to supply heat to the desorption process. Certain membrane upgrading plants with the latest designs can achieve very low methane slip of about 0.5%. However, other designs can have methane slip of 1-4% and the slip from older membrane systems can even exceed 4%. In some membrane applications on the market, liquefaction of the carbon dioxide in the waste gas is used to recover 100% of the methane in the off-gas by cryogenic separation. While cryogenic systems for biogas upgrading should in principle have extremely low methane slip, only one plant is in commercial operation since a few months ago so there is no reliable information. Depending on the regulations in the country where an upgrading plant is operated combustion of the off-gas to achieve low methane emissions may be a requirement. Only the manufacturers of the "Genosorb" scrubber system require combustion of the waste gas and this is used to produce the heat needed in the upgrading process. For more information please see: http://www.sgc.se/ckfinder/userfiles/files/SGC270.pdf

***JRC:** The default values are intended to be representative of all the biogas plants, not just the modern and well operated plants. Modern and well operated plants are strongly encouraged to calculate their own actual values (e.g. if certain membranes with the latest design can have a methane slip of 0.5 %, in the IEA biogas handbook it is reported that some can have a methane slip of 15 %, using the 0.5 or even 3 % methane slip would undeservedly reward the bad technology and not reward the best one, with 3 % the plants using the best technology can still use the actual values to be rewarded for their investment in the best technology).*

From the suggested document, it actually appears that in most cases the off-gases will need to be oxidized (either because of legal emissions limits or because of process optimization), in this case, the default value for OGO technologies (Off-gas oxidized) can be utilized. The conditions for this value are actually not very conservative since a 100% efficiency of methane oxidation is assumed. Operators with much better processes can always calculate their own actual value.

II.8 Biogas substrates transport distances

Q21) The JRC draft report's assumed transport distances for biogas feedstocks (10km for manure and 50km for maize) seem very long to us; such long distances are usually not worthwhile. In Germany for example the transport distance for maize is typically 10-20km and for manure usually less than 5 km.

***JRC:** The 50 Km distance for maize transport (10 for manure) was discussed and decided during the expert consultation in Ispra in November 2011. We have now updated the transport distance to 20 Km for Maize and biowaste, and 5 for Manure.*

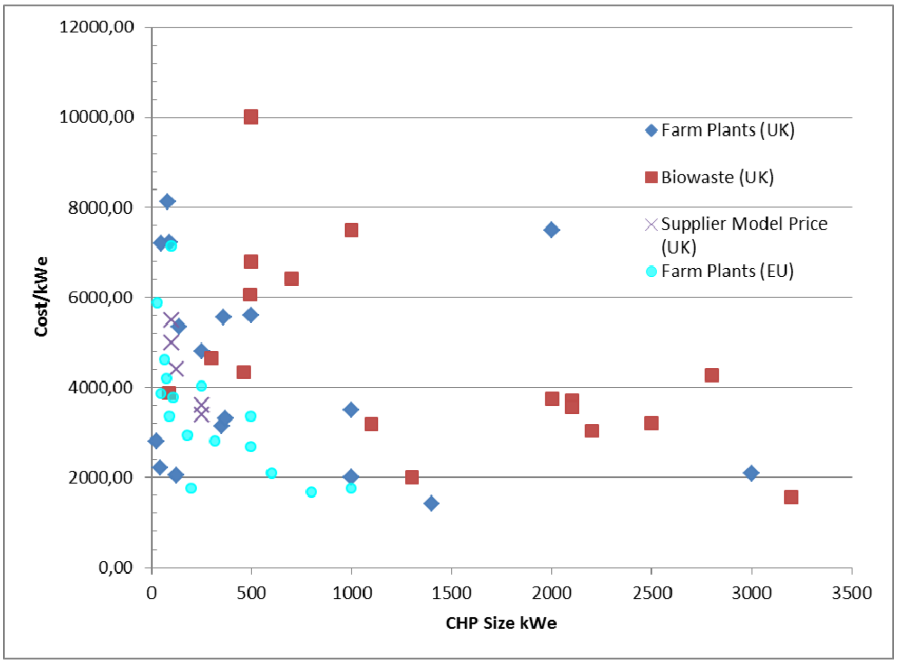
Q22) The transport distance of 50 km for maize as a feedstock for biogas appears too long. This should be revised to more realistic levels.

***JRC:** The 50 Km distance for maize transport (10 for manure) was discussed and decided during the expert consultation in Ispra in November 2011. We have now changed the distance to 20 Km for Maize and biowaste, and 5 for Manure.*

Q23) **Calculation of emissions factors (EF):** Even though the final EF for each biofuel has been calculated, this is in isolation. One way transport distances for a 40 tonne truck for the feedstock have been indicated for example as:

- 120 km for palm oil
- 100 km for maize and barley
- 30 km for sugar beet
- 50 km for wood chip

There does not appear to be any explanation as to the selection criteria which underlie the choice of these distances. However, it seems that inherent in these distances must be an assumption as to the size of processing plant in tonnes input or the expected biogas, electrical or biomethane output. This impression is reinforced when it is noted that a 10 MW gas boiler is included to provide the process heat for the digester operation to produce the biogas. The report needs to justify how and why these distances were selected. The question arises as to what size for example is a 'typical' maize based ethanol plant or wood fired or co-fired power station or biogas plant. The issue can be illustrated by the use of maize for biogas and/or biomethane production (Figure 1). Even if maize would be the only feedstock, the average size CHP plant is less than 0.5 MWe. (Lukehurst *et al* in press). If the biogas is upgraded to biomethane the median output is 350 Nm3 /h. (Task 37). This would equate to 14400 MJ for biogas if based on the assumptions of VS content, etc. used in the report.



Investment costs of 56 combined heat and power biogas plants in Austria, Germany and the United Kingdom (Lukehurst et al in press)

If the area of land needed for a 500 kWe plant is assumed to be approximately 250 ha (depending on crop yield) it would be highly unlikely to require a hinterland with a radius of more than 5 km. This is based on the practical reality of plant operation, crop rotation, etc. Figure 1 is based on an analysis of 56 biogas plants in Austria, Germany, and the UK (Lukehurst et al, in the press). Some 85% of these individual plants are farm based. Where maize is used as a feedstock and usually co-digested with other crops or manure it is either produced on the farm or by close neighbouring farms. Thus the use of a 100 km delivery distance would be both unrealistic and yield an unjustifiably high emission level for the transport element of the formula.

The EF for the transport element, if a biogas or biomethane plant is based on maize would **only** be appropriate for very large centralised plants such as the Güstrow BioEnergie Park
http://www.nawaro.ag/en/company/projects/guestrow-bioenergypark/

in Germany. In this case an agglomeration of 40 x 500 kW plants is an example.

The application of this this a-typical extreme distorts the EF to the disadvantage of biogas and biomethane.

JRC: *The distances for maize and manure transport (50 for maize; 10 for manure) were discussed and decided during the expert consultation in Ispra in November 2011. We have now changed the distance to 20 Km for Maize and biowaste and 5 for Manure. The 100 km transport distance mentioned is related to maize and barley grains used for 1st gen. ethanol production and not biogas. Ethanol production and grains transport is a* *much more global industry undergoing global markets rules. This is not the case for the more local uses of silage maize and farm biogas plants.*

Furthermore, the boiler size was just indicative of the type of data that were used (emissions and efficiency equal to the natural gas boiler used for all the other pathways). We recognise that the 10 MW size is too big for any biogas plants and it is now changed with a 1 MW boiler with a thermal efficiency equal to 90%.

Q24) **Manure based biogas plants:** The calculations for a manure-only biogas plant of the scale on which the calculations are made are totally unrealistic. The objective of dairy herd management is to maximise the feed conversion rate and therefore minimise the amount of methane lost either through exhalation or in the slurry. The slurry is amongst the lowest yielding methane (0.3 g/kg VS) feedstocks (Al Seadi et al. 2013). It seems that the amount of methane in a 40 tonne road tanker and the cost to haul that tank over up to 100km needs to be calculated. Then, an estimate should be made of the cost of a biogas plant which requires a 10MW boiler to provide the heating for the digester. This will demonstrate the nonsensical assumption behind the calculation of EFs for comparing biogas production with ethanol etc. This leads onto the rest of the weakness in the assumptions for manure quality. Additional supporting data will be provided at a later date if needed. It appears that cow manure with a 15% DM content is used as the basis of the EF calculations. This is at the very highest end of the range just as it leaves the cow and before dilution with urine. Between 8-10% DM would be more usual. Even 10 km haulage of manure to biogas plant unless co-digested with much higher methane yielding feedstocks, as for example at the centralised Danish plants, would be uneconomic and is therefore an unrealistic pathway for use as comparison with other biofuels. It is highly unlikely that such plants would ever be built.

JRC: *The transport distance for manure, as agreed at the expert consultation in Ispra on November 2011, was 10 km. It has been now diminished to 5 km to take into account these considerations. It is also worth to point out that a methane yield value of 0.3* g_{CH4}*/kg VS* <u>*must be wrong;*</u> *it might have been a 0.3* kg_{CH4}*/kg VS (too high!) or 0.3 m3 biogas/kg VS, which is the value that we have actually used in our calculations. The IPCC reports a maximum methane potential of 0.24 m3* $_{CH4}$*/kg VS for dairy cows manure, but that is also rarely obtained in actual operations; that is why the value used in our study is lower, around 165 l* $_{CH4}$*/kg VS or 300 l* $_{biogas}$*/kg VS.*

Q25) **Average silage maize collection:**
In the JRC input data report, JRC assumes an average transport distance of 50 km for silage maize. This value seems very high. For example, the 2012 french LCA study on biomethane assumed an range of 15-25 km for biogas production between 100m3/hand 300 m3/h (equivalent to 500 kW to1 500 kW power capacity). AGPM and CEPM ask JRC to reassess this value.

JRC: *The distances for maize and manure transport (50 for maize; 10 for manure) were discussed and decided during the expert consultation in Ispra in November 2011. We have now changed the distance to 20 Km for Maize and biowaste and 5 for Manure. We would, however, appreciate if you could specify what French study you are referring to by providing references.*

II.9 Biogas plants useful heat production and utilisation

Q26) Biogas:

a. Heat utilisation is not considered in biogas plants with heat and power co-generation. Only considering the power production in a co-generation plant leads to an under-estimation of the energy efficiency of the installation, and consequently, to an underestimation of the GHG savings. According to a survey conducted by the BiogasHeat project (IEE/11/025), heat is utilised in a considerable number of biogas plants by selling to district heating networks or industrial units. While the percentage is low in MS like DE (~1%) it reaches almost one third in DK. The actual level of heat utilisation is likely to be much higher as in many cases the heat will be used on the farm (heating stables, drying processes, etc) in addition to being used to warm up the kettle.

Minimal levels of heat utilisation are required or encouraged in a number of MS, including DE. Thus, it can be expected that new installations will have a higher ration of heat utilisation.

For these reasons, the heat component should be included in the biogas pathway for co-generation installations.

JRC: *The rationale of not considering the heat as output of the CHP engine is that useful heat export is driven by demand and infrastructures and it varies largely between installations and geographic locations. the heat is normally used internally to supply process heat, mainly to the digesters. Allocating some emissions to an average heat use would undeservedly reward the biogas plants that do not export the heat, while, probably, the biogas plants that do export the heat would use the actual value because their percentage of export would likely be higher than the one in the default value. We recommend the use of actual values to the plants that actually export heat. However, in the default values GHG emissions calculations the useful heat recovered for the heating of the digester is included.*

The "biogasheat" project report on biogas heat use in EU concludes that: "In general, the actual status of heat utilization from biogas plants is not satisfactory. Although some heat is used for own purposes and internal processes, the commercial heat use of biogas is rare even though an enormous potential exists. Furthermore, in many countries it is difficult to describe the current situation, as reliable data on the heat use in biogas plants are lacking".

Rebuttal) It is unrealistic to expect the calculation of actual values in a large number of biogas plants due to the enormous effort this requires. We think that guidance for the heat export is required, and separate default values for heat use should be calculated. We think that this is an important point, which should be addressed.

We agree that there is a large unused potential. Providing default values for heat utilisation can contribute to supporting greater investments into this area.

JRC: *We think there is a misunderstanding on this point. We have not inserted the exported heat as a structural part of the default values (thus allocating part of the emissions to heat and part to electricity) because of the reasons stated above.*

However, because of the structure of the methodology (that was defined already for the COM(2010) 11 document), operators can, without declaring the whole actual value, apply their own final conversion efficiencies to the values presented as default (which are presented on the basis of the energy carrier, e.g. 1 MJ of pellet, 1 MJ biogas etc…). In addition to this, in case of a CHP producing useful heat and electricity, operators can *apply the allocation formula given in the methodology. The formula itself provides a lot of flexibility so that with a relatively simple calculation any possible situation can be reproduced.*

Please find in Section 7.3.2 a detailed analysis of the advantages in terms of GHG savings of co-generating power and useful heat.

II.10 Consistency between Average and Marginal values.

Q27) CONSISTENCY (EU electricity mix): A problem with the JRC draft report is the unfortunate mixing of average data with marginal data in an inconsistent manner. An illustration of how the JRC mixes average and marginal data is the update of "electricity mix" for EU-27 based on a very thorough review of the current electricity production in all EU countries (see all tables in section 3.3). Emissions of GHG per MJ of electricity have increased to 132g CO2eq, which will be used in the calculation of the default values. By comparison, estimated emissions in the Nordic electricity mix are approximately 35g CO2eq / MJ electricity. GHG emissions from the production of diesel have also been updated to represent today's marginal production in the Middle East. Hence, for electricity production the JRC is using average data whilst they are using marginal data for the production of diesel.

***JRC**: More than a discrepancy between the marginal-average approaches, this seems more an issue of different geographic boundaries. The comment states: "By comparison, estimated emissions in the Nordic electricity mix are approximately 35g CO2eq / MJ electricity."*

As we have well explained in the report, default values must be representative for all the EU27 MS, not only for a single European Region.

We are well aware that in Sweden-Norway-Denmark there is a high use of hydro+wind (which significantly lowers the CO_2 emissions per kWh), but we are considering EU27-average data.

Furthermore, we think the most important issue especially when results are evaluated and compared on a relative basis (such as in the case of comparing values defined as "GHG savings") is the use of consistent emission factors for fossil fuels and chemicals. In other terms: the Fossil fuel comparator chosen (no matter how it is defined), should be used also as the emission factor associated with the supply of such fossil fuels or material. This is the approach used in the calculations presented in this report.

Rebuttal) Why is then a marginal approach used for diesel, which would be inconsistent?

***JRC (Update 2017):** Only average values are used in the calculations. See Chapter 2 for details.*

Q28) The JRC report should consistently use average data and not mix it with marginal figures. As an example of the use of marginal figures, the JRC draft report assumes the gross electrical efficiency of a CHP engine to be 36%. We would like to underline that this is very much at the low end of the possible range of 33-45% electrical efficiency. The European average of CHP on farms is approaching 200kW with average efficiencies of 39 to 42%.

***JRC:** The IEA biogas handbook actually reports a 30-42 % efficiency range. The highly efficient engines are mostly pilot injection engines; in that case the use of diesel should be accounted for (either bio or fossil). Furthermore, within the scope of default values* *are included all types of technologies, newer, older, optimized or not. As a consequence we cannot ignore the low range of the available engines.*

However, it is important to notice that, in the methodology defined in the COM(2010) 11 report and maintained in the SWD(2014) 259, the final energy conversion is left out of the default values (that are instead provided on the basis of the final energy carrier, e.g. 1 MJ pellet, 1 MJ chips, 1 MJ biogas etc…see chapter 7 of this report). This implies that the final electrical efficiency is left as a free parameter for operators to insert based on their own measured values.

Q29) Another general aspect in the report is the mixing of average data with marginal data in an inconsistent manner, for example in using average data for electricity while using marginal data when it comes to diesel.

JRC: *See answer to Q27.*

II.11 General remarks on the JRC report and figures

Q30) Our overall conclusion is that the JCR draft report lacks a detailed interpretation chapter as described in the ISO standard for LCA (ISO 140 44) to reach sufficient scientific quality. In an interpretation chapter the JRC would go through all the input data and its quality and type (marginal data vs. average data, etc.) to ensure consistent calculations and comparisons. Special focus is on the sensitivity analyses which should identify critical parameters that are important for the final results and where additional efforts should be made to obtain as good and relevant input data as possible

JRC: *The JRC report is technically not an LCA study; it is an inventory of data reporting the input values used to calculate GHG emission savings. The simplified LCA methodology is set in COM(2016) 767. Data quality is checked by including the largest possible datasets available; however, it appears that there is a basic misunderstanding on the* <u>*scope*</u> *of the default values set in legislation: the geographic scope of such calculations is clearly EUROPEAN and should not be analysed at single MS level. This is similarly done in the Directive 2009/28/EC Annex V values were, though, a provision is given to MS to report on NUTS 2 cultivation average values in order to better mimic local and specific conditions. Increasing the level of geographic disaggregation would inevitably decrease the spread in the input values (and results) but that is not the scope of the values set in the EU legislation.*

Furthermore, apart from geographic and climate differences which clearly influence specific processes (i.e. mostly cultivation emissions and other emissions depending on temperature such as digestate storage emissions) there are many more sources of variability such as technological differences and lack of experimental data.

As mentioned above, geographical differences are the most difficult to tackle in an effective way in the EU default values. When it comes to technological differences we try to disaggregate the values and separate the pathways for the most technologies were the broader differences exist (e.g. see the disaggregation of biogas upgrading pathways). When it comes to lack or scarsity of experimental data we try to investigate the largest possible set of modelling and empirical data: publications, handbooks, emissions inventory guidebooks, LCA databases and whenever we receive them, proprietary data from stakeholders. Thus we continue to invite stakeholders to send us as many and as detailed practical (referenced) data as possible as they will allow us for better precision.

Finally, the final version of the report contains an additional section 7.3 (not present in the report version commented by the stakeholders) where specific sensitivities are analysed in details. We think that this additional analysis, added to the variety of pathways presented, gives quite a comprehensive view of the variability of the results, still considering the factors of uncertainty explained above.

Q31) In the current draft report JRC mixes a variety of types of data with very different quality and uncertainty. JRC seems to put a lot of effort into describing and verifying factors and input data with marginal impact on the final results, while not making the same efforts on very important factors, such as biogenic nitrous oxide and emissions of methane from biogas production and storage of digestate. As a result of this the draft report suffers from a lack of rigor and scientific approach. This is a problem since policy decisions will be based on scientifically unsubstantiated data and deficient calculations.

JRC: *The aim of the consultation is exactly to present the assumptions behind the calculations and to get the most representative and up-to-date data. We think we have used the most representative and recent data and as included in this document, we have also further updated assumptions and values used. Furthermore, we have added a specific section (7.3) including additional sensitivity analysis of the results.*

Moreover, where time and opportunity allow it, the data are also used in peer-reviewed LCA publications where the data are evaluated and validated in the peer-review process which shows how our values are definitely not "scientifically unsubstantiated and flawed" (e.g. Boulamanti et al., Biomass and Bioenergy 53 (2013) 149, Giuntoli et al., GCB Bioenergy 5 (2013) 497, Battini et al., Science of the total environment 481(2014) 196, Giuntoli et al., Journal of Cleaner Production 99(2015) 206, Giuntoli et al., Biomass and Bioenergy 89(2016) 146, Agostini et al., Energies, 8(2015) 5324).

Q32) **Introduction:** As far as it is possible to ascertain, this report aims to provide a basis for policy makers who intend to assess the extent to which GHG emissions from fossil fuels used for electricity, CHP and transport fuel can be avoided by their replacement with biofuels. For this purpose therefore, the calculations are based on the comparative MJ/MJ or of the respective energy source which is produced or MJ/g of fertiliser. While this measure may serve the JRC purposes, it is exceptionally difficult to comprehend and requires considerable extra effort and calculation to put it into the more readily understood and used measure for the comparison emission/kWh. At least the conversion factors for MJ to other units should be included.

JRC: *In SI the unit for energy is the Joule (J) and this is the unit used in EU policies. In any case 1 kWh=3.6 MJ.*

We realize that most of the times data are more readily clear and comparable when expressed in other units (e.g. kWh/ton of pellets or kg N/ha etc…). We have tried to add these alternative representations of the values in the "comments" below the data tables. We hope this helps the readability and analysis of other experts.

Q33) The transference of EFs for maize production when based on the same base data as for ethanol production are not fit for purpose when applied to biogas plants as shown above. The section on biogas is not ready for publication and should be revised in the light of widespread and indeed worldwide operating experience. Urgent talks should be arranged with the JRC to produce a valid basis for policy guidance. (CTL)

JRC: *The data for maize cultivation for the biogas pathways are specific for silage maize production; inputs and emissions are different and independent from the ones associated with maize grains cultivation for ethanol production.*

Q34) **General considerations on biogas GHG emissions**
The French LCA study on biomethane emissions has given some interesting clues :

Biogas from liquid manure emits more GHG than biogas coming from biogas plants with high incorporation level of energy crops. This is because liquid manure has very low methanogen potential. The GHG emissions of biogas produced in codigestion (50% maize, 50% manure in fresh matter) pass the 50% threshold. But, from my point of view, the electricity mix is a key point at this stage and therefore, the methodology applied to self consumption.

JRC: *We would appreciate if you could specify what French study you are referring to by providing references.*

Various options for self-consumption have now been defined directly in the list of default values (see chapter 7), this will provide an additional degree of freedom for the operators.

II.12 Geographical and technological specificities and default values

Q35) Also the regional differences within the EU and other variables should be better taken into account: for example the level of methane emissions depends largely on the climate and temperatures: in cold climates the emissions of manure are significantly lower than the given estimations.

JRC: *The methane emissions during manure storage are indeed dependent on the ambient temperature. The use of actual values, if any better data is available, is always recommended. However, the emissions of methane from digestate storage are not always dependent on ambient temperature. As some publications have shown (see for example Hansen et al., J. Environ. Qual., 2006, 35, 830-836 and Gioelli et al., 2011), when the digestate tank is connected to the digester for continuous operation, the temperature in the tank is actually almost independent from ambient temperature due to the continuous supply of warm digestate.*

Annex 3: Stakeholder comments on solid biomass pathways

This annex contains all the questions/comments received by various stakeholders, and the relative JRC answers/rebuttal, relative to solid biomass pathways, following the presentation of the first draft of input data proposed by the JRC to calculate GHG savings from solid biomass and biogas pathways (Brussels, May 2013 and following bilateral discussions).

The questions/comments are grouped by topic.

III.1 Old and new pathways

Q1) Charcoal: It is true that the EU imports charcoal, but this is (as far as I'm aware of) for BBQ use etc only. I have not heard of any industrial charcoal sue for electricity and/or heat production, and I doubt this will occur in the future, so I wonder how relevant it is to keep a default chain for charcoal in the document.

JRC: *We have acknowledged exactly this point also in the report. As the pathway was inserted in a previous official document of the Commission (COM(2010) 11) it is considered relevant to provide explanations for the reason why it would/should be dropped from future documents on the subject.*

Torrefied pellets: On the other hand, it is a pity that torrefied pellets are not included in the default pathways. In the last three years, a lot has happened in the development of this this technology, we nowadays have a number of semi-commercial pilot plants operating & producing, and the first trans-atlantic shipments are a fact (albeit small volumes for testing purposes for European utilities). It is quite possible that in 5 years time, significant amounts of torrefied pellets could be exported from the US and Canada (and other world regions) to the EU. Torrefied wood pellets require more biomass inputs for the torrefaction process, but also reduce energy during subsequent pelletisation (as the material is far less fibrous) and typically have a higher energy density (20-23 GJ/tonne, in theory it could also be higher), and also a higher volumetric density (650-750 kg/m3 instead of 625-650 kg/m3 for normal wood pellets, see slide 8 of the presentation attached, but see also opinion of Bo Hektor below)). In any case, not including this chain is a missed opportunity and will likely lead to problems over the coming years. While we understand that getting public data on the process is difficult and often confidential, Industry will be happy providing data as far as known today. Please do contact IBTC International Biomass Torrefaction Council/Michael Wild at michael@wild.or.at to establish contact to the relevant parties.

JRC: *We also recognize the (future) relevance of torrefied pellets especially for import routes. In this sense, in fact, we have already contacted ECN (who is a frontrunner for the research in torrefaction processes and now also in technology with their partnership with Andritz) and we hope to be able to have a pathway based on current, real, process data soon. Nonetheless, as also mentioned in the comment, the perspective for full-commercialization are around 5 years and thus even with very good data on the current technology status, this is far from the general, average validity that a 'default value' should have. For this reason we maintain our opinion that it is too early to provide a default value for torrefied pellets, but we think that we will be ready for a future update of the list of values (theoretically, updates to Annex V values are foreseen to be developed every 2 years).*

III.2 Road and rail transport assumptions

Truck fuel consumption: Data for truck transport are from European studies. Exporting countries overseas have bigger trucks and sometimes more liberal rules. Empty return trips requires less fuel (CA 50%) The standard values suggested in the report are 3-4 times higher than our values above).

JRC: *We have found in the literature values for diesel consumption for large trucks in the range of 0.21-0.26 l/km for empty cargo and between 0.29 – 0.35 l/km for full cargo. When combined we obtain the value indicated in the report. Furthermore, LABORELEC data agree with our data (See reply to Q10).*

However, we have looked into the data provided by the EEA/EMEP inventory guidebook 2013. Based on the values for Tier 2 fuel consumption and N2O emissions and Tier 3 CH4 emissions and based on the fleet composition obtained from the database COPERT, we have modified our fuel consumption to:

- *Weighted average (over distance per truck type) for fuel consumption: 30.53 l/100 km (including empty return trip)*

Train fuel consumption: The report claims that it has applied N. American data. Still our studies from B.C. arrive at values that are one tenth of that. We are applying unit train transport and the data are double checked with both grain transport from the Prairies and with ore transport Kiruna- Narvik. A common mistake that appears in the North American standard data bases is that they have applied data for single cars. Should be checked.

JRC: *The only value taken for North American conditions is the one related to Diesel consumption in freight trains. This value is taken from GEMIS 4.8.1 (indicating 25 MJ diesel/km for 100 t of payload). We usually consider GEMIS as a very reliable source so we will not change this value at the moment, unless additional data and evidence can be provided on the fallacy of the GEMIS data and by a factor of 10. We would be glad to receive additional data.*

CONCLUSIONS TRANSPORT (1): In many (most) cases, standards will give misleading results. Therefore, if standards are established, there MUST be opportunities for trade stake holders to apply own verified data. Otherwise, "good" performance data would be punished, etc.

JRC: *Correct, this is exactly the possibility provided within the Directive 2009/28/EC to declare actual values rather than using the default values. Operators can also use disaggregated default values for some parts of the pathway and declare actual values only when it can show improvements compared to the default factor.*

CONCLUSIONS TRANSPORT (2) Possible standards must reflect future and relevant conditions, not be based on invalid historical information.

JRC: *Default values are designed to mirror typical, average and conservative conditions in the market and not future, optimized processes.*

Default values used for solid biomass (wood chips) transportation: Mainly the values used for distance, load size and moisture content are unrealistic and should be revised. A) Finland and Sweden use trucks with 60 t weight and soon to be raised to 76 t by the end of 2013.

JRC: *Longer and Heavier Vehicles (LHVs) (up to 60 tonnes of total weight) are allowed in Finland and Sweden with some trials in The Netherlands and Germany. However, these trucks are NOT allowed within the Directive 96/53/EC and are also not included in the new Commission proposal for the amendment of such directive (COM(2013) 195 from April 2013). LHVs are allowed to circulate in single MS and also to cross one border if the two MS allow it. However, this is not the standard in EU and thus it cannot be included among the default values. Operators in countries that allow LHV can declare an actual value for the transport step.*

The moisture varies between different feedstocks. Average moisture at roadsize after seasoning is about 40% for Finland. This value is for harvest residues, stumps and small-diameter wood (rough average).

JRC: *Wood chips for energy are generally traded at different moisture levels (EN 14961-1 M10 to M55+). Furthermore, for imports from third countries, wood materials (including wood chips for any purpose) need to be thermally treated according to the International Standards for Phytosanitary Measures No. 15 - ISPM 15 (heat exposure of 56°C for 30 minutes).*

Additionally, short transport distances may be profitable even with chips at 40 – 50% moisture (e.g. the case presented by Jäppinen in Finland) but long-distance trade would probably not be feasible with moistures higher than 30%.

Furthermore, biological activities would be unsustainable when transporting large bulks of chips at high moistures, while for values <30% these activities are minimized.

Finally, even though seasoning might not be enough to dry wood down to 30% moisture in Scandinavian countries, this is not true for the rest of Europe where moistures of 30 – 35% can be achieved by seasoning (even in high precipitations countries such as Ireland albeit particular attention is required to the seasoning technique– http://www.coford.ie/media/coford/content/publications/projectreports/cofordconnects/ccn09-ht17.pdf).

In view of these considerations, and the importance of moisture mostly for long-distance trade, we propose to leave a value of 30% in our default calculations.

500 km of truck transport seems too high, 100 km is a representative distance for Finland.

JRC: *In the philosophy of the default values calculations we have to cover also conservative cases and long-distance transport of pellets and chips are a possibility that should not be forgotten (especially where access to riverways and sea is not possible, e.g. Austria to Italy). At any rate, the declaration of actual values for actual distances would be very straightforward.*

Truck transport: We observe relatively the same specific diesel consumption for trucks returning empty. Load is effectively about 30 tons (note: check this is also the same consideration in BIOGRACE II assumption). Our question would be:

would it be possible to have actual data when able to show that trucks return with a certain load?

JRC: *Good to see that our data converge with the ones from LABORELEC. Regarding the declaration of actual values, this is indeed allowed by the Directive and it is recommendable to use actual values when these are available.*

Train transport: We note that the train transport is considered as applicable to Western Canada (only?). However, we also have train transport in the US cases. If we compare the figures (0.252 MJ/t.km) diesel, with those assessed for USA, it is relatively close (0.00568 l/tkm soit 0.209 MJ/tkm).

JRC: *The default for long-distance shipping is taken to be Canada and we do not have at the moment pathways specifically representing the US situation. The default values are not characterized specifically by origin but rather by distance ranges. US pellets will probably fall in the category up to 10000km. Also our train fuel consumption agrees with LABORELEC data.*

III.3 Maritime transport assumptions

Load factors of bulk carriers: On the load factors of dry bulk carriers (but also trucks and trains). I think the data available at VREG should be a gold mine (and I understood that you have contacted them): they have audited data form wood pellet imports from all over the world to Belgium, and these should provide the best available data on many of the parameters in your default chains.

JRC: *We have contacted VREG. They are not authorized to reveal the information since those are confidential. However, we have received a report from LABORELEC and we respond to their comments in the separate answer (see answer to Q14).*

Maritime shipping fuel consumption: Maritime shipping.(a) I was happy to note that the report share my opinion that the load factor above 600 kg per m3 is weight, below it is volume (possibly that point is a little bit higher) That means that an argument in favor of densified torrefied pellets with high density would not be valid (energy density would, though).(b) However, the study has made some assumptions that seem strange to me. They have reduced the payload with the argument that ships normally call on several ports and therefore mostly ships are not fully loaded. Obviously, this has been the case in the early phases of the bio-energy trade, but it would not be relevant for well organized future supply chains. For long distance shipping the pay-load should be equivalent to net DWT. Also take note of the fat that new modern bulk ships have higher pay-load but remain in the same “old” category. (c) Return trips form a complex problem. For shipping ports located close to main bulk trade routes (e.g. Europe-Asia via the Panama canal) it is easier to get return freight. Here, shipping companies, as a rule of thumb, assume 1/3 of the distance to be ballast, while for other destinations, 2/3 or even 100% is assumed.

JRC: *We have received similar comments from LABORELEC and we are implementing changes. A) We see that with new bulk carriers (SUPRAMAX category) the "design" stowage ratio for the cargo is higher than we assumed, closer to 750 kg/m3, which means the transport of pellets is not weight limited (and we have seen this in actual* *carrier shipping manifestos). However, the use of larger carriers also implies a lower specific fuel consumption, this is now corrected in our calculations.*

B) The assumption of 30% of the trips under ballast is exactly the conclusion to which we have arrived analyzing a few shipping manifestos from GDF Suez bulk carriers. We have changed our methodology accordingly. See answer to Q14 for the detailed changes.

> Maritime transport of wood pellets: We are relatively concerned about values mentioned in the report about maritime transportation of wood pellet. Firstly, using handysize for transporting wood pellets is not the only (and maybe not the most favoured) option, regarding logistics efficiency. Supramax can also be used, but they are not referenced (neither in the BIOGRACE II tool). Though not explicitly mentioned, we assume that the specific fuel consumption you refer to (0.12 MJ/t km) is the one of carriers that are travelling empty on the way back. We think this assumption is not realistic and should not be taken as default. So as to support this argument, you will find in Annex 1 the typical routes of (wood pellets) carriers. You will note that assuming empty backhaul is not consistent at all with what happens in reality. In certain cases (rare), the ship might not be loaded for the return journey – this can be explained by: draft restriction at load and/or discharge port. Heavy cargo (iron ore / cement), voluminous cargo (grain). In one case it was the idea to load up to full capacity but supplier have problems getting the cargo so cargo interests took the decision to sail with less cargo (and be penalized on paying deadfreight).

JRC: *This information is indeed very helpful in drafting assumptions closer to the real situation. Having observed the data sent by LABORELEC and having investigated further with other pellets operators, we have now introduced a new category of bulk carrier,* ***SUPRAMAX****, with a DWT of 57000 tonnes and we have calculated a new specific fuel consumption from the IMO data equal to 1.09 g_{HFO}/tkm (FULLY LOADED, one-way). This new category will be used for all trans-oceanic shipping while the smaller HANDYSIZE carriers will be used for shorter distances (e.g. import from Baltics and Russia).*

Furthermore, we have noticed that most of the SUPRAMAX carriers are designed with a stowage ration of about 0.75, which means that also the density of pellets (ca. 650 kg/m^3) is not enough to guarantee a weight-limited cargo but it will be volume-limited. Considering the data received for the two bulk carriers, GDF SUEZ Ghent and North Sea, it is possible to estimate the average distance that the carriers have travelled with an empty cargo (under ballast) during their lifetime. This results in a percentage ***over the total distance covered of 22% and 31% respectively****. These data can be used to assign to each cargo a share of the total empty travel of the cargo.*

In this way the total consumption can be assigned as follows:

$$Total\ Fuel\ Consumption\ \left[\frac{g_{HFO}}{tkm}\right] = \frac{FC_{@Cargo} + FC_{@Ballast} * (CF/(1-CF))}{Cargo_{Outward}}$$

Where, $FC_{@Cargo}$ is the fuel consumption at cargo load in the outward journey, $FC_{@Ballast}$ is the fuel consumption under ballast and CF is the Capacity factor defined as the share of distance travelled by the ship under ballast over total distance travelled. Cargo is the cargo loaded in the outward journey.

By using this formula it is possible to assign to the pellet cargo only a share of the empty trips of the carrier as well as it would be assigned to all other cargos.

The complex issue is to choose a relevant CF: according to the GDF Suez data, this should be between 22 – 31%; according to another stakeholder (Bo Hektor, SVEBIO) this value is about 30%; according to the average values provided by IMO, this value is about

*45%. **Based on these considerations we have opted for a value of 30% for the Capacity Factor.***

This leads to the following update fuel consumption for shipping of pellets and wood chips by bulk carriers:

- Pellets shipped by Supramax (@ 650kg/m3) = 1.62 gHFO/tkm (incl. empty fraction)
- Chips shipped by Supramax (@ 220 kg/m3) = 4.06 gHFO/tkm (incl. empty fraction)
- Chips shipped by Handysize (@ 220 kg/m3) = 6.38 gHFO/tkm (incl. empty fraction)

Transport default values: Comment on page 20 suggests that default shipping emissions for solid biomass haven't been updated and won't change – are there specific figures available for biomass?

"Updated ship data based on International Maritime Organization (IMO) data have been used for crop, vegetable oil and ethanol shipping. Sugar cane ethanol, palm oil and soya figures have also been adjusted."

The UK Ofgem/DECC calculator does not include emissions associated with backhaul. If backhaul is to be included, there should be consistency with how backhaul is applied. There is significant variation in the figures currently used in the UK Ofgem/DECC calculator. The new JRC defaults range from 0.13 to 0.5 MJ/t.km. The impact this has on calculation outcomes is considerable. We would urge the group to continue to review current data as new IMO legislation being introduced globally for the freight industry means that more up–to-date data is widely available. (http://www.martrans.org/docs/publ/REFEREED%20JOURNALS/WMUJMA%20EMISSIONS%202009.pdf)

***JRC:** Shipping emissions will be updated according to various comments and new sources that we have received (see answer to Q14). Our values for fuel consumption and CO_2 emissions are already taken by an official (and to our knowledge the most recent) report by the International Maritime Organization*

(http://www.imo.org/blast/blastDataHelper.asp?data_id=27795&filename=GHGStudyFINAL.pdf)

III.4 Energy requirements for pellet mills

Process heat for pellet mills: On the use of bark/wood chips for drying: I think bark does not (always) need to be collected from the forest, but also form other wood-processing industries, who may have an over-supply even after covering their own energy demands. Wood pellet mills can be co-located with other (wood processing) industries, and may utilize waste heat produced from other industrial processes. I do not know any wood pellet plant that has its own (bio-fuelled) CHP plant. This would probably only be possible for large pellet plants (because of the economies of scale), but still this is basically far more expensive then getting electricity from the grid. I had cc'd the EU, US and Canadian Wood pellet associations (Christian Rakos, Seth Gunther and Gordon Murray) – they would probably be in the best situation to discuss what feedstocks are used predominately for drying, their origin/transport, etc.

JRC: *We still think that in the average-thinking that drives the default values modelling, it is difficult to rely on residues coming from other processes as this is very labile. Furthermore, when harvest residues or even SRC are collected and chipped, not always (almost never) the bark is removed from the white wood, thus it is difficult to assess whether only bark is used for heat provision or simply the chips are used. This can always be included in the calculations of actual values. We have contacted the Wood Pellet Association of Canada and their reply is discussed in answer to Q17.*

Finally, the use of CHP is introduced in the pathways in order to promote best practices, but the typical case (heat from wood boiler + grid electricity) is treated as the most common one.

Drying of wood feedstock: You will find attached a pdf "SGS-Wood Pellet Process-Drying-2013.pptx" that gives you an overview of the material characteristics, drying techniques and energy balance. Please note the diversity of cases depending on the pellet plant considered…

JRC: *The data on heat supply in pellet mills were very interesting: according to SGS data, it looks like US and Canadian mills are actually using their own pellets to supply heat to the process, while in European mills it appears that mostly fresh chips/bark are used. Furthermore, it is interesting to see that actually some CHP plants are already registered to be operating in mills. The last slide in the SGS presentation suggests (for Case 2/2a: wood boiler and power from the grid) to use either pre-dried chips or own pellets, which is exactly what we have assumed in our models (Case 2 uses pellets, Case 2a uses pre-dried chips).*

Gordon Murray from the Wood Pellet Association of Canada confirmed to us that the pellet mills in Canada use either planer shavings or sawdust/chips as feedstocks for the drying. Mr. Murray claims that around 15% of the feedstock is used for drying and 85% is used for pellet making. This is lower than our number (28% is used for chips boiler) but that is because we consider fresh wood chips to have 50% moisture, while the particular situation of Canada (using Mountain Pine Beetle killed stems and wood that has already been air dried in the forest) allows them to have feedstocks at 35% moisture content at the mill gate.

Electricity consumption of the pelleting process: The power use calculated in the JRC report looks consistent with the typical figures SGS obtained from audits.

	MJ/MJ	kWh/MJ	kWh/mt
pellets from sawmill residues (p319)	0.028	0.007778	128.3
pellets from round wood (case 3, p323)	0.05	0.013889	229.2

Let's say the range 100-150 kWh/ mt is typical for pellet plant using fresh sawmill residues and 180-250 kWh/ton is typical for pellet plants using round wood, with electrical crush.

We would support the idea to have default available for new plants (where no historical data is available) but not for plants which have been operating for some time (for which a calculation based on the actual power use should be compulsory). The "default values" can be used, but potential "actual values" defined by independent auditor and validated by the necessary documentation (bills, consumption data onsite, …) have the priority in the hierarchy of the data to be used. This would be an incentive to have continuous improvement of the supply chain energy balance.

JRC: *We are glad that our values are within the range of the audited values from LABORELEC, but in fact the data had already been provided by LABORELEC back in 2011. Regarding methodological issue on default values, the Directive indicates that operators can use the default or declare actual values but it is not possible to exclude some processes/operators from using the default values. This is also at the basis of the reasoning for which default values generally represent conservative assumptions and are increased by 40% over the respective typical values.*

Pelleting Energy: The defaults provided in the JRC document combine pelleting energy and drying energy. The UK Ofgem/DECC solid biomass carbon calculator requires this information to be split out into the two separate modules and Drax collect data on this basis.

The pellet mill energy default values in the input database are extremely high, based on actual data Drax has been collecting from pellet mills in North America and Europe.

We understand that the input database default figure is based on the use of natural gas in pellet mills. This is not a realistic representation of what happens in the pellet industry, it is the exception rather than the norm. As GHG targets tighten, it will be increasing important for pellet mill designs to move to the most efficient systems possible making this scenario unrealistic.

<u>Figures</u>

Energy use measured in MJ/MJ pellets (sawmill residues)

0.028 MJ/MJ(pellets) x 19 MJ/kg = 532 MJ/tonne =147.7kWh/tonne

The Ofgem/DECC value is 39.8kWh/tonne - this is a significant increase to apply to calculations based on default figures.

Energy use measured in MJ/MJ pellets (stemwood)= 950MJ/tonne = 265kWh/tonne.

The UK Ofgem/DECC value of 41kWh/tonne. The JRC figure greatly exceeds the highest reported values from data provided by suppliers of pellets to Drax and is not representative of the industry.

JRC: *The JRC report does not combine power and heat demands, but they are provided as separate values in* Table 68 *(0.05 MJ el./MJ pellet and 0.185 MJ heat/MJ pellet for fresh chips).*

Furthermore, the power and heat demands are independent from the source from which they are obtained. We have calculated several cases for the supply of process power and heat: case 1 is indeed covering the case in which a natural gas boiler is used to provide process heat. This case is not common, indeed, but there is at least a case in Russia where this is applied and that is why this case is covered in our calculations. Case 2a (using wood chips for process heat and power from the grid) is probably the most common case on the market (see answer to Q17).

Regarding the power and heat demands in pellet mills, these values were actually provided by LABORELEC and are based on actual pellet mills audited by SGS for the Flemish authorities. LABORELEC has also confirmed that our values are within the range of their measured values (see answer to Q18).

We have checked the assumptions in the Ofgem calculator and indeed the value indicated is extremely low (143 MJ/tonne of pellet → 39.7 kWh/tonne → 0.0084 MJ/MJ pellet) and outside any range of values indicated in the literature.

We had access also to some real data from Swedish pellet mills and their data (from electricity bills) were equal to about 130 kWh/tonne pellet for sawdust mills and 167 kWh/tonne pellet for fresh chips pellet mills, thus much closer to our chosen values than to the values in the Ofgem calculator.

We have contacted E4Tech, who are the creators of the Ofgem GHG calculator. Their answer has been that they were not the ones to insert this value in the tool but that it derived from DEFRA's Biomass Environmental Assessment Tool and it is referenced from a single pelletization plant described in a rather old report from DTI (http://webarchive.nationalarchives.gov.uk/+/http://www.dti.gov.uk/energy/renewables/publications/pdfs/BU100623.pdf). E4Tech's suspicion, which we share, is that this value refers only to the power consumption for the pelletization press and not for the whole plant. E4Tech has already informed Ofgem and DECC that these values need to be updated.

III.5 Forest logging residues logistics

Diesel consumption forest residues: Diesel consumption from production of tops, branches, etc. in integrated logging operations should be close to nil, as that should be allocated to harvesting of the logs and pulpwood, which is the main purpose of the operation.

JRC: *This is not correct. Indeed emissions from falling and de-limbing of stems are NOT allocated to tops and branches at all. Those emissions are assigned to the production of stems; further, the RED methodology explicitly states that biomass residues should be allocated zero GHG emissions up to the point of collection. However, the collection, forwarding and chipping of the residues falls into the residues pathway since these emissions are caused by the bioenergy pathway (otherwise the residues would be left on the forest floor or burned on-site).*

Logistics of forest residues: When harvesting from energy plantations, or "energy stands", the boles (or even trees or tree sections) would be chipped at road side etc. but at a later point in the supply chain. In most cases, that would solve problems of losses, secondary contamination, homogeneity (by possibilities to central debarking), etc. In most cases, the positive effects will outweigh the possible higher hauling cost: Even long distance transport can be carried out in form of (debarked) round-wood shipping.

JRC: *When referring to "energy stands" in the sense of planted forests harvested for energy purposes (such as in South-East U.S. for example), the logistics of such biomass will fall under the stemwood logistics and that is accounted in the pathway "chips/pellets from stemwood" where seasoning is done at roadside and dry matter losses are limited.*

However, when talking about Short Rotation Coppice (SRC) plantations managed for bioenergy under very short rotations (3-7 years), it is assumed in our inventory that a combined harvesters-chipper is used. This means that wood chips will need to be stored with the subsequently associated dry matter losses.

Regarding long-haul of entire stemwood is indeed not included but so far we have not found many proofs of this as a common logistic choice (for bioenergy purposes, of course). Long-distance shipping of pellets seems to be the most common tradable woody good for bioenergy. See also, Lamers et al., Global Wood Chip Trade for Energy, IEA Task 40, June 2012, http://www.bioenergytrade.org/downloads/t40-global-wood-chips-

study_final.pdf *: pag. 5:* "Fuelwood comprises of the lowest annual trade volumes. It is regarded a rather local product; with less than 1% of its production being traded annually according to official statistics. Large-scale trading of fuelwood requires special handling in bulk transport. This reduces the bulk (energy) density and makes long distances less economically feasible. Most trade takes place crossborder i.e. short- or mid-range in bagged form, conglomerated in nets, or stacked on pallets. Recorded trade streams outside Europe are between South Africa and its neighboring countries (foremost Swaziland and Namibia), Canada and the USA, and across South East Asia".

> Bundling of residues is not an actual option because it turned out to be un-economical.

JRC: *It is interesting to know that the technique is not feasible thus not actual anymore.*

III.6 Short Rotation Coppice

> Cultivation data: Considering the range of geographic sources of biomass, forest types and forest management practices, the defaults for cultivation are derived from management practices from one region only. There is a large amount of literature in the academic press which could be used to develop this. We would recommend the JRC broaden the scope before embedding defaults based on one forest management system (the following organisation may be a good source of background documentation http://www.ncasi.org/).The assumptions made for eucalyptus practices (described as 3 year coppicing operation) is not a realistic scenario for bioenergy plantations. We would urge the JRC to interact with commercial groups in this area to get an industry perspective of current and likely future practise.

JRC: *According to the literature (see for example Gabrielle et al., GCB Bioenergy 5 (2013) 30-42):* "Growing cycles may be shortened to 7 years with the same productivity as long as stand density is kept within a 2000–2500 stems ha 1 range, as was already tested with poplar (Berthelot et al., 1994). Similarly, **SRC with shorter rotations with 3 year harvesting cycles are being tested and developed**. This scheme was illustrated with willow (Dimitriou & Aronsson, 2005), and requires far higher stand densities, between 10 000 stems ha 1 and 15 000 stems ha 1. Such systems are currently being trialled in France with eucalyptus and poplar."*. They in fact model 7 harvests per 3 years of growth each, so it looks like the industry trend is exactly to shorten the rotations and increase density of stems. Our values agree with this trend.*

Regarding data sources, it is true that there are many academic and research studies on SRC plantations in Europe, however, almost all of the data are retrieved from small, research-based applications and thus not really on a commercial size. Eucalyptus cultivation in Brazil is instead an established practice for pulpwood production and that is why we have chosen data from that region.

We have now also included values for poplar cultivation in EU based on various agricultural practices, as described in answer to Q24.

> Short rotation coppice: The JRC report only considers SRC pathways based on short rotation Eucalyptus plantations, which are mainly established outside the EU. No calculations are provided for European species, such as poplar, willow or black locust. Given that commercial production of short rotation coppice is already practiced at considerable scale in the EU, and that support under EU Rural

Development Policy can be provided for increasing this production we consider it necessary to provide default values also for pathways based on European species. A large body on production data and input needs for SRC has been established, which should be taken into account. I will send some references early next week. Actually, the W2W study already provides some data (pp. 45ff.) that do not seem to be used any longer.

JRC: *Two additional processes for the cultivation of poplar, with and without the use of fertilization, in Europe have been added to the calculations. However, it is important to stress out that so far in EU there is a lot of information available at the research scale, but little at the operational scale.*

Cultivation practices for poplar use for the wood industry are different and can be optimized for energy production (e.g. shortening rotation) but this is not yet widespread at commercial level, it is rather limited to experimental plots (<10000 ha in UK (Matthews), 2000 ha of pulp SRC in France (Gabrielle et al., GCB Bioenergy 5 (2013) 30-42) etc…).

Poplar is currently cultivated in EU mostly for pulp and for furniture with rotations ranging typically around 9 – 12 years. However, poplar has been considered also as a species suitable for biomass for energy production under short rotation practices. Significant variations in yields and agricultural practices can be found in the literature, since interest in woody biomass for bioenergy is still recent (see for example Hauk et al., 2014).

Dedicated SRC cultivation of poplar can undergo a rather intensive management (irrigation, weed and pest control, fertilization). However, poplar can also be cultivated in marginal land or in areas where other cultures cause significant nitrogen leaching (e.g. buffer strips). In order to reflect these two possible situations, two processes are proposed in these calculations (see chapter 6.1).

III.7 General remarks on JRC work on solid biomass

CONCLUSIONS. The work behind the report seems to aim at finding an average of typical case for standards for the various products in the bio-energy field. However, as the conditions for production varies within a wide range, it will be important that production units which perform better than the standards, would have possibilities to apply their own verified values in the evaluation processes.

JRC: *This possibility is included in the RED, and economic operators are invirted to use actual values for their own process if these are available.*

Use of LHV: expressing all values in MJ wood, as done in BIOGRACE, is not really practical (as the LHV doesn't vary linearly with humidity, thus conversion is not always simple way forward).

JRC: *It should be clarified that all the calculations from JRC are based on the <u>LHV of the Dry part of the fuel</u> and not on the actual definition of LHV (which includes the heat lost due to the latent heat of vaporization of the moisture content and which it is used in the Directive 2009/28/EC for the purpose of energy allocation). In that case indeed the values would not be proportional to the moisture content and it would make things much more complicated. The basis of calculation is thus basically proportional to dry weight.*

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